THE HONG KONG

INSTITUTION OF ENGINEERS

ELECTRICAL DIVISION

香 港 工 程 師 學 會

電 機 部

One day Symposium

Friday, 14th November 1986

Development of Electrical Power

電 力 的 發 展

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Symposium Programme

08.30 Registration and Coffee

09.00 Introduction

- Symposium Chairman: Mr. A.D. Longmore, BSc(Eng), DipMS, FHKIE, CEng FIEE, MBIM.
  Welcomed by: Mr. M.C. Lau, BSc(Eng), FHKIE, CEng, MIEE, MIERE.

09.05 Opening Address

- President: HKIE Mr. E.H.C. Tao, BSc, MSc, FHKIE, CEng, MIMechE, FCIBSE, FCIArb, FASME, FASHRAE.

1. Power Systems

09.10 'Some Recent Developments in Nuclear Power for electricity generation '

- Speaker: Dr. M.R. Yeung, BSc, MSc, PhD, Lecturer, HKU.

09.30 'Network Development in Kowloon and the New Territories'

- Speaker: Mr. Hans Yu, BSc(Eng), MHKIE, CEng, MIEE, Central Kowloon District Manager, CLP.

09.50 'Supply to Guangdong and Problems Associated with Interconnection with Guangdong Power System'

- Speakers: Mr. C.K. Law, MSc, MHKIE, CEng, MIEE, System Planning Engineer, CLP.
  Mr. Fred K.Y. Lau, BSc, CEng, MIEE Generation Development Engineer CLP.

10.10 Discussion

10.30 Coffee

2. Power Equipment

10.50 'The Construction and Commissioning of the generating plant at Castle Peak 'B' Power Station'

- Speakers: Mr. J.M. Pearson, BSc, CEng, PEng(Ontario), MIMechE, MHKIE, Project Manager, CLP.
  Mr. N.R. Salmon BSc, CEng, MIMechE, Project Engineer, CLP.
  Mr. R. Henderson, Manager, GEC.

11.10 'Variable Speed Drives'

- Speaker: Mr. K.H. Yung, Senior Engineer, Engineering Department, Project Division, BBC Brown Boveri Ltd.

11.30 'Factory Built Assemblies of L.V. Switchgear and Controlgear'

- Speaker: Mr. A Horton, Chief Engineer, Federal Electric Ltd.

11.50 Discussion

12.10 Lunch

3. Operation & Control

14.10 'Growth of Reactive Power Compensation for Transmission and Industrial Purposes using Thyristors'
– Author: Mr. R.J. Prizeman, Regional Manager, Reactive Compensation Department, ASEA Transmission.
(Presented by Mr. Albert Chik, General Manager, ASEA)

14.30 'Selected Stability Problems in Power System, Excitations Control and Stabilizers'
– Speaker: Dr. Bayer Wolfgang, Sen. Technical Manager, Siemens.

14.50 Coffee

4. Electrical Installation

15.05 'Fire Performance Cable and its impact on the FOC Rules and 15th IEE Wiring Regulations'
– Speaker: Mr. R. Getgood, BSc, CEng, MIEE, Resident Manager, Pirelli General Cables.

15.25 'The Application of Residual Current Circuit Breakers'
– Speaker: Mr. J. Rickwood, BSc(Eng), CEng, MIEE, Company Standards Engineer, Crabtree Electrical Industries Ltd.

15.45 'Proposed Code of Practice for the Wiring of Fixed Installations' in Buildings'
– Speakers: Mr. H.N. Chan, BSc, MSc, MHKIE, CEng, MIEE, Sen. E&M Engineer, EMSD.
Mr. S.K. She, MSc, MHKIE, CEng, MIEE, E&M Engineer, EMSD.

16.05 Discussion

16.30 Summing up: Symposium Chairman

Closing Address
– Dr. The Honourable S.L. Chen, C.B.E., JP, Group Managing Director, The Hong Kong Electric Group.

Note: It is regretted that the Paper No.2 has been substituted due to unforeseen circumstances.

Acknowledgement

The Electrical Division of the Hong Kong Institution of Engineers would like to express its sincere appreciation and gratitude to the following persons and organizations for their contribution to the symposium:

Speakers/Authors

Mr. E.H.C. Tao
Dr. The Honourable S.L. Chen,C.B.E., J.P.
Dr. Mankit Ray Yeung
Mr. C.K. Law
Mr. Fred K.Y. Lau
Mr. J.M. Pearson
Mr. N.R. Salmon
Mr. R. Henderson
Mr. K.H. Yung
Mr. A. Horton
Mr. R.J. Prizeman
Mr. Albert Chik
Dr. Ba·yer Wolfgang
Mr. R. Getgood
Mr. J. Rickwood
Mr. John H.N. Chan
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Analogue Technical Agencies Ltd.
The Hong Kong Electric Co., Ltd.
The China Engineers Ltd.
Hong Kong and Kowloon Electrical Contractors Association Ltd.

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1. POWER SYSTEMS

Paper No. 1

Some Recent Developments in Nuclear Power for electricity generation

Speaker: Dr. M.R. Yeung, BSc, MSc, PhD,
Lecturer, HKU.

SOME RECENT DEVELOPMENTS IN NUCLEAR POWER FOR ELECTRICITY GENERATION

Abstract

The purpose of this article is to present some recent developments of nuclear power in the world, major reactor types and their manufacturers. Emphasis is also given to the nuclear programmes of nations of interest in this region. In addition, design features of the major components of the proposed Daya Bay Station nuclear island will be discussed and highlighted.

Introduction

Industrial development and improvement in our way of life are highly dependent upon an abundant supply of inexpensive energy. The total energy consumed annually by a nation is a measure of the level of the national economy. Meeting this ever-growing need of power will require diverse sources of energy. The present practical sources of energy are:

1) Fossil fuels; coal, gas and petroleum

2) Hydroelectric; river and tidal

3) Wind

4) Solar; thermal and photovoltaic

5) Geothermal

6) Nuclear fission

The contributions of wind and solar are interesting but rather limited and costly to become a large percentage of the total energy production in the near future [1, 2]. Geothermal energy can be a very economical source of energy of heat for direct use. However, it is not always available where needed at an economical price [1]. The hydroelectric option is attractive in areas with large water supply but is very geographically dependent. The reserves of crude oil and natural gas are limited and it is argued that their use should be restricted for higher priority applications. This leaves coal and nuclear fuels as the economical sources of energy produced on a large scale for many nations.

Since 1970's, there is a growing commitment to nuclear power as a source of electricity generation among many nations. This trend is particularly apparent in the Southeast Asia. The world picture of nuclear power is given in table [1] which lists the nuclear power capacities of the most advanced nations as well as some nations of interest for comparison.

Reactor Types and Manufacturers

Fission occurs when a fissionable nucleus captures a neutron. Capture upsets the internal force balance between neutrons and protons in the nucleus. The nucleus splits into two lighter nuclei, and an average of two or three neutrons is emitted. The resulting mass of products is less than that of the original nucleus plus neutron. The difference in masses appears as energy in an amount determined according to Einstein's formula, $E = mc^2$. If one of the neutrons emitted is captured by another fissionable nucleus, a second fission occurs similar to the first. When the reaction becomes self-sustaining so that one fission triggers at least one more fission, the phenomenon is termed a chain reaction. The device in which this chain reaction is initiated, maintained, and controlled is called a nuclear reactor.

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Many different power reactor concepts have been proposed and built in the last three decades. The present article is limited for the most part to the following reactor classes that it appears will constitute the preponderance of the world's nuclear power capacity for the foreseeable future: (1) pressurized-water reactors moderated and cooled by light water; (2) boiling-water reactors that utilize light water as both coolant and moderator; (3) heavy-water (D_2O) modernated, pressure tube reactors that may use light or heavy water as coolant; (4) gas-cooled graphite moderated reactors; (5) fast reactors cooled by sodium or by helium.

Regardless of their design differences, the reactor core is joined to the turbine/condenser system by two or more parallel loops. For designs such as PWR, the reactor coolant is kept below saturation temperature and a steam generator must be used to transport the heat generated by the reactor core to the secondary system to generate steam for the turbine-generator set. If the reactor coolant is a gas or a boiling liquid, the possibility exists of eliminating the steam generators and using a direct cycle in which the reactor coolant and the working fluid are the same.

A list of the reactor vendors of all these types of reactors is given in Table 2. The table does not include the Russian designs because the Soviets limit their PWR exports to the Eastern bloc nations and the RBMK design is not available outside Russia. The PWR technology was originally developed by the U.S. and later successfully transferred to France, Germany and Japan through technology transfer programes. BWR technology transfer followed the same pattern. Heavy Water Reactor is a different technology developed by the Canadians and was exported to a few nations. On the other hand, gas cooled reactors have been the primary design for the U.K. nuclear power industry but contribute very little to the U.S. electricity supply. Except the French Super Phenix, which was commissioned in 1983, the Fast Breeder Reactor is basically still in an experimental stage among the world's nations.

Nuclear Programme of Japan

With very small fossil energy resources of its own, Japan has a much stronger need to expand its nuclear power programme than a country such as the United States where there are other domestic energy sources available. In 1982, nuclear power supplied 19.5% of the electricity generated and this figure grew to 22.9% in 1984. It is projected that nuclear power will supply about 39% of the electricity generated by the year 2000 [4].

Japan is served by nine electric power companies and eight of these utilities already either operate or are constructing nuclear power stations. The ninth, Hokuriku Electric, is planning to build its first nuclear plant by 1988. In addition, the Japan Atomic Power Company is also involved in the development of nuclear power and acts as an electricity wholesaler. Each of the utilities use only one reactor type – four using PWR and four using BWR. In terms of megawatts on line, Tokyo Electric Power Company (Tepco) (7747 MW nuclear capacity) is the world's largest investor-owned nuclear utility. The nuclear capacities of the Japanese utilities are given in table 3 [4].

The recent rise in nuclear plant cost has both the Japanese government and industry concerned and they are looking into ways of reducing the cost. These include standardized designs, reduced construction periods and modified purchasing practices. Tepco reported that the major equipment cost for its Kashiwazaki Kariwa Units 2 and 5 were 15% less that those of similar equipment for Unit 1. On the other hand, Japan has seen, over recent years, an average of 54 months from start of construction to commercial operation. The complete construction period of Kansai Electric's Takahama –3 took only about 50 months. The approach being used to cut construction times and costs are more extensive use of prefabrication at the factory rather than at the site, using larger cranes, automated on-site welding and more construction jobs in parallel.

Table 1 Nuclear Power Capacities of Nations (1986)

	Units	Net MW(e)
U.S.A.	129	119,012
France	63	57,563
U.S.S.R.	74*	57,238
Japan	45	34,320
W. Germany	27	28,016
Canada	22	15,026
Spain	17	14,483
United Kingdoms	42	14,388
Sweden	12	9,425
S. Korea	9	7,266
Taiwan	6	4,924
China	3	2,100

* Includes Chernobyl - 4

Table 2 Reactor Types and Vendors

Reactor types	Vendors	
1) Pressurized Water Reactor (PWR)	Westinghouse	(USA)
	Combustion Engineering	(USA)
	Babcock & Wilcox	(USA)
	Framatome	(France)
	KWU	(Germany)
	Mitsubishi	(Japan)
2) Boiling Water Reactor (BWR)	General Electric	(USA)
	Toshiba	(Japan)
	Hitachi	(Japan)
	ASEA/ATOM	(Sweden)
	Ansaldo Meccanico Nucleare	(Italy)
3) Heavy Water Reactor (CANDU)	AECL	(Canada)
4) Gas Cooled Reactor (GCR)	GEC	(UK)
	National Nuclear Corp	(UK)
	General Atomic	(USA)
5) Liquid Metal Fast Breeder Reactor (LMFBR)	Novatome	(France)
	Westinghouse	(USA)

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It is true that the Japanese acquired the PWR and BWR technologies from Westinghouse and General Electric, respectively, but the design and construction of nuclear power stations in Japan has changed greatly in the past decade. In 1970, Japanese contribution to the nuclear power plants was about 50%. To-date, this figure has grown to 98 – 100% [4]. The present goal is to develop, the "Advanced PWR" (APWR) and "Advanced BWR" designs and to deploy these advanced reactors in the 1990s. In fact, Japan has become the focus of the development of the most advanced Light Water Reactor (LWR) designs.

The design work of the APWR is done jointly by Mitsubishi and attached Westinghouse with the participation of the Japanese PWR utilities. The goals for the APWR include an output of 1350MW, improved safety margins, lower fuel cycle costs, lower power density, better load following capability and higher burnup (18 months between refueling). The work on the advanced BWR also started in 1981 and the development is carried out by General Electric, Toshiba and Hitachi, with the participation of the Japanese BWR utilities and Japan Atomic Power Company. The ABWR would have a number of changes which includes lower construction cost, improved load following capability, easier repair and inspection procedures and reduced occupational exposure. In addition to the development work on the advanced LWRs, Japan is also actively pursuing research in GCRs, Heavy water reactors and LMFBRs.

Nuclear Programme of Taiwan

When people discuss nuclear power, it is sometimes easy to overlook Taiwan. In 1984, Taiwan Power's nuclear power plants supplied about 47.9% of Taiwan's electricity [5]. Only France and Belgium obtain a larger percentage of their electricity from nuclear power. In Taiwan there is only one utility company, the state-owned Taiwan Power Company (Taipower), which currently operate six light water reactors – four BWRs and two PWRs with a total capacity of 4884MW, Taipower does its own construction management and was able to complete the first unit Chinshan-1 from initial concrete to fuel loading in 64 months. All six units were brought into commercial operation in a six and a half years period. Because Taiwan power is able to generate nuclear electricity at a cost less than half of those for oil-fired generation, the use of nuclear power to displace oil has allowed Taiwan to keep the electricity rate down [5].

The development of Light Water Reactor engineering and service technology is being pursued by Tai power in three areas [6]:

1. Establishing design review capability by cooperating with Belgatom and the Institute of Nuclear Energy Research (INER).

2. Establishing architectural engineering capability by forming Pacific Engineering and Constructors Ltd. (PECL) and Ebasco-CTCI jointly with Bechtel International and Ebasco of New York, respectively.

3. Localization of nuclear component manufacturing.

Being deficient in fossil fuel resources, Taiwan has been committed to nuclear power and the development of its nuclear programme is based on international technology transfer.

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Nuclear Programme of China

Despite a relatively long military nuclear programme, China did not start its civilian nuclear power industry until late 1970s when the "Four modernizations" campaign was launched. In China, coal and water resources are relatively abundant but the geographic distribution of these resources is very uneven, i.e., major coal production centre in the north but industrial centres in the South-East. With a national electricity generation capacity of only 86.5GW, (about 86W/capita) [7] China's need to increase its electricity production is, indeed, a very urgent matter. China proposed that as many as 15 nuclear units be in operation or under construction by the end of 1990s,These included 1 unit at Qinshan, 2 units at Daya Bay, 2 – 4 units at Sunan, 2 units at Liaoning and 6 others [8]. In 1986, the plan was drastically cut back to just Qinshan and Daya Bay, at least for the next five-year plan. The Qinshan plant is a domestically designed 300MW PWR with some imported components. The Daya Bay project, a joint venture of China and Hong Kong, is a Framatome designed twin-unit PWR plant (2 x 900MW) situated approximately 50km from Hong Kong. When the plant is completed in early 1990s, the electricity generated by the plant will be shared by Quandong Province and Hong Kong. Naturally, the Daya Bay plant will be a booster to the electricity deficient Quandong Province which presently has a total capacity of only approximately 2100MW [7].

With regard to the future, it has been indicated by Chinese officials from time to time that China would like to use the Qinshan unit 1 to scale up to a 600MW design which will be the standardized design for eventual mass production [8]. Considering the present fragmented nature of the electricity grids of China, this probably is a more sensible approach.

Nuclear Steam Supply System of Daya Bay Plant

The Nuclear Steam Supply System of the Daya Bay Plant comprises a 3-loop Pressurized Water Reactor (PWR) with an output of 2905MWth [9]. The Reactor Coolant System (RCS) is made up of the reactor vessel and three coolant loops each has a steam generator and a reactor coolant pump as shown in Figure 1. The reactor vessel is the most important Reactor Coolant System component which houses the fuel elements and the core support structures (reactor internals). The steam pressure in 67.5 bars at the steam generator outlets.

The Reactor Coolant pumps (RC pumps) are of the vertical, centrifugal radial outlet type fitted with a controlled leakage shaft seal arrangement, and are designed to pump reactor coolant through the reactor vessel and the steam generators. Each RC pump is equipped with a flywheel to ensure sufficient flow rate to maintain core cooling in the event of loss of pumping power.

Each loop of the RCS contains a vertically-mounted U-tube steam generator. The steam generators generators consist of two integral sections: an evaporator section and a steam drum section. The evaporator consists of a U-tube heat exchanger, while the steam drum section is located in the upper part of the steam generator and houses moisture separating equipment. In the Framatome steam generator, the high pressure, high temperature reactor coolant flows in the tubes and the low pressure secondary steam/water mixture flows on the shell side. Feedwater enters the steam generator through a nozzle on the upper shell and is distributed by the feedwater ring into the downcomer annulus. The feedwater mixes with the recirculation flow and enters the tube bundle near the tube sheet. Boiling occurs as the flow rises through the tube bundle.

The Framatome advanced fuel assembly (AFA) features a 17 x 17 square array as shown in Figure 2. The nuclear fuel uranium dioxide is housed in the zircaloy cladded fuel rods which are structurally bound together to constitute a fuel assembly. Control rods provide rapid neutron flux control for power shaping and shutdown. For operation convenience, control rods are usually grouped into many banks. During normal operation, all banks are withdrawn from the reactor core. The movement of the control rod clusters is controlled by the Control Rod Drive Mechanisms (CRDM) mounted on the reactor vessel head. If power to the CRDM is cut off either deliberately in reactor trip or because of an accidential power failure, all control rod clusters instantly fall into the core by gravity and shut down the reactor.

The Framatome nuclear island is equipped with Engineered Safety Features System to cope with accidents. The function of Engineered Safety Features System is to assure core cooling and to avoid the release of fission products from the containment to the environment following a loss-of-coolant accident (LOCA) or steam line break. For redundancy, all Engineered Safety Features Systems are arranged in two physically separated trains.

Conclusion

Since the economic well-being of a society is closely linked to the electricity generation, the need for some nations, especially those developing ones, to upgrade their electricity production capabilities are rightfully justified. Because of uneven distribution of resources, different nations use different combinations of power systems to safisfy their needs. Based on the recent developments, it is apparent that nuclear power will continue to be an increasingly important role in the energy mix of this region in the foreseeable future.

