



RELIABILITY

An Engineering Excellence



The Hong Kong Institution of Engineers - Electrical Division
The 16th Annual Symposium, 1998



**THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION**

The Sixteenth Annual Symposium

Thursday

15th October 1998

***RELIABILITY -
AN ENGINEERING EXCELLENCE***

at

Ballroom
Sheraton Hotel
Nathan Road
Kowloon
Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

09.00 Welcome Address

- Ir Vincent W.S. Tong
Chairman, Electrical Division, The HKIE

09.05 Opening Address

- Ir Otto L.T. Poon
President, The HKIE

09.10 Keynote Speech

- Mr K.C. Kwong, JP
Secretary for Information Technology and Broadcasting
Information Technology and Broadcasting Bureau
The Government of The HKSAR

1. Power Systems

09.40 Guangdong Nuclear Power Station Operating Performances

- Mr Peter H.Y. Chow
Executive Deputy General Manager
Mr Qian Jinhui
Deputy Director, Science & Technology Committee
Guangdong Nuclear Power Joint Venture Company, PRC

**10.00 Hongkong Electric's Distribution Network Reliability
Enhancement - A Total Approach**

- Mr K.T. Yeung
Area Engineer
Transmission & Distribution Division
The Hongkong Electric Co. Ltd., Hong Kong

10.20 Discussion

10.40 Coffee Break

2. Large Projects

11.10 The Hawaii H-3 Tetsuo Harano Tunnel - A High Reliability Power System

- Mr Keene Matsuda
Assistant Vice President
Parsons Brinckerhoff Energy Services
New York, U.S.A.

11.30 Power Supply Distribution - CLK Terminal Building and Infrastructure

- Ir K.W. Tong
General Manager
Ir Y.C. Ng
Manager - Systems
Engineering & Maintenance Department
Airport Management Division
Airport Authority Hong Kong

11.50 Discussion

12.10 Lunch

3. Products and Legislation

14.00 Product Reliability

- Ir Dr John Lo, JP
Executive Director
Clipsal Industries (Holdings) Ltd., Hong Kong

14.20 Statutory Control of Electrical Product Safety in Hong Kong

- Ir H.C. Lai
Senior Electrical & Mechanical Engineer
Electrical & Mechanical Services Department
The Government of The HKSAR

14.40 Reliability and LV Products

- Mr Claude Milhaud
Area Manager
Low Voltage Equipment and Systems Department
Low Voltage Power Distribution Segment
Schneider Group, France

15.00 Discussion

15.20 Coffee Break

4. Reliability Management

16.00 Electric Power Industry Reliability Management in Mainland of China

- Ms. Huang Youru
Director
Electric Reliability Management Centre of
China Electricity Council, PRC

16.20 An Integrated Approach to Managing RAMS of Railway Assets

- Mr C.K. Lai
Quality Improvement & Reliability Manager
Operations Engineering Department
Mass Transit Railway Corporation
Hong Kong

16.40 Discussion

17.00 Summing Up

- Ir W.H. Wong
Symposium Chairman
Electrical Division, The HKIE

Closing Address

- Ir Prof. Y.C. Cheng, JP
Vice Chancellor
The University of Hong Kong

Acknowledgement

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Speakers / Authors

Mr K.C. Kwong, JP	Ir K.W. Tong
Ir Prof. Y.C. Cheng, JP	Ir Y.C. Ng
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Mr Peter H.Y. Chow	Ir H.C. Lai
Mr Qian Jinhui	Mr Claude Milhaud
Mr K.T. Yeung	Ms Huang Youru
Mr Keene Matsuda	Mr C.K. Lai

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Paper No. 1

GUANGDONG NUCLEAR POWER STATION OPERATING PERFORMANCES

Speakers : Mr Peter H. Y. Chow
Executive Deputy General Manager
Mr Qian Jinhui
Deputy Director, Science & Technology Committee
Guangdong Nuclear Power Joint Venture Company
PRC

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Paper
No. 1

ABSTRACT

This paper provides an overview of the operating results achieved and experience gained over the past four years of the GNPS since its commercial service in 1994. All aspects of management including nuclear safety culture, operations and maintenance, radiation protection and radwaste controls and environmental monitoring are examined and summarised. The major development targets and action plans for next five years are also set out.

NOMENCLATURE

AC:	Alternating Current
CNNC:	China National Nuclear Corporation
CI:	Conventional Island
EDF:	Electricite de France
EIR:	Environmental Impact Report
FSAR:	Final Safety Analysis Report
GNPJVC:	Guangdong Nuclear Power Joint Venture Co., Ltd.
GNPS:	Guangdong Daya Bay Nuclear Power Station
IAEA:	International Atomic Energy Agency
INPO:	Institute of Nuclear Power Operations
ISI:	In-Service Inspection
NDT:	Non Destructive Test
NEPA:	National Environmental Protection Agency(China)
NI:	Nuclear Island
NNSA:	National Nuclear Safety Administration in China
PWR:	Pressurised Water Reactor
RO:	Reactor Operator
SRO:	Senior Reactor Operator
WANO:	World Association of Nuclear Operators

1. INTRODUCTION

GNPS is the first large twin-unit commercial nuclear power station constructed in the mainland China. Its NI is M310-type PWR supplied by Framatome of France with a nominal capacity of 2905 MWt. Its full speed rotation at 3000 rpm turbine generator is the product of British company GEC with a nameplate output of 984 MWe. With the first concrete poured on August 7, 1987, the two units of GNPS were put into commercial operations on February 1 and May 6, 1994 respectively bringing to a conclusion its construction programme spanning over a period of six and a half years. Significant achievements have been accomplished since GNPS went on stream, as, for instance, the US-based McGraw Hill publication "Powerplant International" conferred on GNPS the 1994 Powerplant Award as a peer acknowledgement by the international electric power industry of the initial achievements of GNPS.

At this point in time, the two units of GNPS have both entered their fifth fuel cycles. GNPS performance over the past four years has demonstrated, in convincing terms, that GNPJVC, as the owner of the station, can construct GNPS with distinction, but also can equally operate the station with safety and quality.

This paper firstly outlines the performances of GNPS over the past four years before proceeding to summarise the positive practices and experiences that should be replicated for the future operations of the station. On this basis, a description of the major development targets is

presented in brief for the next five years.

2. OVERVIEW OF GNPS OPERATING PERFORMANCES OVER THE PAST FOUR YEARS

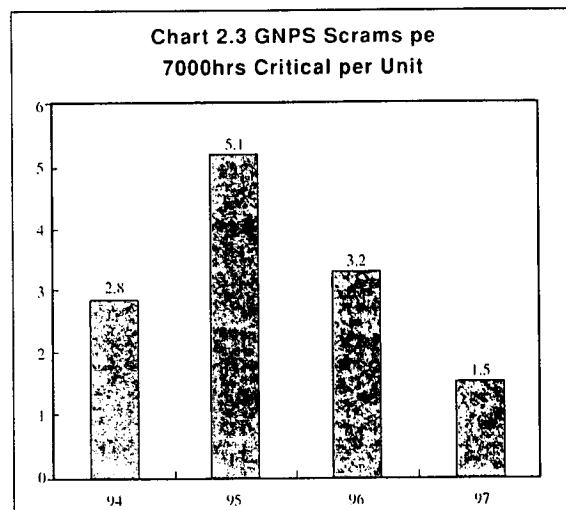
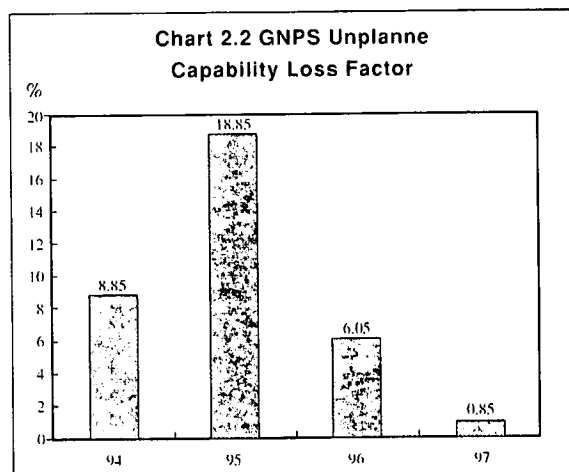
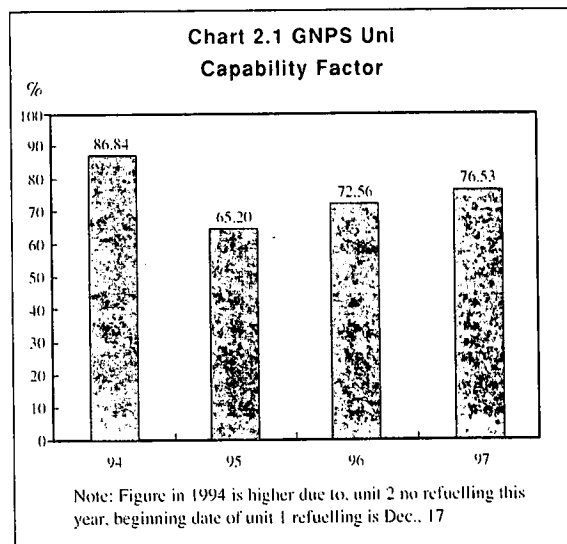
2.1 GNPS PERFORMANCES

The two units of GNPS had generated a combined cumulative total of 46.44 billion kWhs by the end of 1997 since their commercial availability. Both units have maintained a sound safety record over the past four years. However, it has certainly been far from plain sailing for GNPS. In the following sections, the authors will briefly summarise the main difficulties encountered during initial operations of GNPS together with the major achievements obtained over the past four years.

When we look back on the operations of GNPS to date, it is fair to say that the first two years were relatively difficult. Apart from the generic problems, which are commonplace in the early period of operations such as equipment defects and lack of experienced personnel, GNPS has also met some unique problems.

The first unique problem transpired on July 1, 1994. At the time, internal leakage of hydrogen occurred in Unit 1 generator due to the cyclic motion of a ferric particle resulting from the alternating changes of magnetic field in the generator. This effect is known as electromagnetic worming effect. This particle were identified as a small piece of tool steel which had been embedded in the insulation of conductor during manufacture, and had eroded gradually insulation until cutting through the subconductor to cause hydrogen to leak into the stator cooling water. In order to replace the damaged conductor, Unit 1 was shut down for 41 days.

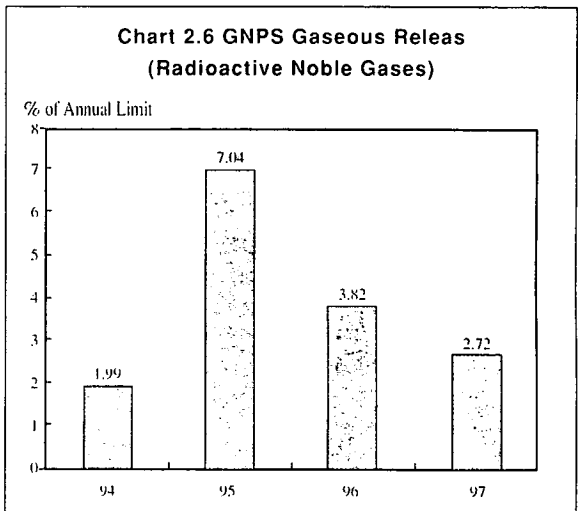
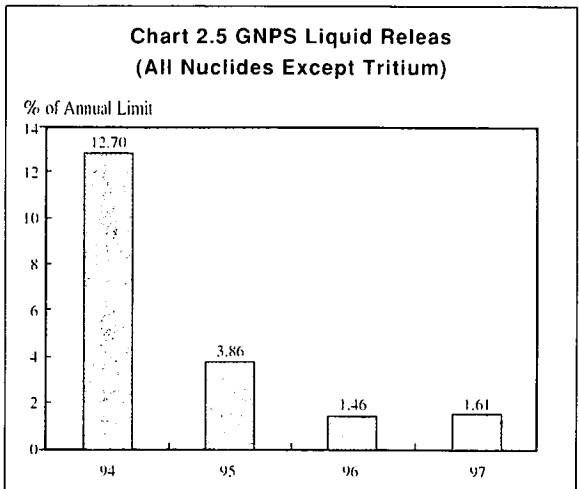
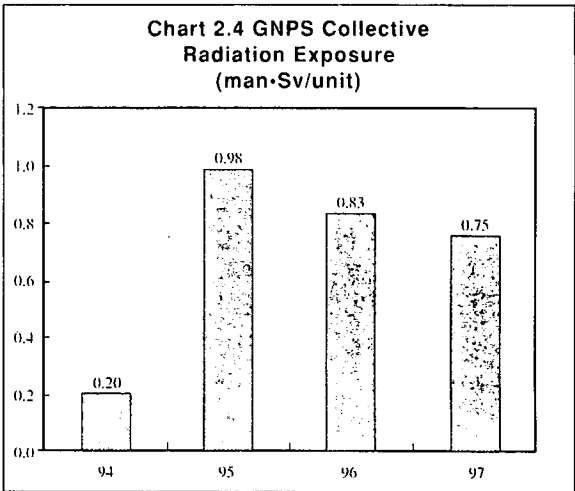
The second problem involved a key component of the reactor. Upon completion of the initial refuelling outage of Unit 1, usual control rod drop time test for each one of the 53 control rod clusters was performed for the first time on



February 14, 1995, in line with the applicable Technical Specifications requirements. As a result, it was found that the drop times of 7 control rod clusters had exceeded the acceptance criterion of 2.15 seconds. With the concerted efforts of both GNPJVC and the equipment supplier, the root cause was identified as the control rod guide tube being a new design which had not been fully bench-tested for its suitable use and corresponding corrective measures were adopted to reduce the drop times in line with the above criterion and the total time used to correct this problem was four and a half months. At the end of June 1995, the entire solution adopted to resolve the control rod problem was endorsed by NNSA, and the unit was successfully reconnected to the grid on July 2, 1995. This episode had caused the unplanned capability loss factor of the year to reach 18.85% and the unit capability factor to fall to 65.2%.

Charts 2.1, 2.2 and 2.3 show the annual steady improvement trends of GNPS in terms of unit capability factor, unplanned capability loss factor and number of reactor scrams. From the charts, we can see that the unplanned capability loss factor has dropped to 0.85% in 1997, which is better than the median value (2.2%) of the nuclear power stations in the world for the same year. The reactor scrams per 7000 hours critical have also decreased considerably. Such improvement has certainly not come easy, because there are more than over 700 protection signals capable of leading to automatic scrams of the unit. Any equipment defect and human error associated with the foregoing signals can result in an accidental shutdown of the reactor. What deserves special mention in this context is that Unit 1 has achieved "one cycle trouble free" operations in 1997, which represents a milestone accomplishment for GNPS. It amply demonstrates that the equipment reliability, professionalism and skills of the operation crews, effectiveness of the Quality Assurance system applied during the course of operations and maintenance of GNPS have all reached a satisfactory level.

It may be necessary to explain why the GNPS unit capability factor in 1997 was 5.4% lower



than the world median value in the same year. This was caused partially by the limitations imposed on the annual generation within the first five years of commercial operation as stipulated in the Electricity Sales Agreement with the grids viz China Light and Power Company Limited and Guangdong Electrical Power Holding Company Limited. The situation was further compounded by some time-consuming special tests required during first several refuelling outages after plant commissioning such as the Class A Strength Test of Containment, the NDT on reactor pressure vessel as stipulated in the maintenance programmes and ISI programmes. Barring the above two factors, it is expected that the GNPS unit capability factor will improve by a significant margin in the coming years.

Looking back on the operating achievements of GNPS, we should automatically bring up the record of the three safety barriers of GNPS. It is well known that the three barriers are the nuclear fuel metal cladding, reactor coolant pressure boundary and containment building. The leakage rate of the three barriers has been contained within the limits established in the applicable Technical Specifications. The GNPS fuel reliability indicator for 1997 is 3.7 °— 10-2 Bq/gm, which is notably lower than the median value (7.8 °— 10-1 Bq/gm) of the PWRs elsewhere in the world for the same year. This means the performance of fuel assemblies is good and cladding leakage is minimal. In terms of magnitude, the leakage rates of the second and third barriers have been contained within 10% and 20% of the applicable limits prescribed in the Technical Specifications. Based on the above, we can say that the integrity of the three barriers of GNPS has been intact over the past four years.

GNPS has also maintained a satisfactory record on the collective radiation exposure and release of radioactive effluents over the past four years. Charts 2.4, 2.5, 2.6 and 2.7 depict the annual collective radiation exposure and total activity of the radioactive releases in terms of annual regulatory limits. These releases include all radioactive nuclides in liquid except

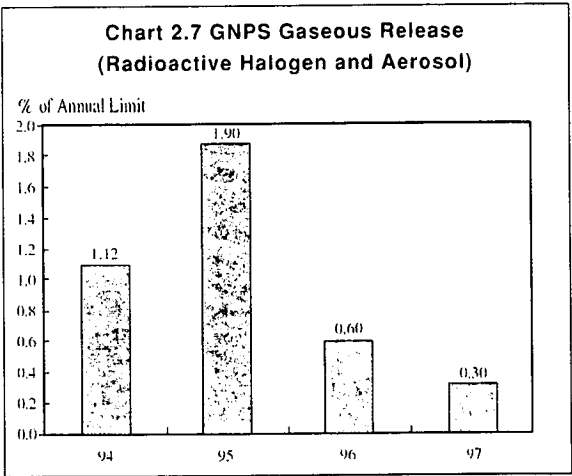
tritium, radioactive noble gases and radioactive aerosol and halogen.

Chart 2.4 indicates that the collective radiation exposure has been kept at a exceptionally low value over the past several years and the figure of 1997 of 0.75 man°Esv is within the world best quartile value. Charts 2.5, 2.6 and 2.7 indicate that liquid and gaseous releases point to a clear descending trend over the past several years, and only represent a very small proportion of the annual regulatory limits as stipulated by the government authorities.

2.2 PERFORMANCES COMPARISON BETWEEN GNPS AND WANO

After four years of commercial operations, it is now appropriate to perform a comprehensive comparison between the operating performance of GNPS in 1997 and the statistical data compiled by WANO for the same year. There are altogether twelve indicators to be used to measure the performance level of a nuclear power plant.

Chart 2.8 provides an overall comparison between the various GNPS performance indicators in 1997 and the world median values (also known as industrial values) and best quartile performances for the same year. Charts 2.9 to 2.20 sum up the performances for WANO members in 1997. For details of explanation on WANO performance indicators, reference should be made to the Attachment "A brief introduction to WANO performance indicators."



**Chart 2.8 Comparison of 1997 Indicators between
GNPS & World's Nuclear Power Plants**

Indicators	Unit Capability Factor	Unplanned Capability Loss Factor	Scrams per 7000 hours Critical	Unavailability of the Safety System			Thermal Perfor- mance	Fuel Reliability (PWR)	Chemistry Index ** (PWR Recirculat- ing SG)	Collective Radiation Exposure	Volume of Solid Radioact ive Waste	Industrial Safety Accident Rate
				RIS** (PWR)	ASG** (PWR)	AC Emergency Power						
Unit	%	%	1 7000 hrs -unit	component unavailability train		Unavailability train	%	Bq gm	N/A	man·Sv unit	M ³ unit	1 2×10 ⁵ man·hour s
GNPJVC	76.5	0.85	1.6	0.003	0.001	0.014	99.2	3.7 E-02	0.4 (96)	0.75	105	0.4
Median Value of World NPPs	81.9* (three years)	2.2	0.0	0.001	0.001	0.002	99.1	7.8 E-01	0.26 (96)	1.32* (three years)	56* (three years)	0.5
Best Quartile of World NPPs	86.4* (three years)	0.4	0.0	N/A	N/A	N/A	99.7	N/A	N/A	0.74* (three years)	23* (three years)	0.13

Note: * Mean values between 1995 and 1997.

** PWR statistics for RIS - High Safety Injection, ASG - Auxiliary Feedwater, Fuel Reliability and SG - Steam Generator

It should be noted that the statistics of CNNC, operator of the Qinshan Nuclear Power Station, and GNPJVC are separately shown in the charts because they are two independent WANO members. In addition, Chart 2.17 adopts the statistics of 1996 as GNPS has not yet adopted the new WANO statistics methodology applicable to chemistry indicators in 1997.

From the above charts, we can conclude that six indicators of GNPS in 1997 have reached the median level viz. the so-called industrial values. They are the unplanned capability loss factor; availability of auxiliary feedwater (ASG), thermal performance, fuel reliability, collective radiation exposure and industrial safety accident rate. The other six indicators demonstrate some disparities or gaps compared with the world median values, and they are the unit capability factor, automatic scrams per 7000 hours critical, availability of high pressure safety injection (RIS) and emergency

AC power supply, chemistry indicator and total volume of solid radioactive waste discharged.

3. MANAGEMENT EXPERIENCES GAINED FROM FOUR-YEARS' OPERATIONS

Current operations of GNPS point to the fact that GNPS has already gone through a healthy initial development stage in its operating history. Whilst the management experiences and expertise summarised below may appear self-evident for operators of nuclear plants, they do constitute, in many ways, new management insights acquired under the specific circumstances of GNPS. The practices and experiences over the past four years of GNPS will certainly serve as a useful and meaningful source of references for future nuclear power plants not only for GNPS but also for others in the mainland China.

Chart 2.9 Unit Capability Factor
Worldwide 1997 Median Performance

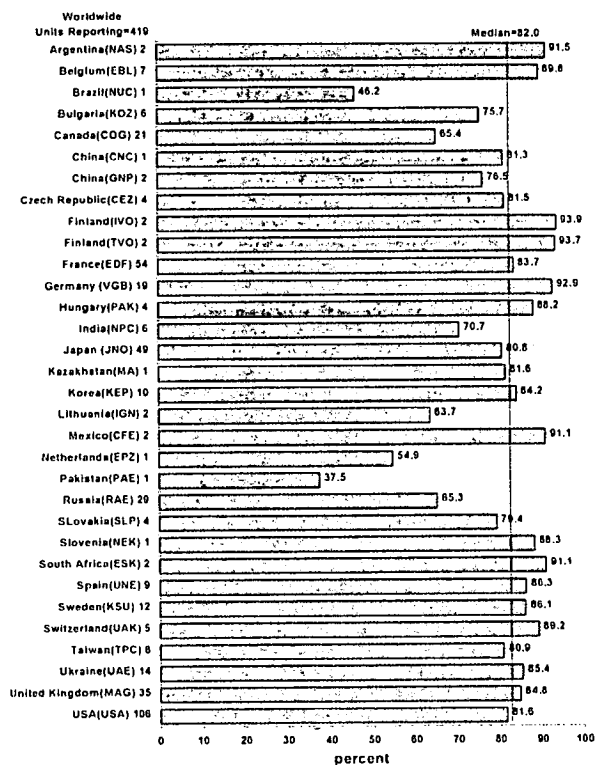


Chart 2.11 Unplanned Automatic Scrams per 7,000 Hours
Critical
Worldwide 1997 Median Performance

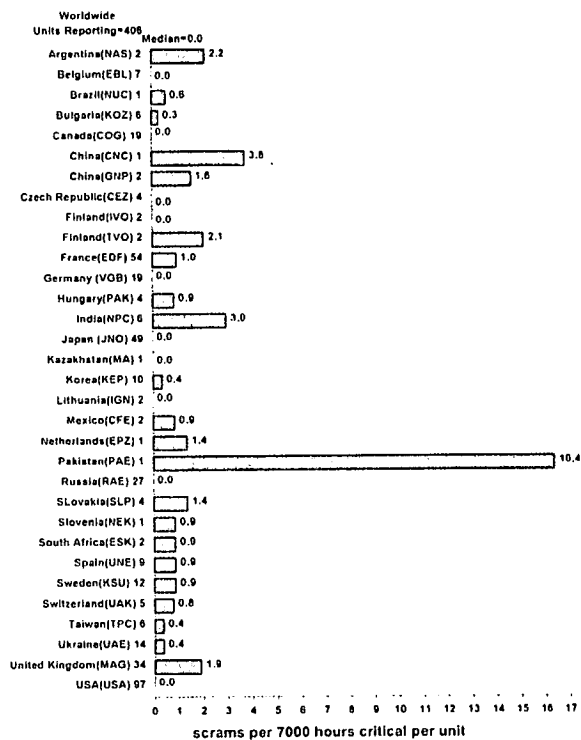


Chart 2.10 Unplanned Capability Loss Factor
Worldwide 1997 Median Performance

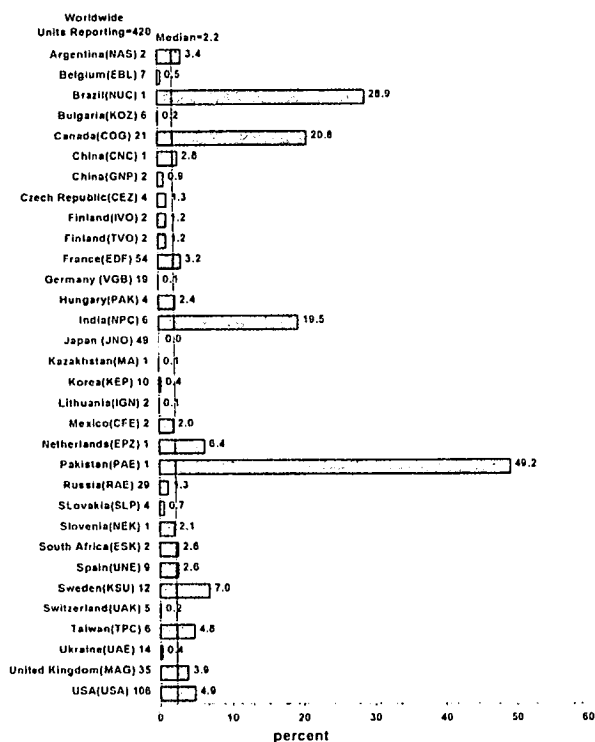


Chart 2.12 Safety System Performance
High Pressure Injection System 1997 Median
Performance for PWRs

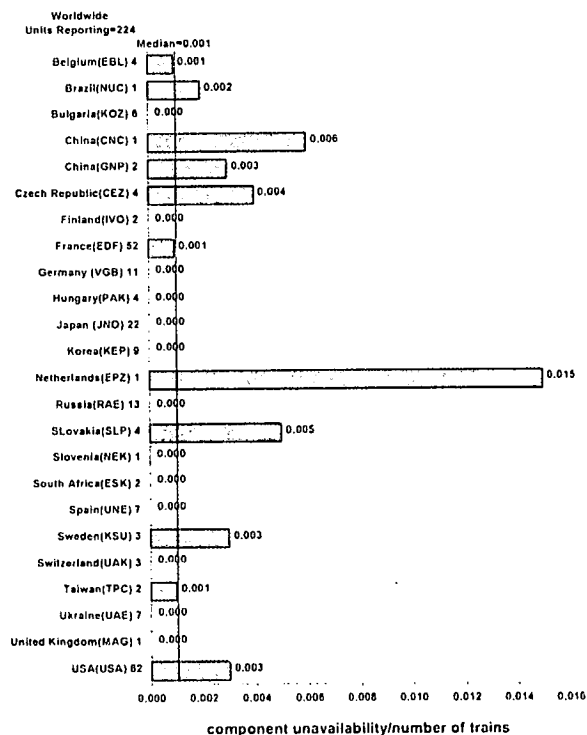


Chart 2.13 Safety System Performance
Auxiliary Feedwater System 1997 Median Performance
for PWRs

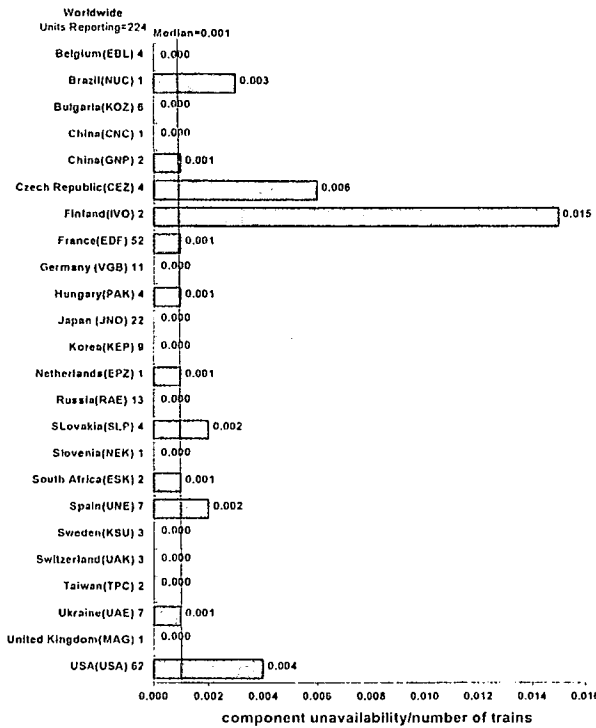


Chart 2.15 Thermal Performance
Worldwide 1997 Median Performance

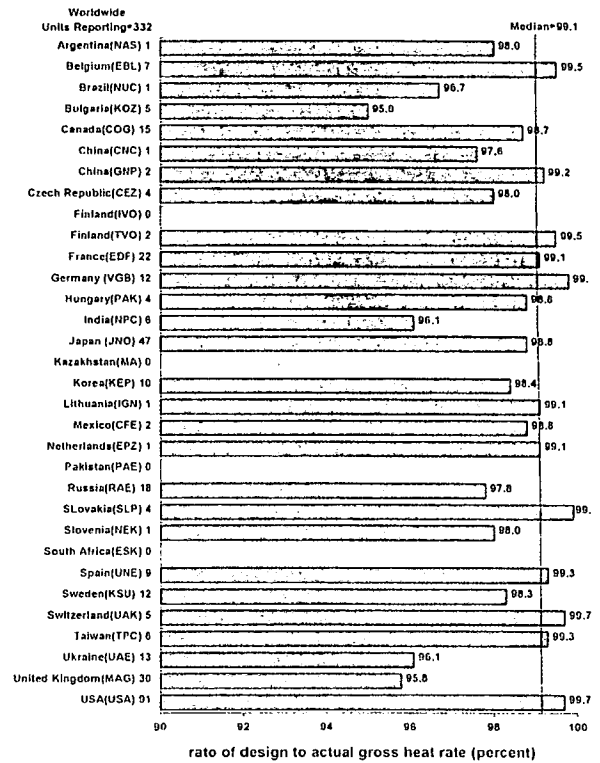


Chart 2.14 Safety System Performance
Emergency AC Power System 1997 Median Performance

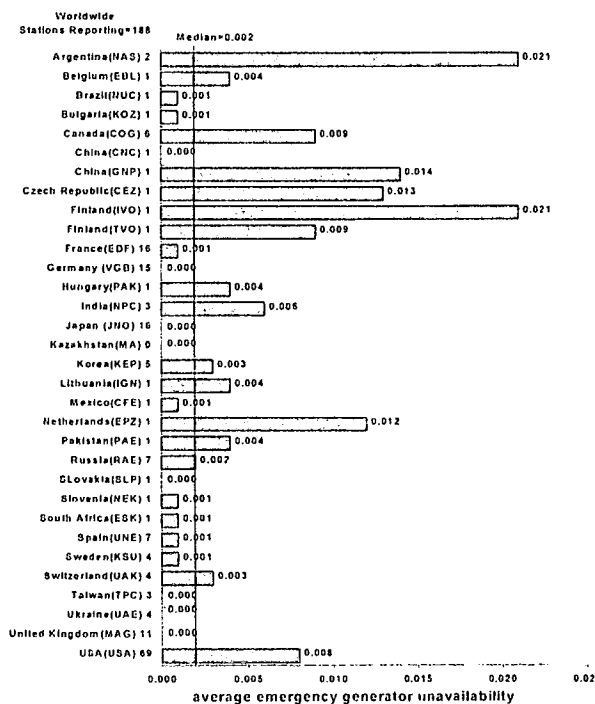


Chart 2.16 Fuel Reliability Last Operating Quarter
Median Performance for PWRs

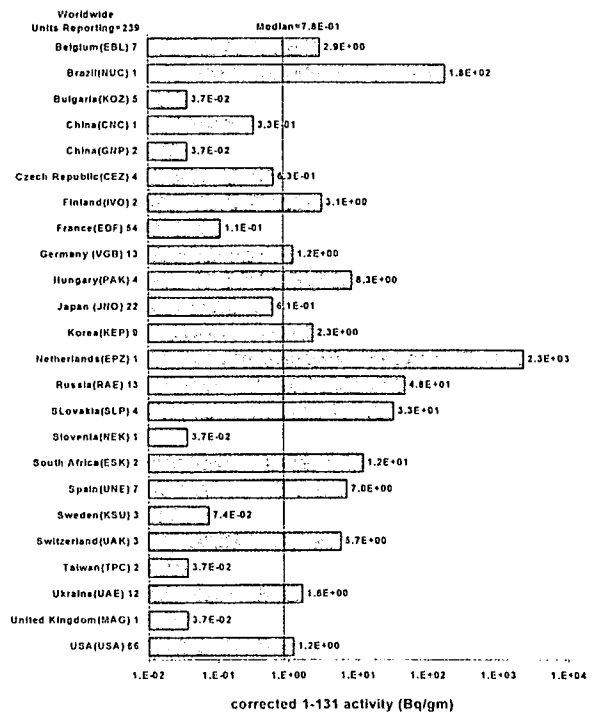


Chart 2.17 Chemistry Index
Recirculating Steam Generators without Morpholine
1996 Median Performance for PWRs

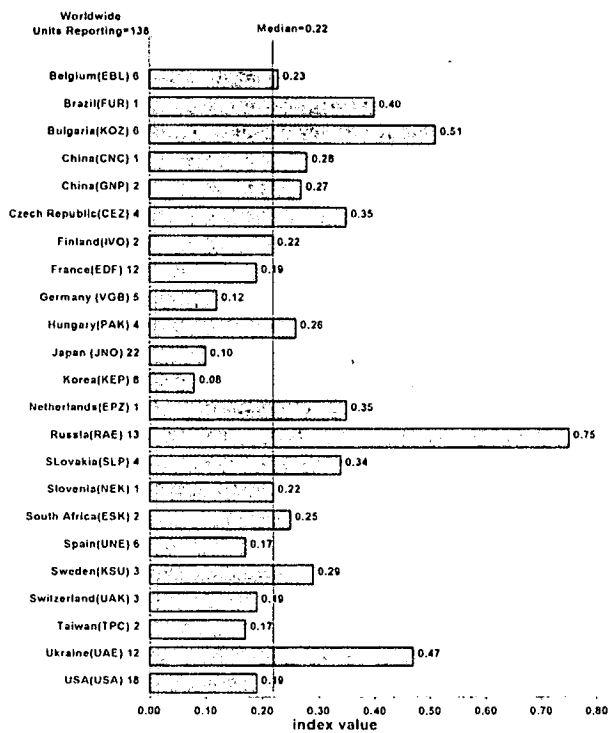


Chart 2.19 Volume of Solid Radioactive Waste
Worldwide 1997 Median Performance

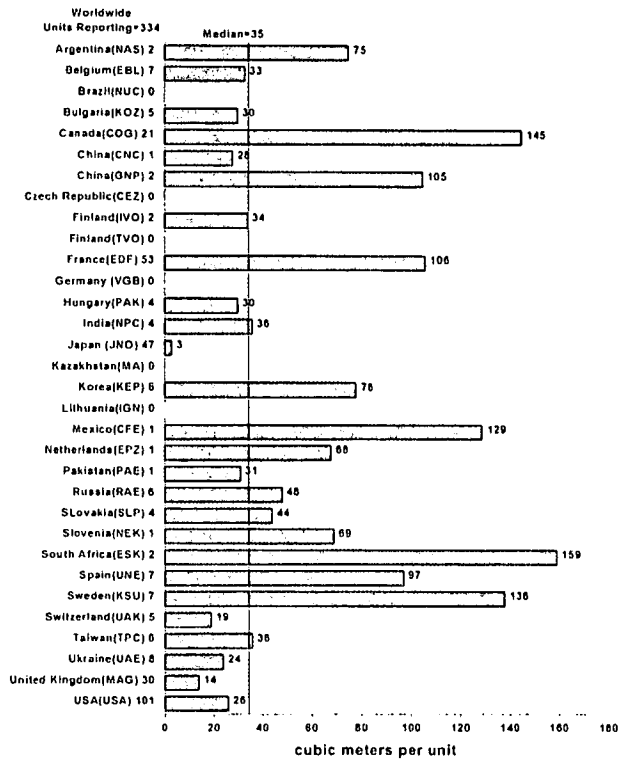


Chart 2.18 Collective Radiation Exposure
Worldwide 1997 Median Performance

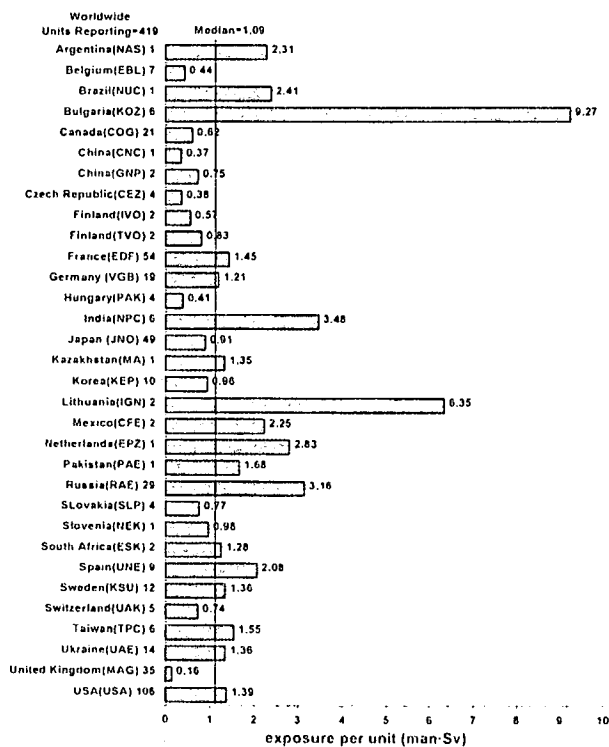
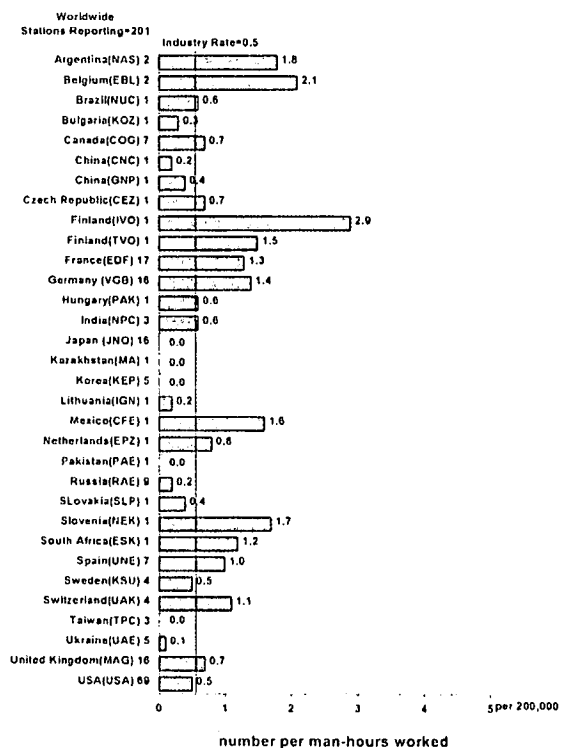


Chart 2.20 Industrial Safety Accident Rate
Worldwide 1997 Median Performance



3.1 STRICT COMPLIANCE WITH CODES

There has been strict compliance with the National Nuclear Safety and Environmental Protection Codes, and GNPJVC has consistently lived fully up to the Commitments made to both NNSA and NEPA.