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Table 3 Japanese Nuclear Utilities

Utilities	Type	MW(e)
Chubu Electric Power Co.	BWR	2396
Chugoku Electric Power Co.	BWR	1230
Hokkaido Electric Power Co..	PWR	1158
Japan Atomic Power Co.	PWR BWR GCR	2670
Kansai Electric Power Co.	PWR	7030
Kyushu Electric Power Co.	PWR	5110
Shikoku Electric Power Co.	PWR	1922
Tohoku Electric Power Co.	BWR	497
Tokyo Electric Power Co.	BWR	12015

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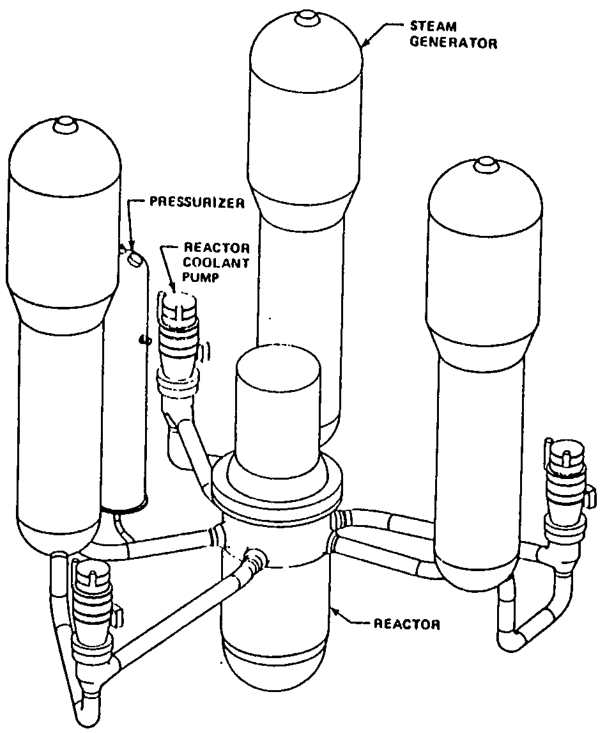

Figure 1. Simplified Diagram of Three-Loop NSSS

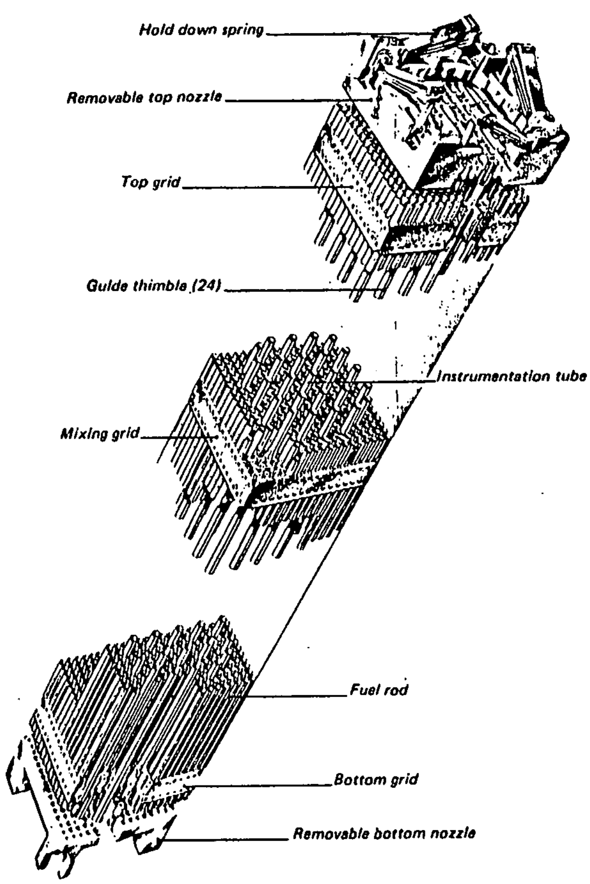

Figure 2. Advanced Fuel Assembly (AFA)

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— Notes & Questions —

Paper No. 2

Network Development in Kowloon and the New Territories

Speaker: Mr. Hans Yu, BSc(Eng), MHKIE, CEng, MIEE, Central Kowloon District Manager, CLP.

NETWORK DEVELOPMENT IN KOWLOON AND THE NEW TERRITORIES

Introduction

The most people, Hong Kong conjures up an image of the harbour, with vast high rise developments on both Hong Kong Island and the Kowloon Peninsula. This is the picture of the territory most familiar to the visitor. Indeed development of the Kowloon Peninsula, together with the industrial areas to the east and the west has over the last 20 years been intense, to the extent that of 1.2 million electricity consumers, some 800,000 are to be found in the area noted. Looked at another way about 75% of the supplied load, or about 2200MW, is to be found in only 130 km^2 or about 15% of the supply area. The growth in maximum demand over the past ten years has averaged 10% per annum, with a correspondingly high growth in unit sales of 9% per annum. With the continued economic growth and major developments in the new towns of the New Territories, as well as the redevelopment of the established urban and industrial areas, increase of electrical demand is expected to continue.

It is within such a setting that electricity consumers come to expect and demand a supply of electricity that is adequate, reliable and economic. Placing equal emphasis on these three requirements, a system of supply, a network has evolved, and this paper traces through part history, part concept and part application of the equipment necessary to distribute electrical power.

As we approach the last years of the twentieth century, it is interesting to note that electricity, as a commercial product, has been with us for over 100 years. In 1882, as a result of the effort and vision of Thomas Edison, Holborn Viaduct Power Station began supplying electricity in London, and this was probably the first commercial power station in the world.

Within a similar historical time scale, in 1898, a mere 16 years after the opening of Holborn Viaduct Power Station, electricity came to Guangdong. The Canton Electric and Fire Extinguishing Company was founded in 1898 by a certain Fung Wa-chuen. (Perhaps the name of the company reveals Fung's desire to make money not only from electricity, but also from its other less welcome aspects). Despite the diversified nature of Fung's company, however, financial difficulties led him to seek help from the Hong Kong based Shewan Tomes Company, a company for which Fung had acted as compradore for many years. As a result the then recently established Shewan Tomes' subsidiary, China Light and Power Syndicate, took over the Canton Electric & Fire Extinguishing Company is 1900.

Thus China Light acquired the Canton Power Station and, at the same time, acquired land at Chatham Road in Kowloon where the company first produced electricity in 1903 with an installed capacity of 225 kW.

The expansion of electricity usage in the Kowloon Peninsula and the New Territories has followed the fortunes of the territory generally and in 1921 the first machine at Hok Un Power Station was commissioned. The maximum load at this time was about 1.4MW, and the Hok Un site was to be the scene of subsequent expansion of generating facilities for almost the next 50 years, ending with the commissioning of the first 120MW set at Tsing Yi in 1969. At this point the maximum load had risen to 700MW.

Supplying over 1.2 million consumers in Kowloon and the New Territories including several of the outlying islands, with a peak load of 3200MW and also supplying power to Guangdong Province, the area of the People's Republic of China immediately to the north of Hong Kong, requires specific policies to interpret the 'adequate', the 'reliable' and the 'economic' parameters of supply.

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The need for an economic and reliable supply of electricity to support the continued growth of Kowloon and the New Territories is vital. From the generation point of view, this has been accomplished with the construction of Castle Peak 'A' Power Station, which was commissioned in 1982, in addition to the two existing power stations at Tsing Yi and Hok Un. Castle Peak 'A' Station houses 4 X 360MW sets; the 'B' Station will ultimately house 4 X 680MW sets of which two are now in operation. These units are all dual-fired (coal and oil) but presently operate on coal enabling consumers to benefit from the cheaper generation costs associated with the more stable coal market.

The Supply Network Concept

General

A supply network can be simply described as a means of transferring power from the point of production to the point of use. In its simplest form it is a length of wire from a generator to a load. This simple idea has been outgrown by urbanization and industrialization, which created the need to transfer power in bulk from relatively remote generation sites to the load centres and then distribute the power within the centres themselves.

To accomplish this task economically and reliably, a more sophisticated approach to the supply is required. Several voltage levels are used, together with a wide variety of plant and equipment, which must be designed, engineered and operated safely and efficiently.

Electricity is a fundamental requirement of modern living. Lighting, cooking, radio, television, air-conditioning – the list is long. At the touch of a button, people expect electrcity to be instantly and safely available for their requirements.

Low Voltage Network

The low voltage supply, (346/200 volts) is designed as the fundamental means of affording supply to the vast majority of consumers.

As the number of such supplies to consumers grows, there is a need to create a low voltage network supplied from strategically located transformers. Many buildings are supplied directly by transformers located in a substation within the building. In the rural area low voltage overhead lines will be found performing much the same function, and supplied from pole-mounted transformers. Other commonly accepted loads, such as traffic lights and street lighting can be supplied from this low voltage network.

Higher Voltage Distribution Networks

Low voltage networks can only supply localised areas, limited by geographical size and level of demand. Once larger areas or greater power requirements are considered, economics dictate the need to introduce higher voltage levels into the network.

The next higher voltage level in use throughout the world is in the 10 kV/20 kV range. Obviously the higher the voltage, the more power that can be handled, but at the same time the plant and equipment used must be compact to economise on the use of building space, and be readily available in the market to be cost-effective. Within this 10 kV to 20 kV range, 11 kV is extremely common, and has been adopted as the high voltage distribution system in Hong Kong. Originally 6.6 kV was widely used until the 1960's since when it has been progressively replaced by 11 kV.

Certain areas have adopted a voltage level towards the higher end of this range – Singapore for example has a 20 kV system. Had compact and relatively cost-effective 20 kV equipment been available in the 1960's, a good case could possibly have been made for its introduction into Hong Kong.

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Within Kowloon & the New Territories, and moving up the voltage scale, the next level in common use is 33 kV. At one time this voltage served as a true transmission voltage, supplying bulk power to various load centres, for subsequent distribution at 6.6 kV or 11 kV. As demand built up, transmission at 33 kV was superseded by 66 kV, and eventually 132 kV. Nevertheless, 33 kV is still retained as a primary distribution voltage, though long term plans are now in hand for its ultimate retirement. 66 kV has been largely superseded by 132 kV, and technology is now such that direct transformation from 132 kV to 11 kV is economically viable, and in densely loaded urban environments has significant advantages over other transformation ratios.

Thus we reached the situation where 33 kV, 11 kV and LV networks formed what one could term the distribution system, with 132 kV forming the transmission system, i.e. bulk transfer of electricity from the power stations to the major load centres.

Transmission Network

When the decision was taken in the late 1970's to construct Castle Peak Power Stations to meet the projected load growth, it was also recognised that a higher capacity transmission system able to transfer larger amounts of power from Castle Peak to the load centres was needed. To minimise the environmental impact of a multitude of 132 kV overhead lines, and also for technical reasons, the decision was made to construct this new transmission system at 400 kV.

Interconnection with Neighbouring Power Systems

With the growth of the power system in Hong Kong, significant benefit can be derived from interconnection – reduction of spinning reserve, and inter-utility power transfers.

The CLP system was interconnected with Guangdong (Shenzhen) in 1977 by a 50MVA 66 kV circuit. This was followed by two 132 kV interconnections also with Shenzhen, with a third 132 kV circuit to Shekou recently commissioned, giving a total installed interconnection capacity with the Guangdong Authorities of some 400MVA.

Further interconnection with Hong Kong Electric Company has been in service since 1981, with the commissioning of 2 X 240MVA 132 kV submarine cable circuits.

Bulk Transmission System

400 kV System

There are four overhead circuits carrying power from the Castle Peak site with two circuits per tower line. One pair of circuits forms a northern supply leg with the other pair forming a southern supply leg, both linking up at Tsz Wan Shan to form a complete ring. The northern leg has intermediate 400 kV substations at Yuen Long (Au Tau locality) and Tai Po (Hong Lok Yuen locality), with the southern leg's intermediate substations located at Lei Muk Shue and Lai Chi Kok.

All of the 400 kV substations noted above are supplied by overhead lines i.e. no 400 kV cable is used. This is done for economic reasons because as can be imagined, 400 kV cable is very expensive. However, large 400 kV overhead lines cannot be brought to the actual load centres for physical and amenity considerations, and thus in the case of Tai Wan Substation, located in the Hung Hom area, 400 kV supply is by means of underground cables. Figure 1 shows the geographical layout of the system.

Power is then deliered from these 400 kV substations to the respective load centres by underground cables at a lower voltage, one which is more economical for underground cables, i.e. 132 kV is used. Consequently these major 400 kV substations house transformers which step down the voltage from 400 kV to 132 kV.

132 kV System

To a certain extent the 132 kV system fulfills a similar transmission function, and power from Tsing Yi Power Station is delivered to the major 132 kV substations within the supply area.

The 400 kV and 132 kV systems form the backbone of the transmission network, i.e. the means of delivering large amounts of power from the relatively remote power stations at Tsing Yi and Castle Peak to the centres of population in urban Kowloon and the New Territories.

Distributing the Power

Having delivered power in bulk at 400 kV and 132 kV to the various population centres, there remains the final problem of delivery to the consumers' premises, and for convenience we may consider this as 'distribution', although various voltage levels are used.

Direct use of 132 kV System

The modern practice is to use 132 kV also as a 'distribution' voltage whereby substations are supplied at 132 kV and transform directly down to 11 kV. These 132 kV substations are called 'primary' substations and are located as near as possible to the areas they supply. They are almost always supplied by underground cables.

Use of 33 kV System

Before the advent of the 132 kV system, 33 kV was used in Hong Kong as a transmission voltage carrying power to many parts of the urban area and the New Territories. The 11 kV distribution system was supplied by 33/11 kV transformers in a similar way as the modern 132/11 kV system. 33 kV is still in quite extensive use in the older urban areas such as Tsim Sha Tsui, East Kowloon and the New Territories.

Whilst it is not being actively extended it still has a role to play, pending its long term replacement by direct 132/11 kV transformation. To maintain supply to this 33 kV system, therefore, it is quite common to find transformers at major 132 kV substations stepping down to 33 kV and feeding the 33 kV distribution system.

11 kV System

The 11 kV system is a major element of the distribution system, taking power from the primary substations and supplying the many distribution substations. In the town area 11 kV circuits are installed underground but an extensive network of 11 kV overhead lines supplies the more rural area.

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Typical System Designs

400 kV System

The security of the network as a whole depends, initially, on the degree of security of the system supplying it, i.e. the transmission system.

Thus, it is normal practice to find the highest degree of security applied to this system, reflecting the large amount of power handled, and the consequent large number of consumers supplied by any particular section of the extra-high-voltage (EHV) system.

Specific faults are catered for; circuit breaker faults, busbar faults and certain double circuit outages are taken into account when considering the integrity of generation infeeds.

As an example of application of transmission security standards to the aspect of switchgear configurations, the 1½ switch substation provides high security as shown in Figure 2.

It can be seen that three switches are shared by two circuits, hence the 1½ nomenclature, but the whole arrangement is secure from a busbar fault or a single circuit breaker fault and isolation for maintenance will not affect any supply. A very flexible operational arrangement is obtained at no higher cost than a conventional double busbar arrangement.

132 kV Direct Transformation

In addition to its albeit diminishing role as a true transmission voltage, 132 kV is now used extensively as a 'distribution' voltage utilising 132/11 kV direct transformation, as previously noted.

132/11 kV substations based on a standardised design, and which will ultimately accommodate three 35MVA 132/11 kV transformers, are planned to tap power from circuits emanating from bulk supply substations via 132 kV ring-main-units. For amenity reasons, the area transmission network is predominantly made up of underground cables and indoor substations equipped with metalclad switchgear. A typical 132 kV supply system is shown in Figure 3.

11 kV System

The high degree of dependence on electricity in a densely populated urban community has been, and continues to be, one of the main preoccupations of the distribution design philosophy.

This has led, over the years, to an urban 11 kV system relying for its operation on the installation of automatic circuit breakers at all distribution substations and an associated cable system using pilot wire protection. Figure 4 shows a typical system, fed from a primary substation. In this case four 11 kV cables are connected into a ring system and the design is such that, in the event of any single cable fault, supplies to all substations fed from the ring will be maintained.

Each primary substation supplies several such blocks of load, and although each ring operates independently, normally open interconnection between rings is installed, where possible linking rings supplied from adjacent primary substations. Such interconnection is useful in transferring load between primary substations for maintenance work. This is shown in Figure 5.

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LV System

Finally, back to our starting point, the LV system. Figure 6 shows how consumers occupying a high rise building are supplied from an 11 kV/LV transformer located within the building.

From the central LV distribution board, located adjacent to the transformer, a series of rising mains and lateral mains distribute the power throughout the building, ending with a supply to each individual consumer, not forgetting that vital piece of equipment yet to be mentioned – the energy meter.

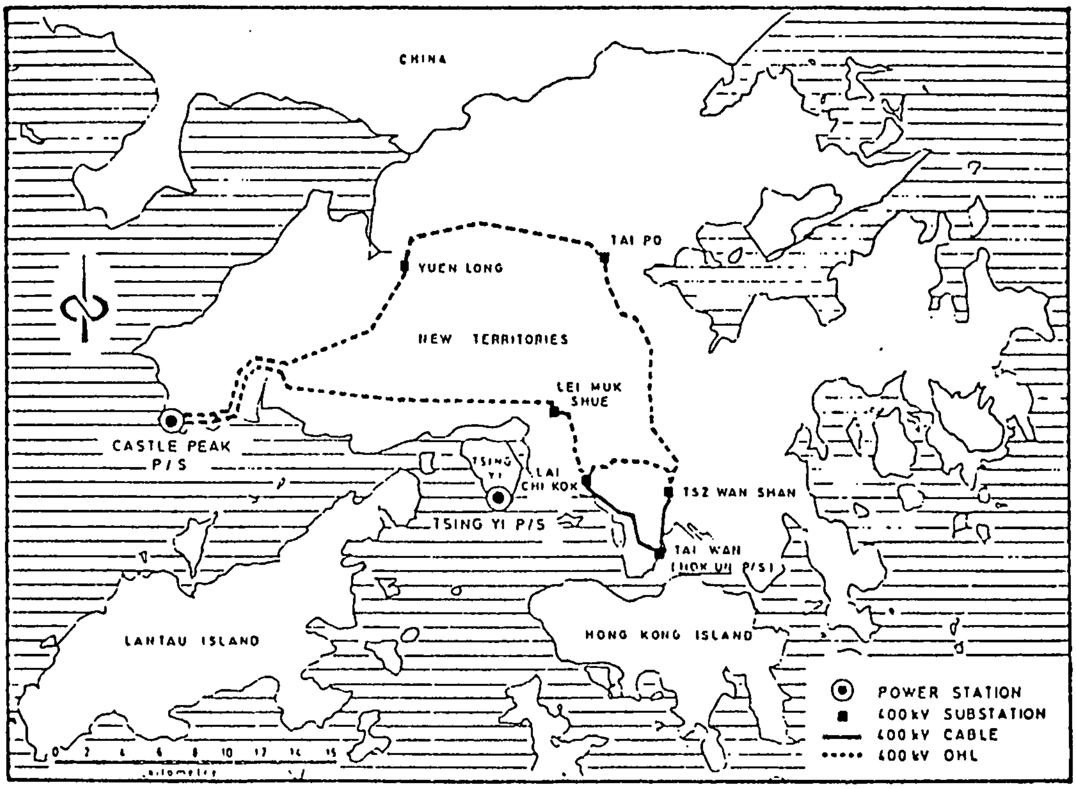
Conclusion

This paper has described in outline the development of the distribution and transmission system in Kowloon and the New Territories. It is fairly typical of electricity supply practice throughout the world to solve the problem of supplying electricity to densely populated urban areas. It is hoped that when next you see the power company digging trenches which disrupt the flow of traffic and using pneumatic drills which assault the senses, you will be in a position to understand some of the problems that have to be solved, and some of the methods we employ to develop our networks to provide

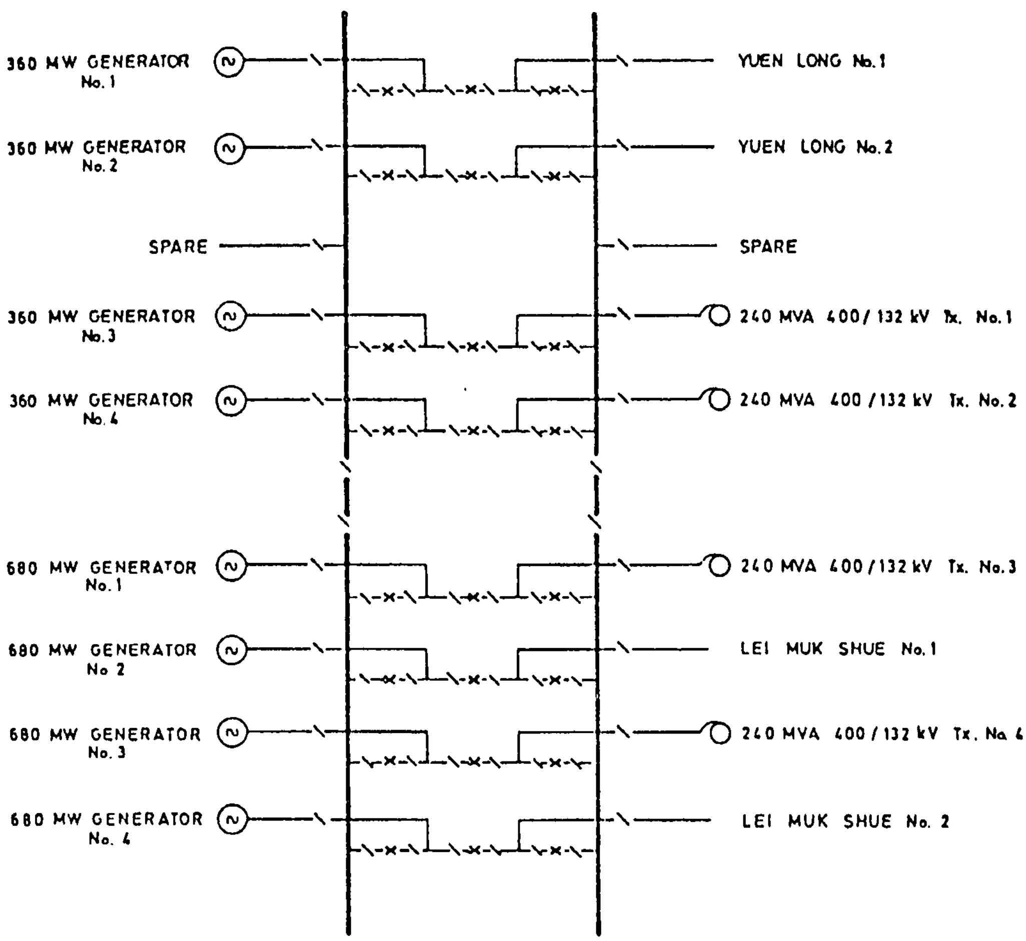
'adequate, reliable and economic' means of electricity supply.

Acknowledgements

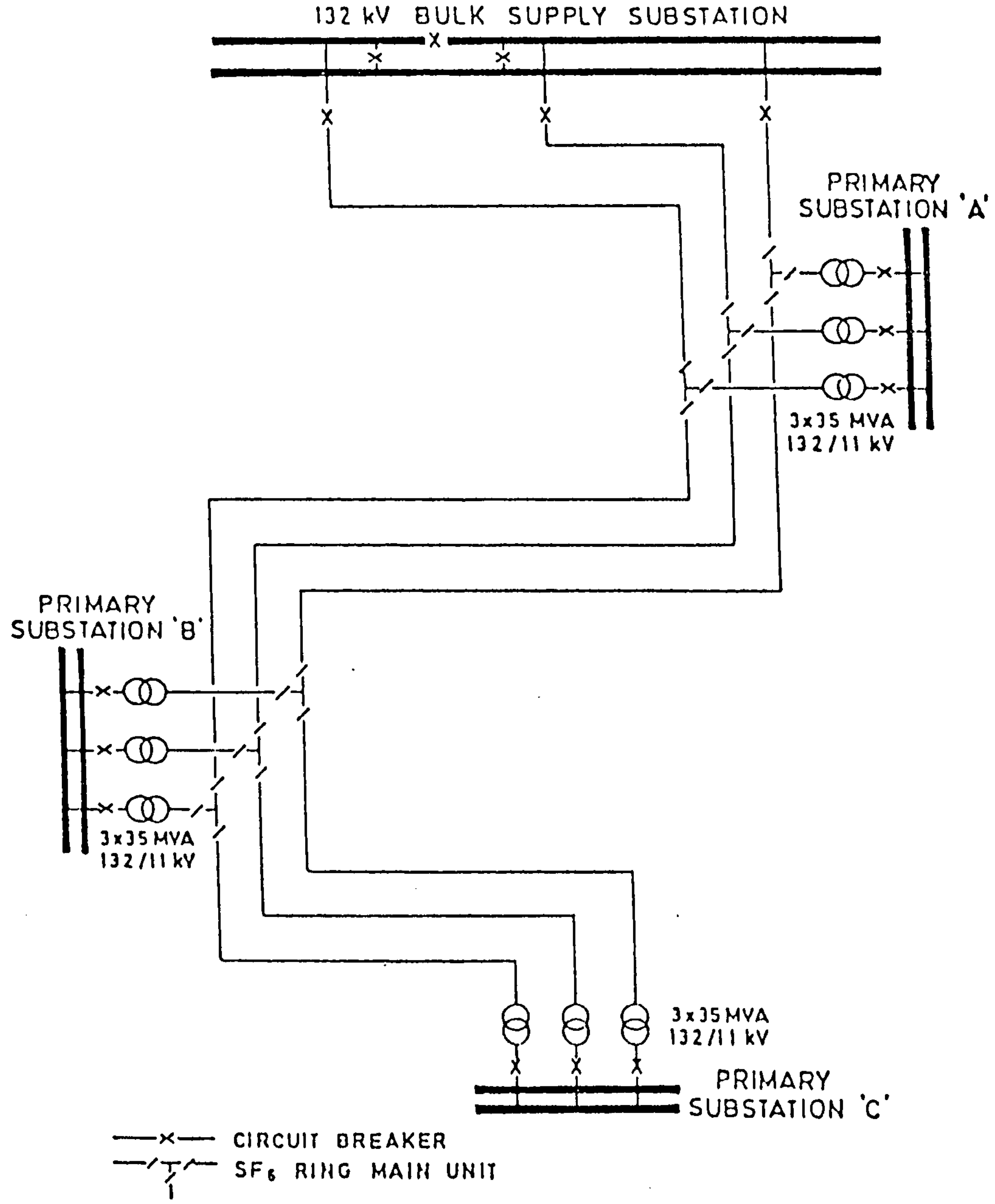
As presenter and editor of this paper, I would acknowledge the assistance given by my colleagues in the Transmission & Distribution Department of CLP, and in particular the permission given by CLP to quote from "Power – the Story of China Light" by Nigel Cameron, and from "Responding to Growth, CLP's Power Transmission & Distribution Development Programme" by W.F. Stones, Managing Director of CLP.



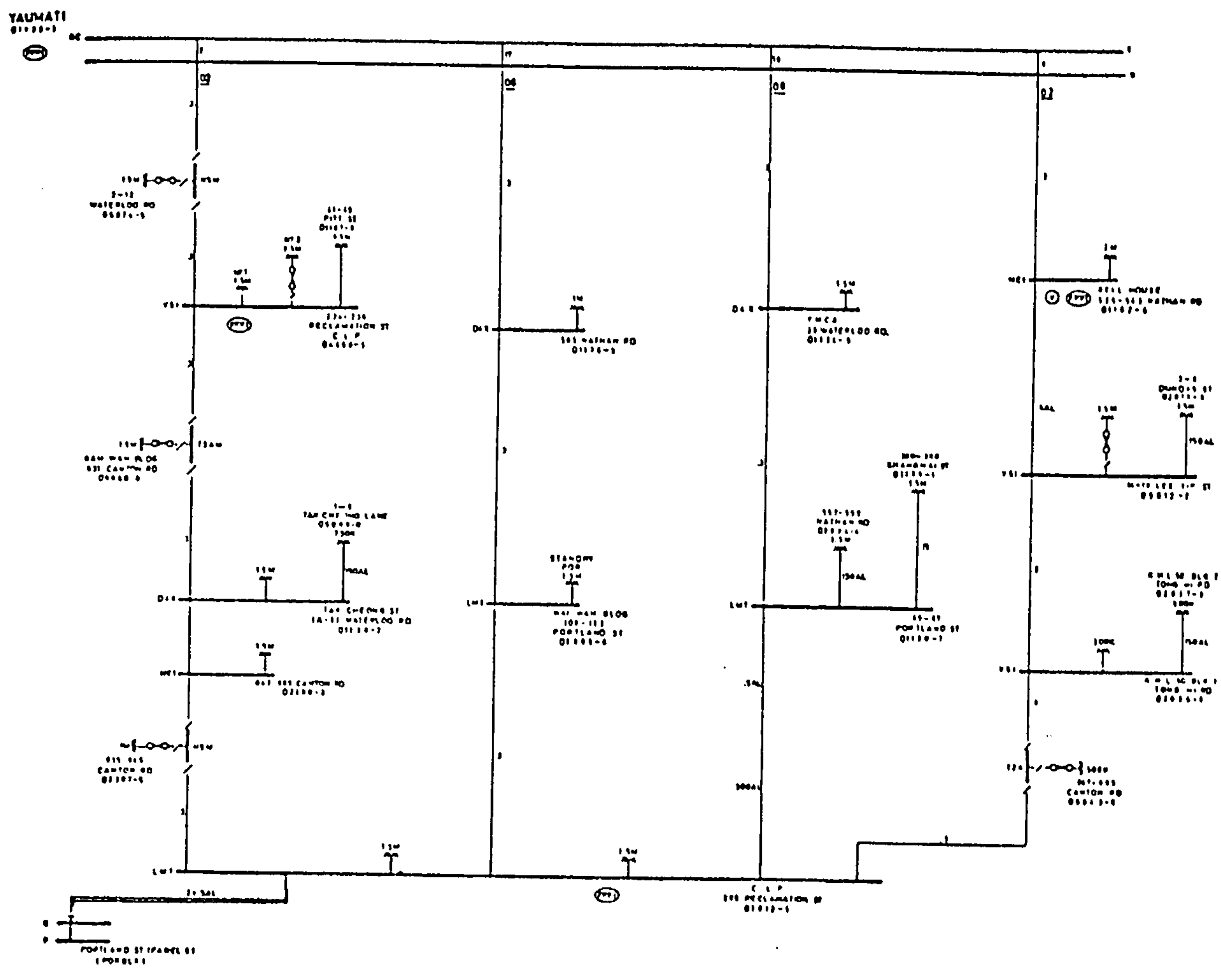
NETWORK DEVELOPMENT IN KOWLOON AND THE NEW TERRITORIES	LAYOUT OF 400KV SYSTEM	FIG. 1



NETWORK DEVELOPMENT IN KOWLOON AND THE NEW TERRITORIES	400KV SWITCHGEAR LAYOUT AT CASTLE PEAK POWER STATION	FIG. 2



Network Development in Kowloon and the New Territories	Arrangement of 132KV System supplying a series of 132/11KV substations	Fig. 3



NETWORK DEVELOPMENT IN KOWLOON AND THE NEW TERRITORIES	TYPICAL 11KV DISTRIBUTION NETWORK	FIG. 4

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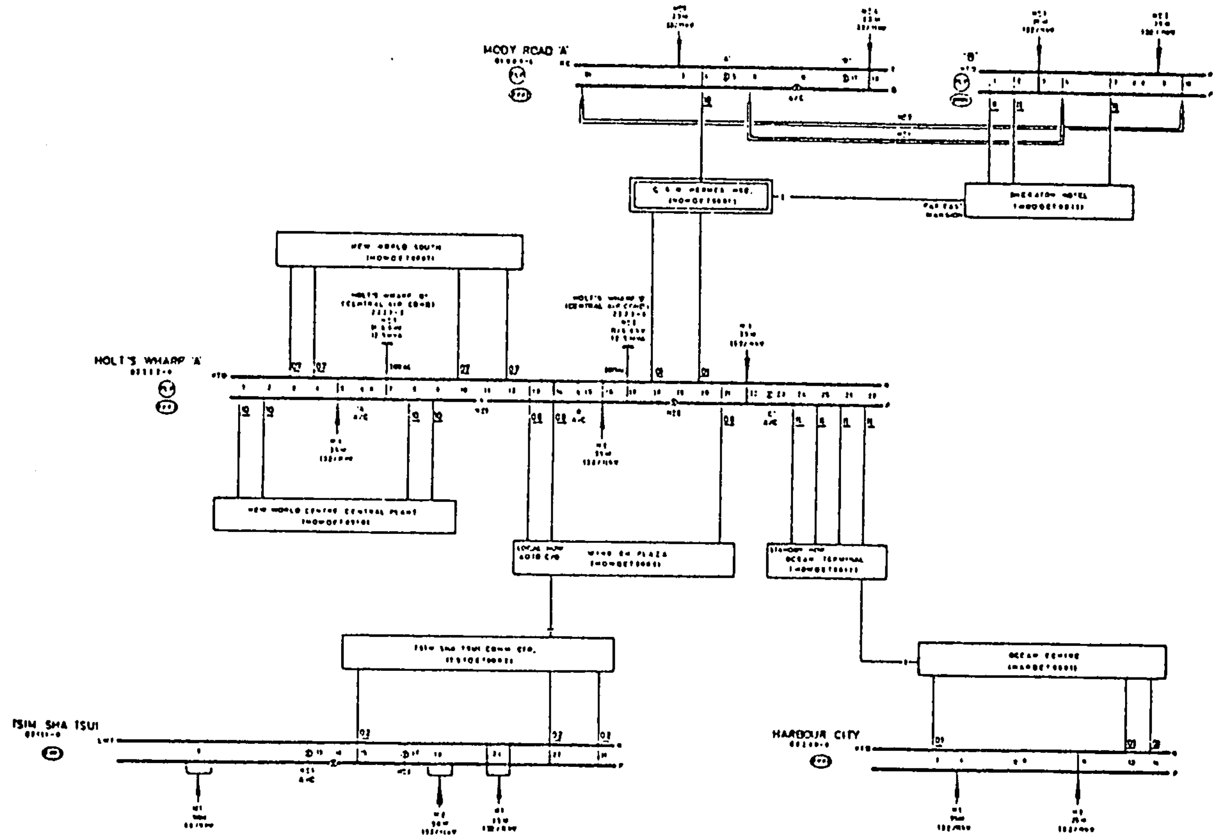

NETWORK DEVELOPMENT IN KOWLOON AND THE NEW TERRITORIES	OVERALL 11KV DISTRIBUTION LAYOUT	FIG. 5

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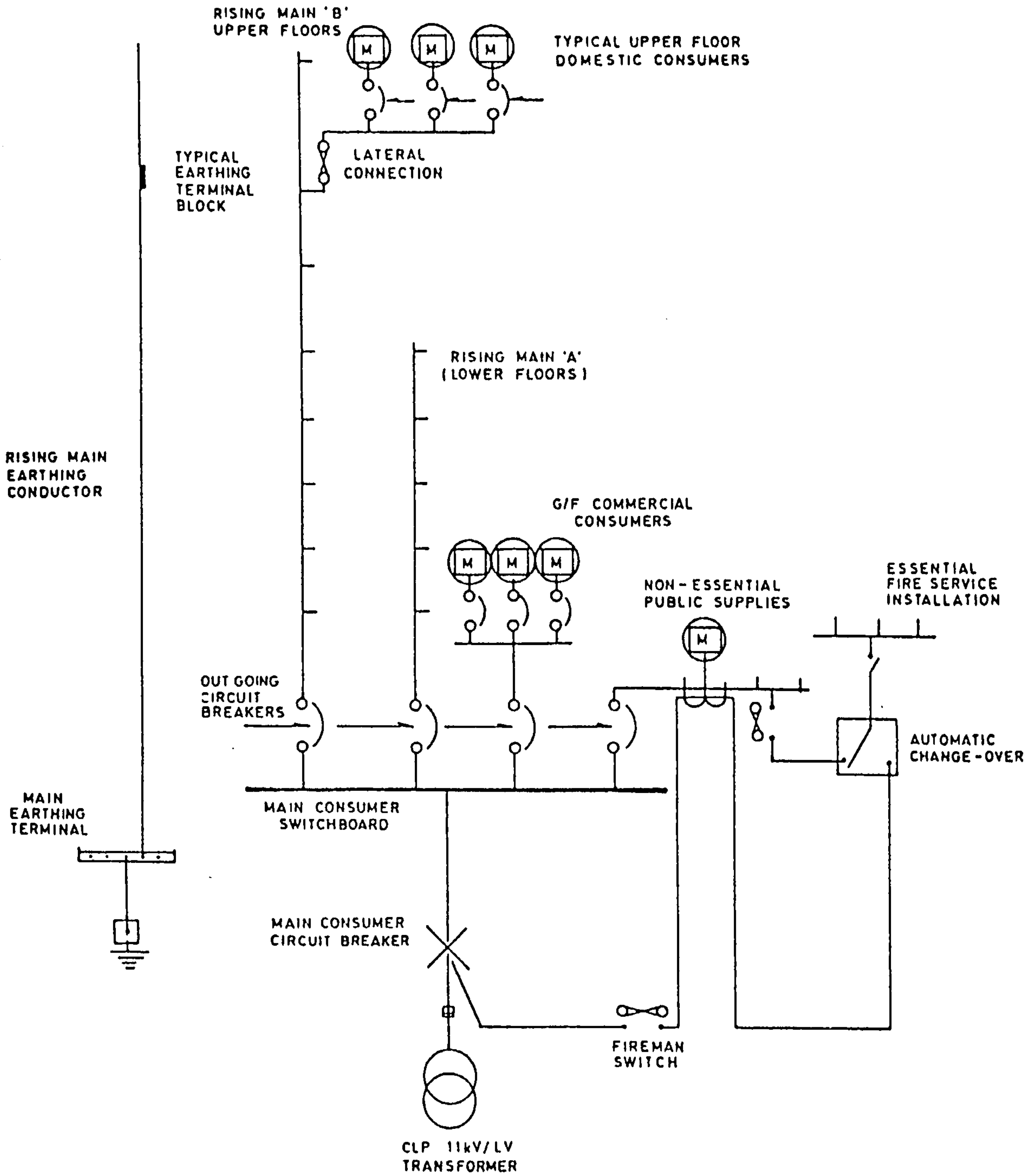

Network Development in Kowloon and the New Territories	Typical LV supply to a multistorey building	Fig. 6

— Notes & Questions —

Paper No. 3

Supply to Guangdong and Problems Associated with Interconnection with Guangdong Power System

Speakers: Mr. C.K. Law, MSc, MHKIE, CEng, MIEE, System Planning Engineer, CLP.
Mr. Fred K.Y. Lau, BSc, CEng, MIEE, Generation Development Engineer, CLP.