GNPJVC has fully complied with the licensing system governing nuclear plant operations, nuclear safety and environmental monitoring regulations in China. NNSA and NEPA carry out the foregoing regulatory watchdog functions on behalf of the Chinese Government. GNPJVC has strictly fulfilled its commitments established in the FSAR and EIR.

The operating status of GNPS has always been highly transparent to both NNSA and NEPA, and GNPJVC has submitted to them daily and monthly operating reports and other reports as required by the regulators. In 1997, GNPS also received a total of 45 correspondences from the foregoing regulatory bodies. In response, GNPS sent 170 replies to document and record its commitments and implementation status on the agreed action items.

3.2 STRICT PRE-JOB AUTHORIZATION PROCESS

Adequate resources have been made available to support high-standard training programmes with strict pre-job authorization process enforced.

One of the principal lessons learned from the Three Mile Island accident is that, if the educational level of a reactor operator is inadequate, he will tend to incorrectly apply his judgement on physical phenomena thereby worsening the situation in case of an accident. This imposes more stringent requirements and very high standards on all institutions and personnel engaged in the nuclear power activities.

As delineated above, GNPS is the first commercial nuclear power facility in mainland China. To ensure the availability of high quality operating crews, 112 key persons were

selected and sent to the nuclear power stations of EDF in France to undergo systematic training over a period of one year or longer depending on the types of jobs the trainees receiving their training. The Training Centre built in the vicinity of GNPS involved a total investment of 19 million US Dollars and was put into use in August 1990. Subsequently, in July 1992, commissioning of the Full Scope Simulator was completed and made available for training purposes. By the end of 1997, the Centre had conducted 22400 man^o Pweeks of training load for various kinds of training programmes.

GNPS has formulated an authorisation system linking to job responsibilities closely with knowledge, skills, industrial safety and radiation protection requirements. Even contractor personnel are also required to undergo training and obtain authorizations prior to job assignments. With respect to RO and SRO, the involved staff must sit for written and oral examinations before being granted operating licenses by NNSA. By the end of 1997, 93 persons had obtained RO licenses and 53 of them had attained SRO licenses at GNPS.

3.3 NUCLEAR SAFETY CULTURE

GNPS has consistently placed great emphasis on nuclear safety culture to ensure safety at all times

In 1986, the most severe nuclear accident to date occurred in Chernobyl Nuclear Power Plant in the former USSR. To draw a serious lesson from this accident, the international nuclear power industry conceived the brand-new concept of "nuclear safety culture". Prior to this, the international nuclear community had stressed reliance on "Quality Assurance" to forestall human errors, viz. placing emphasis on personnel "complying with procedures". In the wake of the Chernobyl accident, however, the international nuclear community recognised that it would not be adequate to just require people to "adhere to procedures". It was realised that equal emphasis should be put on the safety awareness and attitude on the part of all the organisations and personnel involved in the nuclear power industry all over the

world. Furthermore, high premium should also be placed on the initiative and capability on the part of the staff to correct human errors. As a result, "nuclear safety culture" has specified more comprehensive and new criteria for all levels of management and staff involved in the operations of nuclear power stations.

Promotion of "nuclear safety culture" at GNPS is, first and foremost, demonstrated by the fact that all levels of management at GNPS assign supreme and overriding priority to nuclear safety on a permanent basis. As mentioned in Section 2 of this paper, in order to address the control rod drop time issue of Unit 1 in 1995, the unit had been shut down for a period of four and a half months. Such course of action had directly resulted in the reduction of 1.5 billion kilowatt-hours in the annual generation output for the year. Nevertheless, it served to ensure that the principle of "safety first" became deep-rooted in the hearts and minds of the GNPS management and staff. The handling of the issue has effectively become a live example of the promotion of "nuclear safety culture".

Another important aspect of the promotion of "nuclear safety culture" is manifested by the establishment of a comprehensive internal safety surveillance and supervision mechanism including the assignment of Safety Technical Advisors to work independently of the operating shifts at GNPS. By working alongside the operating shifts, these advisors perform independent safety assessments on the operating conditions of the twin units, and regularly write up Safety Status Weekly Reports, and this practice was recommended as a "Good Practice" by the IAEA Operational Safety Review Team to all the other nuclear operators world-wide.

The third aspect of the implementation of "nuclear safety culture" is the emphasis on the transparency during the analysis of events arising at GNPS and on the principle to not hide human errors at any time. Within GNPS, the formal operating experience feedback system has been set up such that all abnormal events are reported within 24 hours to facilitate timely analysis and implementation of the required corrective measures so that lessons can be

drawn without delay.

3.4 OPERATING DOCUMENTATION SYSTEM

GNPS has exerted enormous efforts to set up and improve upon the Operating Documentation System with same vigor as efforts made to maintain hardware viz plant systems and equipment in healthy and operable conditions.

GNPS Quality Assurance system requires proper documentation for all activities at plant, viz:

- Write down what shall be done
- Do according to what is written down
- Write down what has been done

GNPS has therefore put in place a complete documentation management system to assure that all operating documents are updated on a timely basis and circulated to the users in a well controlled manner.

Back in November 1989, GNPS set up a procedure writing task group composed of Framatome, EDF and GNPS experts. Before the initial fuel loading, more than 8,000 technical procedures had been drafted. Of this, 1709 operating procedures had been validated during different phases of commissioning or made effective on the full scope simulator. 5300 maintenance programmes and maintenance procedures were successively checked and validated during the course of routine maintenance and refuelling outages. The remaining will be validated during the plant's 5th year and 10th year outages.

3.5 OPERATING TECHNICAL SPECIFICATIONS REQUIREMENTS

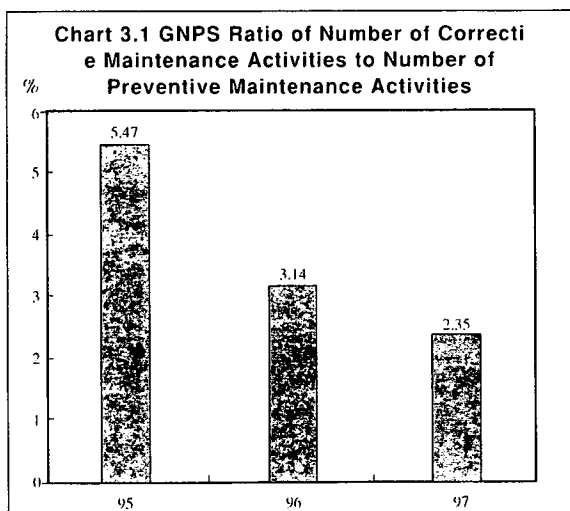
GNPS has steadfastly complied with the operating technical specifications requirements, in service inspection programmes and preventive maintenance programmes in monitoring, inspecting and maintaining the plant systems and equipment in a healthy state.

It is well known that all plant systems with

safety functions are activated or put into operation when the nuclear plant experiences abnormality or accident scenarios. In accordance with the Technical Specifications requirements, all these safety systems must be inspected to verify their availability through periodic tests during normal operations of the nuclear plant. GNPS has strictly adhered to the periodic test regulations since its commercial service with around 3340 various types of safety-related periodic tests carried out per annum. All periodic tests must prove beyond doubt that the safety systems are available, and corrective actions for the failing systems must be implemented within strict deadlines. Otherwise, the unit is required to be brought to a safer operation condition in line with Technical Specifications requirements viz from a reduced load operation to a complete unit shut-down.

In order to guarantee the validity of the second safety barrier, GNPS conducts various NDT on the pressure containers and pipings of the reactor coolant system during a refuelling outage according to ISI programmes and submits the resulting data to the NNSA and other statutory authorities.

Chart 3.1 shows the year-by-year falling trend of the ratio between corrective maintenance and preventive maintenance issues from 1995 to 1997. The chart proves that the health condition and maintenance quality associated with the GNPS systems and equipment have been steadily improving on an annual basis.



3.6 CLOSE RELATIONSWITH SUPPLIERS

For a nuclear power station whose principal equipment has been supplied by overseas suppliers, it is necessary to maintain close relations with the main suppliers to ensure plant reliability and availability.

In early 1991, GNPS began to define the technical support mechanism for GNPS after it entered commercial service. Prior to the commercial operations of the first unit, GNPS had reached commercial agreements with both Framatome and GEC to provide technical assistance in the future. Over the past four years, GNPS has obtained various and effective supports from the main suppliers, such as supplying spare parts, clearing up pending items left over from the construction stage, performing special maintenance activities during refuelling outages, eliminating equipment defects and implementing modifications based on the experience feedback gained by the suppliers. The self-reliance capability in maintenance has been enhanced by leaps and bounds whilst turbine generator or conventional island (CI) maintenance activities have been nearly all localized and more than 90% of NI maintenance activities have been made by GNPJVC personnel during the fourth refuelling outage. However, close cooperation with the main suppliers shall be maintained in the future to ensure continuing reliability and availability of plant.

3.7 MAINTAIN EXTENSIVE EXCHANGE & COOPERATION

GNPS has maintained extensive international exchanges and co-operation to draw on the rich experiences from its international peers.

During the operation preparation and commercial services, GNPS has been able to obtain extensive supports from EDF. These include EDF seconding a seasoned French expert to assume the position of GNPS Plant Manager. After the office of the Plant Manager was handed over to a Chinese expert in July 1997, GNPS has continued to maintain extensive co-operation with EDF. As a result,

it can be said that the management approach of GNPS is a re-creation in its own right conceived on the basis of the integration of management experiences from EDF with the specific circumstances of GNPS in China.

As noted above, the safety of nuclear plant has no national boundary. How to continuously improve nuclear plant safety and reliability is the common challenge facing all nuclear plant operators world-wide. In addition to maintaining extensive links with EDF, GNPS also keeps in close touch with IAEA, WANO and other nuclear plant utilities. GNPJVC is also a member of FROG (Framatome Owners Group). All these links enable the GNPS managers to take note of the achievements accomplished by the international colleagues, and to ensure their achievements and practices stay transparent within the international nuclear community.

4. THE BUSINESS DEVELOPMENT TARGETS OF GNPJVC

In October 1997, GNPJVC unveiled its first 5-

year Business Plan (1998-2002). Through the preparation of this business plan, GNPJVC has subjected itself to a stringent self-analysis on its strengths, weaknesses, external opportunities and threats, and subsequently mission and vision for GNPJVC were established together with the targets set up based on the benchmarking with other good performing nuclear power plants in the world and a series of improvement plans was established in order to improve the management standards with an aim to reaching the goals as set in our mission.

The 5-year Business Plan (1998-2002) is briefly described as follows:

OUR MISSION

Our mission is to generate electricity over the long term in a safe, reliable and cost effective manner for the benefit of our customers, shareholders, employees and society.

Our mission includes the establishment of a sound base for the development of nuclear power in Guangdong Province.

CHART 4.1 PERFORMANCE COMMITMENT TARGETS

YEAR	SAFETY				PRODUCTION		
	UA7	UAx	COLL. RAD. EXPOS.	ISAR	UCF	UCLF	PCLF
	$\frac{1}{7000}$ hrs·unit	%	man·Sv/unit	$\frac{1}{200000}$ man-hrs	%	%	%
1998	1	0.9	0.84	0.3	79	3	18
1999	1	0.9	0.82	0.2	81	3	16
2000	1	0.8	0.75	0.2	84	3	13
2001	1	0.6	0.70	0.2	86	2	12
2002	0.5	0.5	0.65	0.1	86	2	12

Note: UA7

- Unplanned Automatic Scrams per 7,000 Hours Critical

UAX

- Safety System Unavailability

Coll. Rad. Expos.

- Collective Radiation Exposure

ISAR

- Industrial Safety Accident Rate

UCF

- Unit Capability Factor

UCLF

- Unplanned Capability Loss Factor

PCLF

- Planned Capability Loss Factor

OUR VISION

The safety and economic performance of our plant will be on par with the world median performance within two years and on par with the best in the world within five years.

OUR PERFORMANCE TARGETS

The performance targets were set as shown in Chart 4.1.

OUR IMPROVEMENT PLANS

The improvement plans which focus on important issues, such as nuclear and industrial safety, plant capability, cost reduction programme, spent fuel disposal are established.

Through the efforts by all the staff in GNPJVC and with the continuous supports from the state and provincial authorities including the grids, GNPJVC has the confidence that in the foreseeable future GNPS will become one of the best performing nuclear power plants in the world.

operators to establish INPO. The second accident led to the formation of WANO consisting of nuclear operators from all over the world. Both organisations have been working hard to continuously promote nuclear safety and reliability through strengthening experience exchanges between nuclear power stations in the world. One of the important activities of these two organisations is to collect and publish 12 operating performance indicators every year. INPO has been implementing this programme for 17 years up to now, and WANO has been pursuing this for 8 years to date.

As the 12 indicators (hereinafter referred to as WANO indicators) can, to a large extent, comprehensively showcase the management performance level of all nuclear plants, all nuclear operators are using them as a yardstick for peer comparison. Such comparison has naturally become a powerful driving force to motivate nuclear operators world-wide to improve their management performance on a consistent basis. The statistical data associated with the 12 indicators indicate that, overall, the safety and reliability of nuclear plants have had marked improvements irrespective of nuclear plants in the US or elsewhere in the world.

Next, a brief introduction will be given to the meaning of 12 WANO performance indicators:

Items 1 and 2: UCF (Unit Capability factor) and UCLF (Unplanned Capability Loss Factor).

$$UCF = \frac{(REG - PEL - UEL) \times 100\%}{REG}$$

$$UCLF = \frac{UEL \times 100\%}{REG}$$

- REG - The reference generation output of the unit during the period of the involved statistics. It is the maximum capacity of the unit multiplied by the number of hours being considered for the statistical period.
- PEL – Planned generation loss during the statistical period.
- UEL – Unplanned generation loss during the statistical period.

The above two factors indicate the availability of the unit maximum capability and unplanned loss during

ATTACHMENT

A BRIEF INTRODUCTION TO WANO PERFORMANCE INDICATORS

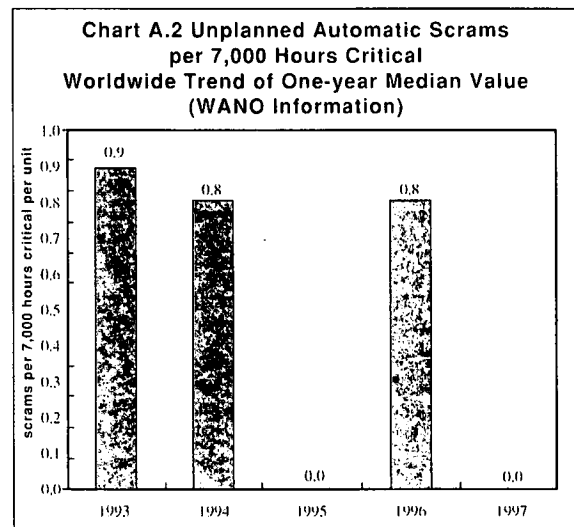
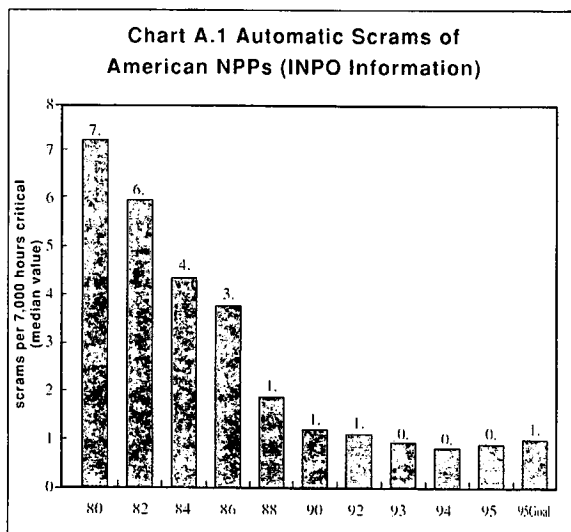
It is well known that two severe nuclear accidents in the history of nuclear power development have occurred to date, viz. the Three Mile Island Nuclear Plant accident in US in 1979 and Chernobyl Nuclear Power Station accident in the former Soviet Union in 1986. They remind the industrial circles that, even though the design and construction of a nuclear power station fully comply with the nuclear safety specifications and standards, disastrous accidents could occur at the end of the day if its operator did not properly manage the plant. This would not only wreak havoc on a nuclear power plant, but also seriously shatter the confidence of the international community in the development of nuclear power. Nuclear safety therefore effectively transcends national boundaries.

The first accident prompted the US nuclear plant

the statistical period, respectively. They globally reflect the reliability and efficiency of the operation and maintenance activities associated with the equipment of the unit.

Item 3: UA7 (Unplanned Automatic Scrams per 7000 Hours Critical)

Automatic scram constitutes an important safety measure in the in-depth defense mechanism of a nuclear plant (generally known as Reactor Protection System). When certain parameters in the reactor or the plant system deviate from the normal range and reach the protection threshold values, the protection system will automatically shut down the reactor. Of course, this protection system must be very reliable and shall not fail to activate. For this reason, it must undergo periodic tests to verify its effectiveness. However, once the system activates, it will not only result in fluctuations in the grid system thereby affecting the generation plan, but also cause major transient to the plant system leading to buildup of fatigue effect for certain components. In recognition of this, the number of automatic scrams accumulated within a given year must be kept to a minimum. Charts A.1 and Chart A.2 highlight the improvement situation of the UA7 Median Values of nuclear power stations in US and other countries published by INPO and WANO in different years. From Chart A.2, it is obvious that, in 1995 and 1997, the UA7 Median Values has reached zero, viz., within the foregoing two years, at least half of all the operating nuclear power stations world-wide have achieved One Cycle Trouble Free operations. However, the same chart shows that it is extremely difficult to maintain at this top level e.g. in 1996, UA7 dropped back to 0.9.



Items 4 to 6: UA_x (Safety System Unavailability)

The following three indicators can be used to measure up the safety for PWR, viz the Safety System Availability:

- High Pressure Safety Injection System
- Auxiliary Feedwater System
- AC Emergency Power System

Whilst the first two fluid systems are normally installed for each unit apiece, the last system is always shared by several units in a station. Therefore, the first two systems are calculated on a single unit basis, and the AC Emergency Power is the average value in a station.

The calculation method of these three figures is:

$$UA_x = \frac{(\text{Known unavailable hours} + \text{Estimated unavailable hours})}{\text{Required system available hours} \times \text{Number of trains of the system in a unit (or whole station)}}$$

Item 7: THP (Thermal Performance)

The formula is:

$$THP = \frac{\text{Design gross heat rate} \times 100\%}{\text{Actual gross heat rate}}$$

Item 8: FRI_p (Fuel Reliability)

The FRI_p of PWR is calculated according to this

formula:

$$FRIP = [(A131)_N - 0.0318 (A134)_N] \times [(L_n/LHGR) \times 100/P_o]^{1.5}$$

In this formula:

- > $(A131)_N$ - I-131 Activity of coolant normalized from clean up rate at the time when the coolant activity was measured to reference clean up rate (Bq/gm).
- > $(A134)_N$ - I-134 Activity of coolant normalized from clean up rate at the time when the coolant activity was measured to reference clean up rate (Bq/gm).
- > L_n - Fuel rod reference linear power (16.5kw/m).
- > LHGR - Average fuel rod linear power value at 100% unit power (kw/m).
- > P_o - Average reactor power (%) at the time when the coolant activity was measured.

If $FRIP > 1.9 \times E^+ Bq/gm$, there is a strong possibility of fuel cladding being defective. The fuel cladding forms the first barrier of the three barriers of a nuclear plant.

Item 9: I_{ch} - Chemistry Index

For the PWR with a recirculating type steam generators, its chemistry index is

$$I_{ch} = \left\{ \frac{Ka}{0.8} + \frac{Na}{20} + \frac{O_2}{10} \right\} / 3$$

- > Ka - Cation conductivity rate of steam generators blowdown (£gs/cm, at 25°C).
- > Na - Density of sodium in steam generators blowdown (ppb).
- > O_2 - Density of dissolved oxygen at the outlet of condensate water pumps (PPb).

From the above, we can see that the indicator is a kind of synthetic measurement of the quality of the water on the secondary side of the steam generators aimed at preventing the corrosion of the steam generators tubes.

It is the weak point of the second safety barrier of the pressurized water reactor.

Item 10: Collective Radiation Exposure

This indicator is the average value of the total dose of all the persons in the nuclear power station including the personnel of the owner and personnel of the contractors, in a year shared out equally to each unit. It is a measure to determine the effectiveness of radiation protection plan.

Item 11: Volume of Solid Radioactive Waste

Any kind of solid radioactive waste produced by a nuclear power station must go through conditioning process to enable it to be ready for transportation and ultimate disposal. This indicator is used to measure the total volume of the external packaging for all the solid radioactive wastes produced by each unit per annum after conditioning. It is also a yardstick to measure up the radiation level for the nuclear plant.

Item 12: ISAR (Industrial Safety Accident Rate)

Industrial safety accident rate is the number of accidents per 200,000 or per 1,000,000 man-hours worked for all utility personnel permanently assigned to the station that result in one or more days away from work (excluding the day of the accident), or one or more days of restricted work (excluding the day of the accident), or work-related fatalities. Contractor personnel are not included for this indicator.

Values for the industrial safety accident rate indicator are by member rather than individual plants. They are computed by separately summing and then dividing the number of accidents by the man-hours worked at all plants operated by the member. Values computed by this method are more useful for comparisons than the average of the individual plant indicator values because industrial safety accident rate statistics available for other industries are typically computed in this way.

Paper No. 2

**HONGKONG ELECTRIC'S DISTRIBUTION NETWORK
RELIABILITY ENHANCEMENT - A TOTAL APPROACH**

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HONGKONG ELECTRIC'S DISTRIBUTION NETWORK RELIABILITY ENHANCEMENT - A TOTAL APPROACH

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ABSTRACT

The reliability of distribution network greatly affects the reliability of supply to our customers. The Hongkong Electric Co., Ltd. (HEC) has adopted a total approach in improving the reliability of its distribution system, which includes regular system reliability study, network design review, equipment enhancement and better IT supports etc. This paper outlines the total approach that HEC has taken in improving the reliability of the 11KV and LV distribution system.

1. INTRODUCTION

The Hongkong Electric Co., Ltd. (HEC) began supplying electricity in Hong Kong in 1890 and is now one of the oldest electricity utilities in the world. At present, the distribution system of HEC covers the Hong Kong Island, Lamma Island and Apleichau serving over 0.5 millions customers. The distribution system had undergone continuous changes in the past 100 years and is now one of the most reliable network in the world. The supply reliability rating achieved in 1997 was well over and above our pledged figure of 99.9975%, which is, the average duration of supply interruption due to forced outages was well below the pledged 13 minutes per customer per year.

To achieve a reliability rating of such figure is by no means an easy task. Both the design of the network, the equipment making up the network and the people who operate the network are equally important in achieving the end result. A systematic and 'total' approach is adopted in the past two decades to improve system reliability.

Basically this total approach has two important aspects. First, we have to take a 'life cycle' aspect of the network, that is all stages of the 'life cycle' of the system and its components have to be taken care of in an integrated manner.

Secondly, there should be a 'feedback' mechanism whereby experiences obtained at different stages of the 'life cycle', normally by different groups of people within the organisation at different time frame, are feedback to each other for system or equipment improvement. The 'feedback' mechanism can be divided into two levels. At 'operational' level, the feedback system which deals with day to day operational information shall ensure no important data are lost and that all events are dealt with in a 'close loop' manner. At regular frequency, such 'operational' information should be reviewed and studied from the system level to provide impetus for the next phase of development and enhancement. Review of effectiveness of previous enhancement should also be done at such regular review.

This paper attempts to share the experiences of The Hongkong Electric Co., Ltd. in applying this total approach in distribution network reliability enhancement and some of the fruitful achievements.

2. LIFE CYCLE OF NETWORK

The life cycle of the distribution system could broadly be divided into four stages, which are design stage, development stage, maturity stage and refurbishment/upgrading stage. Due

considerations on reliability shall be accorded to all stages of the life cycle in order to achieve a high overall reliability.

Design stage is the stage where ideas are gathered and consolidated. Many factors will affect the design of the network and its components such as economical and social considerations, development potential and available technology. In most cases, optimization among the above factors has to be made.

Development stage is the stage where the product is transformed from drawing board to realisation. During the development stage, the product will undergo many modifications or improvements to fine tune the product to suit the local conditions, changing needs and actual performance. This is the stage where the network continue to improve, grow and expand.

Maturity stage is the stage where the product reaches its maturity. This is the stage where the network is approaching its design and performance limits. Due to inherent limitations, further expansion or improvement of the system may not be justified. Most of the resources will be spent in maintaining and up keeping the system. This is also the stage where the system reliability stabilised and may start to degrade near its end.

Refurbishment/upgrading stage is the stage where the resources putting in maintaining the aged products near the end of their useful life to the desired state of reliability and availability is no longer justifiable. In addition, the performance or capability of the product may no longer satisfy the latest and often increased customer expectations. Under such situation, refurbishment/upgrading will be a reasonable move from both economical and customer services points of view. Formulating the refurbishment/upgrading policy is as important as designing a new system. This will ensure that the reliability of the system can be maintained in accordance with customer expectation and requirements.

3. SYSTEM RELIABILITY STUDY

Before 1985, there was no regular systematic reliability review for the transmission and distribution system. Studies on the performance of the network were carried out on an adhoc basis. The first comprehensive T&D reliability study was performed in 1985 with the objective to improve the T&D equipment. Since 1985, the system reliability study was conducted regularly at 3-yearly interval. The scopes of studies covered all equipment at all voltage level in the T&D network, from primary transmission equipment at 275KV to auxiliary equipment in the LV network as well as protection and communication equipment.

The main themes of the studies are to review the performance and requirements of the equipment since last review, to review the implementation progress and effectiveness of the recommendations in the last study and to propose improvement plans to further enhance the system. The studies also expanded in recent years to include system inventory, micro-level performance statistics, spare parts and logistic review.

This system of reliability studies now becomes the core of the feedback mechanism where day to day operational data are gathered and analysed in a systematic manner from the overall system point of view. Each department is responsible to review their parts of the system. The study results will be compiled and improvement plans will be proposed. The proposed improvement plans will then be scrutinized by a separate committee for the formulation of the final improvement plans.

Five rounds of system reliability study have already been conducted so far and many enhancement plans were implemented and many are still ongoing.

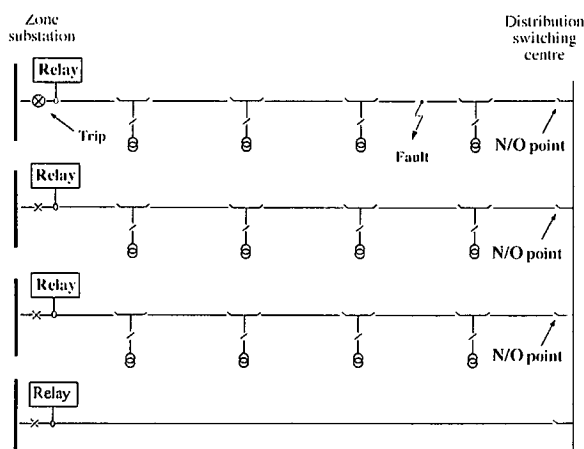
4. 11KV DISTRIBUTION NETWORK

In HEC, the MV distribution network had

already gone through one complete product life cycle. In the very beginning of the distribution system, 6.6KV was used as the MV distribution voltage. However, from 1946 to 1966, the electricity consumption in Hong Kong Island had increased by 12 times which made the 6.6KV system no longer sufficient to meet the demand. In order to meet the high electricity demand in the 60's, 11KV distribution network was introduced. The 6.6KV system was eventually phased out in the late 60's and the 11KV network became the only distribution system in HEC since 1970.

The 11KV distribution network is basically a radial feed network with load break ring main unit to form an 'open ring'. Each feeder is interconnected with other feeders to form the feeder group by means of normally open (N/O) switches. The typical feeder group diagram is shown in Fig.1. This network has the merits of simplicity and high utilisation factor. However, the availability of the network is less than that of the close ring system. If any component failed in one of the 11KV feeders, the fault could only be cleared by the circuit breaker at the zone substation. As a result, the whole feeder leg will lose the supply. The fault has to be isolated before the supply could be restored. The time required to restore the supply greatly depends on the time required to locate and isolate the faulty component from the network.

Fig. 1 Typical 11kV Network



4.1 AUTOMATION OF DISTRIBUTION NETWORK

Without the help of fault indication and remote switching facilities, it usually took hours to identify and isolate the faulty section. To meet the ever increasing demand of continuous supply from the customers, HEC had started the feasibility study to automate the distribution network in mid 70's. The feasibility study result was by no means encouraging as the technology in distribution automation at the 70's was very primitive. In addition, the 11KV ring main unit available with remote control facilities was also very limited. To overcome all these technical hurdles, HEC had established a special team to handle and develop the necessary hardware of the remote terminal unit (RTU). Joint development with switchgear manufacturer was also conducted to develop the necessary ring main unit with remote control feature for HEC. After years of development, HEC started to automate its network in 1979, initially at 112 selected substations at Central District. Up to now, 100% automation on over 3,100 distribution substations in HEC network has been achieved. With these facilities installed, the average supply restoration time has significantly been reduced. In 1997, the average supply restoration time for 11KV network is less than 4 minutes.

4.2 FROM OVERHEAD TO UNDERGROUND

Hong Kong is situated in the sub-tropical area where typhoons will often hit this Island in the summer season. Well in the design stage of the 11KV distribution system, decision had been made to use underground cables except in the mountainous terrain in Lamma Island. In early 90's all 11KV overhead lines were phased out which made the HEC's 11KV distribution system a purely underground system.

4.3 MULTIPLE SOURCE INFEED

Another important consideration of the supply reliability of the distribution network is the availability of backfeed capacity during 11KV equipment failure. To achieve a highly reliable network even under 11KV equipment failure

(mainly cable failures) while maintaining a reasonable utilisation factor, each feeder group is designed to consist of 4 feeders with one lightly loaded clean feeder as backup source. In addition, the supply sources of all 4 feeders are fed from different zone substations or different zone transformers within the same zone substation. Hence, under all single contingency situations, the supply to each feeder group could be maintained.