SUPPLY TO GUANGDONG AND PROBLEMS ASSOCIATED WITH INTERCONNECTION WITH GUANGDONG POWER SYSTEM

Synopsis

This paper outlines the history of sales of electricity supply to the Guangdong Province by China Light & Power Co., Ltd., the phased increase in capacity, some problems encountered and special means of resolution. It also presents the planned development in larger scale interconnection in the early 1990's when the Daya Bay Nuclear Power Station comes into service.

Background

Following the adoption of the open-door policy in China in the late 70's, the development activities of the Guangdong Province have increased rapidly. Its growth in electricity demand has outplaced its electricity generation development. Rotation of supply outages has been required.

The possibility of China Light & Power (CLP) supplying electricity to Guangdong Province was first raised in 1978. Subsequent contacts between CLP and Guangdong General Power Company (GGPC) resulted in an agreement of the first phase of system interconnection, under which CLP would supply one million units per day at a transfer level of 50MW.

Following the completion of the initial phase of the interconnection project in a record time of less than three months (including design, erection and commissioning), the interconnection network has been enhanced and expanded.

Phased Development of the Interconnection Network

The interconnection was expanded to a capacity of 100MVA in 1981. It was later upgraded to 150MVA in 1983. To meet additional supply requirements, it was further expanded to the present capacity of 270MVA. These developments are summarized in the following table:—

Stage	I	II	III	IV
Circuit No.	1	2*	2	3
Supply Point from CLP	Fanling 66kV	Fanling 66kV	Tai Yuen 132kV	Ting Kok Rd 132 kV
In-feed Point to GGPC	Shenzhen 110kV	Shenzhen 110kV	Shenzhen 220kV	Shenzhen 110kV
Commissioning Date	3/79	1/81	7/83	7/85
Gross Interconnector Capacity	50MVA	100MVA	150MVA	270MVA

* The OHL is of 132kV 100MVA design and operated at 66kV.

Table 1 – Phased Development of the CLP – GGPC Interconnection

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Since the tie-lines were established in different stages and connected to various voltage levels of the GGPC system, load balance between these circuits is difficult to achieve. As the result of the uneven distribution of load among the three interconnecting circuits, the net maximum transfer capacity is found to be about 230MW under normal operating conditions.

In July 1985, a contract was concluded between CLP and Merchants Steam Navigation Company (CMSN) for supplying power to Shekou and the adjoining Che-wan area. A 132kV 120MVA OHL/Submarine cable has been installed and scheduled to be commissioned before the end of 1986 to deliver power to Shekou from CLP's Yuen Long 132kV network. This circuit can serve as an additional interconnector between CLP and GGPC via the Shekou – Shenzhen 110kV circuit if required at a later date.

Fig. 1 shows the overall supply arrangement following the commissioning of the Shekou feeding circuits.

Sales of Electricity to GGPC

In line with the continuous increase of the interconnector capacity (as shown on Fig. 2), the total sales to GGPC for the past seven years were generally in the upward trend as tabulated on Table 2 below and graphically shown on Fig. 2.

Year*	Sales (GWh)	
1979	158	April - Sept.
1980	310	
1981	254	
1982	239	
1983	323	
1984	641	
1985	988	
1986	830	Oct. - May

* Referring to financial year between Oct. and Sept.

Table 2 - Sales Record for Supply to GGPC

The GGPC electricity demand from CLP is very much affected by the amount of rainfall and hence the availability of low cost hydro-electric power in Guangdong Province. This can be exemplified by the sales to GGPC in 1981 and 1982 when there was abundant rainfall in Guangdong Province.

Problems Associated with the Operation of the Interconnectors

During the seven years of operation, several operational problems were encountered. Among the others, the problems on tie-line control, system protection, system oscillation and communication were of major concern and had required special means of resolution.

Frequency and Tie-line Control

Frequency and tie-line control was carried out in a rather crude manner in the first few months of interconnection when the power transfer was at 50MW. System frequency was controlled by the hydro-electric units through automatic regulators in the GGPC system whereas the tie-line flow signal was relayed back to CLP's Tsing Yi Power Station (the largest CLP station at that time) for manual transfer regulation.

The CLP's computerized Automatic Generation Control (AGC) system was commissioned in late 1979. Since then, CLP has been using the standard "Tie-line Bias Frequency Control" for regulating both the system frequency and tie-line transfer whereas GGPC continues to regulate system frequency using their hydro units. In principle, both system frequency and tie-line transfer should be able to be regulated at their scheduled values. However, due to the shortage of installed generation capacity in the GGPC system, there have been difficulties during the GGPC's high load periods when the regulating capacity was used to meet the system demand. System frequency and tie-line transfer are practically regulated by scheduled load curtailment in the GGPC system. Therefore, occasionally larger deviations of system frequency from 50Hz were recoreded.

Looking ahead, the situation should improve as more generation capacity is scheduled to be installed in the GGPC system in the next few years. Furthermore, when GGPC commissions its new system control centre in about two years' time, a computer system will be available to execute the standard "Tie-line Bias Frequency Control" for much better co-ordination with the CLP's control efforts.

Protection

A sound protection system is essential in maintaining a secure supply to the consumers and also in preventing damages being incurred to the transmission and distribution plants. The protection equipment for the three circuits currently in use includes the following:–

Transformer – Differential protection as primary protection, supplemented by a distance protection to protect the HV winding.

Circuit – Duplicated distance protection with direct inter-tripping via voice frequency channel.

Back Up – IDMTL OC/EF and high set DTL OC/EF protection.

Other than the above-mentioned conventional circuit protection, an under-frequency protection scheme was also adopted to decouple the two systems in time of severe generation loss in either system.

Detailed studies revealed that, for some faults in the interconnected system, it might become unstable and the two systems would oscillate with the centre of oscillation on the interconnection transformer. Splitting the two systems was found to be the only practical means of preserving the run-away systems. Out of step decoupling schemes were adopted to decouple the GGPC system at suitable decoupling points under such power swing conditions.

Dynamic Stability

Similar to many other loosely interconnected power utilities of the world, CLP has experienced low frequency power oscillations. After the commissioning of the Castle Peak Power Station and the first stage of the 400kV network in March 1982, power oscillations of less than 10MW peak to peak were observed on the GGPC interconnector.

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In early 1984, a number of incidents involving oscillations of greater magnitude occurred during the light load conditions, when the number of machines in the system was reduced and the transfer through the interconnector was high. Preventive measures were developed and implemented as described below:–

(a) Short term measure – by reducing transfer to GGPC and keeping an extra oil-fired unit at Tsing Yi Power Station overnight. Even though these measures eliminated the problem, they imposed some financial penalty.

(b) Medium term measure – the gain of the Excitor Control System (ECS) for the Castle Peak 'A' (350MW) generators were reduced, without deteriorating the transient response of the machine. This was proved to be a cost effective interim method to eliminate the dynamic instability problem.

(c) Long term measure – installation of Power System Stabilizer (PSS) on all generating units at Castle Peak Power Station was adopted as the permanent preventive measure to eliminate system oscillations.

Communication

Good and reliable communication is essential to ensure safe, reliable and efficient system operation which includes the remote monitoring and control of the transmission plant at Shenzhen by the CLP System Control Centre. Previously, communication between the control centres was effected through a pilot cable owned by CLP and through the public telephone systems. Such arrangement was found to be very unreliable. The pilot cables were often damaged due to construction works on both sides of the border. Therefore, a microwave link between CLP and Shenzhen S/S was established at the end of 1985. This microwave channel connects the GGPC Shenzhen – Guangzhou network to complete the voice/signal connection between the two systems.

Mutual Benefits

The initial objective of the interconnection between CLP and GGPC was to make available electric power to reduce the shortage of electricity in the GGPC system and in particular the Shenzhen Special Economic Zone. As the tie between the two companies is strengthened, the interconnection operation has resulted in benefits to both parties through the mutual support during difficulties and needs of either party. In he last few years, there were emergency situations caused by sudden trips of CLP generating units. In many of such occasions, GGPC back-fed the CLP system, offering assistance for rapid recovery.

GGPC demand is generally low in the summer months but high in the winter months due to the hydro power being more readily available in summer. This favourable supply pattern has resulted in improvement in CLP's system load factor and better utilization of generating plant.

Future Development

Guangdong Nuclear Power Project

In depth investigation had been carried out in 1981 on the feasibility of the development of a nuclear power station in Guangdong for supplying energy to Guangdong and Hong Kong. It was concluded that it would be technically and economically feasible to accommodate 2 x 900MWe PWR power station in the combined system.

In order to facilitate the large import of nuclear power to the CLP system, the interconnection network was proposed to be upgraded to 400kV. In the network design, the Nuclear Power Station will be connected directly to Dongjiao Substation of the GGPC system by a 500kV 1800MVA overhead line circuit and to Tai Po 400kV Substation of the CLP system by a 400kV 1800MVA overhead line circuit. The Power Station will be further connected to Shenzhen Substation near the border by a 400kV 1800MVA overhead line circuit which will be upratable to 500kV. This Shenzhen Substation will be in turn connected to GGPC's Dongjiao Substation by a 500kV 1800MVA overhead line circuit and to CLP's Yuen Long Substation by a 400kV 2 x 1800MVA overhead line double circuit. The 500kV and 400kV system will be interconnected at Shenzhen Substation and at the Nuclear Power Station with 2 x 900MVA transformers equipped with on-load tap changers at each location. The agreed nuclear transmission network is shown schematically in Fig. 3 and geographically in Fig. 4.

In line with the agreement, CLP is expected to receive 70% of the annual output from the nuclear power station. A seasonal energy sharing scheme will be operated, by which CLP will import more of the nuclear output during the summer and less power during the winter period.

Pumped Storage Development

The load pattern of the CLP system is characterized by he low demand during the daily trough period which is typically about 40% of the daily peak demand. Therefore, some base load plants may have to be part loaded or even two shifted at night. In doing so, the utilization of the plant will be lowered.

A pumped storage scheme will be able to improve the situation, by utilitising the low cost coal/nuclear energy to pump water and sotre power in the upper reservoir in the form of potential energy. This stored energy can then be used to generate power during the peak load periods in place of the more expensive oil-fired generating plants.

A review by CLP and GGPC on the development of such project is currently being carried out.

Conclusion

There has been significant expansion since the implementation of the first phase of the CLP-GPC interconnection at 66kV level. At the moment the two systems are linked together via a total capacity of 270MVA comprising two 132kV and one 66kV circuits.

Sales of electricity to GGPC for the previous seven years have been in general increasing. They have been, to some extent, affected by the availability by hydro-electric power in Guangdong.

The difficulties associated with the tie-line power control were due to the shortage of installed capacity to meet consumer demand and the lack of modern control equipment in the GGPC system. The situation is expected to improve in the next few years.

In order to maintain a satisfactory operating system, under normal and contingency conditions, comprehensive system decoupling schemes are adopted to guard against power swing and under-frequency situation.

Low frequency system osciallations between the CLP and GGPC systems were experienced. After in-depth analysis, Power System Stabilizers have been installed on all Castle Peak generators.

To futher improve the reliability of communication between CLP and GGPC, a microwave link was installed between CLP and Shenzhen.

With the proposed introduction of the nuclear power station, the interconnection between the two systems will be strengthened by three 400kV circuits each rated at 1800MVA.

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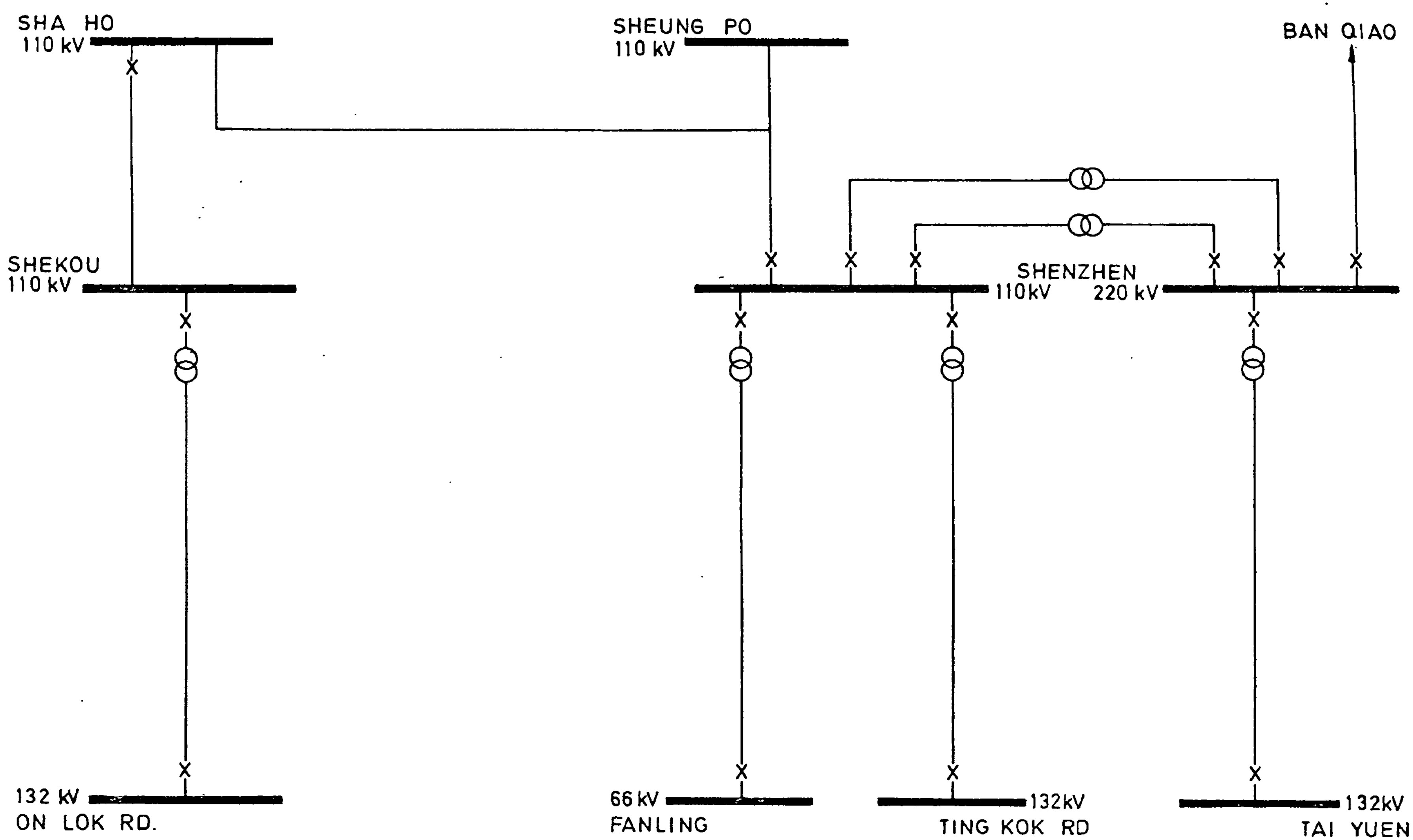

FIG. 1 SCHEMATIC OF CLP – GGPC INTERCONNECTION NETWORK IN 1986

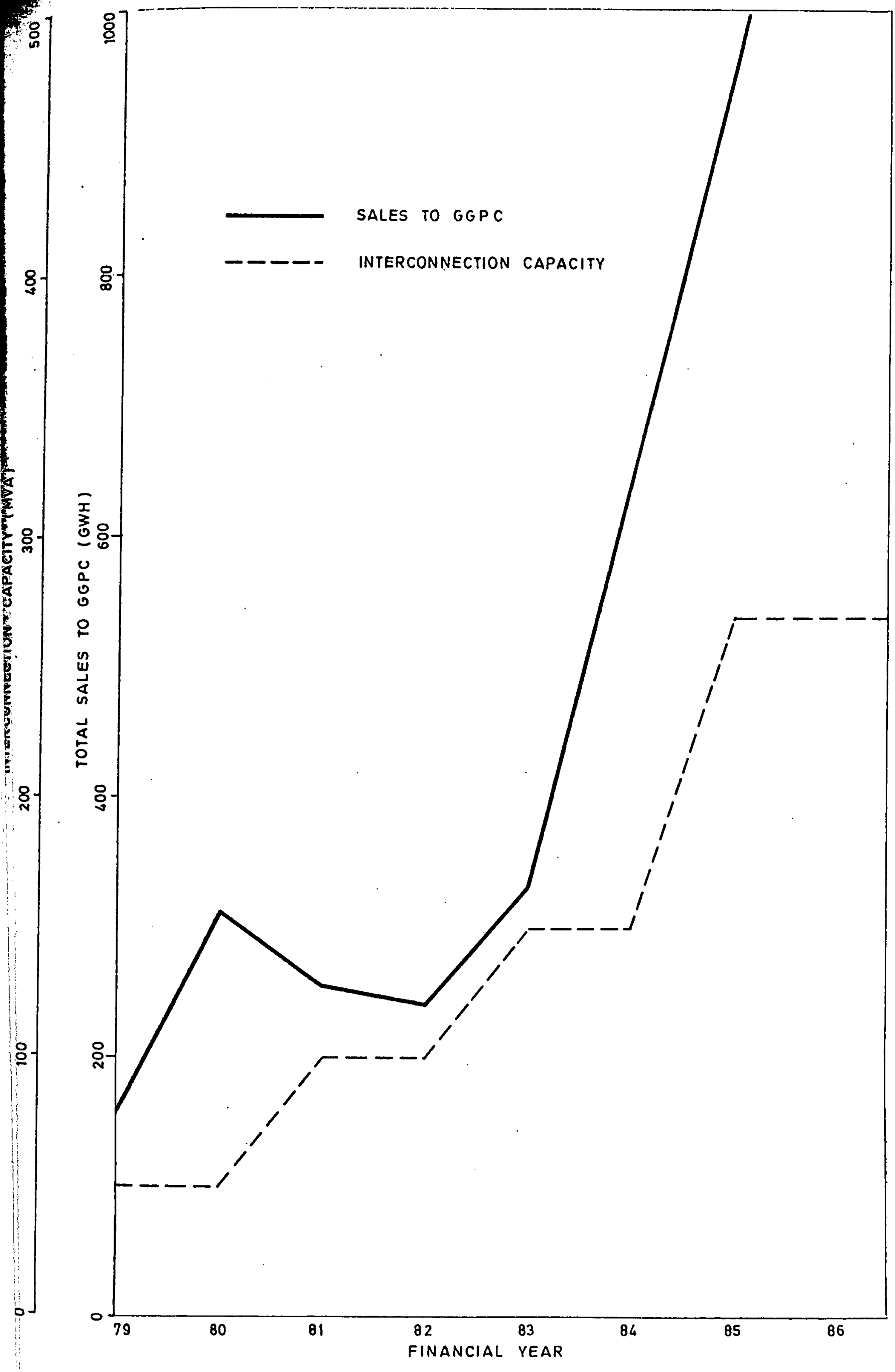

FIG. 2 INCREASE IN INTERCONNECTION CAPACITY WITH GGPC AND TOTAL SALES (76 - 85)

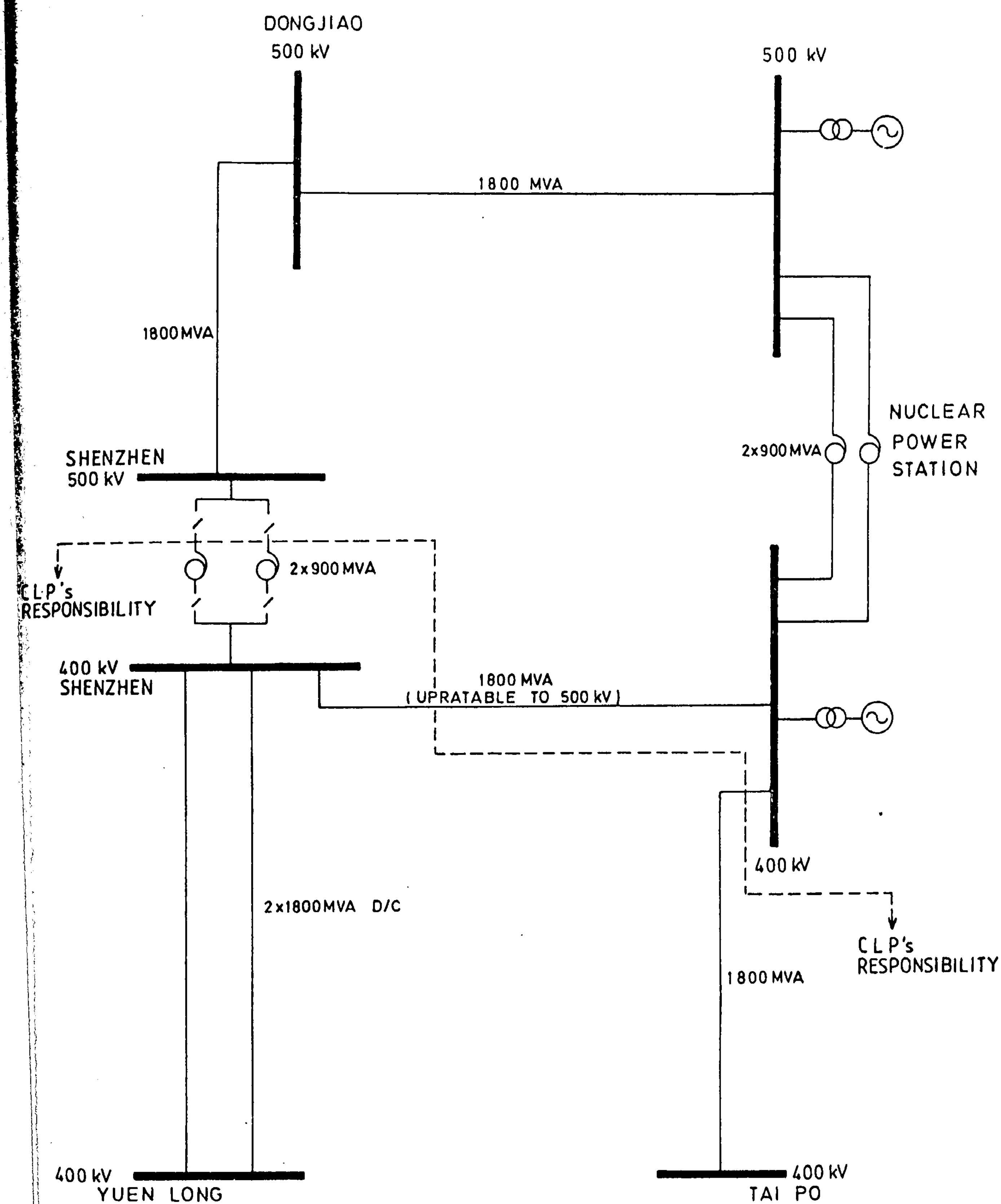

FIG. 3 SCHEMATIC LAYOUT OF THE AGREED NUCLEAR TRANSMISSION NETWORK

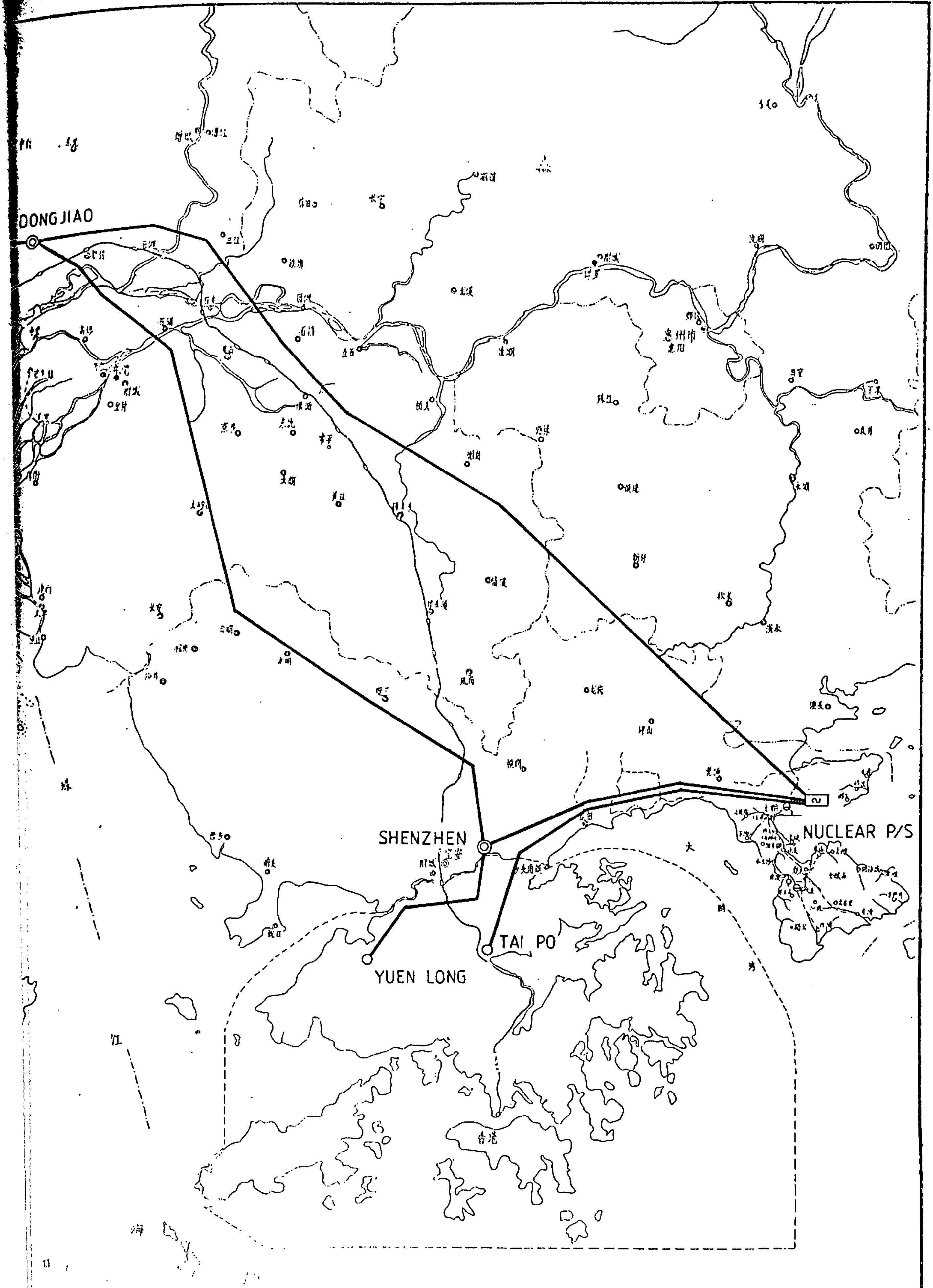

FIG. 4 GEOGRAPHICAL LAYOUT OF THE AGREED NUCLEAR TRANSMISSION NETWORK

— Notes & Questions —

2. Power Equipment

Paper No. 4

The Construction and Commissioning of the generating plant at Castle Peak 'B' Power Station

Speakers: Mr. J.M. Person, BSc, CEng, PEng(Ontario), MIMechE, MHKIE, Project Manager, CLP.
Mr. N.R. Salmon BSc, CEng, MIMechE, Project Engineer, CLP.
Mr. R. Henderson, Manager, GEC.

THE CONSTRUCTION AND COMMISSIONING OF THE GENERATING PLANT AT CASTLE PEAK 'B' POWER STATION

Abstract

A description of the generating plant at the 4 x 677.5MW Castle Peak 'B', coal-fired, power station is given. Two units are now in operation and the final unit is scheduled for completion by 1990. The contract strategy adopted is explained, highlighting the responsibilities for project management, project engineering, erection and commissioning retained in-house by CLP and GEC's contract responsibilities for the design and supply of the total generating plant plus the provision of specialist engineering services to assist CLP in the on site activities. The strategies adopted to tackle the construction and commissioning are reviewed and the methods by which CLP and GEC worked together to ensure the successful execution of the project are described.

Introduction

The Castle Peak 'B' power station, when completed in 1990, will comprise 4 X 677.5MW coal-fired generating units. The projected total capital cost of the station is approximately HK$13.5 billion. The apportionment of this total figure by main cost centres is as follows:–

		%
(i)	Civil works (including land)	21
(ii)	Plant F.O.B. supply	44
(iii)	Plant Freight and Insurance	3
(iv)	Erection and Commissioning	9
(v)	Project Management	6
(vi)	Financing; including interest during construction and exchange rate variation provisions	17
		100%

The power station is owned by the Castle Peak Power Company Limited (CAPCO), in which Exxon have a 60% holding and China Light and Power (CLP) 40%. CLP is responsible for the management of the joint assets, through both the construction and operational phases.

GEC Turbine Generators Limited were awarded the contract for the design and supply of the total power station plant. Babcock Power Limited are the principle sub-contractor to GEC for the supply of the boilers and associated plant.

The 'B' station is located on the same site as the 4 x 350MW Castle Peak 'A' station at Tap Shek Kok on the western edge of the New Territories area of Hong Kong, adjacent to the mouth of the Pearl River estuary.

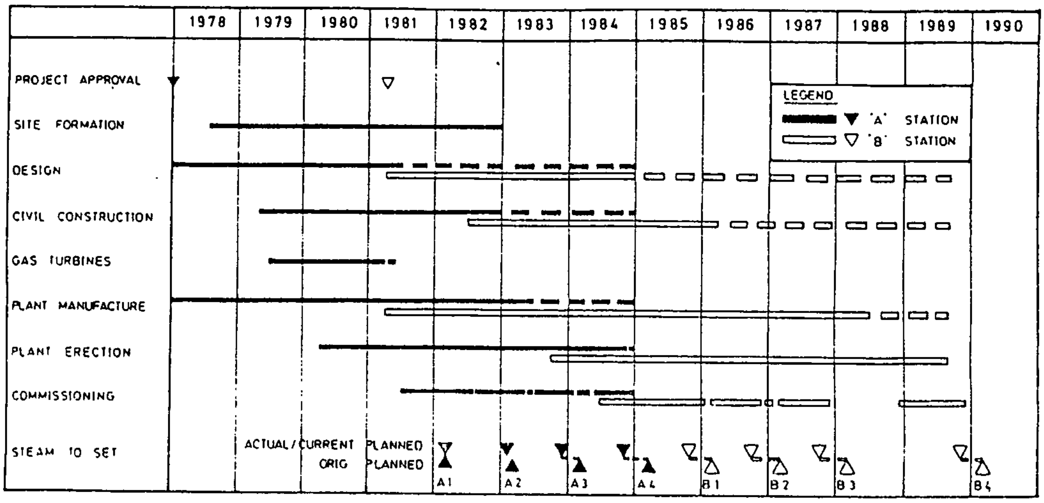

Figure 1 : Programme for Castle Peak 'A' & 'B' Power Stations

Figure 1 shows in simplified form the programme of the major activities for both 'A' and 'B' station projects. It can be seen that the four 'A' station units entered commercial service between 1982 and 1985. The first 'B' station unit was commissioned in late 1985 and the second unit is now operational, undergoing commissioning trials before it enters commercial service in January 1987.

The remaining two units are scheduled to enter commercial service in 1988 and 1990. On completion the combined generating capability of the 'A' and 'B' stations will exceed 4,000MW, making this one of the largest power generating facilities in the world.

The power stations feed into the CLP transmission system, which covers the Kowloon Peninsula and New Territories areas of Hong Kong and which is interconnected with the adjacent Guangdong Power Company (GPC) and Hong Kong Electric (HEC) systems. The initial plans for the power stations were drawn up in 1976/77 in order to meet the forecast growth in the demand for electricity through the 1980's. These forecasts have proved correct, growth in demand having averaged some 10% p.a. Another key decision made at the planning stage was the adoption of coal as the primary fuel. At that time all generation in Hong Kong was oil based. The subsequent movement in coal and oil prices has resulted in the coal based generation from Castle Peak costing, on average to-date, less than half the price of oil based generation. Thus in addition to the requirements to commission the units on schedule to meet demand growth, there have been strong incentives to advance the programmes in order to provide coal based generation to replace existing oil based capacity. The use of coal, however, introduces technical difficulties which had to be addressed regarding environmental pollution and coal storage and handling in Hong Kong's extreme climatic conditions. The stations will consume over 8 million tonnes of coal per year, with up to 1 million tonnes being stored on site at any one time. Approximately 1 million tonnes of ash per year will be produced which has to be acceptably disposed. (Reference 1).

In view of the scale of the investment, its technical complexity and the demanding schedule, CLP's project management team and the contractors have faced a challenging task in ensuring that the cost, operating performance and programme objectives are met. This paper reviews some of the strategies adopted to meet these challenges on the 'B' station project, detailing certain of the improvements made in the light of experience from the 'A' station project. Particular coverage is given to the plant erection and commissioning. The plant erection involves the assembly of, literally, tens of millions of components on a site 9,000 miles remote from the place of manufacture. The labour force employed, which peaked at 2,000 men, is essentially Cantonese speaking whereas all relevant instructions and drawings are in English. Diverse erection skills have had to be developed, ranging from high pressure welding to computer control systems installation. In addition a permanent engineering staff team has to be established and trained to be able to undertake the long term operation and maintenance of the plant.

Principle Features of the Power Plant

Operational Requirements

To match the requirements of the power system, the Castle Peak generating plant has to be capable of operation in a wide variety of modes – base load, continuous load-following down to approx. 30% output, with fast reserve pick up capabilities and daily two shifting (overnight shut-down) – and to be capable of rapid reloading following system load rejections. A paper was presented at the recent CEPSI conference covering the operational requirements and the corresponding plant engineering in some detail. (Reference 2).

Plant Selection Philosophy

In specifying and selecting plnat, CLP's objective was to procure equipment with a proven record to ensure high levels of reliability and availability, and which was capable of flexible operation to meet the system needs. High generating efficiency over a broad operating range was also desired, given the extensive part load operation envisaged. An additional requirement was to minimise operational manning levels by providing adequate levels of reliable automatic control to facilitate the flexible operating regime envisaged. Given the rapid rate of development in control technology it was difficult to rigidly enforce the proven plant concept in this area as this would have lead to the selection of out of date and interior equipment. Discrete changes to incorporate state-of-the art control equipment were accepted for 'B' station, but only after careful and cautious evaluation.

For example, the turbine automatic run up and loading system is based on microprocessor control, where previous systems have been hardwired electronics. However the hardware involved (DEC PDP 11/23 computer) is well proven and the control concepts were not new, the novel feature being the specific programming software. Particular emphasis was placed on works testing of such prototype equipment to validated its integrity. (Reference 3).

Plant Description

Turbine Generator

The turbine is a 4 cylinder (high pressure (HP), intermediate pressure (IP) and 2 X low pressure (LP)), single reheat, 3000 r.p.m. tandem machine. Design MCR HP steam inlet conditions are 16.3 MPa, 538°C and the IP inlet conditions are 4.1MPa, 538°C.

There are 4 H.P. and 4 I.P. stop and governor valve groups operated by an electro-hydraulic governing system. To maximise part load efficiency and to improve operational flexibility, given throttle valve governing, the boiler and turbine plant is designed for variable pressure operation.

High operational flexibility/reliability and two-shift operation with very rapid run-up and loading is achieved utilising a turbine design with:–

- Disc and diaphragm construction which allows reduced rotor gland diameters.
- Short span rotors with two bearings for each rotor giving HP and IP rotors with critical speeds above their operating range.
- Full double casing construction to minimise temperature gradients across the casting walls.
- Absence of partial arc admission which increases temperature changes and thermal stresses in the high pressure rotor.
- Highly symmetrical high temperature casings with well proportioned flanges to minimise thermal distortion.
- High procure steam chest of simple, thermally favourable geometry.