4.4 DUAL FEEDER GROUP TOPOLOGY

Apart from the multiple source infeed topology which is designed to cater for single equipment failure in the feeder group, dual feeder group topology is also adopted since the 90's to reduce the impact of equipment failure to customers. For new distribution substations with more than one transformer, the transformers will be supplied from different feeder groups or different legs of the same feeder group as far as practicable. If there is any failure on 11KV distribution network, the building supplied by the substation will not lose their supply completely.

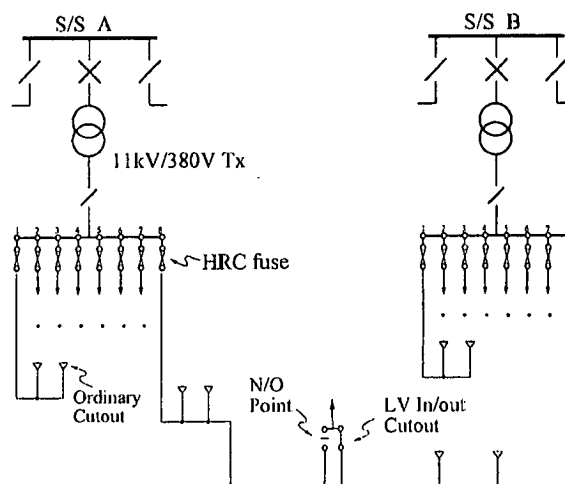
5. LV DISTRIBUTION NETWORK

On the low voltage side, 200/346V was first adopted in 1920 and the voltage prior to that was only 100V. To be in line with the commonly adopted low voltage system in other parts of the world, the voltage was gradually upgraded to 220/380V from January 1993 to February 1997.

Unlike the 11KV distribution network, the LV distribution network is basically a single end feed network dominated by radial feeders. With the introduction of LV in-out type cutout in 1986, the network was gradually converted from radial feed network to open ring network with interconnection cables as shown in Fig. 2.

Up to the present moment, there are about 14,000 LV cables in service with one third of them interconnected. To further enhance the supply reliability, more interconnection cables will be formed in the coming years.

Fig. 2 Typical LV Network



In addition to underground cable, LV overhead lines were also used in rural area. 5-wire insulated overhead line system was widely used before 1990. To enhance the reliability of the LV overhead line system, aerial bundle cable (ABC) system was introduced in 1990. Active upgrading schemes were carried out since then and the 5-wire system was completely phased out in 1995. Where practicable, open-ring ABC system with open point will also be formed. The ABC system has greatly improved the supply reliability to rural area and there were only a few supply interruptions on the LV overhead system recorded in 1997, mainly due to falling down of trees during typhoon.

6. DISTRIBUTION EQUIPMENT

Reliability of the distribution equipment plays a very important role on the overall reliability of the distribution network. It is necessary to ensure that all equipment are designed and manufactured to the required international standards. In addition, it is also necessary to ensure the equipment are designed/adapted for the local installation conditions. Specifications of distribution equipment are prepared by experienced engineers with field experiences in operation and maintenance of that particular type of equipment. Besides, special committee with members from different departments will

meet and review the performance of the equipment especially in the design and development stage. The following sections highlight some of the key activities that HEC has made to improve the reliability of the distribution equipment/substation.

6.1 SUBSTATION DESIGN

In HEC, the distribution equipment will be installed indoor in either distribution substation or stainless steel pillar. It is necessary to ensure the equipment are operated within the designed ambient temperature. In designing the distribution substation, due consideration has been given to ensure natural ventilation could take place. In addition room temperature sensor and transformer temperature sensor are installed such that the forced ventilation system will be activated automatically when the temperatures exceed the corresponding preset limits.

In addition to temperature sensors, flood prevention system which consists of sump pump and 2-stage flooding alarm are installed in basement substations or sunken substations after the torrential rain storm in May 1992. With this system, System Control would be informed of the potential flooding problem and necessary action could be taken before equipment failure occurred.

Although SF₆ equipment are widely used in distribution substation which are relatively insensitive to installation environment, many mechanical parts such as switchgear operating mechanism are prone to dusty environment. To ensure the mechanical parts will not be contaminated by dust, new distribution substation will be divided into two separated compartments. The HV compartment will be used to house the 11KV ring main unit where no mechanical ventilation will be provided to reduce dust ingress. For the LV compartment, transformer and other dust insensitive equipment, forced ventilation will be installed. It is believed that this arrangement will further increase the reliability of the equipment as well as reduction in maintenance effort.

6.2 DISTRIBUTION EQUIPMENT FAULT ANALYSIS

In order to evaluate the reliability of each type of distribution equipment, a systematic approach in analysing the failure rate is required. A special committee consists of members from different departments is formed which prime objective is to investigate the cause of failure of each failed equipment. For each failed equipment, dissection will be carried out, sometimes with representative from manufacturer, to investigate the cause of failure. Analysis results will be properly documented which will be used to compile the performance indices of that particular equipment. In addition, the committee will also discuss with manufacturer to formulate improvement plans. If the failure is due to ageing and the failure rate is on the increasing trend, the committee will also propose refurbishment/upgrading plans for senior management's consideration. With this structured analysis on the performance of distribution equipment and the respective improvement plans, significant improvement on the reliability rating of several major distribution equipment are observed in the past few years.

6.3 MAINTENANCE POLICY

After almost 30 years of development, the HEC's 11KV distribution network has almost reached its maturity stage. Proper maintenance policy has to be formulated to up keep the reliability of the system. In the past, fixed interval preventive maintenance was conducted on distribution apparatus. This policy is simple and easy to administer. However, this policy assumes the installation and service conditions of all equipment are identical, which obviously is not the case. Recently, HEC has adopted the reliability centred maintenance principle where the maintenance cycle depends on the service conditions of the substation and equipment. To determine the maintenance frequency of that particular substation, dust samples are collected and the concentrations are analysed. Based on the dust concentration level, the substation inspection and cleaning cycle and

maintenance cycle are determined.

With this policy implemented, it is expected that the maintenance work will be carried out in a more efficient and effective manner and the reliability of equipment could be improved.

7. DEVELOPMENT OF INFORMATION SYSTEM

The use of computer in the engineering aspect of distribution system such as Mapping Computer and Distribution Computer is well known to utilities. However, it is equally important to apply computerized management and control techniques to enhance the reliability as illustrated in the following applications.

7.1 LOAD STATISTICS SYSTEM

The load statistics system is an in-house developed application in 1991. This system makes use of the huge amount of load data captured by Distribution Computer and provides a user friendly platform for the user to study the load and other operational data of the distribution system. Planner could review nearly every daily load data in every substation. These information include all the analogue data retrieved by the Distribution Computer such as transformer voltage, transformer currents, LV cable currents and even room temperature. Graphical load trends could also be displayed by the system. With these data in hand, system planner could then derive the necessary reinforcement plan before the equipment reach its full capacity. This will ensure all equipment be operated up to and within its design limit and will avoid premature equipment failure. The same set of data can also be used for operational use such as arrangement of backfeed under fault condition.

7.2 DEFECT HANDLING SYSTEM

The defect handling system is the main feedback system at operational level. This system is an in-house networked PC application developed in 1991. This system

captures all the defects or special events and stored them in a database. The cases will be classified in accordance with their nature and the responsible section will be alerted to take necessary action to handle/rectify the defect. This system has captured over ten thousands records since its commissioning and has ensured that even seemingly unimportant cases are handled in a close loop manner and are properly documented for subsequent analysis.

The PC based defect handling system is now being upgraded into a host application with better work flow control and will be launched in end 1998.

7.3 MAINTENANCE SCHEDULING SYSTEM

To cope with the large amount of transmission and distribution maintenance activities, a "job sheet" system was first developed in 1984 on the mainframe computer platform. This system captured the maintenance activities and the frequency required on each and every piece of equipment and produced the relevant job sheet automatically to notify the responsible department. The system was later replaced by another in-house application called Maintenance Scheduling System (MASS) on another host computer in 1996. This second generation system is more flexible and contains more rules than the old one. Furthermore, users can view the maintenance next due list such that he can plan his maintenance work in advance.

8. CONCLUSION

This paper has briefly outlined the approach that HEC has taken to enhance the supply reliability of the distribution system. Examples of enhancements on the distribution system made over the past 20 years are also introduced. With all these enhancements implemented, the HEC's distribution system has developed into one of the most reliable systems in the world as reflected in its reliability rating achieved.

As illustrated above, such achievement would

hardly be attained without a total approach which the author would like to share the experiences with others.

9. ACKNOWLEDGEMENT

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Paper
No. 2

REFERENCE

- [1] L. Chan, P.K. Chan - "Transmission and Distribution of Electricity in Hongkong Electric - Past, Present, and Future", HKIE Symposium 1997

Paper No. 3

**THE HAWAII H-3 TETSUO HARANO TUNNEL -
A HIGH RELIABILITY POWER SYSTEM**

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THE HAWAII H-3 TETSUO HARANO TUNNEL - A HIGH RELIABILITY POWER SYSTEM

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New York, U.S.A.

ABSTRACT

The electrical power distribution system designed by Parsons Brinckerhoff for the one-mile long, twin-bore, Hawaii H3 Tetsuo Harano Tunnel was a high reliability system with an emphasis on redundancy and flexibility in order to maintain operation of all critical tunnel loads. For maximum reliability, full use was made of the various sources of power for tunnel loads which included two separate radial utility circuits at 46 kV each, one on-site 500 kW emergency diesel engine-generator, and numerous uninterruptible power supplies located throughout the tunnel. If both of the utility circuits were unavailable, a load-shedding scheme was enacted to maintain power to critical loads. The primary distribution system consisted of two separate medium voltage 12.47 kV metal-clad vacuum switchgear substations located at each end of the tunnel. Under normal conditions, each 12.47 kV substation was operated in a split-bus configuration with one-mile long, cross-tunnel 12.47 kV feeders connecting respective buses together for maximum reliability. In addition, a complex scheme of hard-wired interlocking 12.47 kV breakers permitted automatic reconfiguration following occurrences such as loss of utility, bus fault, feeder fault, etc. Double-ended 480 V unit substations with full-size transformers provided a highly reliable 480 V distribution system for critical loads such as tunnel ventilation fans, fire pumps, etc. Primary 12.47 kV feeders to the unit substations and all other co-located devices were installed in separate conduits to prevent a faulted cable damaging other circuits. Because of the numerous different configurations that the 12.47 kV breakers could operate in, especially with a bus-tie breaker, relay settings for all 12.47 kV breakers were set to the maximum loading level that each breaker would see for maximum reliability and flexibility. For faster response time and to aid in diagnostics of the system, the 12.47 kV switchgear breakers and 480 V main and bus-tie breakers are monitored and operated

remotely from the control room at the Halawa portal.

Major reliability features of the H3 power system are:

1. Transmission voltage of 46 kV from utility for higher reliability
2. True redundant 46 kV feeds from two utility substations
3. Full-size main substation 10 MVA transformers
4. Total four sources of power (two utility feeds + generator + numerous UPS units)
5. 12.47 kV split bus configuration with cross-tunnel feeders
6. 12.47 kV hard-wired interlocked breakers with interposing relays
7. 480 V double-ended unit substations with full-size transformers
8. Separate raceway for 12.47 kV feeders to unit substations
9. 12.47 kV relays set for maximum loading
10. Remote operation of power system via control room

1. INTRODUCTION

The H-3 Tetsuo Harano Tunnel is a 1.6-kilometer (km) or 1-mile long, twin-bore tunnel that is an integral part of a new 26-km (16-mile) four-lane interstate highway that connects the windward and leeward sides of the island of Oahu. The inbound tunnel (carrying traffic towards Honolulu) and the outbound tunnel (carrying traffic away from Honolulu) traverses through the scenic Koolau mountain

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range. A cross-over section just outside each tunnel portal permits contra-flow traffic if necessary.

At an approximate cost of \$1.3 billion (US) over 30 years, Hawaii's Interstate Route H-3 is the largest public construction project in the state's history. Funding for the project consisted of a 90 percent share by the Federal Highway Administration (FHWA) and a 10 percent share by the State of Hawaii Department of Transportation. Parsons Brinckerhoff provided planning, engineering design, construction management, post-design, and operations and maintenance support services for the H-3 Tetsuo Harano Tunnel, as well as overall program management for the entire 26-km (16-mile) length of Interstate Route H-3.

The electrical power distribution system for the H-3 Tetsuo Harano Tunnel is based primarily on a requirement for a highly reliable power supply to critical loads. Thus, a high level of redundancy has been designed into the power distribution system to provide alternate paths of power for tunnel ventilation, lighting, fire fighting and detection, traffic control, and central computer and communication systems. However, total interruption of power to the lighting system cannot be tolerated because a sudden blackout within the tunnel could cause driver confusion and/or vehicular collisions.

2. UTILITY POWER SOURCE

The primary source of power to the tunnel is from the local electric utility, Hawaiian Electric Company (HECO). For maximum reliability, bulk power from HECO is provided through two separate high-voltage 46 kilovolt (kV) overhead transmission lines, as opposed to lower voltage distribution circuits. Distribution circuits generally have limited power transfer capability and are typically connected to other customers, which may affect the reliable supply of power to the tunnel.

Each 46 kV transmission line originates from a

separate HECO substation to provide true redundancy. Thus, a single HECO substation failure will not affect both circuits. Conceivably, only an island-wide outage would affect both HECO substations. One HECO transmission line traverses up the Halawa Valley to the tunnel at the Halawa portal, while the other line comes from the opposite direction up the Haiku Valley to the tunnel at the Haiku portal.

Each HECO 46 kV transmission line is a radial circuit that terminates at an outdoor substation located just outside each portal: HECO Halawa H-3 Substation at the Halawa portal, and HECO Haiku H-3 Substation at the Haiku portal. Each HECO substation is owned and operated by HECO and contains a 46 kV primary disconnect switch, a 10 megavolt-amperes (MVA), 46-12.47 kV transformer, and a 12.47 kV secondary circuit breaker. Figure 1 shows the main one line diagram of the power distribution system.

Normally, each HECO 10 MVA transformer is expected to carry half of the worst-case design load of 5 MVA. However, if one of the two HECO lines becomes unavailable, the entire tunnel load of 10 MVA can safely pass through the opposite transformer.

3. EMERGENCY POWER SOURCES

Two other sources of power back up the two HECO 46 kV transmission lines: a single 500 kilowatt (kW), 480 V, three-phase, diesel-driven, emergency engine-generator and numerous uninterruptible power supply (UPS) units and battery/inverter units.

Since it is unnecessary to provide full backup power for the entire tunnel load of 10 MVA, the emergency generator is sized for the prolonged operation of only the following emergency loads as necessary:

- One 100 horsepower fire pump
- Emergency tunnel (nighttime intensity) and viaduct lighting

- Emergency power and lighting in the four portal buildings
- Emergency power and lighting in the control building
- Control room computer and other communications systems

The UPS units provide continuous power without interruption during a normal power HECO failure and also provide clean power for the supervisory and control system and its peripheral equipment. The supervisory and control computer system is particularly sensitive to overvoltage, undervoltage, transients, switching surges, frequency variations and, most of all, loss of HECO power. The effect of loss of power and random disturbances of the power supply on a computer could result in memory loss, garbled data, erroneous transfer and needless self-shutdown.

A typical UPS unit consists of an isolation transformer, alternating current (AC) to direct current (DC) rectifier, static inverter (DC to AC), static transfer switch, battery charger, and a battery bank capable of supplying power for a limited period. The supervisory and control system UPS units contain a battery bank with a 15-minute capacity.

For tunnel lighting, battery/inverter units with fast transfer capability are used. The transfer time from normal utility power to battery inverted power is quick enough to maintain high intensity discharge (HID) lighting without encountering restrike of the lamps. The battery bank for the tunnel lighting units has a 90 minutes capacity in order to comply with code requirements for safe egress.

For prolonged operation, the emergency generator supplies power to the UPS units and the tunnel lighting battery/inverter units. Thus, extended operation of the tunnel in absence of any utility power from HECO is limited by the amount of diesel fuel stored on site which is used by the emergency generator (plus any operational restrictions imposed due to lack of tunnel ventilation capacity).

All emergency loads fed from the emergency generator pass through an automatic transfer switch (ATS). The entire power distribution system contains both 12.47 kV ATSs and 480 volt (V) ATSs. With the exception of the seven 12.47 kV tunnel lighting feeder ATSs, all ATSs select between normal power (HECO) and emergency power (generator). A voltage sensor is attached to both the normal power and emergency power lugs on the ATSs to sense if voltage, and therefore power, is available from either or both sources.

Once HECO power becomes available, the ATS begins to sense voltage at the normal power lugs. The ATS, however, does not immediately switch back to normal power. A time delay of several minutes is programmed into each ATS to ignore a momentary or unstable return of HECO power.

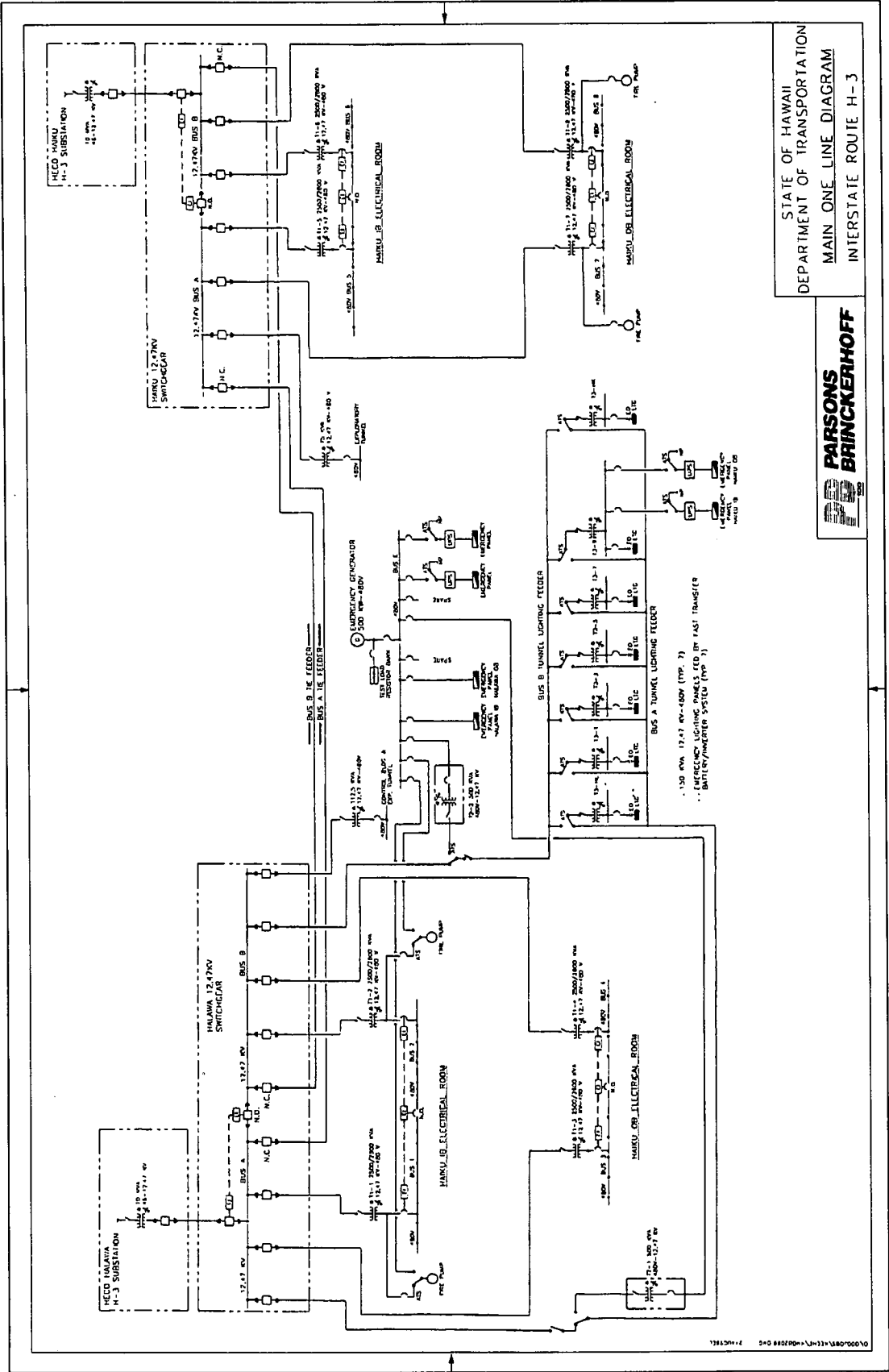
4. 12.47 KV SWITCHGEAR SYSTEM

The 12.47 kV distribution system for the H-3 Tetsuo Harano Tunnel is controlled by metal-clad switchgear with vacuum circuit breakers. The Halawa 12.47 kV switchgear is located in the Halawa inbound portal building and is fed from the HECO Halawa H-3 Substation. Likewise, the Haiku 12.47 kV switchgear is located in the Haiku outbound portal building and is fed from the HECO Haiku H-3 Substation. Figure 2 shows the front of the Haiku 12.47 kV and 480 V switchgear.

Each 12.47 kV switchgear system normally operates in a split-bus configuration (Bus A and Bus B) with a normally open bus-tie circuit breaker. For higher reliability and flexibility, the bus-tie circuit breaker can be closed so that Bus A and Bus B essentially operate as one common bus.

The Halawa 12.47 kV switchgear is considered to be the Bus A source of power, where power originates from the HECO Halawa H-3 Substation. Likewise, the Haiku 12.47 kV switchgear is considered to be the Bus B source of power, where power originates from the

Figure 1.: Main One Line Diagram.



HECO Haiku H-3 Substation.

For even higher reliability, tie feeders between the Halawa 12.47 kV switchgear and the Haiku 12.47 kV switchgear provide alternate paths for power flow. The Bus A Tie Feeder originates from a feeder circuit breaker at Halawa Bus A and connects to a circuit breaker at Haiku Bus A. Likewise, the Bus B Tie Feeder originates from a feeder circuit breaker at Haiku Bus B and connects to a circuit breaker at Halawa Bus B. Both tie feeders are 1.6-km (1-mile) long and consist of three 15 kV cables installed in an underground, concrete-encased ductbank.

In order to prevent a failure of one tie feeder from affecting or damaging the other, each tie feeder runs through a separate ductbank through different tunnels. The Bus A Tie Feeder runs through the outbound tunnel, while

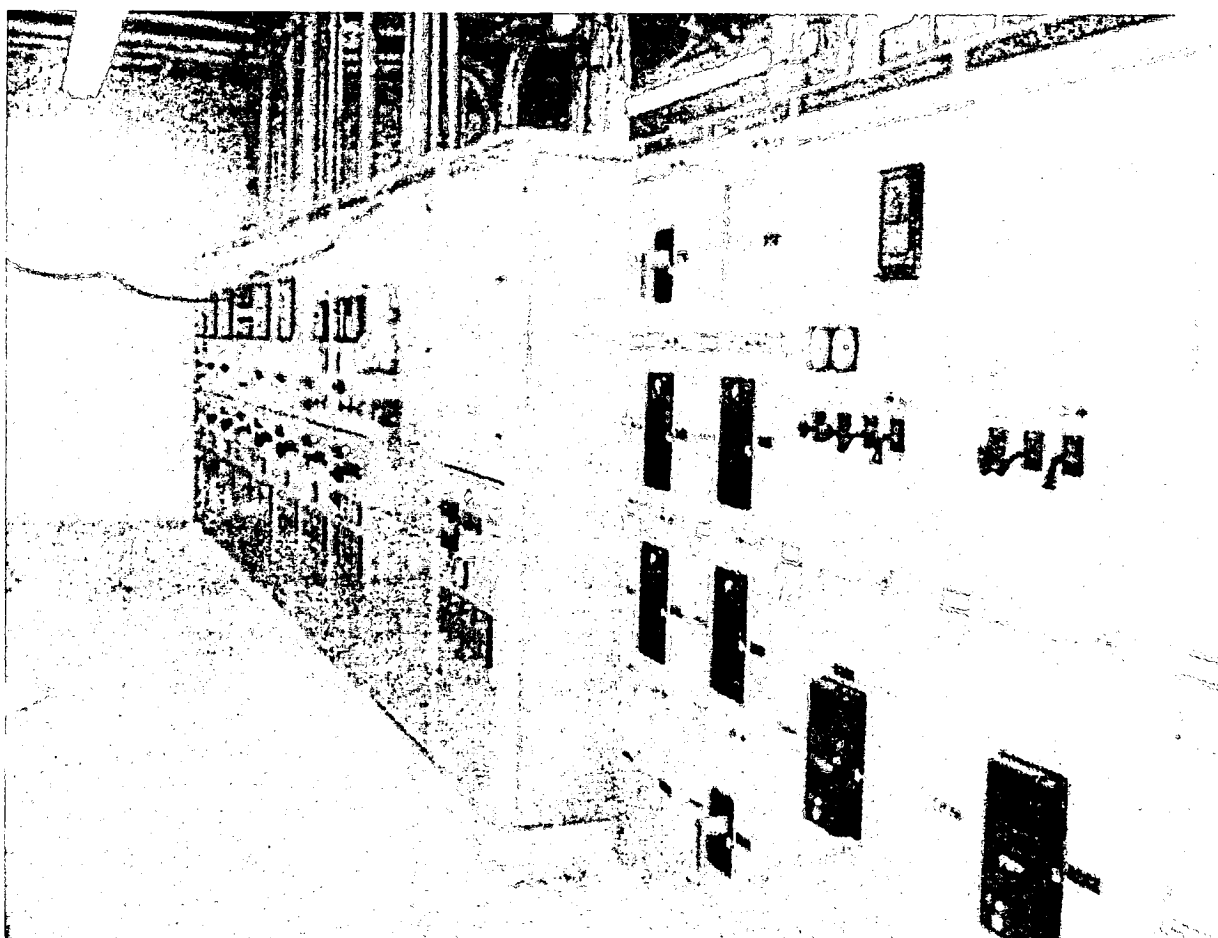
the Bus B Tie Feeder runs through the inbound tunnel.

Thus, the split-bus, tie feeder concept permits half of the loads at Halawa to be fed from Haiku and half of the loads at Haiku to be fed from Halawa. It is widely known that the likelihood of cable failures for long feeders is increased when the feeders are normally de-energized. Thus, the tie feeder concept continuously maintains energized 12.47 kV feeders over the entire 1.6-km (1-mile) length of the tunnel.

Control power and relaying functions for the 12.47 kV switchgear and 480 V switchgear are accomplished using DC power. For maximum reliability, a separate and dedicated battery bank is furnished.

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Figure 2.: Front of Haiku 12.47 kV switchgear (left) and 480 V switchgear (right).



5. PARALLELING OF HECO CIRCUITS

With the tie feeder connection between the Halawa and Haiku 12.47 kV switchgear, it appears that the two HECO sources may be paralleled. HECO, however, specifically prohibits paralleling of the two HECO sources at any time, and the 12.47 kV switchgear system has been specifically designed to prevent a paralleling condition.

Since the two 46 kV HECO transmission lines originate from separate HECO transmission substations, they could easily have different phase angles even though their voltage levels are identical at 46 kV. When two circuits are operating in parallel with differing phase angles, the peak sinusoidal voltage occurs at different times, thereby subjecting all points along the electrical distribution system to a much higher voltage than normal. In addition, the two different voltage waveforms combine to produce an altered waveform, which is generally unacceptable to sensitive electronic equipment.

A series of interlocks is in place in the 12.47 kV and 480 V switchgear systems to prevent any paralleling of the two HECO sources. This interlocking feature of circuit breakers is automatic and cannot be altered.

For example, the main circuit breaker and bus-tie circuit breaker at the Halawa 12.47 kV switchgear are electrically interlocked (EI) such that both circuit breakers can never be closed simultaneously; one or both of the circuit breakers must always be open. If such an interlocking scheme were not in place, the closure of the Halawa bus-tie circuit breaker would permit power from the HECO Haiku H-3 Substation to parallel power from the HECO Halawa H-3 Substation at Bus A of the Halawa switchgear (through the 12.47 kV tie feeder from Bus B of the Haiku 12.47 kV switchgear).

6. AUTOMATIC RESTORATION

Not only does the interlocking of 12.47 kV

circuit breakers prevent a paralleling condition, it also provides one of the more significant reliability features of the 12.47 kV switchgear system. The interlocking of the 12.47 kV circuit breakers is integral to the automatic restoration of power to lost loads following a loss of HECO power, feeder fault, bus fault, or any combination of these failures.

In addition, for maximum reliability, the interlocking of 12.47 kV circuit breakers is accomplished through a hard-wired system of control wires over the 1.6-km (1-mile) between the Halawa and Haiku 12.47 kV switchgear. Due to the excessive distance, interposing relays are used at either end of the control circuits to compensate for the accompanying excessive voltage drop.

The control interlock trips for the 12.47 kV circuit breakers are listed below. Circuit breaker trips resulting from overcurrent conditions, faults, or utility direct transfer trips are not included below since they are typical functions for relays controlling medium voltage circuit breakers.

The Halawa main circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Haiku main, Haiku bus-tie, and Halawa Bus A tie feeder (sending) circuit breakers are closed.
- Trip if the Haiku main, Halawa bus-tie, and Haiku Bus B tie feeder (sending) circuit breakers are closed.
- Trip on utility undervoltage after time delay.

The Halawa Bus A tie feeder (sending) circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Halawa main circuit breaker locks out.
- Trip and lock out if the Haiku Bus A tie feeder (receiving) circuit breaker locks out.
- Trip on utility undervoltage after time delay in tandem with the Halawa main circuit breaker.
- Close if both the Halawa and Haiku bus-tie

circuit breakers are open and the Halawa main and Haiku Bus A tie feeder (receiving) circuit breakers are not locked out.

- Close if the Halawa main circuit breaker is open, the Halawa Bus B tie feeder (receiving) circuit breaker is open and not locked out, the Halawa bus-tie circuit breaker is locked out, and the Halawa main and Haiku Bus A tie feeder circuit breakers are not locked out.
- Close if the Haiku Bus A tie feeder circuit breaker is tripped and not locked out, the Haiku bus-tie circuit breaker is locked out, and the Halawa main circuit breaker is not locked out.
- Close if the Haiku main circuit breaker is open, the Haiku Bus B tie feeder (sending) circuit breaker is open, and the Halawa main and Haiku Bus A tie feeder circuit breakers are not locked out.
- Close if the Halawa main circuit breaker is open, the Haiku Bus B tie feeder (sending) circuit breaker is locked out, and the Halawa main and Haiku Bus A tie feeder (receiving) circuit breakers are not locked out.
- Close if the Haiku bus-tie circuit breaker is open, the Haiku Bus B tie feeder (sending) circuit breaker is locked out, and the Halawa main and Haiku Bus A tie feeder (receiving) circuit breakers are not locked out.

The Halawa bus-tie circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Halawa main circuit breaker locks out.
- Trip if the Halawa main, Haiku main, and Halawa Bus B tie feeder (receiving) circuit breakers are closed.
- Lock out in tandem with a Halawa Bus B tie feeder circuit breaker lock out unless both the Halawa main and Halawa bus-tie circuit breakers are closed.
- Close if the voltage is normal on Halawa Bus A or Halawa Bus B but not both Bus A

and Bus B, the Halawa main circuit breaker is not locked out, the Halawa Bus B tie feeder (receiving) circuit breaker is not locked out, and either the Halawa main or Haiku main or Halawa Bus B tie feeder (receiving) circuit breakers are open.

The Halawa Bus B tie feeder (receiving) circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Haiku Bus B tie feeder (sending) circuit breaker is open.
- Lock out in tandem with a Halawa bus-tie circuit breaker lockout.
- Close if the Halawa bus-tie circuit breaker is open and the Haiku Bus B tie feeder (sending) circuit breaker is closed.
- Close if the Haiku main or Halawa main circuit breakers are open, the Halawa Bus A tie feeder (sending) circuit breaker is open and not locked out, and the Haiku Bus B tie feeder (sending) circuit breaker is closed.

The Haiku Bus A tie feeder (receiving) circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Halawa Bus A tie feeder (sending) circuit breaker is open.
- Lock out in tandem with a Haiku bus-tie circuit breaker lock out.
- Close if the Haiku bus-tie circuit breaker is open and the Halawa Bus A tie feeder (sending) circuit breaker is closed.
- Close if the Halawa main or Haiku main circuit breakers are open, the Haiku Bus B tie feeder (sending) circuit breaker is open and not locked out, and the Halawa Bus A tie feeder (sending) circuit breaker is closed.

The Haiku bus-tie circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Haiku main circuit breaker locks out.
- Trip if the Haiku main, Halawa main, and Halawa Bus A tie feeder (sending) circuit breakers are closed.

- Lock out in tandem with a Haiku Bus A tie feeder (receiving) circuit breaker lock out unless both the Haiku main and Haiku bus-tie circuit breakers are closed.
- Close if the voltage is normal on Haiku Bus A or Haiku Bus B but not both Bus A and Bus B, the Haiku main circuit breaker is not locked out, the Haiku Bus A tie feeder (receiving) circuit breaker is not locked out, and either the Haiku main or the Halawa main or the Haiku Bus A tie feeder (receiving) circuit breaker is open.

The Haiku Bus B tie feeder (sending) circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Haiku main circuit breaker locks out.
- Trip and lock out if the Halawa Bus B tie feeder (receiving) circuit breaker locks out.
- Trip on utility undervoltage after time delay in tandem with the Haiku main circuit breaker.
- Close if both the Haiku and Halawa bus-tie circuit breakers are open and the Haiku main and Halawa Bus B tie feeder (receiving) circuit breakers are not locked out.
- Close if the Haiku main circuit breaker is open, the Haiku Bus A tie feeder (receiving) circuit breaker is open and not locked out, the Haiku bus-tie circuit breaker is locked out, and the Haiku main and Halawa Bus B tie feeder (receiving) circuit breakers are not locked out.
- Close if the Halawa Bus B tie feeder (receiving) circuit breaker is tripped and not locked out, the Halawa bus-tie circuit breaker is locked out, and the Haiku main circuit breaker is not locked out.
- Close if the Halawa main circuit breaker is open, the Halawa Bus A tie feeder (sending) circuit breaker is open, and the Haiku main and Halawa Bus B tie feeder (receiving) circuit breakers are not locked out.
- Close if the Haiku main circuit breaker is open, the Halawa Bus A tie feeder

(sending) circuit breaker is locked out, and the Haiku main and Halawa Bus B tie feeder (receiving) circuit breakers are not locked out.

- Close if the Halawa bus-tie circuit breaker is open, the Halawa Bus A tie feeder (sending) circuit breaker is locked out, and the Haiku main and Halawa Bus B tie feeder (receiving) circuit breakers are not locked out

The Haiku main circuit breaker will automatically control interlock operate under the following conditions:

- Trip if the Halawa main, Halawa bus-tie, and Haiku Bus B tie feeder (sending) circuit breakers are closed.
- Trip if the Halawa main, Haiku bus-tie, and Halawa Bus A tie feeder (sending) circuit breakers are closed.
- Trip on utility undervoltage after time delay.

7. TUNNEL LIGHTING FEEDERS

The 12.47 kV tunnel lighting feeders are critical because a sudden blackout within the tunnel could cause driver confusion as well as vehicular collisions. Thus, the power supply to the tunnel lighting fixtures must be highly reliable. A complex combination of two HECO power sources through numerous 12.47 kV Bus A and Bus B configurations, emergency generator feeders, automatic transfer switches, and battery/inverter units provide a multitude of alternate paths for power to the critical tunnel lighting distribution buses for maximum reliability. Upon loss of normal HECO power, electrically operated contactors remain closed to power a sub-panel that feeds critical lighting loads.

There are two 12.47 kV tunnel lighting feeders: the Bus A tunnel lighting feeder and the Bus B tunnel lighting feeder. Each tunnel lighting feeder provides power to seven 12.47 kV ATSS and seven 150 kilovolt-amperes (kVA), 12.47 kV - 480Y/277 V, three-phase, pad-mount transformers, respectively, that are located in

the following locations:

- Halawa vault (located at cross-over traffic lanes on exterior approach to Halawa portal)
- Cross-passage 1
- Cross-passage 3
- Cross-passage 5
- Cross-passage 7
- Cross-passage 9
- Haiku vault (located at cross-over traffic lanes on exterior approach to Haiku portal)

A single upstream 12.47 kV ATS that can select between normal power (HECO) and emergency power (generator) is included in both tunnel lighting feeders. Normal power (HECO) is selected based on the Bus A and Bus B designations of the 12.47 kV switchgear system for the Bus A tunnel lighting feeder and Bus B tunnel lighting feeder, respectively. Emergency power is selected through a connection to a unit substation, which is fed directly from the emergency generator bus through a 480 V feeder. Each unit substation contains a 500 kVA step-up transformer to convert the emergency generator power at 480 V to 12.47 kV (i.e., transformer T2-1 for Bus A tunnel lighting feeder and transformer T2-2 for Bus B tunnel lighting feeder).

8. LOSS OF HECO

The loss of one HECO line is anticipated to be the most common failure. As such, the automatic circuit breaker interlocking schemes designed into the 12.47 kV switchgear system will immediately operate to restore power to lost loads.

To compensate for loss of power from the HECO Halawa H-3 Substation, the 12.47 kV switchgear system first automatically trips the main circuit breaker at the 12.47 kV Halawa switchgear because it senses an undervoltage condition. As a result, circuit breaker interlocks then disengage the Bus A tie feeder by automatically tripping the two feeder circuit

breakers on each end of the tie feeder, i.e., Halawa Bus A (sending) and Haiku Bus A (receiving). At this point, all loads being fed from Bus A at both Halawa and Haiku are lost.

Power is then automatically restored to all Bus A loads by the immediate closure of the bus-tie circuit breaker at both Halawa and Haiku. Thus, the Halawa Bus A loads are now fed through the Halawa bus-tie circuit breaker connecting Halawa Bus B (and ultimately from Haiku Bus B via the Bus B tie feeder). Similarly, the Haiku Bus A loads are now fed from Haiku Bus B through the Haiku bus-tie circuit breaker.

9. LOCAL MANUAL RESTORATION

Three types of failures (HECO down, tie feeder fault, and bus fault) are the basic failure modes for the 12.47 kV switchgear system. In addition, there are two distinct HECO failures (i.e., HECO Halawa down and HECO Haiku down), and two distinct tie feeder faults (i.e., Bus A tie feeder and Bus B tie feeder). However, there are actually four bus faults (i.e., Halawa Bus A, Halawa Bus B, Haiku Bus A, and Haiku Bus B).

Given that there are a total of eight distinct types of failures, the possible combinations thereof are numerous. In considering triple contingency failures, there are nearly one hundred possible combinations. For example, one such triple failure would be: HECO Haiku down followed by a Bus A tie feeder fault followed by a bus fault on Halawa Bus A. Parsons Brinckerhoff prepared a detailed sequence of actions and restoration procedures was prepared for nearly one hundred failure scenarios for use by maintenance personnel and control room operators.

Once the cause of the failures has been remedied, the 12.47 kV switchgear system can be manually restored to the normal split-bus configuration. Manual restoration is possible either locally (physically at the 12.47 kV switchgear) or remotely (from the control room computer). Local manual restoration requires

personnel at either or both the Halawa and Haiku 12.47 kV switchgear lineups in order to open and close the appropriate circuit breakers in the proper sequence.

The 12.47 kV switchgear lineups at both Halawa and Haiku contain a local Automatic-Manual switch (43AM) on the front face of the switchgear. For the majority of the local manual restoration procedures, this local switch must be placed in the Manual position to override the automatic interlocking features designed into the switchgear as previously described. To do otherwise would be futile since randomly opening and closing circuit breakers will simply automatically open and close other circuit breakers.

10. REMOTE MANUAL RESTORATION

Remote manual restoration of the 12.47 kV switchgear system can also be accomplished remotely using the control room computer. The control room is equipped with a visual display of the one line diagram of the power system showing the status of buses and circuit breaker positions. More importantly, circuit breakers can be operated remotely from control room to save considerable time in configuring the power distribution system. Notwithstanding the remote control feature, the original design of the interlocking scheme will always prevent illegal circuit breaker positions.

Remote manual restoration from the control room, however, is limited to only those failure modes that exclude a faulted condition, i.e., feeder fault or bus fault. Due to the severe and serious nature of a fault, the cause of the fault must first be removed and the circuit breaker lockout relay manually reset at the circuit breaker. Hence, local manual restoration procedures will be typically executed following a fault.

Similar to the local 43AM switch, the Halawa and Haiku switchgear are each equipped with a remote Automatic-Manual switch (43COMP) to override the automatic interlocking features of the switchgear system that can be operated

from the control room computer. The 43COMP switch, however, is actually a relay that is energized to duplicate the Manual position and de-energized to duplicate a return to the Automatic position.

11. 12.47 KV RELAY SETTINGS

For maximum flexibility, the 12.47 kV time overcurrent, very inverse relays are set for maximum loading. Considering that each of the four 12.47 kV buses would be feeding an average load of 2.5 MVA, the many possible configurations dictate that each individual relay be set for the maximum loading to maintain continuous operation.

In addition, special consideration was required for the 12.47 kV instantaneous relay settings. With the many transformers fed from the 12.47 kV switchgear, the transformer inrush current upon energization is essentially additive. Therefore, the instantaneous setting must be set accordingly higher. For instance, the 12.47 kV switchgear main circuit breaker instantaneous relays were set to trip at 4,860 amperes (A). This relay setting allows for the case where four 2,500 kVA transformers are operating at full load and four 2,500 kVA transformers and seven 150 kVA transformers are under inrush conditions ($4 \times 115.7 \text{ A} + 4 \times 8 \times 115.7 \text{ A} + 7 \times 8 \times 6.9 \text{ A} = 4,552 \text{ A}$).

12. 480 V DOUBLE-ENDED LOAD CENTERS

Low voltage power to the 480 V switchgear is derived through two 2,500 kVA, 12.47 kV - 480Y/277 V, three phase transformers located in all four portal buildings, i.e., Halawa Inbound, Halawa Outbound, Haiku Inbound, and Haiku Outbound. Each 2,500 kVA transformer has been sized to carry the entire load at the 480 V switchgear buses should the other transformer become unavailable. Similar to the 12.47 kV switchgear system, the 480 V switchgear system is normally operated in a split-bus configuration for maximum

reliability. For additional reliability, the 12.47 kV feeders to the 2,500 kVA transformers are installed in separate raceway in order to prevent a failure of one feeder from affecting or damaging the other.

For the 480 V switchgear system, there are really only two distinct but very similar alternate configurations, i.e., the bus-tie circuit breaker closed with either of the two main circuit breakers open. Although not as complicated as the 12.47 kV switchgear interlocking system, the 480 V switchgear interlocking system still embodies the same concept of electrical interlocks

The 480 V switchgear interlocking system involves only three circuit breakers at each 480 V switchgear: the two main circuit breakers and bus-tie circuit breaker. The interlocking scheme is such that a maximum of two and only two circuit breakers can be closed simultaneously. There is, however, no limit to the number of circuit breakers that can be simultaneously open.

Because the interlocking scheme of the 480 V switchgear system is not as complicated as that of the 12.47 kV switchgear system, restoration of the 480 V switchgear system is easily accomplished both locally and remotely through the control room computer. Since the interlocking scheme is always active, the only way to return to a split-bus configuration is to first open the bus-tie circuit breaker and then close the remaining main circuit breaker.

for power, thereby enabling the system to maintain operation of all loads. Perhaps the most unique and key feature of the power distribution system is the highly reliable, hard-wired, interlocking scheme designed into the 12.47 kV switchgear system. With such a feature, automatic restoration of power to the 12.47 kV switchgear system is immediate, thereby bypassing the need for human intervention.

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13. CONCLUSION

The power distribution system for the Hawaii H-3 Tetsuo Harano Tunnel is a highly reliable system with redundancy and flexibility of operation as its salient points. With two separate 46 kV transmission radial circuits from HECO, one emergency generator, and numerous UPS and battery/inverter units, backup power is widely available for critical loads throughout the tunnel. Another major feature of the power distribution system is the number of different alternate paths available

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**POWER SUPPLY DISTRIBUTION –
CLK TERMINAL BUILDING AND INFRASTRUCTURE**

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POWER SUPPLY DISTRIBUTION – CLK TERMINAL BUILDING AND INFRASTRUCTURE

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ABSTRACT

This paper discusses the Airport Authority's 11kV and 380V power distribution network on the airport island particularly in the Passenger Terminal Building, the single largest airport terminal in the world with floor areas 516,000 sqm. Infrastructure distribution network including the supply to airfield runways will be briefly discussed.

include the Cargo Terminals, Catering facilities, Aircraft maintenance facilities, Hotel, Airlines offices development, Police station, Fire station, Air Traffic Control Tower and the mail center, etc. The CLP 11kV networks are designed and installed by the China Light and & Power Co.

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1. INTRODUCTION

The development of the power supply and distribution network on the Chek Lap Kok airport island is of the same magnitude as a new town development.

The size of the airport island platform of 1248 hectare is equivalent to the size of Kowloon peninsula. The installed capacity of China Light & Power (CLP) supply on the island is 250MVA at the opening date. The power distribution on the airport island can be divided into two main categories:

The CLP supply network and the Airport Authority distribution network.

The CLP supply systems comprise the 132kV and 11kV cable networks. The 132 kV circuits are installed to bring power from the mainland onto the airport island and terminated in the two primary stations A and B.

The CLP 11kV cable networks are installed to supply power to all the franchises and the Government facilities on the island which

2. INFRASTRUCTURE

The design of the infrastructure 11kV and 380V power distribution network was carried by Parsons Brinckerhoff Asia Ltd. (PBA). The design contract C121 was awarded in May 1993 with the design period of one year.

The infrastructure power distribution works were documented as two major contracts, C532 and C534.

Tenders of C532 contract were invited in December 1994 and the contract was awarded to Balfour Beatty in April 1995 with a contract sum of about HK\$106 million.

Contract C532 included the installation of 11kV and 380V networks starting from the 11kV substations down to the 380V main switchboards. The contract included the supply and installation of 24 nos. 11kV stations, 30 nos. 11kV/380V transformers and 22 nos. 380V main switchboards. The total quantity of 11kV and 380V main cables installed exceeded 80 kilometers.

Tenders of C534 contract were invited in

December 1994 and the contract was awarded to the China Engineers in April 1995 with a contract sum of about HK\$104 million.

Contract C534 included the installation of backup emergency generators for the 11kV supply to the Passenger Terminal Building and the infrastructure 380V networks. The contract included the supply and installation of four Caterpillar diesel generating sets each rated at 5MVA and twelve 380V diesel generating sets rated at either 1000VA or 1500VA. The contract also included the supply of one 1500KVA standby mobile diesel generating set.

3. PASSENGER TERMINAL BUILDING

The design of the 11kV and 380V power distribution network in the Terminal Building formed part of the Passenger Terminal Building design and was carried by the Mott Consortium. The design contract C101 was awarded in April 1992 with the design period of two years.

The Building Services Installation in the Passenger Terminal Building C320 included the power distribution network and tenders were invited in July 1994. The contract was awarded to AEH Joint Venture in January 1995 with a contract sum of HK\$1.88 billion.

The electrical works within Contract C320 included the installation of 11kV and 380V networks starting from the 11kV substations down to 220V final circuits. The contract included the supply and installation of 19 nos. 11kV stations, 53 nos. 11kV/380V transformers, 15 nos. main LV switchboards, 960 distribution panel boards and 70,000 luminaires. The total quantity of 11kV and 380V main cables installed were over 135 kilometers and over 2,000 km small wiring were installed for final circuits.

The figures above demonstrated the scale of the power distribution networks which the Airport Authority have built and the challenge ahead

to operate and maintain the supply and distribution networks for the next century.

To monitor and improve the quality of the supply, in conjunction with University of Hong Kong and the Supply Company, transient measurements are being taken and analysed. The reports generated will be used to improve the systems installed.

4. CLP SUPPLY TO CHEK LAP KOK ISLAND

There are two CLP 132kV primary substations Primary A and B on the island serving the Airport island.

It is a very secure network connected to three independent generating sources in Castle Peak, Black Point and the Penny's Bay generating plants. Power is distributed to the Airport Island through Pak Kong, Shum Shui Kok and Tung Chung Bulb Substations via separate routes onto the airport platform. The direct link from Castle Peak to Primary A substation was completed before the airport opening date to increase the security of the power supply to the airport island.

At the opening date, Primary A substation had an installed capacity of 150MVA, built up from 3nos. 50MVA transformers and Primary B had an installed capacity of 100MVA, built up from 2 nos. 50MVA transformers.

Both the Passenger Terminal Building and the infrastructure network receive power from the two primary substations to increase the reliability of the power distribution networks.

5. PASSENGER TERMINAL BUILDING POWER SUPPLY ARRANGEMENT

CLP provided 11kV connections to four 11kV switching substations (PA, PB, PC and PH) within the Passenger Terminal Building with a supply capacity of 84MVA. PA, PB and PH

are fed from CLP Primary A substation while PC is fed from Primary B substation. These four switching substations are inter-connected by 11kV cables on both the CLP and the Authority sides to increase the supply security.

PA, PB and PC switching substations serve the Passenger Terminal Building general supplies and PH is dedicated to serve the 11kV chillers plant. The four 11kV switching substations are configured such that PH also acts as the back up substation and connected to the 11kV back up generating plants.

The 11kV networks in the Passenger Terminal Building are monitored and controlled by the SCADA system. As the first alternative in case of power supply failure to PA, PB or PC, the chillers loads will be shedded to make the PH supply available to serve the main building services load.

In the unlikely event of a total failure of CLP supply or failures to more than one switching substations in the Passenger Terminal Building, the 11kV generating sets located in the GH1 generator house will start to provide power to maintain the operation of the essential systems inside the Passenger Terminal Building. The following systems are classified as essential to maintain the operation of the airport.

- Automatic People Movers
- Baggage Handling System
- Passengers Loading Bridges
- Fire Services System
- Ventilation System
- Public Address System
- Flights Information Display System
- Door Access Control System
- Telephone System
- Airport Operational Database System
- Lifts
- 33% of general lightings

The GH1 emergency generating plant housed four 5MVA diesel generating sets with a capacity of 20MVA at airport opening date. The Authority had placed order for the fifth set and the installation will be completed in the

middle of next year to cater for the essential loads increase upon the completion of the Northwest Concourse extension.

There are sixteen distribution substations within the Passenger Terminal Building. They have been sited to match the major load centers. A typical distribution substation contains either three or four 1500kVA cast resin dry type transformers. Each distribution substation is configured to feed from dual 11kV ring supplies from the 11kV switching substations with Ring Main Units for connection to the individual transformers.

The design has been based on either three or four transformers in each distribution substation with at least one transformer served from an alternative 11kV ring so that essential power supplies will be maintained in the event of the failure of one of the HV ring circuits.

On the 380V main LV switchboard side, there are bus section breakers to separate the different transformer sections of the board. In the event of a partial supply or equipment failure affecting one of the 11kV rings, an automatic changeover mechanism within the LV switchboard will ensure power supplies to the essential loads bus section will be maintained.

From the main LV switchboards, powers are distributed to the various distribution panelboards, motor control centres, communication rooms and other electrical operated equipment within the Terminal using XLPE/SWA/LSF cables. Horizontal cables are distributed on cable ladders fixed along the electrical services tunnel. The services tunnel with a length of over 2200 meters extending from the east end of the Passenger Terminal Building to the west end is the backbone of cables distribution route.

From the services tunnel, vertical riser ducts are provided for the cables to route to distribution panelboards on levels above. There are totally about 960 distribution panelboards within the Terminal to serve the lighting and power installations and tenant supplies.

All the general Lighting and Power (L&P) distribution panelboards are designed to have essential and non-essential sections. The non-essential section MCCBs are equipped with undervoltage relays to cut off the supply in case of power outage. These breakers are monitored and controlled by General Building Management System (GBMS) and will be reinstated back to normal position when normal supply resumes. Under the generators supply conditions and when spare capacities are available, the distribution systems are designed to allow the flexibility to put back more systems on generators supply through the GBMS.

The GBMS provides the control functions to operate the lighting system inside the Passenger Terminal Building to ensure efficient usage of daylight and artificial lights. It also provides the monitoring functions to enable the engineering staff to know the current status of circuit breakers in the main switchboards and panelboards. Under emergency conditions, the GBMS will perform the load shedding functions to ensure the power system under the generators supply will not be overloaded.

All computer and communication equipment supplies that are considered critical to the airport operation will be provided with Uninterrupted Power Supply (UPS) back up. A total of over 550kVA of installed UPS capacity has been installed inside the computer and communication rooms throughout the Passenger Terminal Building.

In conclusion, the power supply to the Passenger Terminal Building is a very secure and reliability system with the following arrangement:

- Dual supply cable networks from the Supply Company
- Inter-connection of the four switching substations by 11kV cables
- SCADA monitoring and control
- Dual ring feed arrangement to transformer substations

- Auto changeover on the 380V main switchboard bus section
- Critical computer and communication equipment with UPS backup
- Back up by 20MVA 11kV generators

6. INFRASTRUCTURE POWER SUPPLY ARRANGEMENT

Similar to the Passenger Terminal Building, CLP provided 11kV connections to four 11kV switching substations (ex, h, d1 and d2) on the infrastructure side with a supply capacity of 70MVA. Switching substations ex and h are fed from CLP Primary A substation while d1 and d2 are fed from Primary B substation. The 11kV networks are monitored by the SCADA System.

These four switching substations and associated 11kV substations provide power supply to the Authority buildings and facilities located on the airport island. These buildings and facilities can be summarized as followings:-

Road Lightings
Apron Lightings
Seawater Pumping Stations
Airfield Ground Lightings
Communication Rooms
Sea Rescue and Fire Stations
Pre-conditioned Air for Apron Remote Stands
Fixed Ground Power for Apron Remote Stands
Perimeter Fence Lightings
Sewage Pumping Stations
Waste Water Treatment Plant
Maintenance Headquarter Building
Ground Transportation Centre
Vehicular Tunnels
Airfield Ground Maintenance Building
Road Traffic Control System
Gate Houses

With the exception of some non-essential services substations, the majority of the 11kV substations are dual fed and ring connected to

provide the supply reliability. In addition to ring connected 11kV supply network, the power supply to Airfield Ground Lighting (AGL) vaults are 200% backed up by generators. Under Cat 1 operation, the CLP supply is used as normal supply and generators as standby. During Cat 2 and 3 operations, the generators are used as normal supply and CLP supply acts as standby.

The design principle of the essential supply backup for infrastructure networks follows the conventional arrangement of using generators and auto changeovers on the 380V main LV switchboards to achieve the purpose.

In conclusion, the infrastructure power supply is also a secure and reliable arrangement similar to the standard of the Passenger Terminal Building to ensure the airfield lightings, associated auxiliary equipment and buildings are operated in a safe environment.

Paper No. 5

PRODUCT RELIABILITY

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PRODUCT RELIABILITY

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ABSTRACT

Reliability engineering is an essential discipline in the manufacturing process, where such knowledge and techniques are applied at the design concept stage right through the production process. Various reliability engineering tools are used to control and predict the performance of a given product even before manufacturing the product.

Reliability engineering is continually evolving. Tools used in reliability engineering such as Histograms, Parato Graphs, Statistical Process Control, Failure Mode Analysis, Mean Time Between Failure Analysis, Quality Function Deployment, and Taguchi methods have been employed by product engineers, designers and manufacturers in evaluating and predicting product performance over their intended application and life span. Various sophisticated test instruments and equipment are used to test product specifications and to accelerate the aging process of the components and the final products. Destructive tests are sometimes employed to gain knowledge on material science and related functions.

What services and help are available in Hong Kong on reliability engineering are addressed in the paper.

1. INTRODUCTION

Reliability engineering at the early stages was chiefly applied to the military products. Reliability engineering as we know it today, is fast becoming an essential discipline in the manufacturing industry. Consumers have long demanded durable and reliable performance from consumer products. Therefore, understanding and mastering the techniques of reliability engineering is important to the success of business in today's competitive market.

Since the Industrial Revolution, engineers have recognized that a product should have a long service life and that during this intended usage life it should give service with no failures apart from the normal wear and tear. Engineers utilized such techniques as Histograms, Standard Deviation Graphs, Control Charts and Scatter Diagrams as the basic tools for Quality Control. These tools were largely developed as aids within the process of Statistical Quality Control to ensure that items produced meet the prescribed specifications. As products became more complex, there were increasing problems with failures over time. Traditional efforts of design and control, although necessary, were not sufficient to achieve both the functional performance requirements and a low rate of failure over time. What has evolved is a collection of tools called "reliability engineering". In general terms, reliability is a design engineering discipline which applies scientific knowledge to assure a product will perform its intended function for the required duration within a given environment.

According to Frank M. Gryna, Vice President of Juran Institute, reliability can be defined as the probability that an item will perform a required function under stated conditions for a stated period of time. This definition has four key elements:

- I. The quantification of reliability in terms of probability.
- II. A statement defining the required product performance;
- III. A statement of the required operating time between failures; and
- IV. A statement defining the environmental conditions in which the product must operate.

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2. QUANTIFICATION OF RELIABILITY

A major new tool in reliability engineering is the quantification of reliability. The process of reliability quantification involves four phases:

- I. Establishment of reliability requirements or objectives;
- II. Apportionment (or Budgeting);
- III. Prediction; and
- IV. Analysis

Fundamentals to the quantification process are some statistical concepts, such as Failure Rate, Time between Failures (TBF) and Mean Time between Failures (MTBF).

3. RELIABILITY TESTS

MIL-Std. (Military Standard) 785B "Reliability Program for Systems and Equipment Development and Production" provides a good reference of effective reliability tools. Various forms of testing the product are designed to simulate field usage. The Standard identifies four areas of testing:

- I. Environmental Stress Screening;
- II. Reliability Development/Growth Tests;
- III. Reliability Qualification Tests; and
- IV. Production Reliability Acceptance Tests.

Tests for reliability focus on three elements: performance requirements, environmental conditions during use, such as normal temperature, high temperature (+100(C) and low temperature (-55(C) and under vibration of 1 to 10 Gs, and time requirements. Performance requirements are defined uniquely for each product. By skillful design of test programs, it may be feasible to verify that the product can withstand the expected stress levels for the required time period and under the expected environmental levels (e.g. temperature, humidity, and vibration). Destructive tests, i.e., testing one item of

product to failure, then repairing it and testing again to failure, through several cycles, may provide useful Material Science data and product durability data. Accelerated testing shortens the testing time by subjecting the product to a more severe condition to simulate the aging process of the product.

4. RECENT CONCEPTS IN RELIABILITY ENGINEERING

The concept of reliability engineering is continually evolving, and so is the concept of quality. In the old days, we had the Seven Basic (Old) Tools. Nowadays, new philosophies are developed and new methods in quality management systems and reliability engineering have evolved. Customer satisfaction (the larger the better) and cost (the smaller the better) are taken as the primary quality characteristics. They give rise to two new and very important tools in reliability engineering - Quality Function Deployment and the Taguchi Methods.

Quality Function Deployment (QFD) is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase. It is a way to assure the final product quality is designed and built into the product. In QFD, all operations are customer and market driven. Hence QFD represents a change from manufacturing-process quality control to product-development-manufacturing quality assurance.

Taguchi Methods are based on the design of experiments to provide near optimal quality characteristics for a specific objective. They include the integration of statistical design of experiments into engineering process. The goal is to reduce the sensitivity of engineering designs to uncontrollable factors or noise. The objective function used is the signal to noise ratio, which is maximized. This moves design targets toward the middle of the design space

so that external variations effects the behaviour of the design as little as possible. This permits large reductions in both part and assembly tolerances which are major drivers of manufacturing cost.

Conformal coating is another technique commonly used in military electronic products. Conformal coatings are used to protect products or devices from severe corrosive environmental conditions, high humidity and dusty environments. There are many types of conformal coating materials available, some can be used as a damping media to handle vibration condition in addition to the above stated characteristics. This type of material will remain pliable throughout the service life even under severe temperature and humidity conditions. The application of conformal coating to consumer products is at its infant stage.

5. IMPORTANCE OF RELIABILITY IN ELECTRONICS

Since components are the basic building blocks of systems, the reliability of the system is determined in large part by the reliability of the components. Performance and life testing of systems and completed products is difficult, very time consuming, and expensive. For these reasons, component reliability information is critical in modern quality systems. Components are functionally tested, accelerated life tested, operational life tested, and burned in at many stress levels. Reliability estimates for components are carefully calculated and catalogued in reference books and databases. Designers use these estimates with systems reliability models to predict system reliability early in the design process. When these predictions indicate that the system may not meet its reliability estimates, the designers may choose different components, add redundancy to the system, use components at less than full rated values, burn-in the critical components to improve reliability, or use other approaches.

6. THE CLIPSAL QUALITY

Clipsal is the market leader in design, manufacture and distribution of a wide range of household and industrial electrical accessory products. Our success as market leader in Asia, is chiefly attributed by our unrelenting philosophy and commitment to quality and reliability. Reliability is designed and built into the product using commonly accepted development aids and is monitored by a task team, which is made up of a multidisciplinary group headed up by the project manager. Some of the key tools used for assessment are as follows:

- *DFMEA (Design Failure Mode Effect Analysis)* is used on all new elements and manufacturing processes to assess the effect that they have on the overall project. This is an ongoing process, which is reviewed at all stages of the development. Of course, TBF & MTBF are closely monitored and assessed.
- *FEA (Finite Element Analysis)* is undertaken on critical elements to assess the levels of stress and likely failure points in the life of the components. This is undertaken under static and dynamic situations.
- *Moldflow* is used to assess the wrappage; shrinkage and reliability of mould fill prior to tooling and is used to assess the production based on the data obtained.
- *Testing* occurs at all phases of the development and introduction of products into our manufacturing process. Assessment and approval of all products generally follow this testing procedure by an external testing authority prior to introduction to the market.
- *SPC (Statistical Process Control)* another monitoring processes are used to maintain the quality and reliability of the Clipsal products in our day to day activities.

Examples of the various tests at Clipsal by slides presentation.

C1 = Clipsal Quality & Reliability Centre

C2 = Temperature Chamber

C3 = Durability Tester
C4 = Durability Tester
C5 = Durability Testers with Temperature Chamber.

Examples of the various reliability test equipment and services made available by HKSTC/CEPREI to industry:

S1 = Anechoic Chamber
S2 = Line Conduct Emission Tester
S3 = Harmonic Analyzer
S4 = Swivel Tester
S5 = Voltage Surge Tester
S6 = Cable Flex-Tester
S7 = Vibration Tester : 1-15 G
S8 = Endurance Tester
S9 = Battery Discharge Tester
S10 = Electronic Component Tester
S11 = Acoustic Microscope
S12 = X-ray Microscope
S13 = Temperature Chamber
S14 = Temperature & Humidity Chamber
S15 = Temperature & Humidity Chamber
S16 = Temperature & Humidity Chamber

seek support from third-party test houses. In Hong Kong, a limited service of reliability testing is available, through the tertiary education institutes and private commercial laboratories. Laboratories in the universities and technical institutes, and those in the private sector offer testing service only to specific test requirement to meet certain demands. With the collaboration of China Electronic Product Reliability & Environment Testing Research Institute (CEPREI) in China, the Hong Kong Standards and Testing Centre Ltd. (STC) offer by far the most comprehensive reliability test services to the electronics industry to help design engineers to identify early failures of components and products due to weak parts, workmanship defects, and other non-conformance as a result of environmental stress. I believe some universities offer fault analysis on printed circuit boards as well as semi-finished and finished products. The Quality and Reliability Centre of the Hong Kong Polytechnic University offers testing and referral services. By utilizing these services, design engineers can ensure that the product will perform the required function satisfactorily under its intended conditions over its intended life span.

7. CONCLUSION SERVICES AVAILABLE IN HONG KONG

Reliability is a product design attribute that cannot be ignored. Design engineers conduct testing on the product to estimate or predict reliability in advance of manufacturing it. These assessments and prediction are a continuing process, which take place at several stages of progression, from design of the product through usage by the consumers. Hence, there is the need of the relevant test facilities available to perform these tasks. At Clipsal, we have our own internationally accredited Research and Reliability Testing Laboratories. For manufacturers that have the required facilities, the tests can be done in-house. However, as the investment of the equipment and the infrastructure for reliability testing is huge, most manufacturers have to

Paper No. 6

**STATUTORY CONTROL OF
ELECTRICAL PRODUCT SAFETY IN HONG KONG**

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STATUTORY CONTROL OF ELECTRICAL PRODUCT SAFETY IN HONG KONG

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ABSTRACT

The Electrical Products (Safety) Regulation was made under the Electricity Ordinance, Cap. 406 of the Laws of Hong Kong with the aim to enhance public safety in the use of electrical products designed for household use. Under this new Regulation, all household electrical products supplied in Hong Kong shall comply with the prescribed safety requirements to ensure that under normal situations the users are protected from possible hazards which may arise from the electrical products. The Regulation also requires the suppliers to ensure that proper certificates of safety compliance are issued for all household electrical products they supplied and to recall hazardous electrical products if deemed necessary. In this paper, the background and scope of the Regulation, the prescribed safety requirements for electrical products, the requirements for certificates of safety compliance, the registration of recognized certification bodies and recognized manufacturers, as well as the recall and prohibition of hazardous electrical products will be explained.

1. INTRODUCTION

Being one of the fastest growing forms of energy, electricity has been serving us as a commercial product for over 100 years. In line with the population growth over the years, the use of electricity has been increasing rapidly in Hong Kong. The total installed generating capacity and electricity sales in the territory have increased from 11.5 MW and 18 GWh respectively in 1921 to 8,963 MW and over 32,000 GWh respectively in 1997. Nowadays, it may be difficult to find a family in Hong Kong which has less than 10 items of electrical products. You may not be surprised to know

that, in 1997 alone, the retained import of household electrical products into Hong Kong was over HK\$ 83 billions

While we enjoy the benefits arising from the use of electricity, very often it is easy for us to forget its potential dangers. Over the past 3 years, a total of 161 electrical related accidents/incidents, which involved 24 deaths and 96 injuries, were investigated by the Electrical and Mechanical Services Department (EMSD) in Hong Kong. Furthermore, according to the statistics of the Fire Services Department, in recent years there were more than 1000 fire incidents per year in buildings of Hong Kong which were suspected to have an electric origin. It is therefore important that effective legislative measures are introduced to provide statutory control over the use of electricity.

The Electricity Ordinance, Cap.406 of the Laws of Hong Kong, was enacted in 1990 to repeal and replace the old Electricity Supply Ordinance. The Electricity Ordinance is now the main enabling legislation on electricity safety in Hong Kong and is supported by subsidiary legislation in the form of Regulations, as well as Code of Practice and Guidance Notes introduced by the enforcement authority, EMSD. It serves to provide for the registration of electrical workers, contractors and generating facilities; to provide safety requirements for electricity supply, electrical wiring and products; and to provide powers for electricity suppliers and the Government respecting electrical accidents and enforcement of the Ordinance. The subsidiary legislation made under the Electricity Ordinance include the Electricity Supply Regulations, the Electricity Supply (Special Areas) Regulations, the Electricity (Exemption)

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Regulations, the Electricity (Registration) Regulations, the Electricity (Wiring) Regulations, and the Electrical Products (Safety) Regulation, while the new Electricity Lines (Safety) Regulation is being drafted and would be ready for enforcement in 1999. The Electrical Products (Safety) Regulation (EPSR), which is the latest set of Regulation introduced up to present, is the main theme of this paper.

2. BACKGROUND OF THE REGULATION

In 1993, the Consumer Council of Hong Kong published in one of its reports that over 80% of the plug samples failed to pass the safety tests conducted by the Council. This was already the 9th test undertaken by the Council on electrical accessories such as plugs and adaptors. The Consumer Council expressed deep concern on the situation which indicated that the lack of relevant statutory control had failed to stimulate the manufacturers to upgrade their products despite constant efforts by the Council to identify substandard electrical products over the years. The concern of the Consumer Council was shared by the Government and it was considered that the problem of unsafe plugs and adaptors should be dealt with on a more urgent basis. While the introduction of the more complicated EPSR to provide comprehensive control over all household electrical products would require more deliberations at that time, it was decided to make a separate set of Plugs and Adaptors (Safety) Regulation (PASR) in advance of the EPSR.

The PASR which applies to any plug or adaptor designed for household use at a voltage of not less than 200V alternating current single phase was enacted in September 1994 and put into operation in March 1995. Taking into consideration of the existing electrical wiring and socket systems in Hong Kong which follow the U.K. practice, only plugs and adaptors complying with the relevant British Standards are adopted to ensure conformity

and eliminate the potential danger arising from the use of plugs and adaptors with different dimensions and designs in conjunction with the said socket system. Besides 2-pin reversible plugs to BS 4573 or EN 50075 for shavers, only 3-rectangular-pin fused plugs rated at 13A to BS 1363 or BS 5733 and 3-round-pin plugs rated at 5A or 15A to BS 546 or BS 5733 together with the corresponding adaptors are allowed to be supplied in Hong Kong. Before the PASR was repealed and replaced in May 1998 by the EPSR, more than 8600 inspections had been conducted to electrical product supply outlets and some 70 prosecutions were successfully conducted under the provisions of this Regulation.

Based on the recommendations of a consultant employed by the Government in the early 90's to study the proposed statutory control on electrical product safety in Hong Kong, a public consultation exercise was conducted in 1994 to seek the views of over 60 relevant organizations on the proposed legislation. The feedback from these organizations had shown overwhelming support to the proposal and their opinions were taken into consideration in drafting the new legislation. After going through the lengthy legislation drafting and enactment procedures, the EPSR was gazetted in May 1997 and a 12-month grace period was allowed for the trade and the consumers to get acquainted with the new statutory requirements. The main provisions of the Regulation have been enforced since May 1998, while the requirements on certificate of safety compliance is expected to be put into effect later this year.