The generator is a 2 pole 50Hz unit with an MCR rating of 677.5MW, 797MVA, terminal voltage 23.5kV and direct cooling with water and hydrogen circuits.

The design is from a range 200 – 750MW which includes standard features:–

- Robust stator and winding support structure provided to cope with any system faults and normal service forces.
- Hydrogen cooling system with fans at each end of the rotor plus four coolers, allowing symmetrical cooling flows and temperature rises.

- Single piece end brackets providing simple construction and fewer joint interfaces.
- Exciter and pilot exciter on common bedplate for delivery as module.
- Rotor windings of silver bearing copper which avoids copper shortening problems.
- Stator water cooling circuits feed and return located at one end leaving the terminals and phase rings at the other for easier access.

There is a basic concept utilised by GEC for the CP'B' turbine generators – Engineering Standardisation, which has proved to be highly successful and is consistent with CLP's proven plant selection philosophy:–

a) The use of a standard design to give high reliability and proven performance by designing standard cylinders which are used in large numbers over a wide range of turbine outputs and applications.

b) High reliability for the design is developed because the designer is allowed to concentrate his research and development into a small number of designs and bring continuous improvements to a soundly based design.

c) In parallel with standardisation a module concept for major components has been developed allowing, if there are no shipping restrictions, major components to be transported to site in complete form.

d) Experience allows construction/commissioning to proceed with proven procedures which themselves become standardised as a result of this and similar projects throughout the world.

Boiler Feed Pumps

A 3 x 50% electrically driven boiler feed pump arrangement was selected on grounds of cost, unit availability and operational simplicity and flexibility. Each pumpset comprises a single drive motor, constant speed booster pump and a four stage pressure pump driven via a variable speed fluid coupling (full load running speed approx. 6000 r.p.m.).

Steam Generating Plant

The boilers are of a natural circulation, two pass radiant design. They are capable of full load operation burning coal and up to 500MW buring oil. The high oil-firing capability was provided as a contingency facility, to cover disruptions in coal supplies due to external factors or local factors such as extreme typhoon weather conditions. Normally the station burns coal, using oil only for light up and low load flame stabilisation. Total changeover from coal to oil can be achieved within a few minutes. Coal is purchased from a wide variety of sources, the specification being as follows:–

	Typical as received	Acceptable range
Total moisture	9.5%	7 to 20%
Volatile matter	27%	22 to 40% dmmg.
Ash	12.3%	Up to 20%
Sulphur	0.58%	0.3% to 1.5%
Calorific value (J/g)	26,200	25,000 to 27,000
Ash initial deformation		1,150 min.
Hardgrove index		44 min.

Firing is via 42 circular dual coal/oil burners grouped in seven rows in an opposed firing layout (4 front wall and 3 rear wall rows). There are seven coal pulverising ball mills (one per burner row), six of which are required for full load with one standby mill.

A good balance of radiant and convective heat transfer is achieved by use of an appropriately sized platen superheater above the furnace. This results in a 'flat' steam temperature characteristic over a broad load range. Full superheat and reheat temperatures can be maintained down to 50% load when burning either coal or oil by use of the gas recirculation and superheater spray systems.

Electrostatic precipitators are used to reduce the dust outlet burden below the statutory limit of 115 mg/Nm^3.

Turbine Bypasses

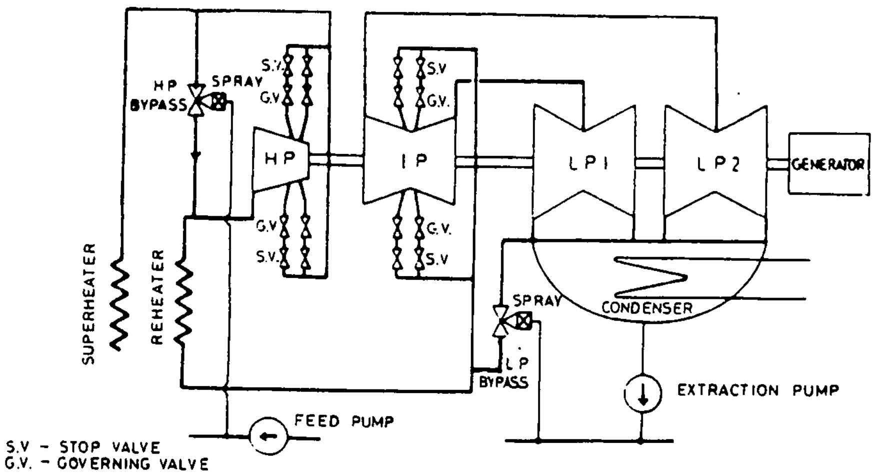

Figure 2 Simplified schematic arrangement of HP and LP bypasses

The HP bypass system allows steam to pass from the superheater outlet to the reheater inlet (Figure 2). In practice there are four, parallel, HP bypass lines each of which incorporates a modulating throttle valve with integral spray attemperation, through which superheater outlet steam is reduced to reheater inlet temperature and pressure conditions. The LP bypass system allows steam to pass from the reheater outlet direct to the condenser via two parallel paths, each again incorporating a throttling and spray attemperation arrangement.

Operationally the bypass is used to accommodate mismatches between the rate of boiler steam generation and turbine steam consumption, thereby preventing unacceptable excursions in boiler pressure. Such mismatch conditions can arise as follows:–

a) Load Rejection

When the power station becomes isolated from the system due to, say, a transmission fault. The turbine output must drop instantaneously to house load (approx. 6%) while the boiler response rate is much slower.

b) Unit Start Up

The bypass can be used to allow boiler firing to be increased in anticipation of the turbine steam demand while ensuring correct matching of steam pressure and temperature conditions. This facilitates fast start-up and loading.

c) Pressure shadowing

The bypass can 'shadow' the normal boiler pressure controls such that in the event of a control upset, due to fault conditions, the bypass will intervene to regulate pressure.

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Control and Instrumentation

The operator controls for all four 677.5MW units are located in a common central control room. For each unit there is an identical unit control panel, designed for single man operation – except during start-up when two operators are required.

The automatic control systems provided to assist the operator and ensure safe and efficient operation of the unit include:

a) Boiler Modulating and Sequence Controls

Microprocessor based distributed digital control system (DDC).

b) Turbine Governor

Modular electronic system providing all control and safety function of turbine primarily through actuation of the turbine steam control valves.

c) Turbine Automatic Run-up and Loading Control

Microprocessor based system which controls rate of steam admission to maintain thermal stressing of the plant within acceptable limits and which monitors vibrations, eccentricities and expansions to ensure the plant is not operated outside its design limits.

d) Turbovisory System

Measures the critical parameters of the turbine generator relating to its dynamic behaviour and supplies data to the operator and the turbine auto control system to enable the machine to be operated safely and efficiently.

e) Automatic Voltage Regulator (AVR)

The brushless excitation control system provides and automatically controls the DC field supply to an exciter generator and thereby regulates the output of the main generator.

f) Burner Management System

Provides sequence control of the lighting up and shutting down of the burners and continuously monitors the flames to ensure healthy combustion, automatically tripping burners if unhealthy.

In addition a computer based Data Acquisition System automatically monitors approximately 2,000 digital and analogue inputs for each unit, displaying information on 3 VDU's located in the United Control Desk via some 100 operator selectable graphical and tabular forecasts. Routine plant status logs are available via printouts, as are post incident and sequence of events logs which are automatically triggered in the event of a plant fault to record the prevailing conditions, thereby assisting in subsequent fault analysis.

The Project Management Strategy

There are diverse approaches adopted by different utilities to the assignment to contractors of the various project responsibilities. These vary from the 'turnkey' approach, with a sinle contractor responsible for the total project, – to the other extreme of the multi contract approach, involving up to perhaps 500 separate contracts.

All power plant construction projects involve significant uncertainties and risks. Security of both project costs and programme is enhanced by maximising the control of risks. For the Castle Peak projects, this has been accomplished by, in the first place, CLP itself taking a direct, very active involvement in Project Management, with as much work as sensibly possible done in-house.

For responsibilities intended for contracting out to other parties, the strategy adopted has been to minimise the number of contracts. The scope of each contract package has been devised to exclude any major risk areas which would be difficult for a single contractor to assess, and which would thus result in higher prices to reflect greater contingencies built into contract prices. As a result, the Castle Peak projects each have of the order of 10 or thereabouts major contracts of relatively large scope. A detailed explanation of CLP's projects strategy is given in reference (4).

A generally similar contract strategy has been adopted for both 'A' and 'B' projects, although following 'A' Station experience, CLP has taken on some additional direct responsibilities to improve control of construction costs.

Responsibilities Contracted to Third Parties

Contractual relationships and responsibilities for Castle Peak 'B' Power Station are illustrated on Figure 3.

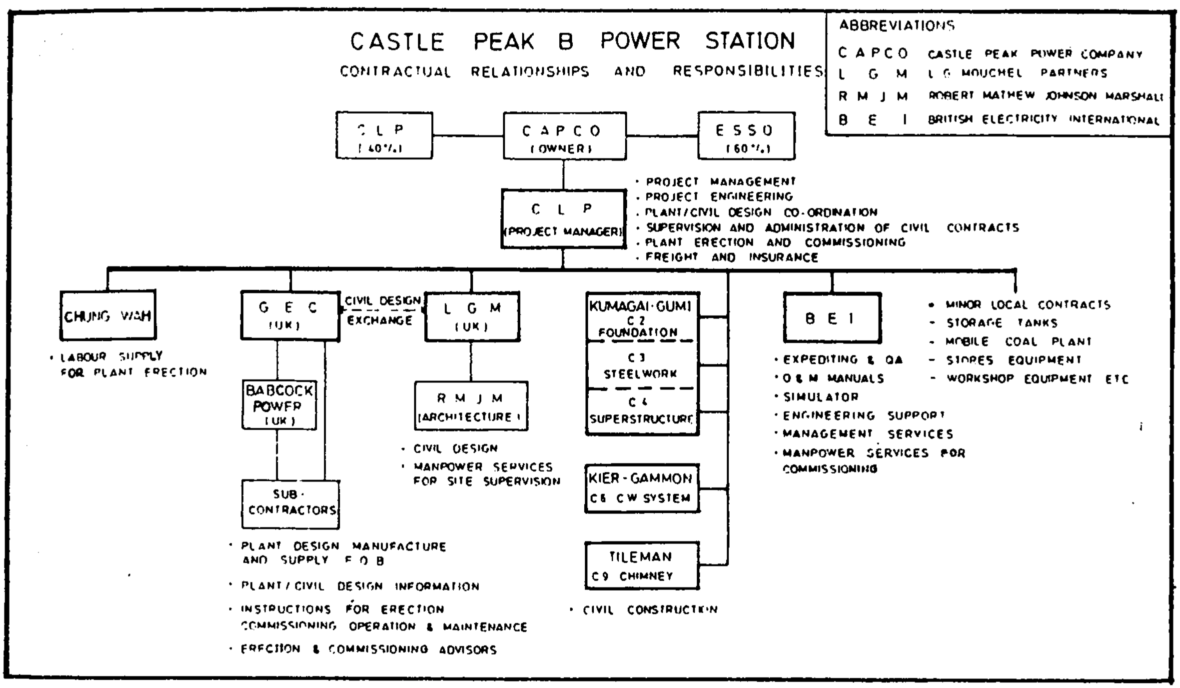


Figure 3 : Castle Peak 'B' Power Station - Assignment of Responsibilities

All plant is supplied FOB by GEC Turbine Generators Company, who are also responsible for the detailed plant design and procurement and for the provision of specialist advisory engineers to assist CLP in erection and commissioning.

Detailed civil design responsibility has been contracted to a civil consultant, L.G. Mouchel & Partners.

Most of the workforce for erection is provided by Chung Wah Shipbuilding & Engineering Company under a labour call-off type of contract; however the supervision of all the workforce is directly by CLP engineers.

British Electricity International have contracted to provide support services from the resources of the Electricity Generating Board in the U.K. These services include:– works expediting and quality control; compilation of GEC's operating and maintenance manuals; the operator-training simulator; and specialist engineering and commissioning assistance, as required.

Responsibilities retained 'in-house' by CLP

CLP has the responsibility for the overall Project Management of engineering and construction of both the Castle Peak 'A' and 'B' Power Stations. The CLP Project Management team has additionally retained the direct responsibility for project engineering, the coordination of plant and civil design, the supervision and administration of the unit priced civil construction contracts, the erection of all plant, and the commissioning and setting to work of the plant.

An underlying factor in deciding the strategy to be followed for project execution is the belief that CLP should take as much direct responsibility as possible for the expenditure; and this leads to heavy inhouse involvement in the project execution.

In the 1520MW Tsing Yi power station project completed in the 1970's, CLP undertook civil design and the construction via an inhouse company. Plant erection and commissioning was also carried out by CLP. This inhouse involvement proved successful in controlling costs and ensuring completion to programme. On completion of the projects, the erection staff were redeployed into maintenance, strengthening that aspect of the organisation and, at the same time, reducing the need for contractors during annual overhaul.

However, in the civil construction area, there was no continuity of work and the workforce had to be laid off. CLP did not take a very active role in plant engineering, the plant specification being in broad terms only. This resulted in certain aspects of the plant not meeting CLP's (unspecified) operational needs and a limited understanding of the equipment. Both these factors were contributory to the somewhat disappointing early performance of Tsing Yi. The conclusion drawn from the Tsing Yi experience was that inhouse involvement produces success, but the areas of involvement must be considered carefully.

Subsequently experience has reinforced the view that the inhouse policy is correct. CLP now undertakes the majority of its own project engineering work (design and specification etc.), project management, plant erection and commissioning. This results in the plant being accurately specified to meet operational requirements and the appreciation of the plant gained through the design, erection and commissioning phases being retained in the company, producing long-term operation and maintenance benefits. It leads to more direct control of costs and programme. Further, cost savings can result by the client accepting responsibility for risk areas which he is more competent to control than the contractor.

Management of erection and commissioning

The risks to be addressed

The skill with which all erection and commissioning activities are performed directly impacts on the technical quality of the finished plant and its operational performance over the lifetime of the plant. Well engineered and designed plant will not perform as intended if it is not well constructed and commissioned. The other two key project objectives of programme and capital cost, are also highly dependent on the effective execution of the erection and commissioning phases of the project.

Plant erection involves the site fabrication and assembly of literally millions of separately delivered component parts. For 'B' Station a total of some 80,000,000 individual parts, comprising 400,000 separately identified items, will be assembled during erection on site, generally to a predetermined sequence over a protracted period.

The efficient execution of erection work to the desired high quality standards requires a wide range and depth of engineering, supervisor and tradesman skills and experience covering mechanical, electrical and control/instrumentation disciplines. The mechanical work is diverse involving extensive rigging; high pressure and low pressure pipework welding; plant welding; and assembly and alignment of very large, precision machinery.

Pre-start commissioning is a protracted exercise performed over many months to progressively check out, start up and set in operation the plant and controls of the large number of supporting systems leading hierarchically to the start up of the complete unit. Commissioning of plant therefore requires a blend of experience and knowledge of both the engineering and operation of power plant covering the whole range of mechanical, electrical and control plant. The sophistication of some of the mechanical plant requires specialised commissioning knowledge and highly specialised hardware and software expertise is also required when commissioning plant incorporating extensive digital and analogue control equipment.

The overall programme for construction for Castle Peak has been short. The compression of the overall programme duration exacerbates the difficulties caused by the general lack of space, since contractors are obliged to work in close proximity to each other. Float periods usually planned between the work of successive contractors in each area have had to be curtailed, leading to many potneital physical interfaces and interference between contractors which unless anticipated and closely controlled will lead to programme disruption and costly claims. A major consideration in CLP taking direct responsibility for plant erection arises in this respect. It is usually considered imperative to complete all civil construction before plant installation commences in the same area. However for Castle Peak, in order to maintain programme, erection activities must frequently commence before the civil works have been completed. No contractor responsible for erection would accept such interference without raising claims for extensions of time and costs with the added penalty of diverting project management attention from the more constructive tasks of forward planning to avoid potential problems.

The 62 hectare site area of the Castle Peak stations is very small for a predominatly coal-fired plant of 4350MW capacity. As a result, throughout the project, the site area available for construction has been very restricted. Initially this was because construction had to follow on immediately behind the progressive formation of the site. Then as operating units and fuel storage areas are progressively handled over to the Operations Department, construction works are continuously squeezed into smaller areas. This has placed additional importance on the orderly planning of material deliveries to the work face and of ground prefabrication work to avoid disrpution of other erection activities.

Communications are a special problem in two respects. First, the language of all drawings and instructions is English which very few of the 2000 erection workforce understand. The CLP bilingual supervising engineers therefore have to act as English/Chinese interpreters in addition to all the normal responsibilities of technical supervision. Second, all plant is designed and supplied from the U.K. Rapid resolution of design queries, plant problems, etc. is clearly much more difficult from 9,000 miles distance.

The non-availability on site when needed for erection of even a small proportion of minor parts can have a disproportionately disruptive effect on the progress of sequenced erection. The shortages may be due to unforeseen manufacturing problems, to oversight by the supplier during procurement, to incorrect sequencing of delivery, to loss in despatch of shipping, to damage in shipping, etc.. The problems are exacerbated when the construction site is remote from the point of supply, leading to long shipping delays to rectify material shortages.

Experience with the first Castle Peak 'A' Station unit highlighted that, when the overall programme is shortened, such that little float remains between planned delivery of materials to site and its erection, the traditional manual planning and hard copy communications systems become too cumbersome and are unable to adequately anticipate impending problems, resulting in an unacceptable level of disruption of erection due to late recognition of material shortages. Although the early 'A'

Station units were commissioned to programme, opportunities to save erection costs in future were recognised. An interactive, computer based, planning, materials management and labour resource management system was adopted, which is described in (4.2.3) below.

Erection Methods

Determination of the Extent of Site Fabrication

At the outset of a project, before design and manufacture commence, it is important to determine the extent to which components are to be fabricated and assembled in the factory before shipping to site. Factors influencing the optimum split between factory and site assembly are:–

- The proportion of the overall programme timescale available for plant installation on site.

- The local availability of skilled tradesmen and supervision for site fabrication and assembly.

- The relative costs of site versus factory construction.

- The logistical problems and relative costs of handling bulky and heavy components during shipping and delivery to site.

Referring to 1.1 above, it can be seen that for the Castle Peak project the cost of plant freight an insurance is approximately half the total plant erection cost. Containerised shipping offers considerable economies and thus the strategy adopted for the large majority of plant restricted material to container sized components for shipping and delivery to site resulting in a larger amount of site fabrication and assembly than on many international power plant projects. There was adequate time in the construction programme for the greater scope of site fabrication and it was established that the costs of additional site fabrication for this site were not greater than for factory assembly. A crucial factors was the availability in Hong Kong of a core of skilled tradesmen, chargehands and foremen with experience of power plant construction from the Tsing Yi project in conjunction with CLP's previous successful experience in training and developing the necessary level and range of skills from the Hong Kong workforce in sufficient numbers to satisfy the peak erection workforce of about 2000.