3. OBJECTIVE AND SCOPE

The objective of the EPSR is to enhance public safety in the use of household electrical products. The means for achieving this objective as detailed in the Regulation include :

- (a) prescribing the safety requirements for electrical products designed for household use and supplied in Hong Kong;

- (b) requiring the suppliers to ensure that their products are in compliance with the prescribed safety requirements and a certificate of safety compliance is issued for every model of electrical products they supplied; and
- (c) requiring the suppliers of electrical products which do not meet the prescribed safety requirements to notify the public of the hazardous defects in the products, to accept a return of the products, and to refund the purchasers concerned.

The scope of the EPSR will include all electrical products which are :

- (a) designed for household use; and
- (b) supplied in Hong Kong (including those imported, manufactured locally or intended for use outside Hong Kong).

Note : Supply means (1) to sell or hire out; (2) to offer, keep, or exhibit for sale or for hiring out; (3) to exchange or dispose of for any consideration; (4) to transmit, convey or deliver in pursuance of - (i) a sale, (ii) a hiring out, or (iii) an exchange or disposal for any consideration; or (5) for commercial purposes, to give an electrical product as a prize or to make a gift of such a product.

The regulation will not apply to electrical products which are :

- (a) under transshipment or in transit through Hong Kong;
- (b) manufactured in Hong Kong for export;
- (c) supplied for reconditioning;
- (d) supplied as scrap;
- (e) travel adaptors; or
- (f) supplied in a place other than Hong Kong under a sale agreement entered into in Hong Kong.

In addition, the regulation will not apply to electrical products which are operated at extra low voltage, i.e. not exceeding 50V a.c. or 120V d.c.

4. PRESCRIBED SAFETY REQUIREMENTS

Under the EPSR, all household electrical products will have to comply with the "essential safety requirements" which are developed based on the Low Voltage Directive adopted in the European Community for the control of electrical product safety. The essential safety requirements aim to ensure that under normal situations the users of electrical products are protected from hazards arising from the products and hazards which may be caused by external influences on the products. It is required that all electrical products shall be:

- properly marked, assembled, connected and insulated;
- designed and constructed to prevent electrical and non-electrical danger;
- designed and constructed to prevent danger arising from temperatures, arcs, radiation and hazardous materials; and
- designed and constructed to meet the expected mechanical requirements, to resist non-mechanical influences in expected environmental conditions and to cater for foreseeable conditions of overload, stable and can be maintained in a specific position.

Certain types of household electrical products which are of special nature and more liable to cause hazards are classified as "prescribed products". In addition to the essential safety requirements, prescribed products will have to comply with the "specific safety requirements" which are basically derived from international and/or national standards. Initially, 6 types of electrical products including plugs, adaptors, extension units, lampholders, flexible cords and unvented thermal storage type electric water heaters are classified as prescribed products under the EPSR but more prescribed products may be introduced as and when required. For particular types of electrical products, some additional safety requirements are stipulated in the Regulation, for example, an electrical product not suitable for direct connection to the domestic electrical supply in

Hong Kong shall carry a warning label, etc. The prescribed safety requirements of the Regulation are summarized in Appendix 1.

EMSD has published the "Guidance Notes" for the EPSR to acquaint the electrical product suppliers with the main provisions of the Regulation and to assist them in making preparations for complying with the new statutory requirements. A list of international and national safety standards, mainly the International Electrotechnical Commission (IEC) standards, which are deemed to satisfy the prescribed safety requirements of the EPSR is included in the Guidance Notes. In general, electrical products manufactured and tested to these safety standards, or other compatible standards that fulfill the prescribed safety requirements of the Regulation, will be accepted.

5. CERTIFICATE OF SAFETY COMPLIANCE

In accordance with the EPSR, every model of household electrical products supplied in Hong Kong will have to be issued with a certificate of safety compliance. A certificate of safety compliance shall include the following information :

- a certificate or test report reference number;
- the name and model/type reference of the product;
- the name and address of the manufacturer;
- the name and address of the person or company who requested testing of the product;
- a standard to which the product was tested and found in conformity;
- the name, address, authorized signature and, if applicable, company seal of the recognized certification body or recognized manufacturer, as the case may be; and
- the date of certification.

For prescribed products, only test certificates

or reports issued by recognized certification bodies or recognized manufacturers registered with EMSD will be accepted as the certificates of safety compliance. In general, test certificates issued by national certification bodies participating in the CB Scheme of the IEC System for Conformity Testing to Standards for Safety of Electrical Equipment, and endorsed test certificates issued by testing laboratories accredited by the Hong Kong Laboratories Accreditation Scheme (HOKLAS) or those bodies having mutual recognition agreements with HOKLAS will be acceptable. Moreover, a self declaration of conformity issued by the product manufacturer will be accepted as the certificate of safety compliance for non-prescribed products. In essence, this means that every model of household electrical products will have to be certified that it has been tested and found to be in conformity with certain safety standard. While the endorsed test certificates or test reports adopted in international trade will be accepted as the certificates of safety compliance, the electrical products that have been tested for such purpose will not need to be tested again for compliance with the Hong Kong regulatory requirements in this aspect. The issuance of the certificate of safety compliance is illustrated in Appendix 2.

The registration process for recognized certification bodies and recognized manufacturers, the criteria for recognition of which are summarized in Appendix 3, under the EPSR has commenced in October 1997. In general, national certification bodies participating in the CB Scheme and those organizations accredited by HOKLAS or mutual recognition partners of HOKLAS are qualified to apply for recognition as recognized certification bodies. For recognized manufacturers, they are required to have quality systems that conform to ISO 9002 and their laboratories have to be accredited by either HOKLAS, mutual recognition partners of HOKLAS or other schemes for assessment of testing laboratories as listed in the International Laboratory Accreditation Conference Handbook and Directory published by the National Association of Testing

Authorities of Australia on behalf of the International Laboratory Accreditation Conference. About 50 recognized certification bodies and recognized manufacturers have been registered and the list of which is available for public inspection at the Customer Service Office of EMSD as well as the EMSD homepage on the internet.

6. PRODUCT RECALL AND PROHIBITION

The EPSR empowers the Director of EMSD to require the supplier of unsafe electrical product to :

- notify the purchasers to whom the supplier or the supplier's agent has supplied the electrical product of the hazardous defects in the product;
- accept a return of the product;
- refund the purchasers any sum paid for the product subject to the surrender of a receipt for the product; and
- publicize the matter through televisions, newspapers and other effective means as ordered by the Director.

In addition to the provisions under the EPSR, the Director of EMSD is also empowered under the Electricity Ordinance to prohibit the use or supply of electrical product that does not meet the prescribed safety requirements. After 3 days have lapsed from the date of the gazette notice on such prohibition, EMSD may seize the product supplied in the market if it is still prohibited. If there is reasonable cause to suspect an electrical product has contravened the Ordinance, EMSD may remove the product from premises other than domestic premises and retain the product for testing. The supplier of such product is liable for the cost of testing if the product is determined to be not in compliance with the Ordinance. In order to trace the origin and destination of unsafe electrical product, the Director may also serve a notice to require a person to provide such information.

7. PENALTIES

A person who contravenes the Regulation is liable to a maximum fine of HK\$100,000 and imprisonment for 1 year on first conviction; and a maximum fine of HK\$500,000 and imprisonment for 2 years on subsequent conviction.

8. CONCLUSION

EMSD is charged with the responsibility of enforcing this new legislation. With a view to identify and eliminate unsafe electrical products supplied in Hong Kong, EMSD will conduct random spot checks to electrical product supply outlets, trace supply sources of electrical products failing to comply with the prescribed safety requirements, and investigate complaints, reports and accidents related to electrical products. About 600 inspections to electrical product supply outlets had been conducted during the first 3 months after the Regulation was put into effect. More than 30 written warnings had been issued to shops found supplying non-compliant products and a number of potential prosecution cases were being handled. Commonly found non-compliant items include extension units with irregular pin holes and without safety shutters, travelling appliances fitted with sub-standard 2-pin plugs, 110V products without proper warning labels, etc. Also, more than 100 accident and complaint cases suspected to involve electrical products were investigated over the same period of time. One of the fire incidents we investigated in June 1998 had resulted in a recall of several thousands electric tower fans suspected to have potential safety hazards.

While the EPSR had gone through the public consultation process during the drafting stages, its successful implementation depends greatly on the understanding and cooperation of the community as a whole. Hence, a constant publicity programme has been put in place to arouse the public awareness of the new statutory requirements as well as the safety

precautions in the use of electrical products. As the responsible authority for the legislation, EMSD will continue to keep track of the latest developments in electrical technologies and safety standards in order to upkeep the legislation in line with the international standards.

APPENDIX 1

The prescribed safety requirements under the Electrical Products (Safety) Regulation can generally be classified into three main types. They are summarised as follows:

1. ESSENTIAL SAFETY REQUIREMENTS

All electrical products shall be:

- (a) properly marked, assembled, connected and insulated;
- (b) designed and constructed to prevent electrical and non-electrical danger;
- (c) designed and constructed to prevent danger arising from temperatures, arcs, radiation and hazardous materials; and
- (d) designed and constructed to meet the expected mechanical requirements, to resist non - mechanical influences in expected environmental conditions and to cater for foreseeable conditions of overload, stable and can be maintained in a specific position.

2. SPECIFIC SAFETY REQUIREMENTS

For prescribed products (which include plugs, adaptors, lampholders, flexible cords, extension units and unvented thermal storage type electric water heaters), in addition to the "essential safety requirements", they have to comply with the "specific safety requirements", which are generally summarised as follows:

- (a) Plugs shall generally be 3-rectangular-pin 13A plugs to BS1363 or 3-round-pin 5A or 15A plugs to BS546, in order to match with the socket systems in Hong Kong. For electrical products designed for connecting to shaver supply units, such as electric tooth

brushes, the plugs shall be 2-pin reversible type to BS4573 or EN50075.

- (b) Adaptors shall generally be 15A, 13A or 5A type to BS1363 or BS546, in order to match with the socket systems in Hong Kong.
- (c) Regarding lampholders, which include the Bayonet lampholders and Edison screw lampholders, they shall be provided with suitable marking, complying with relevant standards and of appropriate materials. For examples, the construction and dimensions of the lampholders shall comply with IEC61-2, etc.
- (d) The requirements for flexible cords include mainly the marking requirements on the outer sheath, the requirements on colour identification, conductors and insulation, and complying with the relevant standards. For examples, the thickness of the insulation shall not be less than the figures given in IEC227 and IEC245, etc.
- (e) The requirements for extension units consist of those for plugs, flexible cords and sockets as mentioned above.
- (f) Regarding unvented thermal storage type electric water heaters, besides the requirements for marking and installation instruction, they shall be provided with adequate protective devices and shall have a guaranteed test pressure.

3. SAFETY REQUIREMENTS FOR PARTICULAR TYPES OF ELECTRICAL PRODUCTS

"Safety Requirements for Particular Types of Electrical Products" mainly include the following:

- (a) All electrical appliances shall be class I,

i.e. earthed products, or class II, i.e. double insulated or reinforced insulated products.

(b) For an electrical product which is designed to receive power from a mains socket, the plug shall conform to the "Specific Safety Requirements".

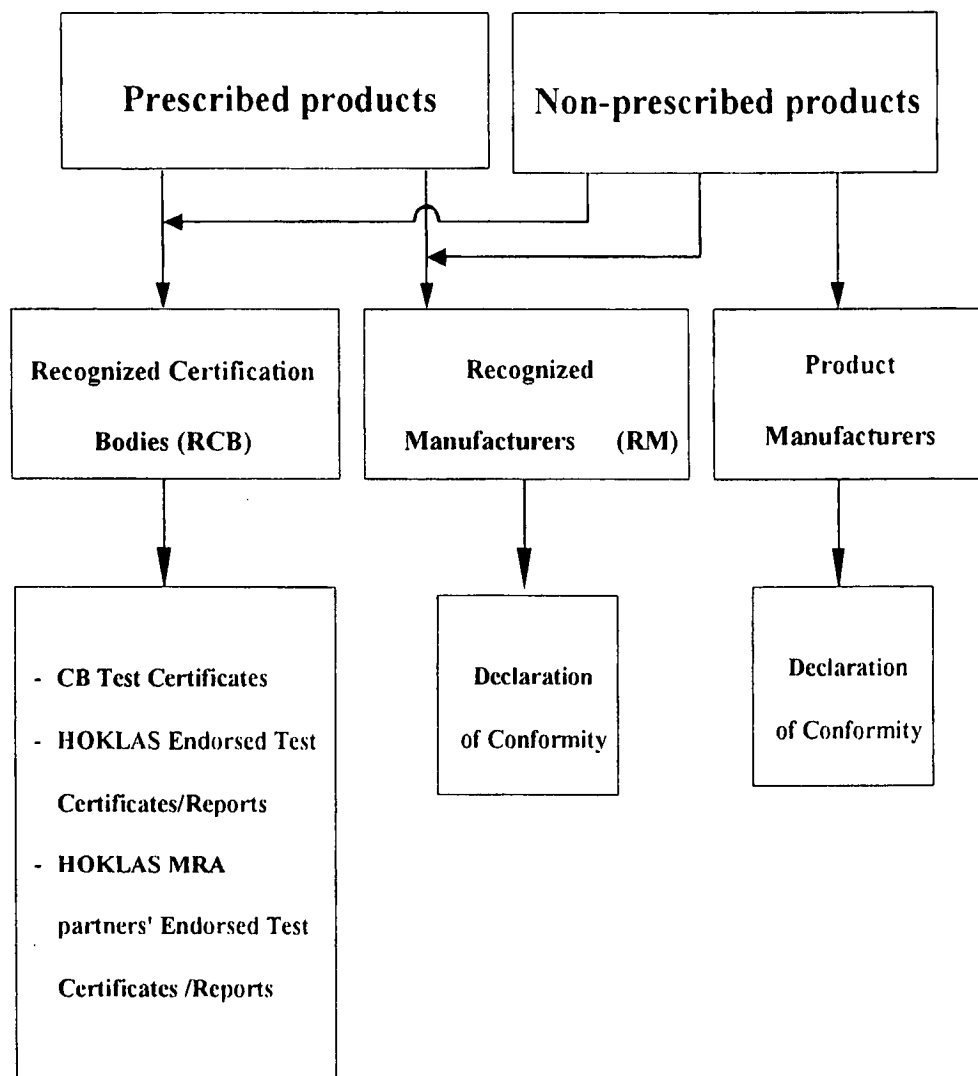
(c) For a class II product provided with an IEC 2-pin plug, the plug shall either be changed to an appropriate 3-pin type or be fitted with a suitable adaptor, before it can be supplied in Hong Kong.

(d) For a direct plug-in type electrical product, the plug-pin shall be of 3-pin design complying with the prescribed requirements.

(e) For an electrical product which is designed to receive power from a shaver supply unit to BS3535 Part 1, the plug pins shall conform to BS4573 or EN50075.

(f) For an electrical product which is designed solely for use at a voltage of less than 200V a.c., for example a 110V product, it shall carry a warning label to indicate that "This product should not be connected directly to the electrical supply system in Hong Kong, otherwise personal injury or damage to property may result.", when it is supplied in Hong Kong.

APPENDIX 2 - CERTIFICATE OF SAFETY COMPLIANCE



APPENDIX 3**1. RECOGNIZED CERTIFICATION BODY**

A recognized certification body is a certification body recognized by the Director of Electrical & Mechanical Services as qualified to issue certificates of safety compliance in respect of a specified class of electrical products. A certification or testing organization applying for registration as a Recognized Certification Body must satisfy either one of the following criteria:

- (a) The organization has been accepted as one of the National Certification Bodies under the IECEE CB Scheme;
- (b) The organization has been accredited by the Hong Kong Laboratory Accreditation Scheme (HOKLAS) managed by the Industry Department, (under the test category of electrical and electronic products); or
- (c) The organization has been accredited by an overseas accreditation scheme which has entered into a mutual recognition agreement with HOKLAS (under the test category of electrical and electronic products).

Application for registration shall be submitted to the Director of Electrical & Mechanical Services in writing together with supporting documents and the application fee as stipulated in the regulation. The applicant will be notified of the application result within 40 working days upon receipt of all necessary information. The relevant application form can be obtained from the Electrical & Mechanical Services Department

2. RECOGNIZED MANUFACTURER

A recognized manufacturer is a manufacturer recognized by the Director of Electrical & Mechanical Services as qualified to issue certificates of safety compliance for the electrical products manufactured by them. A manufacturer applying for registration as a Recognized Manufacturer must satisfy the

following criteria :

- (a) The manufacturer's laboratory has obtained accreditation under :
 - (i) the Hong Kong Laboratory Accreditation Scheme (HOKLAS) managed by the Industry Department (under the test category of electrical and electronic products); or
 - (ii) an overseas laboratory accreditation scheme which has entered into a mutual recognition agreement with HOKLAS (under the test category of electrical and electronic products); or
 - (iii) a scheme for assessment of testing laboratories as listed in the latest version of the International Laboratory Accreditation Conference Handbook and Directory published by the National Association of Testing Authorities (NATA) of Australia on behalf of the International Laboratory Accreditation Conference (ILAC), and
- (b) The manufacturer is required to have a quality system that conforms to ISO 9002 " Specification for Product and Installation" and a quality assurance certificate issued by a Quality System Registration Body as listed in the latest version of the Directory of Quality System Registration Bodies published by the International Organization for Standardization.

Application for registration shall be submitted to the Director of Electrical & Mechanical Services in writing together with supporting documents and the application fee as stipulated in the Regulation. The applicant will be notified of the application result within 40 working days upon receipt of all necessary information. The relevant application form can be obtained from the Electrical & Mechanical Services Department.

Paper No. 7

RELIABILITY AND LV PRODUCTS

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ABSTRACT

The aim of this paper is to answer the question "which installation best satisfies the growing needs in terms of electrical power availability ?".

This requirement can be satisfied by the main functions of LV power centres which is the vital link in any distribution network.

First of all, the main functions of LV switchboard will be presented.

Then, dependability concepts will be quickly introduced.

Finally, the industrial dependability concept will be developed as all installations must be designed to meet customer's requirements including economical aspects.

To achieve this goal, the various technical solutions will be evaluated with regard to dependability.

To conclude this paper, several new developments in the field (like power management) will be studied and the focus will be put on analysing how these developments can reinforce dependability of the LV installations.

GLOSSARY

- HV** – high voltage.
IEC – International Electrotechnical Commission.
IP – degree of protection of low voltage switchboards.
LV – low voltage.
MCC – Motor Control Centre, LV switchboard grouping the control and monitoring elements of a number of motors.
MLVS – Main Low Voltage Switchboard.
MTBF – Mean Time Between Failures.
MTTR – Mean Time To Repair.

MV – medium voltage.

PE – protective conductor.

TTA &

PTTA – Typed-Tested Assemblies and Partially Type-Tested Assemblies: LV switchgear and controlgear assemblies defined by standards imposing certain service conditions, construction requirements, technical characteristics and tests.

UPS – Uninterruptible Power Supply.

Bus (serial) – a communications network over which all data elements, including those related to monitoring, are transmitted one after another.

Communicating Component

– device such as a circuit breaker or relay that is capable to transmitting a wide range of information such as trip unit settings, currents, overloads, causes of tripping and insulation-resistance values.

Intelligent

Switchboard – an assembly including communicating components (circuit breakers, relays, etc.) and a central unit (processing capacity), connected by a communications network or bus. It can function alone or as part of a supervision system.

Protocol – set of rules ensuring cooperation between entities, generally separated by a certain distance, particularly in order to establish and maintain the orderly exchange of information between them.

Switchboard

Central Unit – a processing unit within the switchboard, used to organise digital information forwarded by the communicating components, automate electrical distribution functions and communicate with the installation's supervision system.

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1. INTRODUCTION

This paper deals with the dependability of commercial and industrial low voltage electrical installations. Its aim is to answer the question "which installation best satisfies our growing needs in terms of electrical power availability?".

The subject is dealt with for LV switchboards and focuses on the following problems:

- which switchboard functions guard against failure of the LV distribution system?
- how should they be used?
- with what components?
- in what power system environment (number of sources and loads, type of system earthing)?

The reason for this focus is that LV switchboards are vital links in any power distribution system.

This paper is intended to help operators and designers of electrical installations to:

- determine the points which must be considered. These points are related to the technical choices dealt with in the sub-chapter titled "industrial dependability concepts". The discussion is based on reliability levels calculated on concrete cases and yields solutions in terms of equipment type. A summary is given in the sub-chapter titled "required dependability levels".
- realise the increasing influence of power management systems on LV switchboard dependability.

2. SWITCHBOARD FUNCTIONS

The switchboard is a key part of any electrical installation. It incorporates devices designed to:

- distribute electrical power and protect circuits,

- protect persons,
- control and monitor the installation.

Recent developments in this control and monitoring function have made the switchboard even more vital to the installation. The dependability of the entire installation is largely determined by the dependability of the switchboard. Moreover, the lasting viability of the associated industrial or commercial activity depends on the capacity of the switchboard to keep pace with future needs.

Dependability of electrical distribution means:

- a very low probability of failure (reliability),
- no dangerous failures (safety),
- the ability to operate at any given time (availability),
- fast repair (maintainability).... throughout the entire lifetime of the installation.

These notions of dependability must be taken into consideration right from the switchboard design phase.

Today, dependability requires decentralised management of the installation. For instance, load shedding/reconnection and source changeover automation systems, measurement instruments and protective devices, are placed as close as possible to the application to ensure:

- optimum modularity,
- greater reliability (a local failure does not paralyse the entire installation),
- operating flexibility with local control and monitoring possibilities at switchboard level in addition to centralised supervision. The dialogue between the various distribution levels is considerably simplified by the use of digital communications networks.

As a result of this decentralisation, part of "intelligence" is integrated in the various LV switchboards of the installation which house the main electrical components used between the transformer and the load devices.

The result is a switchboard system including:

- the Main Low Voltage Switchboard,
- the switchboards specific to motor control (MCCs - Motor Control Centres),
- the subdistribution switchboards,
- the final distribution enclosures.

2.1 THE SWITCHBOARD AND ITS FUNCTIONS

The implementation of the functions of a switchboard involves various aspects.

- the LV installation architecture, broken down into various switchboards, enclosures, etc. at various locations, forming the installation layout.

The switchboards are further divided into a number of zones for:

- components,
- busbars,
- connection,
- auxiliaries.

The minimum clearances and safety distances must be satisfied.

- the functional units, providing the electrical functions needed by the user. Each unit includes the components designed to cover a given function, for example protection of a feeder or a set of feeders, motor control, incoming protection, etc.
- the enclosure, providing :
 - protection of electrical equipment inside enclosures against penetration by solid bodies and liquids;
 - protection of persons provided by:
 - i. interconnection of all metal parts (frames, enclosures, including the door) which are earthed using protective conductors (PE),
 - ii. reduction of openings (ventilation, cable entries, etc.) to prevent access to live parts either directly or via tools (e.g. screwdrivers),
 - iii. possible use of barriers to avoid contact with live parts when the door is open;

- degrees of protection

(IP) IEC 529, HD 365 and NF C 20-010 standards define the various degrees of protection of persons (against direct contacts) and equipment (see figure 1) using two numerals and two letters. Impact strength is characterised by a separate IKx index as in European standard EN 50102;

- adaptability

The enclosure must be adapted both to the volume of the components to be housed and to the size of the premises and means of access.

Connections are made from the top or bottom, front or rear, as required.

- internal partitions.

For increased dependability, the cubicles can be divided up by partitions and barriers (metal or not). The various equipment items are installed and cabled in the switchboard in such a manner that they do not interfere with each other, for example through electromagnetic fields, vibrations or arcs. Partitioning is a solution for most of these phenomena and suitable ventilation solves the associated thermal problems.

Barriers and partitions also contribute to:

- protection against contact with live parts belonging to the adjacent functional units,
- limitation of the probability of initiating arc faults,
- protection against the passage of solid foreign bodies from one functional unit to another.

The corresponding levels of dependability are evaluated further on in this document.

These partitions are often related to the switchboard architecture and thus delimit the various zones intended for components, busbars, connections and auxiliaries.

The separation of the various switchboard elements and functions (see figure 2) is defined in standards IEC 439-1 paragraph 7.7 and NF C 63-410.

- form 1: no separation,

- form 2: separation of busbars from functional units,
- form 3: same as form 2 plus separation of all functional units, but not of their terminals for external conductors, from one another,
- form 4: same as form 3 plus, separation of the terminals for external conductors which are an integral part of the functional unit.

• internal electrical connections

Consisting of conductors (busbars and cables) within the enclosure, they carry and distribute the current according to the installation diagram.

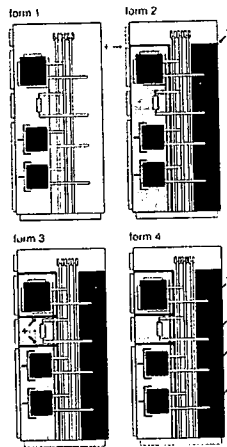
- their cross-sections and number vary according to the nominal currents.

However their characteristics also depend

Fig. 1: Elements defining a degree of protection IP as in standards IEC 529, HD 365 and NF C 20-010.

element	numerals or letters	meaning for the protection of equipment	meaning for protection of persons
first characteristic		against ingress of solid foreign bodies:	against access to hazardous parts with:
numeral	0	(non-protected)	(non-protected)
	1	diameter >, 50 mm	back of hand
	2	diameter > 12.5 mm	finger
	3	diameter >, 2.5 mm	tool
	4	diameter > 1.0 mm	wire
	5	dust-protected	wire
	6	dust-tight	wire
second characteristic		against harmful ingress of water:	–
numeral	0	(non-protected)	
	1	vertically dripping	
	2	dripping (15° tilted)	
	3	spraying	
	4	splashing	
	5	jetting	
	6	powerful jetting	
	7	temporary immersion	
	8	continuous immersion	
additional letter (optional)			against access to hazardous parts with:
	A	–	back of hand
	B		finger
	C		tool
	D		wire
supplementary letter			supplementary information specific to:
(optional)	–		
	H	high voltage apparatus	
	M	motion during water test	
	S	stationary during water test	
	W	weather conditions	

Fig.2: "The forms" defined by standards IEC 439-1, EN 439-1 and NFC 63-410 delimit the various zones in a switchboard.



on other parameters, for example the rated short-circuit withstand current of a switchboard, equal to the root mean square of the current that can be withstood by the switchboard for one second (see standard IEC 439-1).

- their supports must in turn withstand the

corresponding electrodynamic forces and thermal stresses, and also comply with minimum creepage distances.

- as regards control circuits, their coexistence with power circuit is achieved by running them separately and using appropriate connections.

Likewise, the auxiliaries (for form 3 separation or higher) are isolated from the other units and are thus subjected to a less restrictive environment in thermal and electromagnetic terms.

- component connections

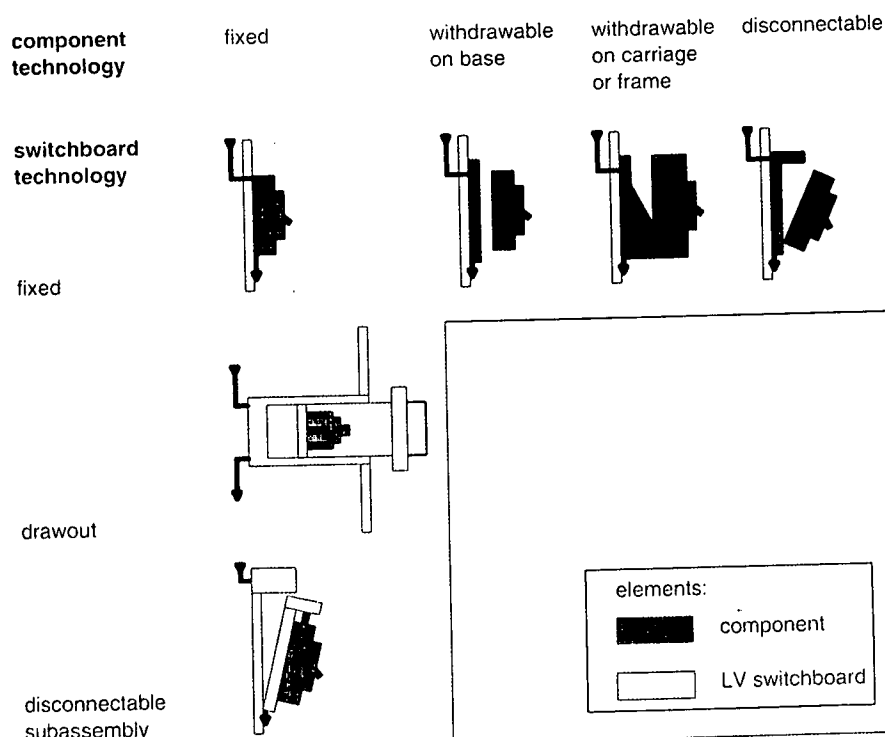
The way a component is connected or installed influences availability and maintainability. Component installation methods include **fixed, withdrawable or disconnectable**.

Reminder:

- a device is said to be fixed when tools are required to separate it from the main circuit,
- a device that is withdrawable from a base or frame (for a heavy device) can be moved to

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Fig. 3: The various possible installation methods for components in an LV switchboard.



a position for which an isolating distance is achieved between its upstream and downstream connecting elements,

- a disconnectable device has a withdrawable upstream connection and a fixed downstream connection.

Likewise, these installation methods are linked to switchboard technology which may be fixed, drawout (racks) or disconnectable (see figure 3).

For example: a withdrawable assembly can be either a switchboard containing fixed devices in drawout units or withdrawable devices (on base or frame) on a fixed panel.

2.2 THE SWITCHBOARD'S FUNCTIONAL GUARANTEE

Switchboard design refers to **standards** governing the entire low voltage domain, and, more specifically, to standards relating to assemblies (cubicles, desks,...).

Compliance with these standards is the minimum guarantee of a level of quality and dependability.

Standards IEC 439-1, EN 60 439-1 and NF C 63-410 define the construction requirements, technical characteristics and tests for "type-tested" and "partially type-tested" assemblies.

- assemblies manufactured in accordance with established types are known as "Type-tested assemblies" (TTA),
- assemblies derived from type-tested arrangements (e.g. by calculation) are known as "Partially type-tested assemblies" (PTTA).

Heat exchange must be controlled within a switchboard to avoid overheating the equipment installed inside. This requires proper ventilation and in some cases a careful choice of installed components to ensure a suitable level of reliability.

Moreover these thermal studies are part of work currently conducted by the Schneider technical sections and aimed at optimising the

technical characteristics of LV switchboards, it particularly concerns:

- power connections (definition of a certain number of parameters as a function of currents),
- short-circuit mechanical and thermal withstand described above (using computer models),
- control and monitoring installation (using studies and tests),
- dependability of low voltage distribution systems through switchboards.

In addition to the above work, the switchboards undergo numerous tests (see above-mentioned standards) to validate the theory and guarantee operation of the resulting assembly.

These tests include verification of:

- temperature-rise limits,
- dielectric properties,
- shortcircuit withstand strength,
- continuity of the protective circuit,
- clearances and creepage distances,
- mechanical operation,
- degree of protection.

Likewise, in order to meet customer needs and ensure the durability of the required quality level, the design, industrialisation and manufacture of LV switchboards must comply with the Quality directives, methods and controls.

3. OPTIMUM DEPENDABILITY

Reduction in the number of failures and the resulting shutdown times increases safety and productivity in companies.

What is more, users today demand a "tailor-made" level of dependability, i.e. an installation adapted to their needs. The notion of optimisation is thus vital, meaning just the right level of dependability in order to ensure the best price.

If this is to be possible, manufacturers, installers and specifiers must master the dependability parameters of their installations.

3.1 DEPENDABILITY CHARACTERISTICS

- dependability parameters. The notions involved in dependability (reliability, maintainability, availability and safety) are all linked. Three of these notions can in particular be associated by their representative quantities which are:

- for reliability, the failure rate (λ) or its reciprocal ($1/\lambda$), the **MTBF** (Mean Time Between Failures).

The failure rate of a transformer is for example $6 \times 10^{-7} \text{ h}^{-1}$ which corresponds to a mean time between failures of 195 years, or to 1 device out of 195 failing on the average each year.

- for maintainability, the value **MTTR** (Mean Time to Repair) is used. This time covers detection of the failure, the time required to supply the spare parts and the actual repair time.
- for availability, the quantification depends on the combined aspects of reliability and maintainability.

The opposite of availability, which is obviously **unavailability** (I_D) is expressed (for most systems) by:

$I_D = \lambda \text{ MTTR}$ where λ represents the reliability and MTTR the maintainability.

For a transformer, if 12 hours elapse between the failure and resumption of power, its unavailability is $= 6 \times 10^{-7} \times 12 = 7.2 \times 10^{-6}$, which is equivalent to 4 minutes of unavailability a year (i.e. $7.2 \times 10^{-6} \times \text{number of minutes in a year}$).

Remember that for a given installation architecture, availability is characterised by a combination of good reliability and efficient maintenance.

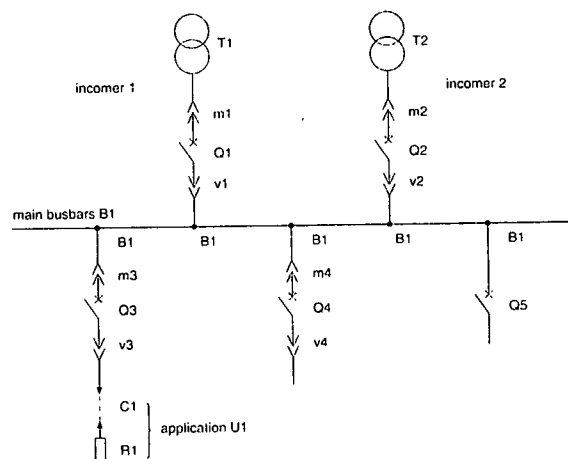
- dependability applied to assemblies. To calculate dependability, the failure tree method must be applied to the LV electrical

distribution system studied

3.2 ANALYSIS

Let us consider the availability of electrical power of application U1, shown in figure 4.

Fig. 4: Example of an electrical distribution system.



The undesirable event at the top of the failure tree is thus absence of power on U1. This event is broken down into four modules as shown in the chart in figure 5.

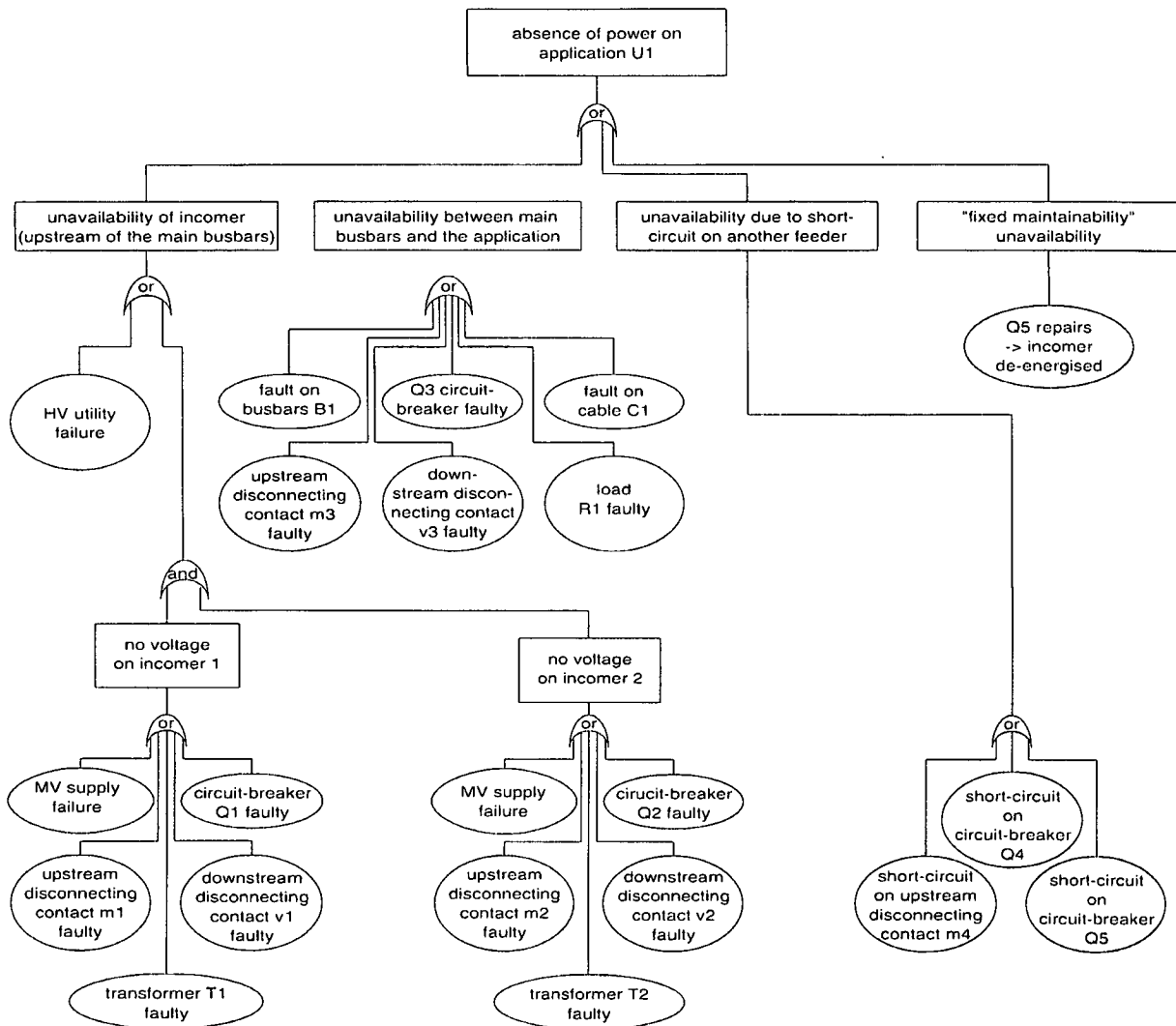
- unavailability of incomer. Each incomer can alone supply the entire LV distribution system on which the application depends. The two medium voltage (MV) incomers are assumed to be taken from two different substations, which virtually reduces the common failure mode to the unavailability of HV (high voltage transmission).

The circuit-breaker failure modes considered for calculation of incomer **unavailability** are:

- spurious tripping,
- refusal to close,
- internal short-circuit,
- temperature rise.

The failures of HV system components, MV incomers, transformers and disconnecting contacts have been considered together.

Fig. 5: Failure tree associated with the diagram in Figure 4.



- unavailability between the main busbars B1 and the application. This sums the unavailabilities of the elements encountered from the main busbars to point U1. Each failure is broken down as finely as possible and results in different repair times. For example, for the busbars:

- loosening of the busbar supports due to strong vibrations may cause the bars to break when they are subjected to a high electrodynamic force. The resulting repair time is several hours (part replacement).
- an object falling on these bars when energised, although highly unlikely given the construction arrangements chosen (form, IP...), often results in

arcing and in a repair time of several working days.

- unavailability due to short-circuit on another feeder

The clearing of a short-circuit occurring upstream of the first protective device on a feeder parallel to the feeder considered results in de-energisation of all the feeders.

We thus have to add up all the short-circuit probabilities by descending on each parallel feeder up to the first protective device.

Downstream, a short-circuit affecting U1 is possible only if there is combination of a short-circuit and failure of a protective device to react, the combined probability of which is negligible.

- "fixed maintainability" unavailability.

Fixed maintainability is the term used to indicate that the repair time depends on the installation method (fixed or withdrawable) and affects use of the other feeders.

Examples (see figure 4): application U1 is affected by repair of Q5 which, as it is fixed, requires shutdown of the incoming supply, whereas repair of Q4, withdrawable, can be carried out with the busbars energised and thus without affecting application U1.

3.3 THE RESULTS

The following results are those corresponding to the usual reliability and MTTR values encountered for the various system components.

Unavailability of the load is 6.4×10^{-5} , i.e. 33 minutes a year. An examination of the relative importance of the different aspects gives the following breakdown of unavailability:

– incomer	45%
– between busbars and application	51%
of which:	
• cable and load	32%
• rest upstream	19%
– short-circuit on another feeder	1%
– fixed maintainability	3%

The various points to be examined are derived from this analysis and will be dealt with in the next section.

3.4 INDUSTRIAL DEPENDABILITY CONCEPTS

As defined above, the installation must be designed to meet the customer's specific requirements. In all systems, just one small element can often jeopardise overall dependability. So if you do not want to end up "pushing a Porsch", the importance of the various technical choices must be evaluated with regard to dependability.

These choices include:

- the diagram (incomer, final application,

system earthing arrangement),

- the connections,
- the electric arcs,
- * the switchboard options (form, connection, fixed or withdrawable components, IP...),
- the motor feeder units,
- the control and monitoring auxiliaries.

3.5 DEPENDABILITY IN RELATION TO THE DIAGRAM

Two elements are of critical importance to dependability:

- the incoming diagram,
- the final applications.

A third element, the system earthing arrangement, also has great influence.

- the incoming diagram

As availability of the incomer affects all applications, whether or not they are critical, it is important, if at all possible, to choose an incoming configuration in keeping with the downstream need. The chosen solution will depend on the environment studied. For example:

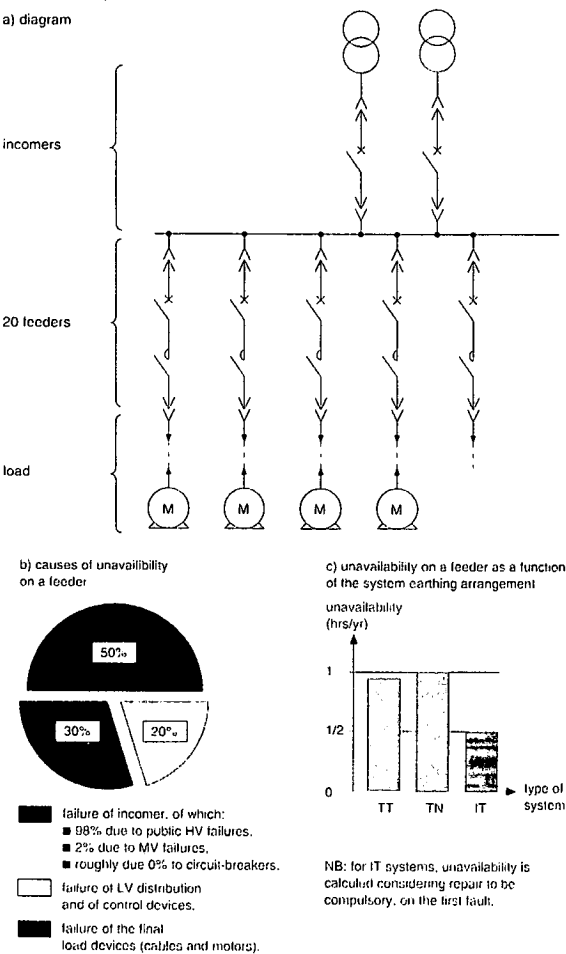
- in isolated regions, it may be hard to obtain an MV line with good availability and even harder to obtain two separate MV lines. In this case the study must consider independent energy production such as by an engine generator set.
- some sectors of industry (chemistry, petrochemistry, paper-making) generate energy (often in the form of steam) through their manufacturing process which they use to drive turbogenerators. The public distribution system is then used as a backup source.

NB: if, despite this, the availability of the incomer is insufficient, a UPS (Uninterruptible Power Supply) must be placed as close as possible to the critical applications.

- calculation of unavailability due to the incomer

On the example in figure 6 (2 parallel incomers, 20 motor feeders), unavailability of the application is roughly 1/2 hour a year, 50% of which is due to failure of the incomer. From this we conclude that unavailability of the incomer, although not always preponderant, may nevertheless account for a large part of total unavailability. We shall see later on that the incomer unavailability percentage ranges between 7% and 90% according to the measures taken to ensure reliability of the rest of the system.

Fig. 6: Unavailabilities due to arcing and connections account for roughly 20 % of causes of system unavailability.



The incomer has two main critical points, namely:

- the high voltage transmission line,
- the medium voltage line;

Transformers, circuit-breakers and disconnecting contacts are 100 to 1000 times more reliable than these two sources of failure.

How can the dependability of the incomer function be improved? There are many possible solutions, and the context is a decisive factor. Greater reliability can be obtained by concentrating on the following points:

- redundant incomers

Two medium voltage lines from two different source substations, used in parallel, solve the problem of unavailability of the medium voltage lines. The unavailability

of the incomer function is now virtually reduced to that of the high voltage system alone which is roughly 17 minutes a year, compared to 10 hours for the MV system. Availability can also be increased by adding one or more generator sets

- splitting into priority and non-priority feeders

The search for increased availability of electrical power nearly always results (depending on installation size) in dividing applications into two types:

- priority,
- non-priority.

In the event of an overload or failure of the main source, non-priority loads are then shed, while priority loads continue to run on a secondary source (second MV incomer, generator set,...).

- source changeover systems

If a failure occurs, circuits can be transferred to backup sources not used in normal operation or to the sources of non-priority feeders, with load shedding of the latter.

Three types of changeover systems are possible:

- synchronous

The main source and the replacement source are or have the possibility of synchronising, thus ensuring changeover without loss of load supply.

This process is used in installations requiring a high level of dependability.

- delayed

This is the most common type of source changeover system. With transfer times ranging from 0.4 to 30 seconds, its use is widespread for industrial and commercial applications.

- pseudo-synchronous

A fast-acting switching device (60 to 300 ms) is used for the source changeover. This system is found, for example, in the following sectors:

- chemistry,
- petrochemistry,
- thermal power plants.

- loads

Unavailability due to the load devices is illustrated in the diagram in figure 6 and concerns for instance the motors and the cables supplying them from the switchboard. Reliability calculations show for example that when using a motor M, 30% of its down time due to failures is caused either by the cable or by the actual motor. It is thus necessary to clearly define the technical characteristics of the loads as regards conditions of use, as well as the maintenance procedures intended to prevent failures.

Most electrical failures in motors are due to phase/earth faults occurring on motor startup.

Insulation monitoring before starting a motor, particularly using the Vigilohm SM 20 developed by Schneider, enables:

- preventive maintenance to be programmed,
- irreversible motor damage to be avoided.

- system earthing

The three system earthing arrangements are

(see figure 7):

- TT system (earthed neutral and earthed protective conductors),
- TN system (earthed neutral and protective conductors connected to neutral),
- IT system (unearthed neutral and earthed protective conductors).

The system earthing arrangement affects availability and maintainability in that the circuit must be broken on a first fault for TN and TT systems but not for IT systems. In addition, the magnitude of the earth fault current depends on the system earthing arrangement and determines the extent of damage caused to the installation and in particular to the loads.

The results of a reliability study are shown on the histogram in figure 6. The IT system, with an automatic system for fast locating of the first fault, is the one offering the best availability, as it ensures that:

- operation is not interrupted (continuity of the production cycle in progress),
- the fault can be repaired when the installation is not in operation,
- servicing can be prepared during production, resulting in increased maintainability.

The IT system is recommended in the following cases:

- presence of loads sensitive to high fault currents,
- high risk of fire,
- installations with generator sets (to prevent damage to the generator by an internal fault),
- need for a high level of dependability (availability + safety), for example in operating rooms in hospitals.

NB: in the IT system, the probability of de-energising due to a second fault (if this fault occurs before the first fault has been located and cleared) is less than in the TN and TT system as the simultaneous presence of the first and second faults is necessary on different phases.

Fig. 7: Choice of system earthing arrangement directly affects the dependability and reliability of the installation.

System	TT	TN	IT
action during an insulation fault	immediate de-energising	immediate de-energising	continuation of operation fault tracking preparation before de-energising
magnitude of fault current (determines damage to installation)	several dozen amps	several kiloamps (short-circuit current)	several dozen milliamps (1 st fault)

We saw earlier that the system earthing arrangement must be selected with great care. Once this choice has been made, the equipment (switchboard and components) can be chosen, and a certain uniformity sought in the reliability of the different links in the chain making up final unavailability.

3.6 DEPENDABILITY AND CONNECTIONS

A switchboard is made up of a large number of connections and it is therefore important to consider the failures they cause.

A connection fails when it ceases to convey the electrical power for which it was designed. A local temperature rise then occurs which may cause irremediable damage to the device and/or the cables.

The importance of good connections is illustrated by the example of an installation with two separate incomers supplying 20 feeders.

The results of the reliability study (see figure 8) show that 88% of total unavailability is due to various failures (incomer, components) and 12% to connections.

A distinction should be made between factory connections and those made on site, as statistics show that the latter are more prone to failure.

In practice, dependability can be considerably

increased by:

- properly sized contact surfaces (overlapping),
- proper surface finish (flat and clean),
- a tightening torque suited to the materials

3.7 DEPENDABILITY AND ARCING

- unavailability due to arcing

A number of events can result in the creation of arcs in the switchboard, for example intrusion of small animals (rodents or reptiles), objects forgotten in the switchboard during maintenance work, a temperature rise or deposition of conducting dust.

The damage caused by electric arcs is frequently serious and leads to shutdown times of up to several hundred hours for an "ordinary" switchboard, i.e. 11 % of its total unavailability (see figure 8). In comparison, for an "improved" switchboard, this percentage is negligible as its shutdowns are limited to the time required to put the distribution system back into working order (cable tightening, cleaning of carbonised surfaces...), i.e. roughly one hour.

To prevent this unavailability, the following three points should be concentrated on:

- risk of arc occurrence,
- arcing time,

- propagation of electric arcs in the switchboard.

These actions aim at reducing both repair times and the extent of the damage caused by arcs.

- preventing arcing

It is better to prevent a problem than to cure it, in other words, to take action on the cause of electric arcs. Note that:

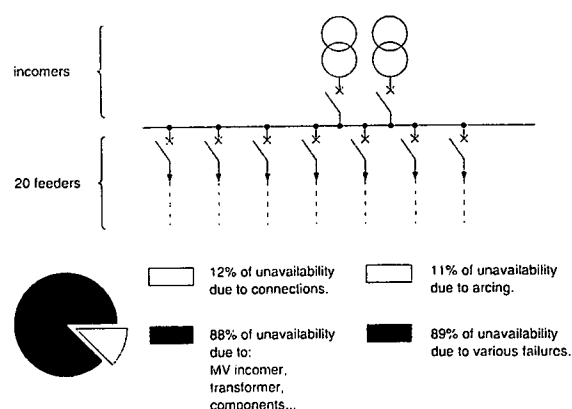
- arcing due to dielectric breakdown does not occur if:
 - i. materials are properly chosen,
 - ii. creepage distances and clearances are complied with.
- introduction of objects or foreign bodies, including conducting dust, and intrusion of small animals, are the cause of numerous electric arcs in LV cubicles.

To prevent arcing, considerable care must be taken with enclosure design:

- i. form,
 - ii. choice of IP,
 - iii. addition of filter...
- when breaking occurs (on a short-circuit or overload), pressurised ionised gases are given off by the protective device and may cause arcing, for example on a nearby busbar. This risk can be eliminated by a carefully designed architecture and/or barriers.
 - a faulty connection can often result in creation of an arc. To avoid this, connections must be correctly tightened (see section on "dependability and connections").
- limiting the arcing time
- Damage caused by arcing can be limited by minimising the duration of the arc. Possible solutions are:
- setting the "short-time delays" (short-circuit protection) to the minimum value that will still provide discrimination. These short delays,

designed to implement time discrimination, delay circuit-breaker tripping on a short-circuit, thus prolonging the arcing time. Note that when zone selective interlocking can be implemented, it is the best solution as it allows absolute discrimination with minimum delays for all distribution stages.

Fig. 8: Unavailabilities due to arcing and connections account for roughly 20 % of causes of system unavailability.



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- using limiting devices which quickly break short-circuit currents, thus limiting the fault current. Arcing time is thus reduced and thermal effects limited.
- choosing a protective device that takes past transient short-circuits into account

The peculiarity of the arc is that it is a somewhat furtive phenomena, for two reasons:

- i. due to switchboard layouts, an arc is quickly extinguished. However the ionised gases that it generates may cause restrikes on other live parts. A number of extinguishing and restrike sequences are therefore possible.
- ii. moreover, the impedance of the arc varies according to the speed at which it moves and the obstacles that it comes across.

However, each time arcing occurs, the equipment is subjected to a number of stresses which can be cumulated.

The solution to the problem is to provide protection systems which integrate the fault over time, i.e. when a fault appears and disappears (or drops below the trip threshold before the protective device trips), this time and current information must be stored in the protective device to obtain tripping if the fault or brief high current values rapidly reoccur. Thus LV circuit-breakers can be designed to store transient short-circuit information in memory and only gradually return to their initial tripping characteristics.

- preventing propagation in the switchboard

The laws of physics cause the arc to move quickly away from the source. To limit its consequences, the arc must not be allowed to spread through the entire switchboard. It is essential to control the arc throughout its duration by:

- partitioning the various switchboard zones; insulated bushings and partitions prevent the arc and its ionised gases from spreading;
- enhancing arc extinction, for instance by implementing
 - i. insulation shrouds around the busbars,
 - ii. busbar geometries that lengthen the arc.

3.8 DEPENDABILITY AND THE SWITCHBOARD "OPTIONS"

The form, type of connection (front or rear), device installation method (fixed or withdrawable) and the degree of protection are all possible options when manufacturing and/or purchasing a LV switchboard.

The example in figure 9 shows the effect of these choices on availability at feeder level.

- form (see figure 2)

Consider form 1 with "unsealed openings"

compared to form 2 with "cable access openings sealed".

The abbreviated expression "cable access openings sealed" means that the user has passed the cables through a bottom plate equipped with a cable bushing.

NB: this arrangement is used for form 2 and above.

This example clearly shows that a wise choice of form increases availability (see figure 9), as it affects:

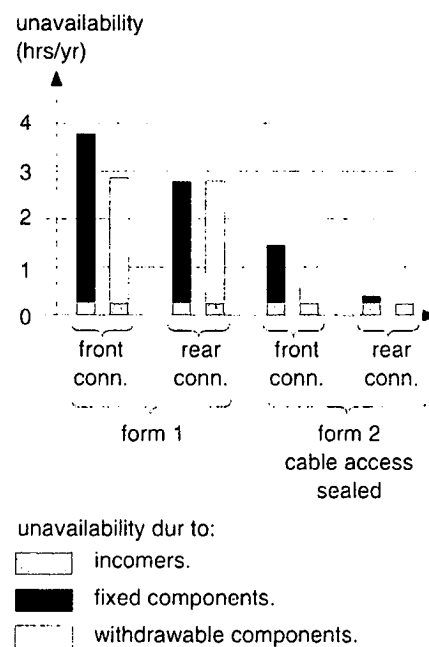
- likelihood of fault occurrence (rodent intrusion impossible),
- arc propagation (presence of partitions).

For good availability, LV switchboards should be partitioned (form 3), including the terminals for external conductor connections (form 4), since, as already pointed out, these connections are the cause of most faults (see paragraph on "dependability and connections").

- front or rear connection

The space reserved for electrical equipment

Fig. 9: Unavailability times depend on switchboard technology and particular on its connection type (the chart corresponds to the diagram in Figure 8).



when designing premises frequently determines the type of connections used. This constraint has a certain effect on availability. Access to a switchboard with front connections only is often difficult, resulting in lengthy repair times compared with switchboards offering dual accessibility (see figure 10).

Note that the unavailability of a switchboard with front connections is even higher if fixed components are used that require tools for dismantling.

To increase maintainability of a switchboard with front connections, designed to stand against a wall, a small servicing clearance should be provided at the rear.

- fixed or withdrawable

Availability can be improved by choosing withdrawable devices (see figure 9). In this way, maintenance is faster and does not affect adjacent feeders.

Since withdrawal takes place off-load (with the circuit open) but with power on, breaking is not necessary upstream and interruption of supply to the other feeders parallel to it is not required.

However the withdrawable option may not offer any great advantage for installations subject to a high levels of unavailability elsewhere (unreliable source, single incomer presenting risks,...) or when excellent maintainability does not affect other feeders.

However, in the case of a form 2 switchboard with front connections, the advantage of using 'withdrawable' circuit-breakers is clear (see figure 9).

Only the first two characteristic digits of the IP (ingress of solid bodies and liquids) are examined in this section.

In this instance unavailability is divided by 3 compared with the "fixed" solution.

- degree of protection (see figure 1)

The first numeral gives the maximum size of objects or particles likely to enter the switchboard, thus limiting the size of the

access points to live parts.

This numeral (1 to 6) increases as size decreases.

The second numeral concerns liquids and describes protection obtained by:

- canopies, covers or baffles protecting against vertical and/or horizontal liquid splashing and jetting,
- seals and suitable devices protecting the enclosure even in the event of immersion.

In conclusion, the higher the first two characteristic numerals of the IP index, the better the protection.

However, all electrical devices produce heat and most of them have a thermal limit.

Excessive imperviousness is contrary to proper switchboard ventilation and may thus affect operation of the components. Heat extraction and/or a suitable choice of devices is thus necessary.

The degree of severity of the environment and the qualification of switchboard operators determine the choice of degree of protection. The necessary protection levels, for each type of premises, are reviewed in figure 11.

3.9 DEPENDABILITY AND THE DRAWOUT MOTOR FEEDER UNIT

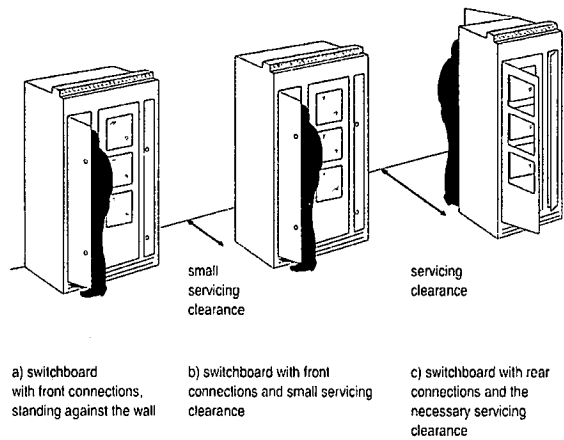
MCC drawout type switchboards are often used in process industries.

Good continuity of service is normally required for motor control. Drawout units allows quick, easy maintenance: the faulty feeder is immediately replaced by an identical device while power continues to be supplied to the switchboard.

A drawout unit corresponding to a motor feeder can be composed (see figure 12) of a fuse, contactor and thermal relay or of a circuit-breaker, contactor and thermal relay.

In terms of availability, both configurations are more or less equivalent in normal operation, but differ considerably should the contactor fail.

Fig. 10: A good compromise between maintainability and floor space can be obtained using a switchboard with front connections and a small servicing clearance at the rear.



In actual fact some 20% of feeder failures are due to contactors (contacts sticking), with the added disadvantage of having to remove the contactor from the drawout unit. The power circuit then has to be opened, which is possible with the circuit-breaker/contactor combination by opening the circuit-breaker. In the other case (fuse/ contactor combination) power must be switched off upstream, thus making all the other motor feeders unavailable.

The consequences of this procedure can be demonstrated for a diagram with 20 motor feeders supplied by 2 separate IVIV incomers, an example illustrated by the results histogram (see figure 12).

Two contactor operating rates can be identified (low and high). The likelihood of failure of a drawout unit are linked to the operating rate of the contactors. It is thus preferable to use a

Fig. 11: Examples of minimum degree of protection (as in NF C 15-100 and practical guide UTE C 15-103)

Sector of use	examples	IP degree
domestic premises	bed room	20
	washroom	27
technical premises	electrical service	00
	air conditioning washer	24
	refrigeration chamber	33
boiler plants and associated premises (power > 70 kW)	fuel storage	20
	coal storage	50
	boiler plant	61
garages and parking areas (area > 100 m2) buildings for collective use	repair shop	20
	washing area	25
	offices	20
	gymnasium	21
	large kitchen	35
farms	alcohol warehouse	23
	hen-house	45
	fodder storage	60
industry	electroplating shop	03
	paperboard manufacturing	33
	quarry	65
commercial and associated premises	art gallery	20
	hardware shop	33
	bakery	50
	cabine tmarker	60

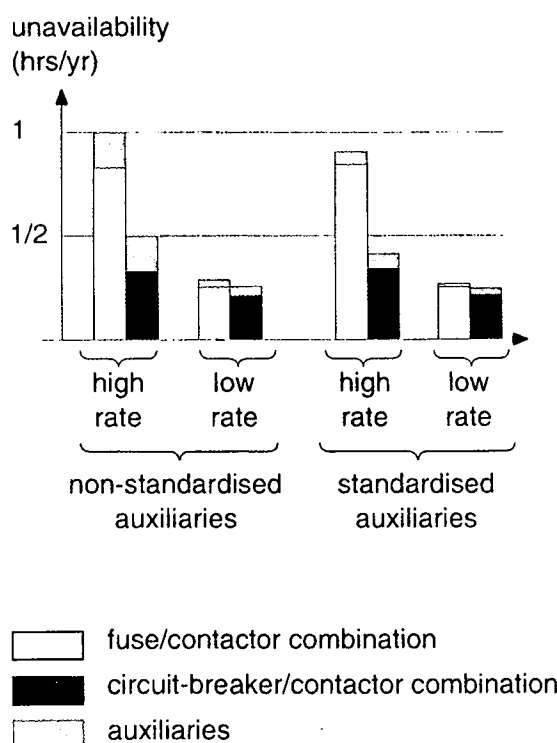
circuit-breaker rather than a fuse as a protective device if intensive use is made of contactors (operating rate and also utilisation categories of loads AC3, AC4, operating voltage....).

3.10 DEPENDABILITY AND THE CONTROL AND MONITORING AUXILIARIES

Using the same example (see figure 12), the influence of the control and monitoring auxiliaries on total availability can be determined.

Their associated failures relate to relays, connections or to their power supply.

Fig.12: Comparison of levels of unavailability for a 20-feeder drawout type switchboard depending on type of components and their operating rate.



The individual wiring of non-standardised auxiliaries is a lengthy process and subject to errors by fitters, resulting in potential failures. To avoid this, Schneider offers standardised products for auxiliary functions (Digibloc, Dialpact,...). These are boards or control and

monitoring modules connected by power distribution blocks or by standardised digital links. These elements centralise information and can be used to implement a wide variety of control schemes.

Furthermore, these schemes can be easily modified by setting board parameters or by associating new modules, with the following advantages:

- time savings on implementation,
- increased reliability by eliminating wiring errors,
- repair time reduced to the time required to replace the board or module,
- open-ended solution.

The results of the reliability calculations on the histogram show that these standardisation efforts increase the availability of control auxiliaries depending on the operating rate (from 30% at low rate to 60% at high rate).

3.11 REQUIRED DEPENDABILITY LEVELS

A large number of technical options are available for LV installations, all offering different dependability levels. The right choices depend on the application and on the choices made at other levels.

For example use of a form 4 switchboard is advantageous provided that the other major sources of failures on the installation have been overcome.

The right approach when designing an LV installation is not therefore to choose and install at random a range of effective, reliable devices in the hope of gaining maximum "peace of mind". In actual fact, each application or sector using LV electrical power requires an appropriate level of dependability, depending on operating imperatives (see figure 13):

- the commercial and service sector includes both of small shops and schools... as well as supermarkets, shopping centres, large banks, office blocks, hospitals.
- industry sector comprises all types of

factories (automobile, aeronautic, textile,...) and has special needs in terms of distribution (power system protection and architecture) and processes (motor control, control system), which are vital in continuous production applications such as petrochemistry, cement works, food processing.....

In what way do these sectors represent different needs? Accidents such as B H O P A L (December 1984), C H E R N O B Y L (April 1986) and P A S A D E N A (October 1989) are evidence of the high risks run by people and the environment. Hence the unfailing question "is it dependable?".

In fact this question is meaningless. As the possibility of failure is always present, however small, the right question is rather: "Is it dependable enough?".

For all sectors this means choosing an acceptable level of probability of dangerous failure (in safety terms) and of dependability (in economic terms):

- in telecommunications, France Telecom has a probability of unavailability of 1 hr/century for telephone exchanges ($\lambda < 10^{-6} \text{ h}^{-1}$).
- in air transport, two dependability conditions are laid down to ensure that:
 - all "overall catastrophic" failures are extremely unlikely ($\lambda < 10^{-9} \text{ h}^{-1}$),
 - all "critical" failures are extremely rare ($\lambda < 10^{-6} \text{ h}^{-1}$).

This figure can be compared with the likelihood ($1 < 10^{-6}$) of a human being dying within the next hour.

- in banks, power failures result in lost entries and recording of erroneous operations. The costs involved in tracking and recovering these errors provide the necessary reference elements.
- in hospitals, safety of persons can be immediately affected by a failure.

Operating theatres and reanimation wards are especially designed to ensure a high

level of dependability.

- in industry, failures also considerably affect continuity of service. An article written by Y. Lafarge and published in "Le Monde" quotes two examples:

- for BSN (Danone), a 10 minute shutdown causes a production loss of 20,000 items, power on which the entire activity of the company depends.

Thus, in the commercial and service sector and industry alike, failures may have economic consequences, cause damage or be a source of major risks.

All of which may affect our everyday life in which good service in 99% of cases ($\lambda = 10^{-2}$) would mean:

- more than 140 new-born babies would accidentally be dropped by doctors and nurses each year;
- no electricity or water for several dozen hours each year;
- your telephone and television would be out of order for more than 10 minutes a week;
- 400 letters an hour would never reach their destination.

These evocative images clearly show the consequences of choice of dependability level. The table in figure 17, although not complete, gives the most important choices for an LV installation and for the various sectors of activity. To specify these choices, the need must be defined and the dependability concepts examined in the previous chapter must be implemented.

4. FUTURE PERSPECTIVES FOR SWITCHBOARDS

Modern switchboard technology has been and continues to be greatly influenced by the development of power management systems. We must therefore look into the implications of power management on dependability. The reader will find that Modern switchboard technology has been and continues to be greatly influenced

		sectors of activity		industry		
		commercial and service sectors		workshops	plants	process manufacturing
		shops	hospitals			
the problem to be solved:						
types of incoming diagrams						
operating imperatives	<p>numerous mobile and portable loads, frequent changes to distribution system, supply by a public power system.</p> <p>continuity of service for certain sectors, risk of fire, presence of generator sets.</p>		<p>uncertain earth circuits (worksites), supply by a public power system.</p> <p>continuity of service for certain sectors, presence of backup generator sets.</p> <p>continuity of service for most of the operation, risk of serious damage by insulation faults (motors, automation), risk of fire.</p>			
recommended system earthing arrangements	<p>↓</p> <p>TT</p> <p>↓</p> <p>IT</p>		<p>↓</p> <p>TT</p> <p>↓</p> <p>IT</p> <p>↓</p> <p>IT</p>		<p>↓</p> <p>TT</p> <p>↓</p> <p>IT</p> <p>↓</p> <p>IT</p>	
			<p>numerous auxiliaries (machine-tools), loads with low insulation resistance.</p> <p>↓</p> <p>TN</p>		<p>atmosphere and/or loads corresponding to high risk of insulation faults.</p> <p>↓</p> <p>TN sub-system</p>	
solutions implemented:						
component type	fixed		fixed		fixed	
	or disconnectable		or disconnectable		or disconnectable	
	or withdrawable		or withdrawable		or withdrawable	
switchboard type	fixed		fixed		with drawout units	
	or with disconnectable subassemblies		or with disconnectable subassemblies		or with drawout units	
form	F1 → to → F4		F2 → to → F4		F2 → to → F4	
	F2 → to → F4		F2 → to → F4		F2 → to → F4	
degree of protection IP (first two numerals)	2 → to → 5		2 → to → 5		3 → to → 5	
	3 → to → 5		3 → to → 5		3 → to → 5	
motor control components						
low rate						
high rate						
technology of control and monitoring auxiliaries	non-standardised (individual wiring)		standardised (boards, modules and connections)		non-standardised	
					standardised	

management provides the installation with greater dependability by integrating information processing electronics in the LV switchboard which thus becomes "intelligent".

4.1 POWER MANAGEMENT

Power management is already used in Building Management systems, which have gradually replaced more centralised systems in industrial, commercial and even domestic applications to supervise, monitor and control the following standard functions and facilities:

- heating and air conditioning,
- fire protection,
- intrusion protection,
- access and worktime control,
- lifts, lighting...,
- energy tariff management

Power management is becoming more and more decentralised for reasons of availability, user convenience and modularity (already mentioned in chapter 1). Over and above the traditional functions performed by electrical equipment (protection, automation, transfer of loads to backup sources), a power management system provides a number of functions in the electrical control and monitoring field.

To cite a few examples:

- automatic, progressive resumption of feeder supply after a fault,
- alignment of consumption to energy supply possibilities at a specific time (load shedding and reconnection, generator start up and shutdown),
- optimisation of sources according to consumption to derive maximum advantage from electricity contracts with differentiated tariffs,
- optimisation of capacitor bank operation,
- contribution to discrimination (coordination of protective devices). It also enables:
- local and remote control and monitoring (indications, alarms, controls and setting modifications
- supervision (graphic representation of system status, event logging and installation control).

The need for power management increases with the need for availability and, more generally, for dependability.

Power management systems have been made possible by the introduction and widespread use of microprocessor technology which at the same time provides an opening towards greater, distributed "intelligence".

4.2 POWER MANAGEMENT FOR GREATER DEPENDABILITY

A power management system relies on two principles when a failure occurs:

- the electrical distribution system can remain as it is and is not at risk by failure of a management module. This is simplified by the use of bistable power control devices such as switches, impulse relays and circuit breakers.
- the protection, control and monitoring systems continue to be independently activated, thus making operation in cripple mode possible. This principle ensures the prime objective of dependability even though certain functions of convenience are temporarily lost. Thus even if the supervision system fails, protection functions will continue to fulfill their task and the switchboard central unit will remain operational.