A small proportion of components were shipped in sizes or weight exceeding container limits where there were particular incentives to perform more shop fabrication or reduce site erection tasks. These include large pressure vessels such as boiler drum, feedwater heaters; bulky, machined fabrications such as condenser shell sections, airheater components, etc.. In addition precision machinery plant which required factory assembly to confirm the accuracy of manufacture as part of the required quality control standards, was, wherever practical, shipped as preassembled components thereby avoiding factory dismantling and reassembly on site. Therefore high pressure and intermediate pressure turbines were each shipped as factory assembled components on specially designed transport cradles. Turbine control valves were also shipped as factory assembled components.

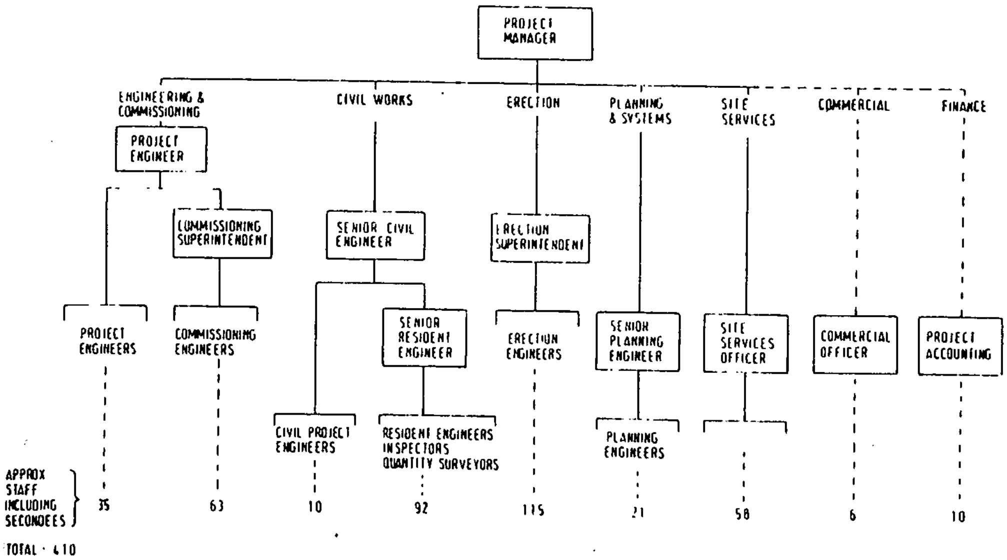
Within the constraints of container limits, plants specifications required the maximum possible extent of factory assembly of components and shop, testing to minimse site erection work and to ensure as many plant deficiencies as possible where found during works testing and corrected before shipping. For example, many turbine generator and boiler auxiliary system – such as various lubricating oil systems, power oil system, various auxiliary cooling systems, burner supply system – were each factory assembled on a common bedplate and pretested in the factory so that they merely required positioning at site ready for external pipework and cabling connections. Instruments, transmitter and control equipments were grouped and factory cabled into panels or racks local to the various equipments.

Organisation

Since September 1982, a single CLP project management term has been responsible for the engineering and construction of both 'A' and 'B' Castle Peak Power Stations.

CASTLE PEAK A & B POWER STATION

PROJECT MANAGEMENT ORGANISATION



The project management organisation structure since early 1984, when the complete team became based in offices on the Castle Peak site, which was effective during the peak period of erection/commissioning for unit B1 is illustrated in Figure 4.

From mid 1984 until late 1985, in order to conclude the last unit of 'A' Station, complete unit B1 and commence unit B2, it was necessary to progressively increase the erection workforce to a peak of almost 2,000 man which was supervised by a CLP team of 105 Hong Kong Chinese erection engineers and technicians responsible to the Erection Superintendent for technical, programme and cost objectives for their defined scope of the work.

As the workforce has reduced (see Figure 6 below), corresponding adjustements have been made to the number of erection supervisors but the organisational structure has been retained. Engineers released from erection duties during 1986 have been redeployed to maintenance duties in the Operations Department thereby retained the knowledge acquired during erection of the plant. With B2 completed, and the workforce reduced to about 1250, the size of the supervision team has reduced to 80 with further reductions planned during 1986 and 1987 to provide opportunities for the staff concerned to move to commissioning work to broaden their experience.

The specialist GEC and BPL erection and commissioning advisors are integrated into the CLP organisation in 'in-line' functions, reporting to CLP staff. For the first 'B' station unit, 22 erection advisors were provided plus 18 commissioning engineers. Approximately half of these engineers were on site continuously through the build and commissioning, covering plant such as turbine generator, boiler feed pumps, boiler pressure parts welding and NDT, precipitators, 400kV SF_6 switchgear, coal plant, boiler controls, turbine supervisory and protection systems. The other advisors were on shorter term assignment to cover particular erection or commissioning activities of specialist items such as burner management, governor, sootblower compressors etc. These advisors fulfil essentially three functions. Firstly, they provide assistance to the CLP team based on their detailed experience and knowledge of the plant concerned. Secondly, they witness and check that the plant has been correctly assembled and commissioned to safeguard the post commissioning contract warranties. Lastly, they act as a rapid communication link back to the UK organisations to explain and resolve problems which arise on site.

As CLP's in-house expertise has matured, the requirements for advisors from GEC have diminished. For example on the third and fourth 'B' station units only 2 full time erection advisors will be on site, one for boiler and one for turbine, primarily to fulfil the second function described above.

In addition to the advisory engineers integrated into the CLP team, GEC maintain their own independent site project management team, including Babcock Power representatives, whose prime function is to ensure that close liaison with the client is maintained to facilitate the communication and resolution of technical, commercial or material delivery problems as they arise.

Enhancements to erection management control system for detailed planning, materials management and labour resource management

There is always scope for improving performance by better management of resources. The opportunity for a single team to erect and commission 8 large generating units in sequence over a 10 year period has provided a unique opportunity to identify problem areas were there is scope for improvements and have sufficient time to develop solutions, overcoming the natural resistance to change and to obtain the benefits from the changes.

Resolution of the shortcomings of some of the previous systems required facilities able to quickly store, process and disseminate very substantial quantities of information for subsequent easy retrieval. Such requirements were by then well within the capabilities of available computer systems. Therefore, during the latter stages of 'A' Station construction and for the 'B' Station, CLP has progressively introduce computer-based systems for planning and control of erection and commissioning activities. In addition, CLP has, with the cooperation of GEC and BPL, developed computer-based integrated material management systems.

There are three major elements comprising the CLP erection management systems:—

(a) Time Management

- Its allocation between the 3,700 sequential/interfacing erection and commissioning activities for each unit.
- Monitoring of progress to programme.
- Execution of adjustments to programme to overcome problems.

(b) Materials Management

- To establish availability of materials when needed for erection.
- Managing their timely retrieval from store to the work place. (Note: 80,000,000 uniquely identified site assembled parts on 'B' Station.)

(c) Erection Cost Management

- Allocation of workmen's time to detailed work activities.
- Monitoring of manhours used at the detailed work package level.
- Continuous measurement of productivity achieved.

The foregoing three elements of the management systems are normally considered separately, but they are in fact closely interrlated and share much common information for data processing (Fig. 5). They are computer-managed systems designed to quickly extract, from a massive and continuously updated data base, reports, work plans and questionnaires to meet the specific needs of all the projects team, including field supervisors, section engineers and senior managers, at different levels of detail and in different formats.

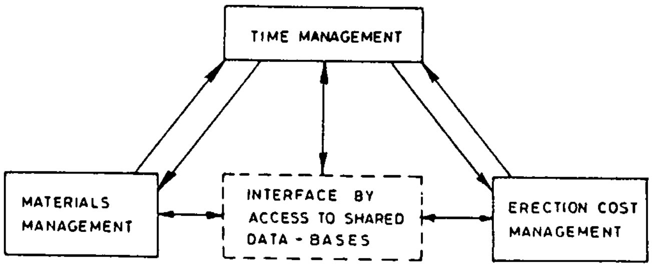


Figure 5 : Erection Management Control System

As an example of the interrelated nature, time management is a schedule of plant erection activities – but these cannot start until the associated materials are available on site. Therefore, material delivery information has a significant effect on erection time schedules. The GEC despatch/shipping system is now computerised and all GEC data listing parts, together with progressively added shipping details, is provided to CLP electronically by weekly computer tape transfer for immediate updating of the CLP materials information data base. Similarly, the optimum erection workforce manning levels are dependent on the planned schedule of work and also on the expected productivity levels, – which are measured by reference to actual progress achieved and manhours expended.

The enhancements achieved by introduction of computer based erection management systems are described in detail in a paper presented at the recent CEPSI conference (Reference 5).

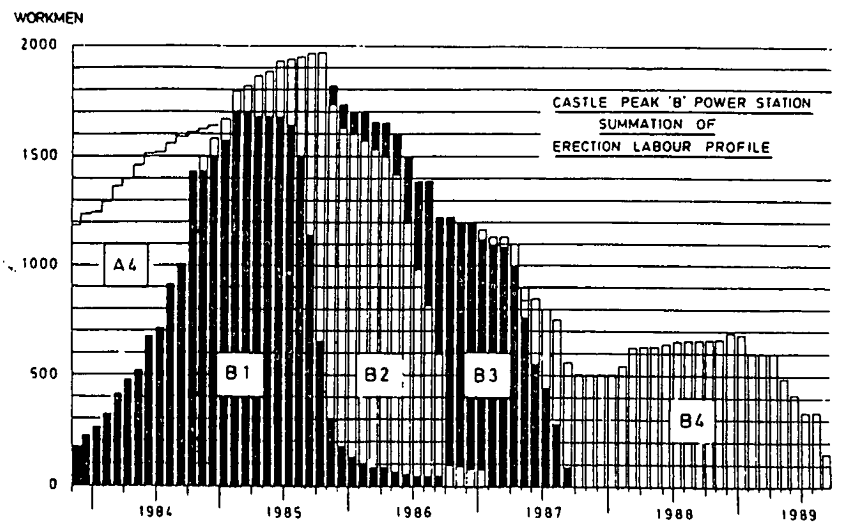


Figure 6 : Total Erection Labour Profile

Figure 6 shows how the total erection labour level varies through the project. The reduction in labour levels for the later units arises from three factors:–

a) Non repetition of certain common station plant (e.g. coal handling, water treatment, etc.) on later units.

b) Reduced overlap between units (i.e. 10 months gap between B1 and B2, 12 months B2 to B3 and 24 months B3 to B4).

c) Improved labour productivity as a result of greater experience and as a result of the improved management of materials deliveries and labour resources via the system discribed above.

Erection labour productivity has improved dramatically to the extent that the manhours now projected to complete erection of the 'B' station, with its much larger units and about 40% more site erection work, will be similar to those required to complete the 'A' station. This improvement is further evidenced by the following comparison:

Unit	A1	A2	A3	A4	B1	B2	B3	B4
Comparative manhours for the same scope of work	100%	83%	65%	65%	71%	58%	49%*	49%*

* Now budgeted

Figure 7 : Comparative Erection Labour Productivity

Documentation and Communications

GEC's contract responsibilities include the preparation of erection and commissioning procedures and documentation. Where modular standardisation of the plant and auxiliary systems has been utilised, then erection and commissioning procedures are also based on standardised and proven techniques.

A variety of enhancements have been made to improve accessibility, accuracy and speed of communications and documentation essential to erection and commissioning progress.

Modern communications systems provide the opportunity for transfer of details of site problems back to the designers in the U.K. very rapidly making it possible to effect very rapid resolution of the multitude of minor problems arising during erection and commissioning. Achievement of a tight programme objective depends considerably on successfully solving problems as they arise during erection, commissioning and initial operation of the unit. If delays arise before designers put forward notification to resolve deficiencies, or supply of replacements for defective or damaged materials is slow, then the backlog of problems grows to unmanageable proportions and will destroy the momentum of the work by unduly diverting attention of supervisors from current and future erection tasks to expedite the backlog of old problems.

Experience on 'A' Station highlighted a need to improve communication of data amongst the erection team. Microfilming of every drawing the revision was implemented for 'B' Station with microfilm copy and microfilm enlarger/printing facilities located conveniently for users distributed in various site offices to permit easy reference to locate desired drawings with instant printing. (Note: Some 50,000 drawings are involved).

In addition the drawings register and other widely used schedules and registers of data, for example the status list of all site engineering/defect reports, are maintained on computer files with direct on line enquiry access available at 25 terminals strategically located around to construction site. This system is linked via the GEC site office terminal to the GEC UK computer. Updated information on progress in UK with the resupply of defective or damaged components, drawing updates etc. is thus continuously available on site.

Commissioning

For 'B' station, the Project Engineer is responsible for the engineering team and also for commissioning and initial operation of the plant. This reflects CLP's view that commissioning is the proving and conclusion of the engineering. This organisational strategy facilitates the rapid resolution of technical problem as they arise when the plant enters serivce.

For the first unit of 'B' station, the responsibilities for direction of the commissioning activities were substantiately delegated to a Commissioning Superintendent. (Fig. 4). For unit B2 the scale of project engineering problems reduced, and the post of Commissioning Superintendent was deleted and the Project Engineer was directly responsible for executing commissioning activities.

Further rationalisation of the commissioning team is planned for commissioning of units B3 and B4 to reduce the dependency on commissioning secondes from British Electricity International and better utilise the expertise acquired by CLP staff from the previous units.

Operations and Maintenance Training

Much of the equipment provided for the 'B' station was outside CLP's previous experience. Accordingly, considerable emphasis was placed on pre-operational training of the station staff. The operations engineers were recruited 18 months before the first unit entered service. An extensive exercise was undertaken in reviewing and digesting the operating instructions supplied by GEC, which total some 11,000 pages of manuals. 'Teach-in' sessions in Hong Kong for the operators given by the GEC and Babcock plant design engineers were organised. In the nine months before until B1 entered service all operators receive extensive training on the unit simulator. The simulator comprises an exact replica of a 'B' station unit control desk, linked to a computer which models the plant dynamics on a real time basis. Facilities are provided for the training supervisor to inject a wide spectrum of plant fault conditions into the model. The modelled behaviour has proved to be closely representative of the actual plant. However, a small team of software engineers is employed full time to update the model to further improve its accuracy. In addition to pre-operational training the simulator is used for refresher training of the shift staff, particularly in emergency procedures covering fault conditions rarely experienced on the actual plant.

The control equipment maintenace staff were sent on formal training courses at the relevant manufactures works in Europe. These courses were timed to coincide with the works testing of the equipment for the first unit which the CLP staff were thus able to witness.

Many operation and maintenance engineers were seconded into the commissioning organisation and were thus able to acquire detailed familiarity with the plant before the station entered service. Training courses were arranged on site conducted by the GEC supplied erection and commissioning specialists.

Operational experience would indicate that the training efforts were highly successful and well worthwhile. From the outset a high level of operator confidence and ability was evident. This was an important factor in enabling the required on load commissioning exercises to proceed rapidly following initial synchronising. Exercises such as full and partial load rejection tests, maximum ramp and step load changing and two-shifting trials are generally more complex, operationally, than the subsequent routine generation activities.

Conclusion

Classically, a successful project is one completed on time, to budget and providing the desired performance. These objectives have to-date been achieved at Castle Peak.

The current budget, given in 1.1 above, is infact significantly lower than the original estimates made at the start of the project. The savings have arisen, principally, from the advancement of the prgramme, reducing interest during construction up to the time the plant commences generating revenue, and from the low utilisation of the original contingency provisions due to the generally smooth execution of the project and the satisfactory performance of civil and plant contractors and the equipment itself.

The first unit was commissioned 4 months ahead of the contract programme established in 1981 and the subsequent units are currently 6 months ahead of schedule. This advance was made possible by the fact that three critical civil contracts:– foundations, steelwork and superstructure, were, following competitive tender, won by the same contractor, Kumagai Gumi. It was therefore possible to eliminate the programme floats which had been provided between contract activities and advance the whole civil programme. GEC were able to better their contractual delivery programme so that advantage could be taken of the earlier civil completion to advance the commencement of erection. The opportunities thus created have been consolidated by the flexibility available in erection progress due to the client being responsible for this activity and by the enhancements described above in material and labour management systems.

The basic indications of a power stations performance are generating efficiency and availability. The contractual tests on the first unit demonstrated achievement of a better sent out efficiency than the design figure of 37.8% (based on 35°C air inlet and 30°C cooling water temperature). Availability is a longer term measure of the integrity and reliability of the plant. Over the four and half years since the first 350MW 'A' station machine was commissioned, 'A' station has recorded an overall availability (including deduction for planned maintenance outages) of 92.3%, a high figure by world standards. Performance to-date of the 'B' station indicates that it will, at least, match this. A further indication of the integrity of the plant is the speed with which it has been possible to achieve full load generation during commissioning.

Unit		A1	A2	A3	A4	B1	B2
Days from first admission of steam to the turbine to achieving full load	(oil-firing)	13	8	9	–	–	–
	(coal-firing)	46	13	14	8	8	4

The strategies which have contributed to the achievement of objectives on this project include:

a) Selection of proven plant and standardised designs wherever possible and the most careful attention in areas where this principle was not followed.

b) Appropriate delineation of risks between the client and contractors and the establishment of close co-operation between the parties to ensure achievement of the joint objectives.

c) In-house responsibility for erection and commissioning, supported by assistance from the plant supply contractor, facilitating both the achievement of programme and cost objectives and the transfer of expertise to the client.

d) Attention to training of operations and maintenance personnel, which is complimented by (c) above.

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— Notes & Questions —

Paper No. 5
Variable Speed Drives

Speaker: Mr. K.H. Yung, Senior Engineer, Engineering Department, Project Division, BBC Brown Boveri Ltd.

VARIABLE SPEED DRIVES

Introduction

Nowadays variable-speed drives are used successfully for all transport and production operations. The deliberated variation of the torque. acceleration, speed and shaft position of the drives enables the often varied demands of modern, optimized production machine to be met. This includes, for instance.

- The flexible adaptation to changing work programs.
- Precise, reproducible maintenance of speeds or torque in spite of load fluctuations or other disturbance.

But variable-speed electric drives also comply optimally with the call for energy saving. They exhibit the following properties:

- High efficiency of motors and power electronics, even at partial load.
- Exact matching to the momentary demand for power by the driven machine.
- The ability to return energy to the supply system during braking.