Moreover, power management reinforces dependability of the LV installations in terms of:

- reliability
 - the power management system reduces the major risk of failure represented by human intervention,
 - complete information eliminates the risk of error in system management.
- maintainability
 - Reliability can be obtained by rigorous design, but product dependability also requires a high level of maintainability. There are two types of maintenance:
 - preventive maintenance is designed to

anticipate problems and thus to limit the risk of shutdown due to a fault (it prevents the fault from occurring),

- curative maintenance is designed to quickly restore the system to its "operating" condition (it locates the fault).

Preventive maintenance takes priority over curative maintenance as it avoids problems during operation. However it requires sound knowledge of the products at all stages and the capacity to detect potential failures. Experiments and tests on equipment can provide this knowledge and a power management system can use it in an optimum manner:

- a preventive maintenance system is established to reduce the number of failures, using the following:
 - operation counters
 - insulation resistance measurement devices...
 - a curative maintenance system locates the fault in the event of a failure.
 - two other systems, remote maintenance and/or remote diagnostics, considerably enhance switchboard operation:
 - remote maintenance ensures surveillance without the need for a control room and a permanent maintenance team on site. Remote transfer of information on failures makes frequent inspections of the various electricity supply points unnecessary.
 - remote diagnostics enable troubleshooting to be conducted on the basis of quantifiable parameters transmitted via a telecommunications system. The reduction in maintenance time is obvious, particularly when outside suppliers are responsible for management and servicing of the installation. Remote diagnostics give them the best chance of repairing the failure on their first visit to the site.

- availability

availability is naturally the result both of reliability and maintainability, as well as:

- prevention of overloads with the solution of load shedding and reconnection to prevent tripping,
- management of sources (switching, coupling and startup of generator sets),
- discrimination of the various protection levels which, as explained above, has an important role in installation availability.

- safety

- safety of persons is guaranteed by reflex protective devices (placed as close as possible to the fault) which, although part of the management system, can function independently if a fault occurs.
- maintenance operations are fewer and can often be scheduled, allowing personnel to work under less stress.
- operating staff are guaranteed additional protection by indication of device status in maintenance areas, and by warning of potential failures.

4.3 THE TECHNOLOGY

Control and monitoring "intelligence" must be organised with sufficient care to ensure a good level of dependability. It particularly calls for implementation of:

- high-performance electronics,
- communication networks using reliable buses,
- software of recognised reliability, for overall control.
- electronic components and circuits are today increasingly reliable, driven by developments in the aerospace, military, nuclear and general public sectors. The reliability levels are easily controlled, since the statistical reliability laws associated with components are perfectly applicable and reliability calculations for assemblies well controlled.

Critical points are backed up by redundancy of all or some parts of the electronic modules or by using components with increased reliability.

- buses are responsible for the development of decentralised intelligent systems and form the communication backbone. The serial links making up the buses enable the transfer of data to many points via a single cable (coaxial or twisted pair). Their reliability has recently been upgraded and it is now possible to isolate them from external disturbances of the electromagnetic type and by using protocols including monitoring of information exchanges.
- system dependability also depends on that of the software controlling the system. In this case, rather than a revolution, we witness a systematic race for rigour at all levels, from design to commissioning (specification and development methods, special tools, highly sophisticated verification and test procedures).

4.4 THE "INTELLIGENT" SWITCHBOARD

The "intelligent" switchboard includes a large part of the power management system (see figure 14), in particular:

- the "intelligent" electrotechnical components,
- specific systems (e.g. insulation monitoring),
- the switchboard central unit
- the digital communications buses.

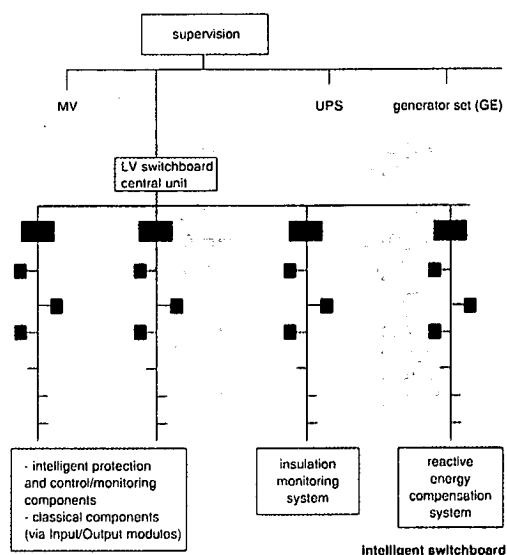
Use of microprocessors means that intelligence is distributed right through to component level (circuit-breakers, switches,.....). In addition to their basic function, they process a variety of information and communicate with the switchboard central unit, thus ensuring:

- "sequencing" of actions (logic and time sequencing),
- capacity to calculate and process many pieces of digital information sent by these devices, sensors and specific systems,

- remote transmission by "serial" bus enabling the control and monitoring system to communicate with the operator and/or the supervision system,
- control and monitoring, both local and remote, as well as supervision (orders are transmitted by bus).

The switchboard can now be said to be "intelligent": the intelligence integrated in the power management system will depend on the degree of complexity of the installation to be managed. The distribution of electrical power in small commercial applications may only require the display of measurements and status information on the front panel of the switchboard, whereas in large buildings, remote control functions are required (lighting, source changeover,.....)

Fig. 14: General diagram showing control and monitoring of an electrical installation and its links (BUS) supervision.



Power management is at present implemented in MV and LV by means of various components. These components, more and more standardised and convenient to use by electricians, will be available in increasingly wide ranges.

The various components in the intelligent switchboard are designed to work together. The consistency, both in terms of hardware and software, guarantees easy implementation and use.

An "intelligent" switchboard with appropriate overall design and made up of consistent, carefully designed and manufactured products, opens the way to efficient power management and the mastering of electrical power with greater dependability.

5. CONCLUSION

The distribution of electrical power must meet increasing requirements in terms of:

- dependability,
- upgradability,
- user friendliness.

Designers thus aim at producing installations which are "intelligent", independent, communicating, modular, reliable and easy to service.

These criteria can all be achieved by decentralisation. The basic functions (protection and control) are performed as close as possible to the application, and only supervision has a "central" position, playing a vital role in distribution management as regards the man/system relationship.

Decentralisation is a design feature of each product, both in their connections (defined between them) and in their overall architecture.

All these items (high power components, control and monitoring devices and electrical connections) are integrated in the LV switchboard. Its role is thus vital for distribution as a whole, given that it has to guarantee overall dependability.

The following points should be borne in mind:

- the incoming diagram and the reliability of the final loads are the points which may most handicap dependability,

- the system earthing arrangement affects availability of final loads and must therefore be chosen carefully,
- connections seriously affect switchboard reliability, thus calling for careful design and implementation,
- switchboard technology, form, degree of protection, connection,... must be adapted to the environment in which the equipment is installed (degree of pollution of premises, qualifications of operators,...),
- withdrawable components are used when they provide the added dependability required,
- drawout motor feeder units are particularly used in process industries for the flexibility and increased availability that they provide,
- auxiliaries with standardised connections and implementation guarantee the reliability of installation control and monitoring.

Dependability is everybody's job, including that of the designer (the right choices from the start), the installer (implementation in accordance with the manufacturer's recommendations and proper practices) and the maintenance engineers (surveillance and preventive maintenance of critical points).

This paper shows how dependability objectives can be achieved and how, by choosing the right options, particularly in terms of technology, the required level of dependability can be obtained.

The "intelligent" LV switchboard, associated with power management, meets the criteria of dependability and user convenience particularly well, providing a solution for both present and future needs. The degree of built-in "intelligence" required depends on the complexity of the installation.

This intelligent switchboard, designed to ensure maximum standardisation, integrates power, control and monitoring and communication via buses. Should changes be made to the distribution system, switchboard modularity and simple parameter resetting of the control and monitoring system ensure easy upgrading. There is no need to redo studies and

tests for each application as the product has already been thoroughly tested.

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**ELECTRIC POWER INDUSTRY RELIABILITY MANAGEMENT
IN MAINLAND OF CHINA**

中國內地的電力工業可靠性管理

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Electric Reliability Management Centre of
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PRC**

ELECTRIC POWER INDUSTRY RELIABILITY MANAGEMENT IN MAINLAND OF CHINA

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摘要

本文介紹了中國內地電力工業可靠性管理的發展，電力工業可靠性管理的組織機構，電力工業可靠性管理的主要指標體系及其在生產管理中的應用。並列出了1991—1997年度中國內地的大型火電發電機組的可靠性指標及主要城市的供電可靠性指標。

ABSTRACT

The development of electric power reliability management in mainland of China, the organization of electric power reliability management in the whole country and the main index systems of electric power reliability management and their applications in production management are presented in this paper. The reliability indices of large thermal generators and those of electric power supply in the main cities from 1991 to 1997 are also listed.

(一) 電力可靠性管理概述

一、概述

可靠性管理是被世界各工業發達國家以及中國所公認的一種科學管理方法，對於一般技術系統來說，可靠性的定義是：一個元件、一臺設備或一個系統在規定的條件下，規定的時間內完成其規定功能的能力。對於電力工業可靠性，更專業的定義為：電力系統各個環節，完成將符合標準的、滿足用戶數量標準的電力和電量輸送至用戶的程度。也就是說電力系統的可靠性是

評估電力系統按所接受的質量標準和所需數量不間斷地向電力用戶供電能力的度量。電力系統可靠性包括充裕度和安全性兩個方面。

充裕度 (adequacy) 是指電力系統根據用戶需要，以元件額定容量和允許的電壓變動範圍制約條件，同時考慮到在計劃的和非計劃的系統元件停運及運行操作的制約條件下，為用戶不間斷地提供電力和電量的能力。充裕度也常指靜態可靠性，也就是在靜態條件下電力系統滿足用戶電力和電量的能力。

安全性 (security) 是指電力系統承受突然發生的擾動（例如突然短路或非計劃地失去系統元件）的能力。安全性有時也稱動態可靠性，也就是在動態條件下電力系統經受住突然擾動並不間斷地向用戶提供電力和電量的能力。安全性的另一個方面指系統的整體性，即電力系統維持聯合運行的能力。電力系統的整體性往往與維持系統連續運行的能力有關，在遭受突然擾動時，一旦整體遭破壞，往往可能導致穩定性破壞，不可控的系統解列，最後造成系統大面積停電。

二、中國電力工業可靠性管理的發展過程

中國從20世紀70年代開始，在電力部門和大學中，都開始著手研究電力可靠性問題，1983年成立了中國電機工程學會可靠性專業委員會，聚集了大學和電力部門的力量，推動電力可靠性管理和理論研究工作。在此階段所進行的工作有：

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- (i) 以擴大眼界為宗旨，廣泛收集當時國際上有關電力可靠性方面的各種資料，匯集介紹到國內來，有計劃地向電力各界宣講，以期建立起對電力可靠性的理論概念，擴大了電力行業實施多年的定性管理的視角；
- (ii) 有針對性地在個別電力企業中進行實踐試點，以期取得電力可靠性統計評價的感性體驗，並從中尋求由定性管理向可靠性定量管理轉化的可行途徑；
- (iii) 有計劃地開展科技宣講和培訓工作。特別是對電力企業的領導和有可能從事可靠性管理的技術工作人員進行培訓，為實行電力可靠性管理準備幹部；
- (iv) 研究國際上已在實施的各種電力可靠性管理模式，尋求適合中國國情的、無論是理論還是實踐都切實可行的管理體系。

以上準備階段進行了五年，取得了預期效果，促成了電力主管部門——當時的水利電力部正式批准於1985年1月成立“水利電力部電力可靠性管理中心”，正式開始在全國範圍內開展工作。開展了發電設備、輸變電設備、配電設備和系統的可靠性統計工作。清華大學、西安交大、上海交大、浙江大學、重慶大學和華北電力學院等大學也開設了電力可靠性的課程和理論研究，電力設計部門開展了在某些工程設計中的可靠性評估的研究，從電力可靠性管理中心成立在全國正式推行可靠性管理到現在已十三個年頭了，經過大量的實踐的驗證，說明可靠性管理作為一種科學的方法，完全適用於電力工業。通過多年的完善，到現在已基本上形成了具有中國電力工業特點的電力可靠性管理體系，特別是比較穩定的電力可靠性信息管理系統。在全國範圍內形成了一支可靠性管理的專業隊伍，並且在實際工作中取得了可喜的成績，每年舉行一次全國性的電力可靠性指標發佈會，在國內外產生了比較好的影響。

三、電力可靠性管理中心的職責及其機構

1、電力可靠性管理中心的主要職責

電力可靠性管理中心的主要職責是：

- (i) 制訂全國性的電力工業各項可靠性管理準則和規章制度；
- (ii) 編制、修訂電力可靠性統計評價辦法、統計編碼和計算機軟件；
- (iii) 負責進行全國電力行業電力可靠性信息數據統計、分析和發佈；
- (iv) 分析、評價、反饋電力系統運行可靠性狀況，提出改善可靠性的建議；
- (v) 組織全國電力行業可靠性經驗交流和人員培訓；
- (vi) 開展國際交流與合作。

為了實現上述職責要求，電力可靠性管理中心大致經歷了三個階段。第一階段是適應階段，即一方面要讓電力企業的具體工作人員適應統計的要求，及時、合格地統計到需要的數據；另一方面，可靠性管理中心也需要從統計實踐中，不斷完善、充實和改進統計辦法，以期取得有效的可用數據，這一歷程大致花了三年時間。

第二階段是嘗試把統計數據和指標用於生產管理中去。電力主管部門開始用可靠性指標——可用系數，來檢驗發電的廠運行實績；以用戶供電可靠率來檢驗供電企業的運行業績，從而促使電力企業日益自覺地從提高可靠性的角度來改善生產管理技術。這一階段還在日益深化之中，電力企業從可靠性管理中取得了實效，(發電機組的可用率已有明顯提高)，從而

使電力可靠性管理的方法和技術，日益成為電力企業自主行動。

第三個階段是進行可靠性信息反饋。電力可靠性管理中心自1992年起，正式按年編制、出版中、英文對照的《中國電力工業可靠性管理年報》，每年舉行一次電力可靠性指標發佈會，向各電力企業、社會各界、國內外電力設備製造廠商公開發佈上年度可靠性指標信息，並對各種電力設備的可靠性水平進行評價，將中國的電力可靠性管理推向社會化、國際化，並促使電力設備製造部門更加注意其產品質量。

電力可靠性管理中心在上述歷程中不斷地加強了自身建設，到目前為止，已建立了以發電機組、火電輔機、輸變電設施和城市供電為對象的可靠性數據庫及相應的編碼、指標體系、統計評價辦法和計算機軟件。集中了全國火電100兆瓦及以上、水電40兆瓦及以上容量的大、中型發電機組運行可靠性數據；容量為200兆瓦及以上的火電機組主要輔機的可靠性數據；全國220千伏及以上電壓等級主要輸變電設施運行可靠性數據以及全國255個大、中城市的用戶供電可靠性數據。

2. 電力可靠性管理中心的組織機構

電力可靠性管理中心為主任負責制，下設三個處，各處分工如下：

綜合信息處：負責全國可靠性統計數據的收集、匯總和評估，以及相應的信息統計軟件的編制、操作和維護：

發電處：負責發電機組及輔助設備的可靠性分析及相應的準則、統計評價辦法的編制和修訂；

供電處：負責輸變電設施和電力系統、城市供電可靠性分析及相應的準則、統計評價辦法的編制和修訂。

3. 全國電力可靠性管理網的組織機構

隨著電力可靠性管理的日益深化，一個由國家電力主部門領導的、以電力可靠性管理中心具體負責的全國性的電力可靠性管理網絡業已形成並日趨完善。網絡的示意框圖見圖一。

此網絡的特點是分級管理並各自向上一級機構負責。在基層企業中建立管理小組，負責本企業的可靠性統計和管理，保證統計數據和及時、準確、完整，並依據有關數據的分析指導，提出改進本企業生產管理的建議；在上一級的企業中，建立可靠性管理領導小組，負責匯總、審核、上報可靠性統計數據，根據上年度可靠性實績，佈置本年度可靠性管理的要求，下達可靠性的目標值，平衡、協調各項改進、完善可靠性的相應措施，

建立這個網絡的必要性和有效性在於它保證了電力可靠性管理在生產管理中日益深化並取得實效。

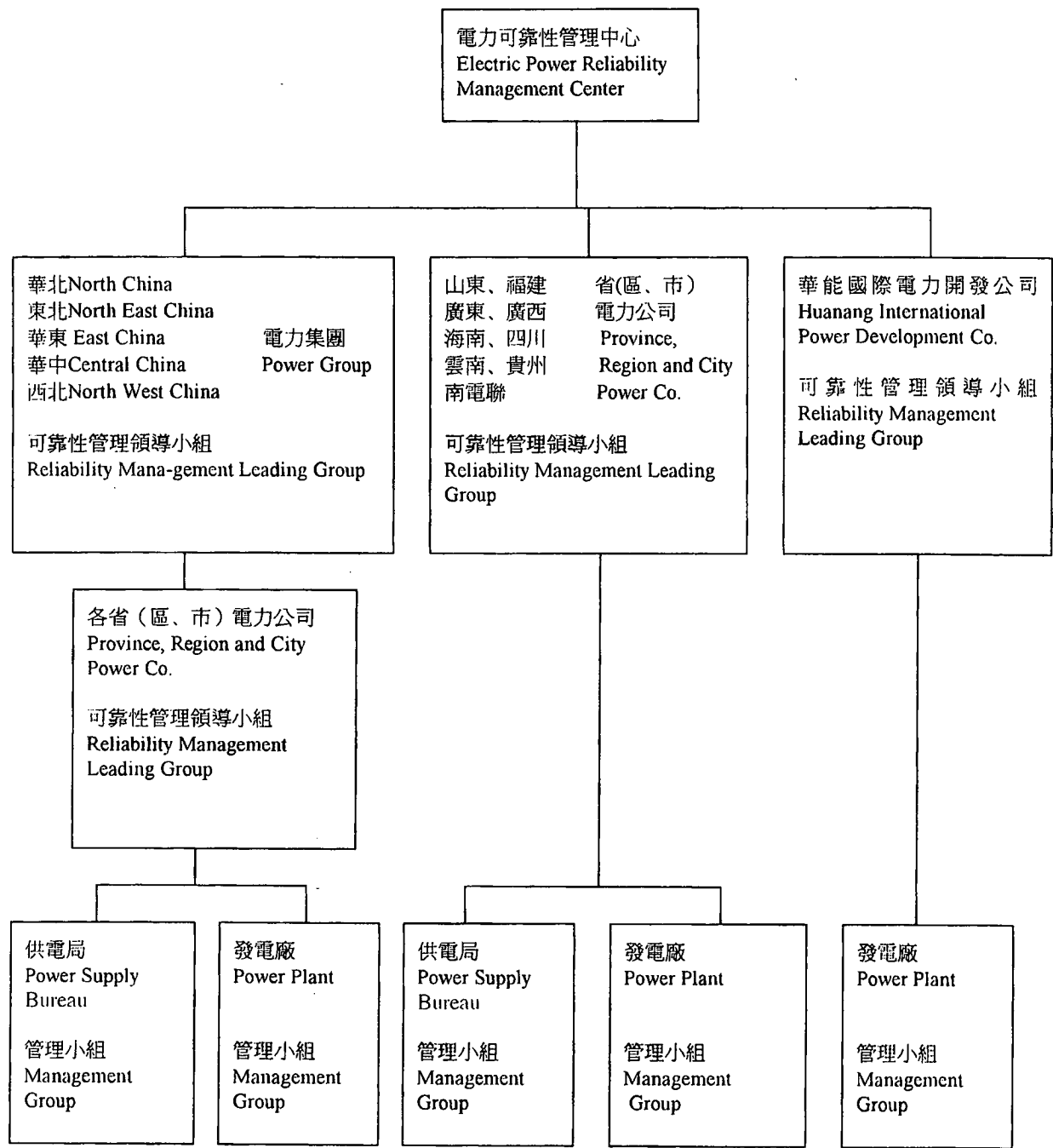
四、電力可靠性管理的主要指標體系及其在生產管理中的作用

可靠性是電力工業重要的性能指標，也是影響電力工業經濟效益的重要方面，它涉及到規劃設計、設備製造、基建施工、科研培訓、管理決策等各個領域。參考國外資料，電力工業可靠性的具體內容列於圖二。

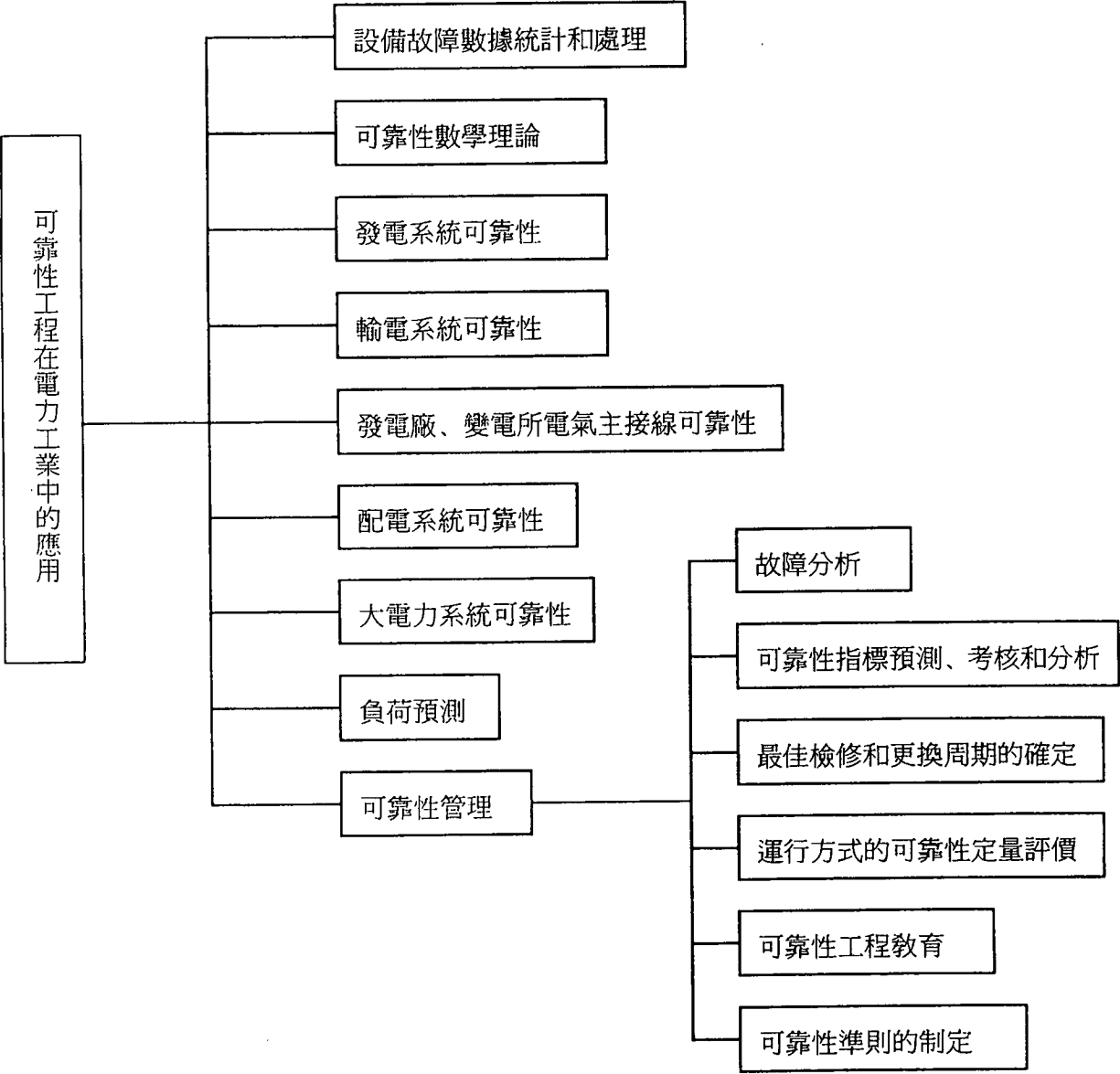
1. 研究可靠性的目的和手段

研究電力工業的可靠性的目的

圖一：全國電力可靠性管理網絡示意圖



圖二：電力工業可靠性具體內容



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就是要提高整個電力系統總體社會效益和經濟效益，準確地評價發電、輸電、配電各類設備及其各構成系統的充裕性和安全性。統稱為可靠性。

在可靠性評價的定性概念發展到定量概念時，各種有關的指標制定就成了評價可靠性的尺度，通常把定量評價的可靠性稱為可靠度。由於定量評價往往使用概率的方法，為此可靠度的一個泛指定義可以歸納為“元件、設備或系統在規範條件下，在預定的時間內完成其預定功能的概率，可靠的反面是失敗和故障，研究可靠性就是要研究故障的規律。而故障總是隨機發生的，它於隨機事件，同時影響故障發生的外界條件也往往帶有隨機性，故障發生後的修復時間也是隨機的。因此，只能用概率論以及其他處理隨機事件的數學方式和有關理論來定量地處理可靠性的問題，而 (i) 可靠性的變化規律得以用數學方式來表達、運算和掌握。(ii) 在相同條件下，不同設備和系統具有共同一致的評價標準。

中國的電力可靠性指標體系及相應的評價方法建立在嚴格的可靠性理論基礎上。對於發電、輸變電、配電的設備及其系統，我們的指標體系，評價標準較為成熟，對大電力系統可靠性的指標體系和評價標準的研究制定還是一個新的課題。

2. 可靠性指標

為了滿足各種不同應用場合對可靠性進行評估的需要，具體規定的指標不盡相同。歸納起來大致有以下幾種：

- (i) 頻率指標：如可靠度、可用系數等：

- (ii) 效率指標：如可修復元件或系統在研究周期的平均故障次數，如非計劃停運次數，強迫停運次數；

- (iii) 時間指標：可修復元件兩次故障間的平均時間即平均工作時間以及故障的平均持續時間（即修復時間）等：

- (iv) 期望值：如在研究周期，設備或系統發生故障的天數的期望值；電力系用於故障，少供電量的期望值等。

目前應用在中國電力可靠性管理中有兩種類型的指標，一種為面向設備的指標，以檢驗設備的生產能力為目標；一種為面向系統的指標，以檢驗系統功能實現程度為目標。這兩類指標，均使用以日歷年度為界的定時截尾方法的點估計值。發電機組、發電輔機和輸變電設施的可靠性指標屬於上述前一類指標。

五、中國電力可靠性管理的展望

隨著中國經濟的發展，對電力供應的可靠性要求愈來愈高，改善和提高電力可靠性水平，已成為中國電力界的共識，電力生產管理中使用可靠性技術和方法的願望和需求日益增長。其中，對電力設備的可靠性要求已明顯地成為選用設備的依據之一，這就要求國內、外製造廠商提供高可靠性和高保證承諾的電力設備。城市供電可靠性的現狀，正召喚著加大城網改造的步伐。電力企業的現代化管理，更需要開發有效的可靠性管理的各種評價準則和辦法。這一切，表明中國電力可靠性管理任重道遠，前景光明。因此，也為加快、加大電力可靠性技術的國際合作，提供了更廣泛的可能性。

(二) 可靠性管理在電力工業中的應用

一、發電廠可靠性

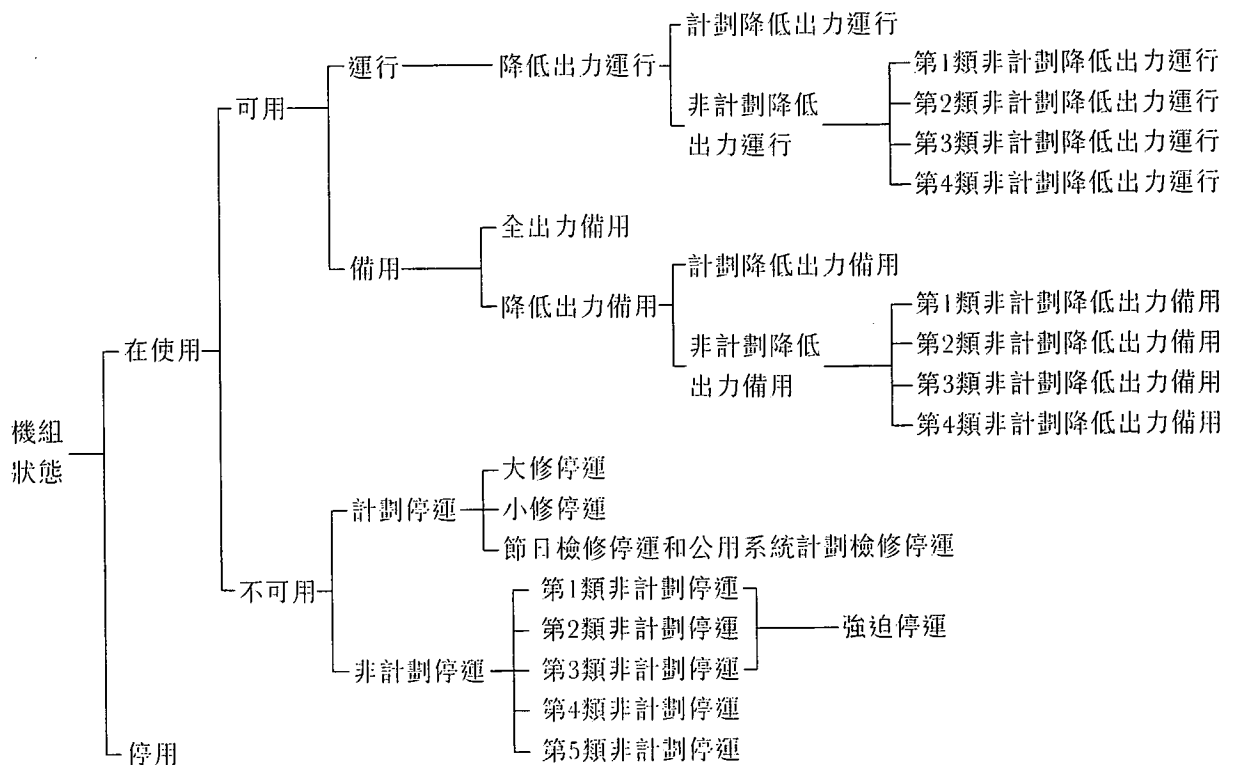
被評估的發電廠在規定的時間內能夠按照規定的技術指標發出預定電力的能力。這種能力的大小，可用可靠性指標來定量表示。分析研究發電廠的可靠性的目的在於從電廠的生產各環節找出使電廠喪失正常功能的因素，全過程地（從規劃設計、設備製造、安裝調試、生產運行、檢修維護等環節）分析其原因，找出對策。同時經過大量的數據統計、分析，提出定量評價的準則，探討提高電廠可靠性的途徑和方法。研究分析電廠的可靠性，有

助於改進上述各環節的質量，提高可靠性管理水平，也有利於提高電廠的經濟性。

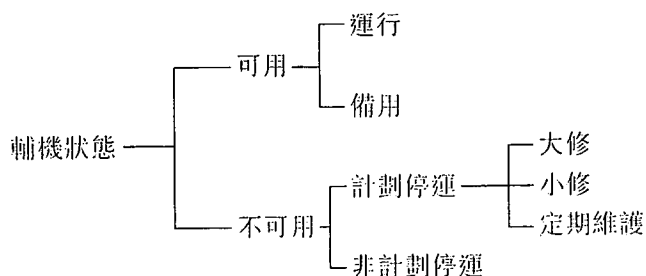
1. 狀態劃分與編碼

發電廠的可靠性，從某種意義上講是建立在組成電廠的設備（包括升壓站的輸變電設備）的基礎之上的。而發電設備的狀態分類與編碼是可靠性統計的基礎。中國的電力可靠性統計的狀態分類與編碼依據故障樹原理由上而下編製。狀態分類保證了在全時域內無遺漏、無重疊，使統計對象在任一時刻必須處於某種狀態中；在某

圖三：發電廠機組和輔助設備狀態劃分原則



發電輔機的狀態劃分



一特定時刻只能處於某一特定狀態中。圖三分別表示出了發電廠機組（鍋爐、汽機、發電機等）和輔助設備（各種磨煤機、泵、風機、高壓加熱器等）狀態劃分的原則。

2. 發電廠機組主要可靠性指標

發電廠機組的可靠性指標主要有：可用系數、等效可用系數、非計劃停運次數和時間、強迫停運次數和時間、強迫停運率、平均連續可用小時、平均無故障可用小時等多項。各指標的計算方法如下：

(i) 可用系數(Available Factor of Single Generator Unit)：

單台機組可用系數 AF 按下列公式計算：

$$AF = \frac{\text{可用小時(AH)}}{\text{統計期間小時(PH)}} \times 100\%$$

式中：

AH—可用小時為機組處於能夠運行（即：運行[Serve State]+備用[Reserve State]）的小時數(Available Hours)。

PH—機組的統計期間小時數-Hours within Static Period (如一年即為8760小時)。

多臺機組或全廠的(Several Units or the Whole Plant)可用系數計算公式為：

$$AF = \frac{\sum_{i=1}^n P_i (AF)_i}{\sum_{i=1}^n P_i} \times 100\%$$

式中 P_i 為第 i 臺機組的額定出力； $(AF)_i$ 為第 i 臺機組的可用系數； n 為機組的臺數。

(ii) 等效可用系數(Equivalent Available Factor) EAF：機組計及降低出力影響(Influence of Unit Derating)後的可用系數，其計算公式為：

$$EAF = \frac{\text{可用小時(AH)} - \text{降低出力等效停運小時(EUNDH)}}{\text{統計期間小時(PH)}} \times 100\%$$

式中 EUNDH (在中國電力百科全書發電卷中用簡化的縮寫 EDH 或 EUDH 表示) 為機組運行中降低出力小時折算至機組全出力停機的等效小時數。

對於全廠或系統中多臺機組的等效可用系數，仍可按機組的額定出力加權而得。

(iii) 強迫停運率 (Forced Outage Factor) FOR：單臺機組的強迫停運率 FOR 的計算公式為：

$$FOR = \frac{\text{強迫停運小時(FOH)}}{\text{強迫停運小時(FOH)+運行小時(SH)}}$$

此指標表徵機組的健康水平對運行影響的程度，全廠或多臺機組的 FOR 仍可按機組出力加權而得。

(iv) 等效強迫停運率 (Equivalent Forced Outage Factor) EFOR：

考慮到降低出力影響後的強迫停運率 EFOR，其計算公式為：

$$EFOR = \frac{\text{強迫停運小時} + \text{第1、2、3類非計劃降低出力等效停運小時之和}}{\text{運行小時} + \text{強迫停運小時} + \text{第1、2、3類非計劃降低出力等效備用停運小時之和}} \times 100\%$$

$$= \frac{FOH + (EUDH1 + EUDH2 + EUDH3)}{SH + FOH + (EUDH1 + EUDH2 + EUDH3)} \times 100\%$$

(v) 平均連續可用小時
(Continuous Available
Hours) CAH :

$$CAH = \frac{\text{可用小時(AH)}}{\text{計劃停運次數(POT)+非計劃停運次數(UOT)}}$$

計劃停運次數 P O T
(Planned Outage Times) ;
非計劃停運次數 U O T
(Unplanned Outage
Times)

(vi) 平均無故障可用小時
MTBF :

$$MTBF = \frac{\text{可用小時(AH)}}{\text{強迫停運次數(FOT)}}$$

3. 電廠的可靠性管理

電廠的可靠性管理是現代化電廠生產管理的中心內容，它包括電廠的出力管理、可靠性指標管理、設施維修和更新管理、運行準則（含規程）管理和人員培訓管理。所謂管理，其內涵包括有關的政策條令、人員組織、實施計劃及應用技術等。電廠可靠性管理的目標是低耗多發下的安全運行。

可靠性指標的管理又是電廠可靠性管理的中心內容，即電廠生產管理的中心內容。其中可用系數的管理目前已成為各電廠主管單位可靠性指標目標管理的重要指標。他們根據該電廠運行可靠性指標的歷史記

錄，考慮到今後的檢修安排和更新計劃，指定並下達該電廠的可靠性目標。電廠的主管領導，根據上級下達的指標，分解與分配至該電廠的職能部門，採取措施以保證可用系數指標的實現。由於可用系數反映該廠的生產能力，不論是電廠的主管單位（如網、省公司等），還是某一發電廠，均必須定期做出本單位的可用系數分析和可用系數預測。尤其是必須根據歷年影響可用系數的非計劃停運事件的原因分析及部件分類，結合各種在線的診斷監測儀器，診斷結果，找出對策，加以消除，做到防患於未然，以求最低的非計劃停運發生，達到最佳的運行（含備用）工況。實現最高的經濟效益。

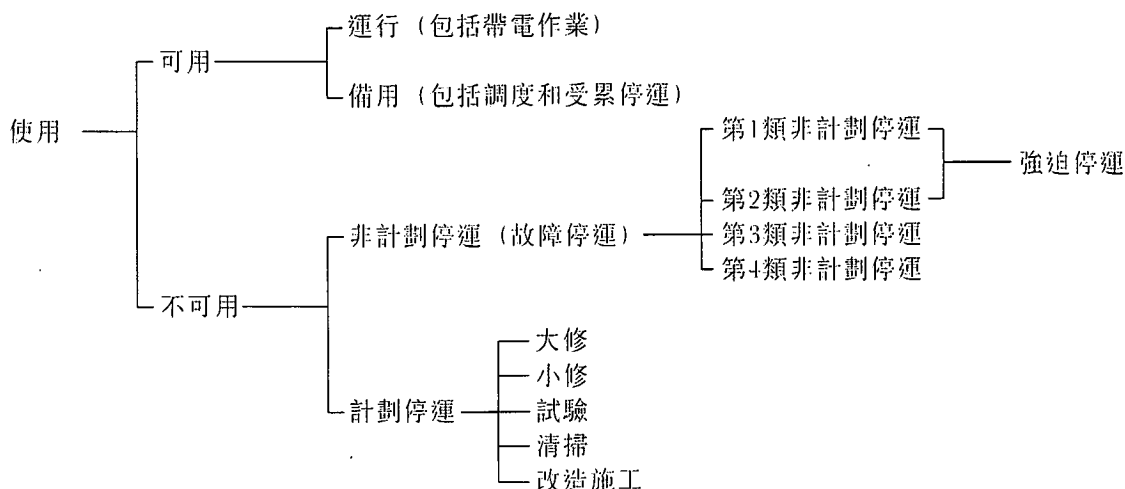
二、輸變電設施的可靠性

輸變電設施的可靠性是以設施功能為目標，面向設施在規定的運行條件下，在預定的時間內，完成規定功能的能力。例如：斷路器的可靠性是指斷路器在規定的運行環境下，在預定的時間內，接通和連續承受正常電流、開斷電路正常電流以及短時承受和切斷規定的非正常電流的能力的量度。輸變電設施可靠性的統計、分析，是深入掌握和評價輸變電設施在電力系統中運行狀況的主要措施。對改進設備製造、安裝質量、工程設計和生產管理等方面也具有重要意義。

1. 輸變電設施分類的狀態劃分與定義

輸變電設施狀態劃分如圖四。

圖四：輸變電設施狀態劃分



使用 —— 設施處於應統計的狀態。

可用 —— 設施處於能夠完成預定功能的正常狀態。

運行 —— 設施與電網相聯接，並處於帶電的狀態。

備用 —— 設施可用，但不在運行狀態。

不可用 —— 設施不論由於甚麼原因引起的不能完成預定功能的狀態。在這種狀態下，設施必須從系統切除，經過檢修才能恢復可用狀態。

非計劃

(故障)停運 —— 設施處於不可用而又不是計劃停運的狀態。分第1-4類非計劃停運。

計劃停運 —— 大、小修，預試、清掃、改造施工。

2. 主要可靠性指標及其計算公式

(i) 非計劃（故障）停運率 UOR：

$$UOR = \frac{\text{非計劃(故障)停運次數(FOT)}}{\text{統計百臺年數}} \text{次/百臺年}$$

$$\text{或} = \frac{\text{非計劃(故障)停運次數(FOT)}}{\text{統計百公里年數}} \text{次/百公里年}$$

(ii) 可用系數 AF：

$$AF = \frac{\text{可用小時(AH)}}{\text{統計期間小時(PH)}} \times 100\%$$

(iii) 運行系數 SF：

$$SF = \frac{\text{運行小時(SH)}}{\text{統計期間小時(PH)}} \times 100\%$$

(iv) 強迫停運率 FOR：

$$FOR = \frac{\text{強迫停運次數(FOT)}}{\text{統計臺年數(UY)}} \text{次/臺年}$$

(v) 平均連續可用小時 CSH：

$$CSH = \frac{\text{可用小時AH}}{\text{統計期間(計劃停運次數POT + 非計劃停運次數UOT)}} \text{小時/次}$$

(vi) 暴露率 (Expose Rate) EXR：

$$EXR = \frac{\text{運行小時(SH)}}{\text{可用小時(AH)}} \times 100\%$$

(vii) 平均無故障操作次數 AOT：

$$AOT = \frac{\text{操作次數(OT)}}{\text{非計劃(故障)停運間隔數(IOT)}} \text{次/間隔}$$

三、供電系統用戶可靠性

供電系統用戶可靠性，直接體現供電系統對用戶的供電能力，反映了電力工業對國民經濟電能的需求滿足程度，是供電系統的規劃、設計、基建、施工、設備製造、生產運行、營業服務等方面質量和管理水平的綜合體現。

1、停電性質的分類

停電性質分類見圖五。

2、供電可靠性主要指標及計算公式

供電可靠率 RS-1——在統計期間內，對用戶有效供電時間總小時數與統計期間小時數比值：

$$RS-1 = \left(1 - \frac{\text{用戶平均停電時間}}{\text{統計期間小時}}\right) \times 100\%$$

若不計外部影響則記作 RS-2：

$$RS-2 = \left(1 - \frac{\text{用戶平均停電時間} - \text{用戶平均受外部影響停電時間}}{\text{統計期間小時}}\right) \times 100\%$$

若不計系統電源不足限電時，則記作 RS-3：

$$RS-3 = \left(1 - \frac{\text{用戶平均停電時間} - \text{用戶平均限電停電時間}}{\text{統計期間小時}}\right) \times 100\%$$

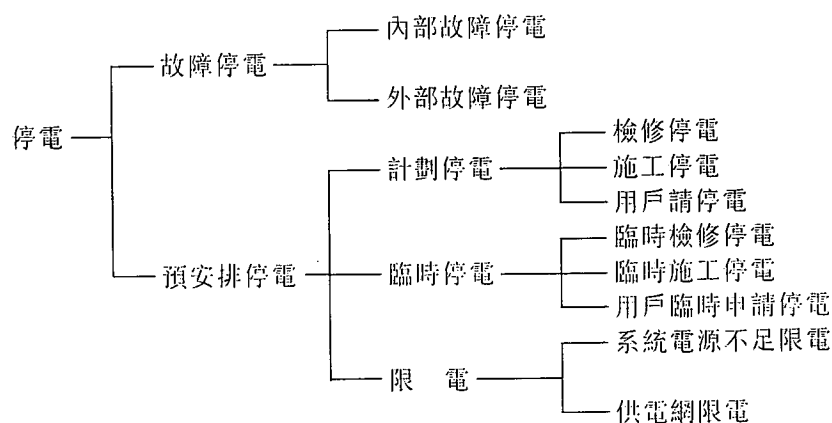
用戶平均停電時間 AIHC：

$$AIHC = \frac{\sum (\text{每次停電持續時間} \times \text{每次停電用戶數})}{\text{總用戶數}} \text{——小時/每戶}$$

四、電力可靠性指標在電力生產中的應用

自94年寧波全國電力可靠性工作會議，及95年張家界全國電力可靠性專責工作會議後，電力工業的可靠性已開始向更深更廣的方向發展。特別是自1994年之後，一年一度舉行電力可靠性指標發佈會，已舉行了四次，形成了制度，得到了規劃設計、設備製造、基建安裝和生產運行部門的讚同和認可，機械工業部在97年的指標發佈會後，就立即召開了質量工作會議，表示要用可靠性管理的數據分析，促進設備質量的提高，各電力企業在雙達標和創一流企業以及基建移交生產達標的工作中均施行可靠性的目標管理，不斷為提高發電機組的等效可靠可

圖五：停電性質分類



用系數、降低強迫停運率、降低停電用戶數而制定整改措施。例如，為了進一步提高供電可靠率，確保創一流重點指標RS-1 \geq 99.90%、RS-3 \geq 99.96%的實現，各網、省公司及供電企業，加強了全過程的可靠性管理，施行可靠性目標管理，制定供電可靠率目標值，分解下達給各基層單位共同努力完成。工作中加強協調好大型工程施工、線路檢修等與變電站的大修時間，以求得同步進行。積極而慎重地推行狀態檢修，以延長檢修周期和縮短檢修時間。積極開展配電網的帶電作業，加大技術措施力度，加大城網改造力度，分地段有步驟地提高110KV及以下各級電壓變壓器的容載比和線路互帶備用能力。採用先進的在線監測設備，配備故障檢修車，快速處理突發性事故。配置移動發電機，解決市政建設臨時供電需要。也就是說以可靠性用戶供電可靠率為龍頭，全過程地加強各項管理和加大配網的技術改造，從而達到最大限度的滿足國民經濟及人民生活對用電的需求。國內外的製造廠商在指標發佈會後紛紛要求部可靠性管理中心提供更詳細的停電事件檢索和相關可靠性指標，從中分析其原因。同時與用戶共同制定改進措施，加大了為用戶服務的力度。作為一年一度公開發佈可靠性指標，對加強設備的全面質量管理和全過程的安全管理，提高規劃設計、設備製造、基建安裝質量和生產使用水平起到了良好的作用。

下面列出了1991—1997年度大型火力發電機組可靠性指標(表一)及主要城市的供電可靠性指標(表二)。

表一 1991-1997 年大型火電機組主要可靠性指標 (Table 1-Main Reliability Index of Large Thermal Generator in 1991-1997)

年份 (year)	100MW				125MW				200MW				300MW				600MW			
	臺數 (Units)	AF (%)	FOR (%)	臺數 (Units)	AF (%)	FOR (%)	臺數 (Units)	AF (%)	FOR (%)	臺數 (Units)	AF (%)	FOR (%)	臺數 (Units)	AF (%)	FOR (%)	臺數 (Units)	AF (%)	FOR (%)	臺數 (Units)	FOR (%)
1991	105	88.49	1.55	68	87.25	3.30	112	82.29	5.91	31	80.72	7.93	1	66.26	10.88					
1992	110	89.04	2.61	74	87.43	3.44	122	83.24	5.84	35	78.83	8.89	2	68.72	10.49					
1993	112	88.83	2.26	81	86.70	3.56	133	85.53	3.93	42	78.54	8.48	5	65.09	21.45					
1994	115	88.76	2.23	86	88.34	2.46	143	86.13	3.68	55	79.09	8.96	5	75.51	5.61					
1995	123	91.08	1.69	92	89.66	1.84	149	87.38	3.09	65	82.77	6.71	6	81.98	6.14					
1996	131	91.59	1.43	96	90.27	1.94	155	87.78	2.64	80	82.89	5.76	6	81.57	2.89					
1997	139	90.99	1.67	106	90.89	1.06	166	88.99	2.05	104	87.26	3.60	7	88.08	3.32					

表二 1992-1997 年主要城市供電可靠率 (Table 2-Electric Power Supply Reliability Rate of Large Cities in 1991-1997)

序號 Item	1992年			1993年			1994年			1995年			1996年			1997年		
	RS-1	RS-3	RS-1	RS-1	RS-3	RS-1	RS-1	RS-3	RS-1	RS-1	RS-3	RS-1	RS-1	RS-3	RS-1	RS-1	RS-3	RS-3
1 北京	99.433	99.755	99.237	99.795	99.795	99.605	99.605	99.769	99.708	99.759	99.841	99.841	99.841	99.841	99.901	99.901	99.904	99.904
2 石家莊	98.846	99.816	98.781	99.854	99.854	99.301	99.301	99.808	99.342	99.811	99.424	99.911	99.424	99.911	99.836	99.836	99.921	99.921
3 太原	99.36	99.704	99.419	99.673	99.673	99.516	99.516	99.68	99.382	99.604	99.6	99.655	99.6	99.655	99.686	99.686	99.716	99.716

表2 續 (Table 2, Continue)

4	呼和浩特	99.543	99.735	98.952	99.646	99.632	99.811	99.45	99.812	99.724	99.826	99.905	99.905
5	天津	99.572	99.642	99.608	99.703	99.751	99.651	99.654	99.711	99.711	99.711	99.800	99.801
6	沈陽	99.804	99.804	99.793	99.793	99.777	99.8	99.803	99.759	99.831	99.796	99.796	99.796
7	長春	99.732	99.753	99.731	99.731	99.75	99.852	99.852	99.831	99.92	99.885	99.961	99.961
8	哈爾濱	99.415	99.505	99.278	99.278	99.794	99.701	99.701	99.822	99.885	99.900	99.923	99.923
9	南京	99.011	99.467	99.12	99.609	99.311	99.612	99.711	99.767	99.812	99.900	99.900	99.900
10	杭州	99.296	99.659	99.621	99.731	99.542	99.559	99.608	99.658	99.703	99.712	99.712	99.712
11	合肥	98.812	99.393	99.161	99.612	99.241	99.046	99.618	99.567	99.701	99.939	99.949	99.949
12	上海	99.764	99.767	99.682	99.683	99.678	99.715	99.715	99.722	99.723	99.758	99.758	99.758
13	鄭州	98.98	99.623	99.504	99.618	99.358	99.639	99.629	99.616	99.706	99.738	99.738	99.738
14	武漢	98.077	99.656	97.644	99.643	98.404	99.603	97.026	99.687	99.697	99.620	99.783	99.783
15	長沙	99.326	99.653	99.495	99.629	99.243	99.614	99.251	99.601	99.492	99.711	99.722	99.722
16	南昌	98.602	98.978	98.999	98.999	99.01	99.418	97.9	99.62	97.897	99.701	99.469	99.754
17	重慶	97.864	99.16	98.85	99.375	98.84	99.61	98.909	99.639	99.357	99.711	99.577	99.713
18	成都	98.17	99.609	98.121	99.602	98.333	99.604	98.231	99.638	98.644	99.713	99.557	99.814
19	貴陽	98.947	99.309	97.503	99.419	99.585	99.603	99.491	99.501	99.575	99.688	99.702	99.717
20	昆明	98.97	99.604	99.327	99.55	99.148	99.622	99.531	99.615	99.612	99.703	99.619	99.710
21	西安					98.904	99.669	93.3	99.65	96.565	99.677	99.031	99.711
22	蘭州	99.674	99.679	99.611	99.644	99.431	99.617	98.891	99.694	98.91	99.868	99.775	99.805
23	西寧	99.672	99.672	99.653	99.653	99.691	99.691	99.601	99.686	99.636	99.8	99.844	99.844
24	銀川	99.837	99.837	99.808	99.808	99.857	99.857	99.803	99.803	99.808	99.887	99.930	99.931
25	烏魯木齊	99.507	99.603	99.328	99.542	99.211	99.593	98.505	99.127	98.765	99.701	99.325	99.499
26	福州	98.94	99.605	87.856	99.599			98.511	99.532	99.367	99.612	99.709	99.709
27	濟南	99.546	99.601	99.494	99.501	99.721	99.727	99.39	99.776	99.85	99.873	99.970	99.970
28	廣州			98.675	99.418	99.264	99.269	99.643	99.643	99.734	99.734	99.769	99.769

Paper No. 9

**AN INTEGRATED APPROACH TO MANAGING RAMS OF
RAILWAY ASSETS**

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ABSTRACT

This paper describes a system assurance framework for managing reliability, availability, maintainability and system safety (RAMS) performance of new railway assets throughout their asset lives. The framework requires that at the very early stage of an asset acquisition or improvement project, an appraisal is carried out to assess the major risks. The perceived level of risk will then help tailor a system assurance programme that meets the technical needs of the project under consideration. The system assurance programme covers the RAMS activities to be conducted during the major phases of a typical project life cycle.

1. INTRODUCTION

The MTR Corporation was established for the principal purpose of constructing and operating, on prudent commercial principle, a mass transit railway system having regard to the reasonable requirements of the public transport system of Hong Kong.

The overall goal of the Corporation is "To be the most customer orientated urban railway in the world", and the Operating Railway should meet the highest standards of safety, reliability and efficiency in the services provided to its passengers and the public at large. To help achieve this goal, the Operation Engineering Department (OED) of the Corporation, which is responsible for providing engineering services to maintain the railway, has developed a system assurance methodology for assuring that

new and modified railway assets are fit for purpose throughout their asset lives. This paper describes the principles of the methodology, how RAMS related engineering activities are integrated into a common framework, and how it can be applied to suit the needs of different equipment.

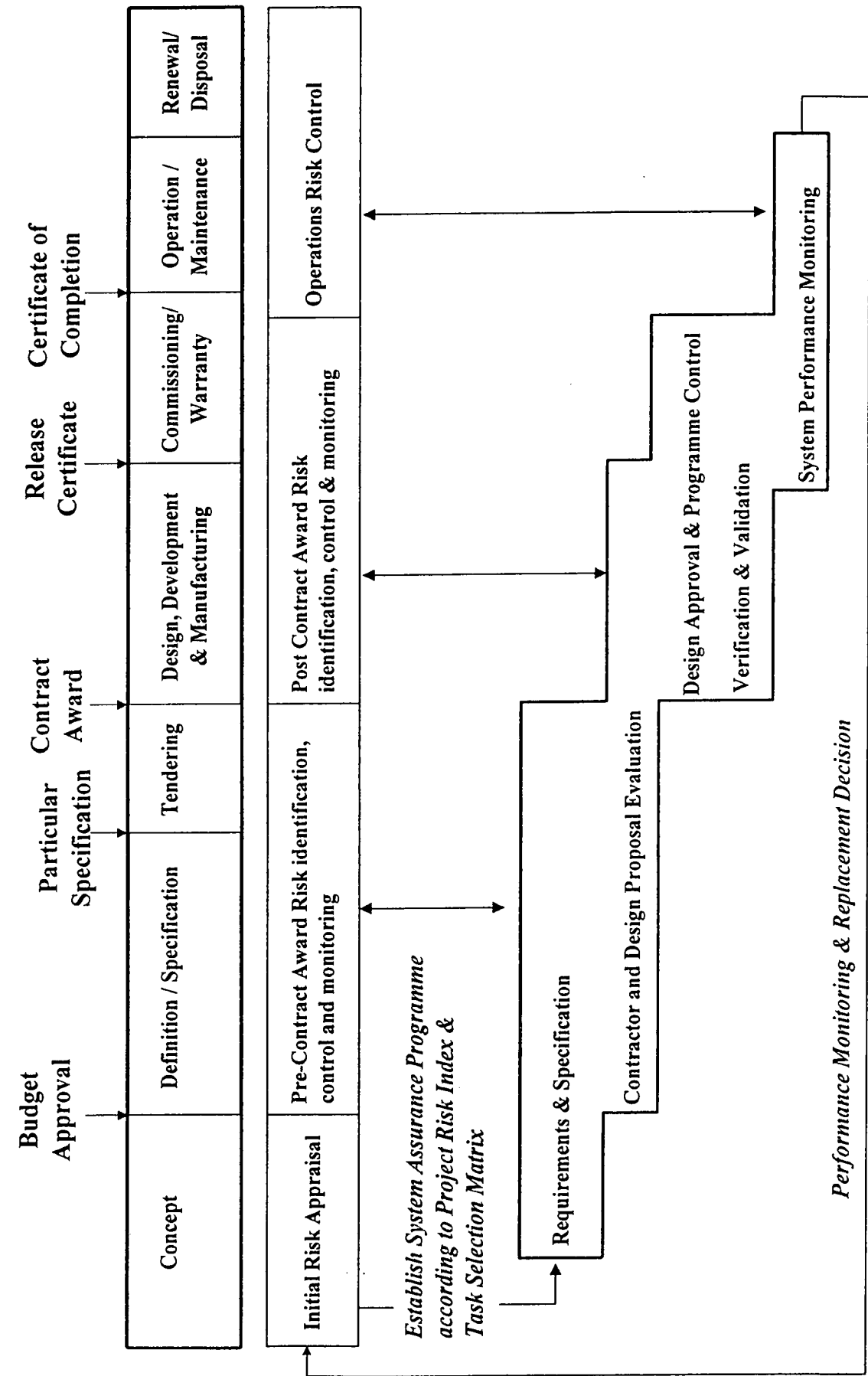
2. OVERVIEW

System assurance involves undertaking specific tasks in various phases of equipment acquisition or modification programmes in order to help ensure that the delivered equipment is "fit for purpose" i.e. it performs consistently to the required safety, reliability and efficiency standards.

The framework requires that at the conceptual/definition stage, a risk appraisal is carried out to identify major risks that can potentially affect project viability and to assign a Project Risk Index (PRI). The PRI indicates the level of system assurance effort required to control the project risk to an acceptable level.

For project risks arising during asset design, construction and operation, the system assurance tasks to be applied will vary according to given selection guidelines. Figure 1 shows how the various types of system assurance activities, which are further discussed in Section 3 of this paper, come together in a closed loop manner to help achieve the "fit for purpose" objective.

Fig. 1 Integrated System Assurance Framework



3. INTEGRATED SYSTEM ASSURANCE PROCESS

3.1 INITIAL RISK APPRAISAL & SYSTEM ASSURANCE PROGRAMME PLANNING

During the concept & definition phase, an initial risk appraisal is conducted as part of the budget submission process in order to help management make the right business decision based on a better understanding of the potential risks involved. The risk appraisal results are reviewed and updated periodically to reflect changing circumstances.

The following eight risk areas are used for assessing project risk:

- a. Health, Safety & Environment - harm to the health & safety of passengers, the public, employees and contractor staff, and adverse effect on the environment during system implementation or future system operations.
- b. Railway Service Disruption - disruption to railway services during the implementation or future operation of the system.
- c. Business Viability - lack of confidence to justify the business case for the project or to obtain a reasonable return on the investment.
- d. Cost Control - difficulty in controlling or estimating final project expenditure which could result in gross overspend.
- e. Project Delay - difficulty in completing the project within the required time scale.
- f. Political/Public/Media Scrutiny - the Corporation may come under additional pressure from various political, media or pressure groups because of the decision to go ahead with the project.
- g. Technical Difficulty - difficulty in the design, manufacturing, implementation, operation, maintenance or eventual disposal of the system.
- h. Meeting Customer Expectation - Risk in this area means difficulty in achieving positive customer benefit due to the nature

and complexity of the project or the rapid development in technology.

The risk level in each of these 8 areas is then appraised on the basis of the best information available at the time on a scale 1-4. Risk Level 1 represents high risk and Risk Level 4 represents low risk. Having determined the Risk Level in each of the 8 Risk Areas, Table 1 is then used to derive a suitable Project Risk Index (PRI), which ranges from 1 to 4 depending on the result of the risk appraisal. A PRI of 1 indicates a high risk of project failure whilst a PRI of 4 indicates a low risk.

Table 2 illustrates how the Project Risk Index relates to the required level of system assurance effort, and is used for identifying the requisite system assurance tasks according to the assigned PRI. The tasks are classified as follows:

Mandatory : These tasks are normally required. In cases where the nature or scope of a project is such that certain mandatory tasks are considered not applicable, such tasks can be waived subject to a formal approval process.

Recommended : These tasks are normally cost effective. The project team considers on a case by case basis which tasks should be undertaken.

Optional : These tasks are usually not required for low risk projects. This is either because such tasks are usually not cost effective for low risk projects or because the existing practices are considered adequate. The project team may wish to undertake them to suit specific project needs.

This "tailored" approach, i.e. matching effort to the need, is similar to the reliability programming methodology advocated by MIL-STD-785B [1] and DEF STAN 00-40 Part 1 [2], but these standards are too generic and broad, and do not always fully reflect the Corporation's needs. The Corporation's system assurance framework provides procedures and technical application guidelines that are compatible with the existing practices of OED.

Table 1: Project Risk Index and System Assurance Requirements

Project Risk Index (PRI)	Definition	System Assurance Programme Requirement
PRI-1	Has Risk Level 1 in four or more risk areas.	Risk is high in many areas due to uncertainties and known concerns. Establish a comprehensive System Assurance Programme to ensure that critical risk issues are identified before project commencement, and adequate arrangement is put in place to control and monitor these risk issues throughout the project until its successful completion.
PRI-2	Has Risk Level 1 in three or less risk areas, or Risk Level 2 in four or more risk areas.	Risk is particularly high in some areas. A simple but effective System Assurance Programme is needed to address the specific high risk areas in order to ensure the successful completion of the project.
PRI-3	No Risk Level 1 but has Risk Level 2 in three or less risk areas, or Risk Level 3 in four or more risk areas.	Risk is slightly higher than normal in some areas. A dedicated System Assurance Programme is not essential but additional effort and vigilance is needed from the responsible project manager/controller in ensuring compliance with project specification, project milestones and safety procedures by contractor.
PRI-4	No Risk Level 1 & Risk Level 2, and Risk Level 3 in three or less risk areas.	Risk arising from the project is acceptable. The potential impact to the Corporation is normal or low. Current project control procedure and practice should fully meet the risk management needs.

Table 2: System Assurance Task Selection

Task No.	System Assurance Task	PRI-1	PRI-2	PRI-3	PRI-4
Requirements & Specification Management					
1	Requirements Analysis	•	•	•	O
2	RAMS Specification	•	•	O	
		•	O		
System Performance Monitoring					
17	Data Recording & Corrective Action System	•	•	•	O

Keys: • - Mandatory O - Recommended 'blank' - Optional

When the applicable system assurance tasks have been selected, a programme plan is developed which ties together all the tasks. The programme plan stipulates all task owners and deliverables, and the task commencement and completion dates are linked to major project milestones.

One of the problems frequently encountered by reliability engineers is the inability to influence design at the early design and development stages, and often this results in wasted effort, and/or additional cost to remedy. In order to ensure that RAMS issues are considered in a timely manner, the emphasis of the programme plan is very much on how the system assurance activities relate to and integrate with other design, development, testing, production, installation and commissioning activities.

3.2 REQUIREMENTS & SPECIFICATIONS MANAGEMENT

For a complex system, it is necessary to address the following types of requirements and determine how best to meet them at the project specification phase:

- a. Customer/user requirements
- b. Functional requirements
- c. System configuration and design characteristics
- d. Man-machine interface and system interfacing requirements
- e. Quantitative and qualitative RAMS requirements
- f. Specific system assurance activities to be undertaken by contractor during design, development, manufacturing and installation
- g. Verification and test requirements

Such requirements can be numerous, and experience has taught us that the following requirement-related problems can often cause programme delays and performance deficiencies:

- Incorrect interpretation of customer needs
- RAMS performance targets not based on actual customer needs

- Unrealistic RAMS performance targets
- Conflicting requirements
- Origin, changes and compliance status of requirements not traceable
- Contractor's interpretations of requirements different from those of the Corporation
- Ambiguous requirements
- Requirements poorly organised
- Requirements out of line with available proven products
- Overly complex systems

In order to minimize abortive work and contractual disputes, the Corporation has developed a systematic process, which involves the application of methods such as internal customer surveys, System Diagrams, Functional Schematics and Operational Flow Schematics etc. for requirements identification, synthesis, tracking and documentation. These methods are particularly useful for defining system interfaces and requirements thereof. They have the ability to support designers, operators, contractors and maintainers to understand and communicate effectively on key functionalities and changes.

3.3 CONTRACTOR & DESIGN PROPOSAL EVALUATION

Managing RAMS within one's own organisation is quite different from managing RAMS from a distance in a contractor's premises. The engagement of a competent and responsible contractor is critically important. Whilst cost is always a major factor in contractor selection, the technical aspects can become overriding concerns for safety or service critical systems. The Corporation adopts a vigorous pre-qualification, tendering and vendor evaluation process which sometimes involves extensive pre-tendering audits and trials. During the project tendering phase the system assurance methodology focuses on the evaluation of potential contractors' capability and their design proposals in terms of :

- a. The comprehensiveness of their system assurance organisations and plans,

- b. Experience in applying system assurance to previous projects,
- c. The accuracy and reasonableness of their claims of compliance with RAMS requirements,
- d. The use of untried technology,
- e. The anticipated performance of proposed designs, and,
- f. Their understanding of the project requirements and appreciation of the Corporation's culture and practices.

3.4 DESIGN APPROVAL & PROGRAMME CONTROL

During the design phase, the following risk and RAMS related engineering and management tasks are undertaken to ensure that the system assurance programme is under control, the issues that can potentially affect project programme are managed, and that the contractor gives adequate design attention to critical RAMS related issues:

a. Project Risk Management

This involves the systematic and comprehensive identification of uncertainties that may delay the project programme, increase the project cost or affect the technical viability of the project. The process covers all financial, contractual, regulatory and technical risk issues, as well as social political issues, that are perceived to be significant and relevant. When the uncertainties are identified, the project team then puts in place risk controlling or reduction measures and allocates responsibilities.

b. System Safety

The objective of system safety engineering is to determine how, and with what frequency, systems could fail to function, what effects such failures will have, and how such failure effects could be mitigated effectively. The first step of the process is the identification of reasonably foreseeable hazards arising from the installation, commissioning and through-life operation of the system. Whilst the inherent safety of

the system is of fundamental importance, it is also necessary to pay a lot of attention to how the installation and trial run of new equipment can possibly affect other existing railway equipment and services. Further detailed qualitative or quantitative risk analyses may be performed if high risk issues are identified. The As Low As Reasonably Practicable (ALARP) principle is applied in determining cost-effective risk reduction measures. Hazard registration, reporting, monitoring and rectification tasks are also undertaken in accordance with pre-defined plans and procedures. When the system commences operational service, the in-service hazards are monitored and controlled by the Corporation's Hazard Registration System.

c. Reliability & Availability

The reliability & availability engineering activities required of the contractor are specified in contract documents. The emphasis is very much on the prevention, detection and correction of inherent reliability deficiencies. Depending on the nature of the system being procured, techniques such Reliability Block Diagrams, Fault Tree Analysis, Failure Modes & Effects Analysis, reliability & availability modelling, reliability prediction and apportionment etc are applied selectively to address specific parts or functions of the system. Reliability design criteria are established and fault tolerant designs are employed to cover critical parts of design.

d. Maintainability, Maintenance Strategy and Support

The system assurance framework focuses on the following 3 aspects of maintenance management:

Maintainability Design - This involves the identification of maintenance design features to be incorporated in equipment during design stage to facilitate maintenance and minimize down-time and repair time. Design criteria which cover parts interchangeability, accessibility of parts and test points, calibration needs,

modularity, use of standard tools etc. are also specified. Mean Time To Repair and other numerical maintainability targets are set on the basis of service needs.

Maintenance Requirements - Traditionally maintenance requirements are established on the basis of supplier's recommendations and in-service experience. When potential benefits outweigh costs, systematic maintenance analysis techniques such as Reliability Centred Maintenance are employed to establish maintenance tasks and frequencies for new and complex systems.

Maintenance Support Resources - Resource requirements such as skill, training needs, crew size, spares, maintenance facilities etc. must all be established well in advance to ensure that when the procured system goes into operational service it can be operated and maintained in its intended operating environment.

e. **Operability & Service Recovery**

The Operating Department, which is directly responsible for delivering station and train services to passengers, is OED's principal customer. The system assurance methodology emphasizes the importance of involving the staff of the Operating Department at the early stages of design to ensure that operational requirements and human factors receive adequate attention. Formal ergonomics and human reliability assessments may be carried out to analyse significant man-machine interface issues. Design features and procedures that enable speedy service recovery following equipment failures are also given early consideration in the design process.

3.5 VERIFICATION AND VALIDATION

In order to avoid costly redesign and rework and to minimize early in-service failures, comprehensive off-site testing during the project design and commissioning phases must be conducted to:

- a. Disclose deficiencies in design, material and workmanship as early as possible,
- b. Identify effective improvement measures,
- c. Check compliance with all requirements, and
- d. Determine operational service readiness.

The system assurance framework provides guide-lines for calling up, on selective basis, physical and configuration verification, environmental tests, endurance tests, simulated-use tests, burn-in tests and pilot station tests to complement standard system development and integration test work. When on-site testing is performed, contingency measures must be in place to minimize potential interruptions to existing railway services should failures occur.

3.6 SYSTEM PERFORMANCE MONITORING

Systematic data collection, reporting and analysis methods must be established prior to the operation/maintenance phase for:

- a. Monitoring performance and identifying improvement needs during the defect liability period, and
- b. Monitoring performance and supporting improvement and replacement decision making during operational service.

A typical performance monitoring method consists of the following activities:

- establish organisation and responsibilities
- determine input data requirements
- collect and record data in accordance with established procedures
- report RAMS performance periodically and highlight significant achievements and major problem areas
- analyse failures to determine causes of failures
- identify improvement measures and implement them in design, manufacturing, operation or maintenance processes

4. CONCLUSION

The system assurance methodology adopted by the Operations Engineering Department of the MTR Corporation is a life cycle process. It provides a coherent and comprehensive framework for managing activities that have direct bearing on the initial as well as the long term RAMS performance of railway systems.

The integrated approach to system assurance emphasizes undertaking system assurance tasks that match the needs of the system to be procured. To be effective such tasks must be performed during the appropriate phases of the system's life cycle, and they must be integrated with other design and manufacturing activities, and deployed with the minimum amount of effort.

REFERENCES

- [1] MIL-STD-785B, "Reliability Program For Systems And Equipment Development And Production", 15 September 1980
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