For the wide variety of requirements specified for variable speed drives, we have now created modular solutions, which are nevertheless flexibly adaptable. They differ in the type of motor used (D.C. or three-phase A.C.) and the type of static converter circuitry. Every variant has a definite capability as regards:--

- Maximum possible speed and power
- Maximum range of speed variation
- Uniformity of the torque
- Response of the control system

An overall view of some drive systems will be given, and every system is backed by a fully developed range of motors and converters. By adding further drive control functions specific to the application, a single or multi-motor drive is obtained that exactly meets with the requirements of the process involved and is matched to the rest of your installation.

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Review

D.C. Drives

The using of D.C. motors as variable speed drives has quite a long history (see Fig. 1, the WARD-LEONARD Connection).

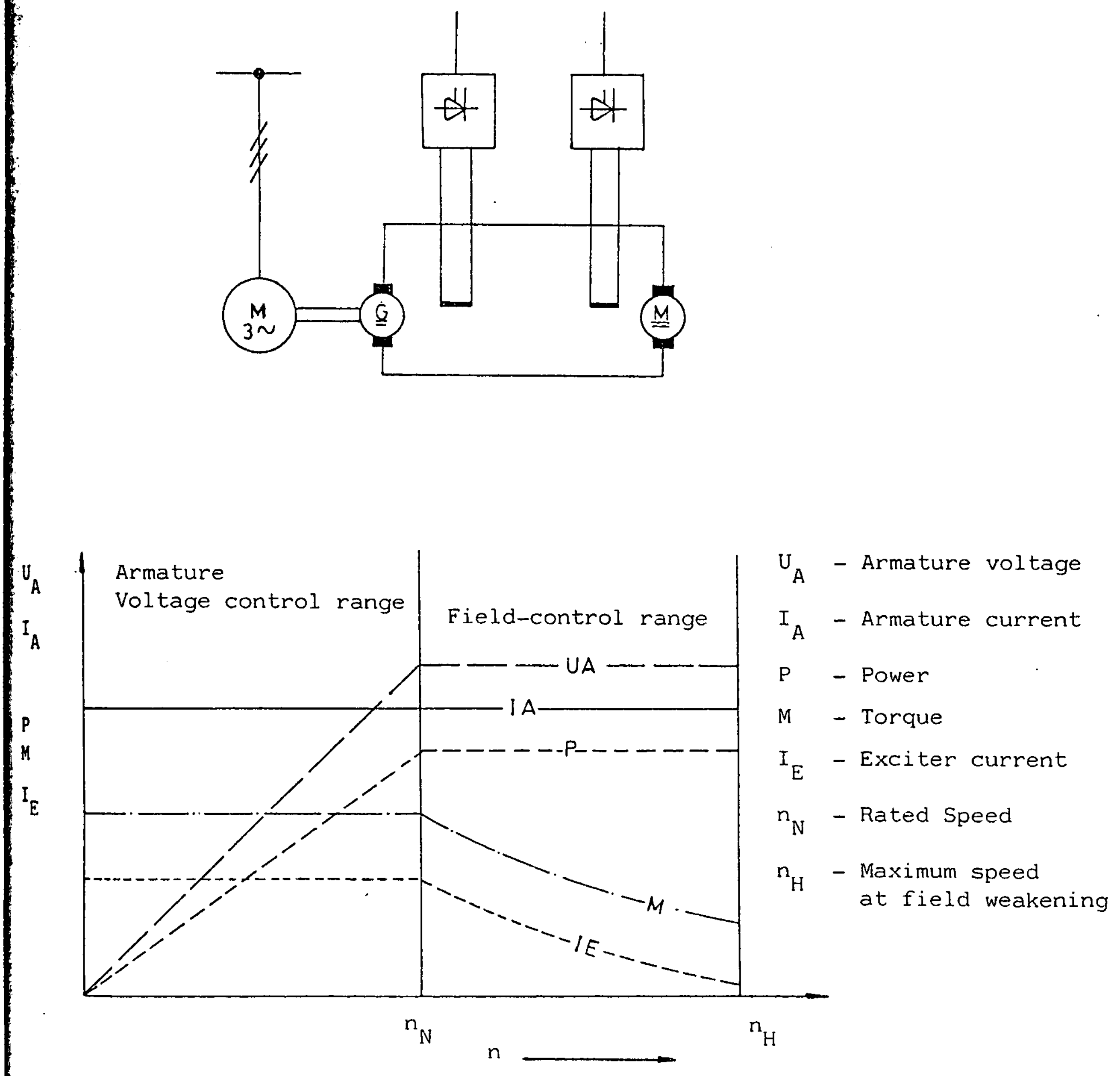

Fig. 1. THE WARD-LEONARD CONNECTION

But due to the progress made in component technology, advance in electronic sector, higher production requirements and system efficiency the Ward-Leonard system is no longer used nowadays, except in some very special occassions.

The using of static converters for speed control of D.C. motors are as shown in Fig. 2.

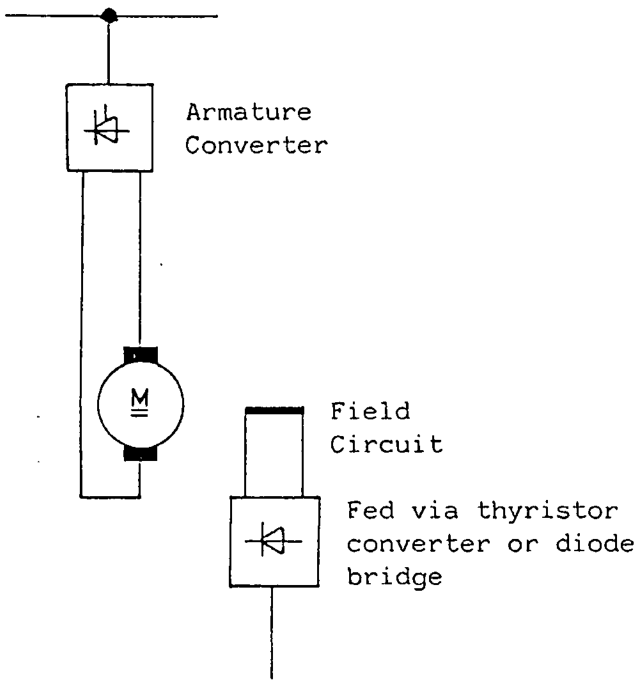

Fig 2.1 D.C. DRIVES WITHOUT TORQUE REVERSAL

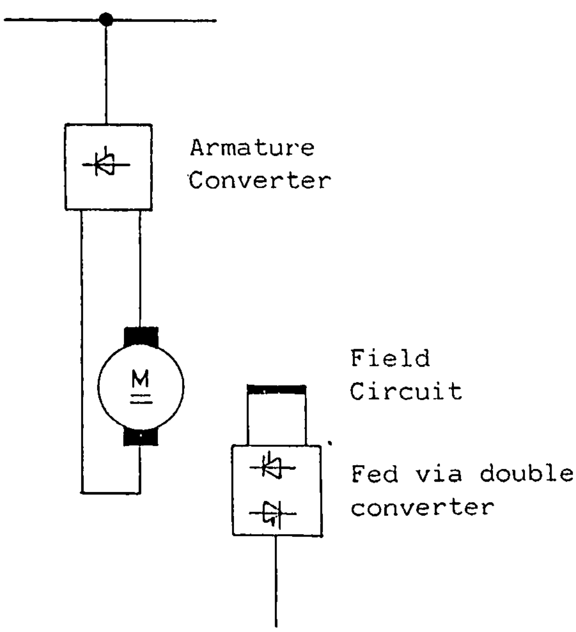

Fig. 2.2 D.C. DRIVES WITH FIELD REVERSAL

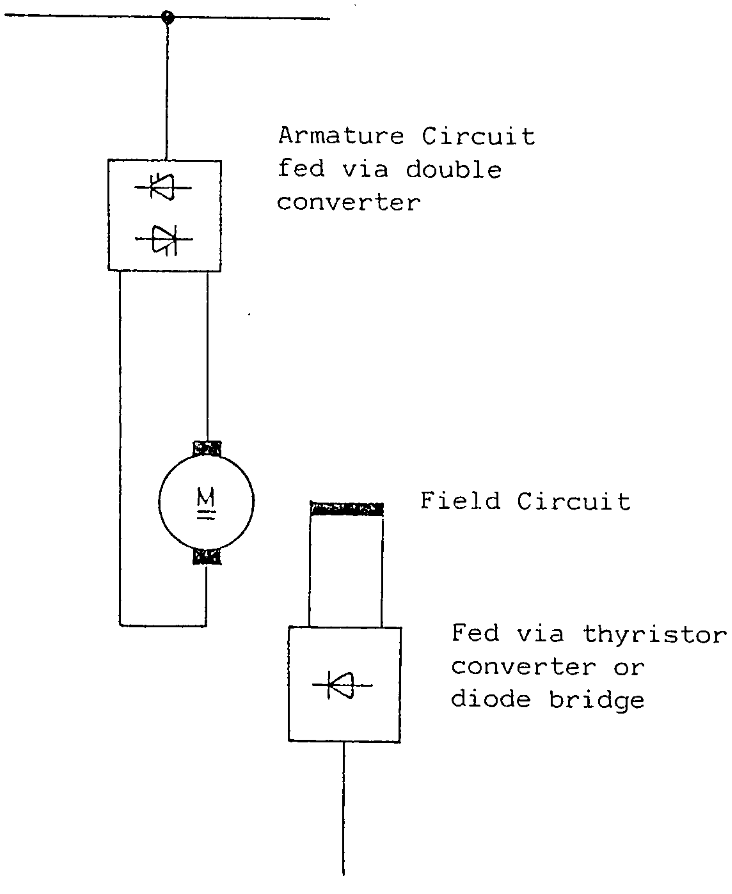

Fig. 2.3 D.C. DRIVE WITH ARMATURE REVERSAL

These type of drive systems are widely used and appear as standard package for power range from 1KW up to 800KW with input voltage of 380 – 415V/3 phase, and output power can be up to 1000KW with input voltage of 440 – 500V/3 phase or up to 1200KW with input voltage of 750V/3 phase.

Under special design, the system can give an output power up to 6MW with output voltage of 1500V/D.C.

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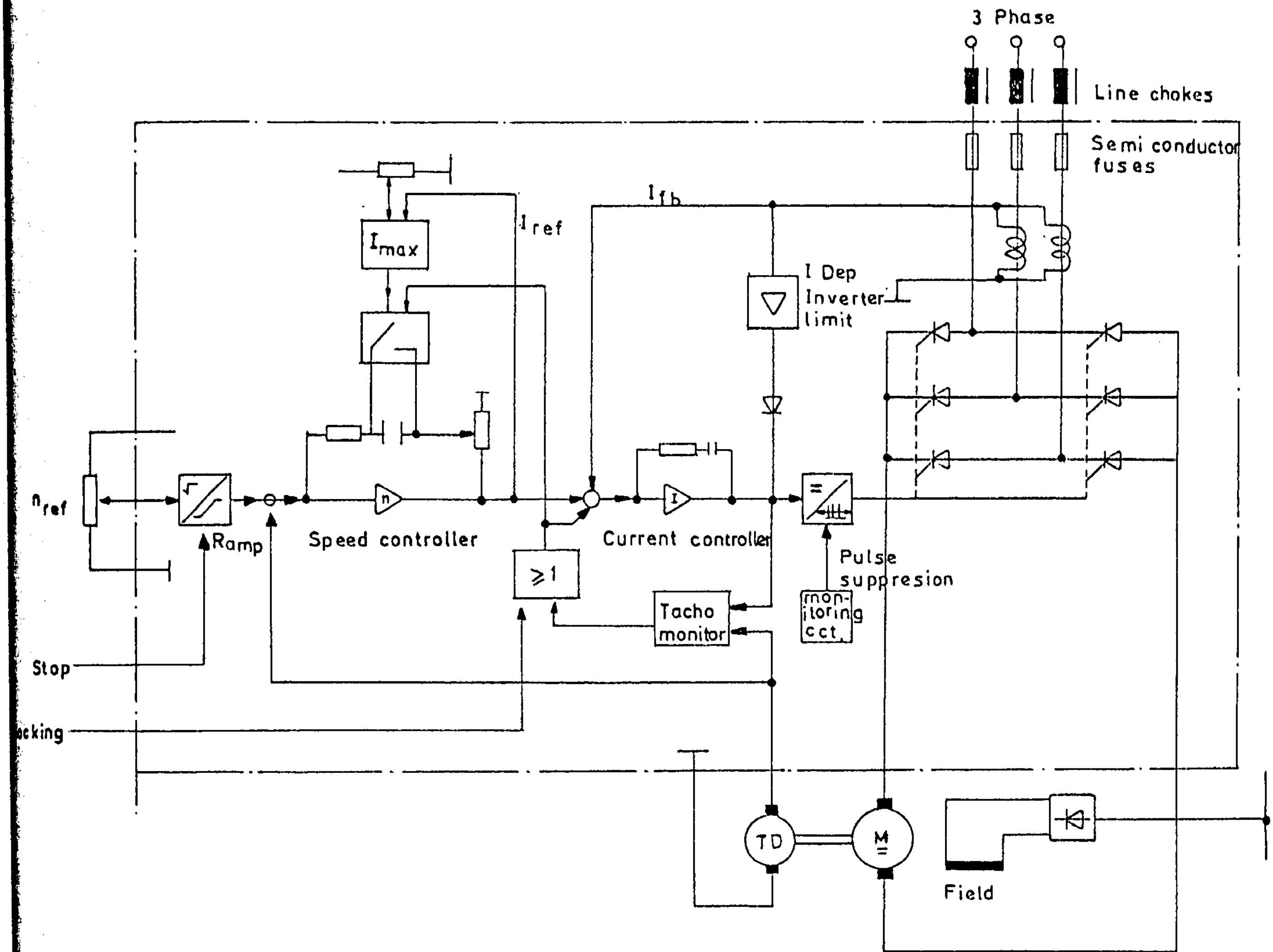
Unidirectional Drives (D.C. Drives without Torque Reversal)

Fig. 3 show the configuration of a simple unidirectional drive. It consists of a fully-controlled three-phase bridge connection with thyristors and the electronic pulse firing and regulator equipment.



I Dep: Current Dependant

Fig. 3 UNIDIRECTIONAL DRIVE

The possible types of duty of this drive system can be illustrated with the aid of the four-quadrants of the torque/speed diagram. Fig. 4.

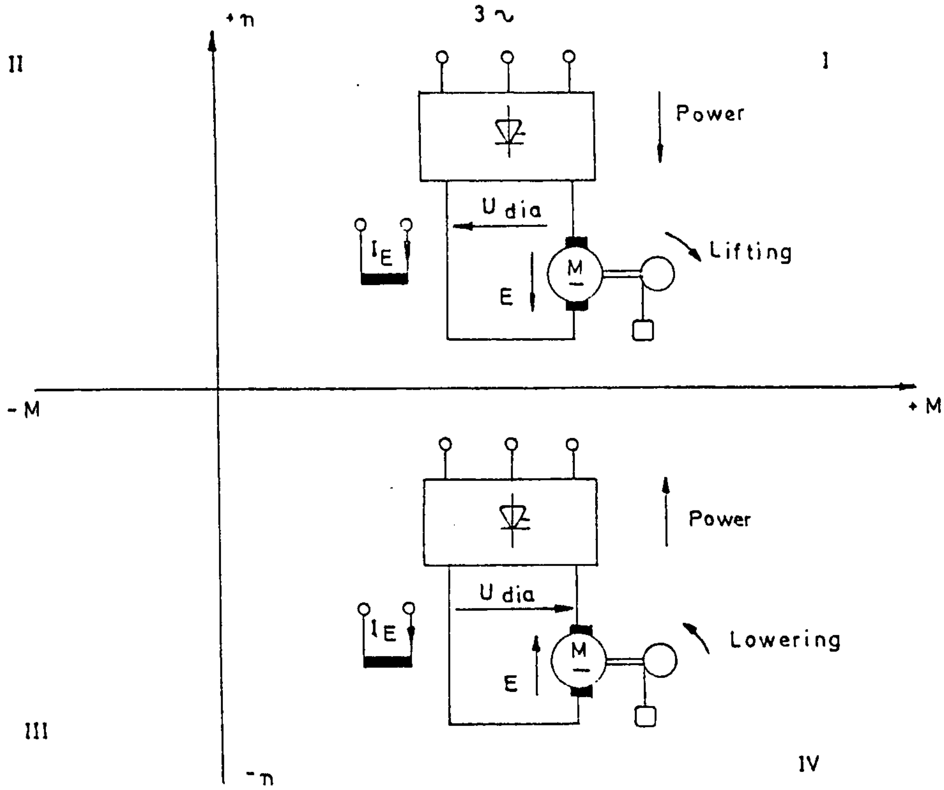


Fig. 4 TWO-QUADRANTS OPERATION

The drive unit operates as a rectifier and inverter, permitting either forward motoring and reverse regeneration (quadrants I and IV) or reverse motoring and forward regeneration (quadrants II and III).

Four quadrant operation can be achieved by the following connections:–

Fig. 5 shows the method of armature reversing, in this case motoring and braking in both directions are possible. Dead times is about 100ms – 300ms.

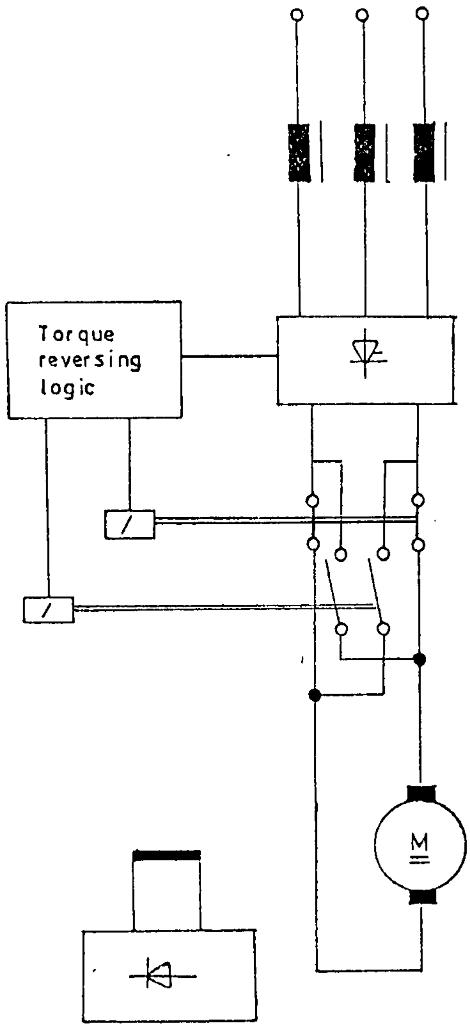


Fig. 5 ARMATURE REVERSING

Fig. 6 shows the method of FIELD REVERSING, but when the torque is reversed, there is a torqueless interval of 0.5 ..... 3 sec.

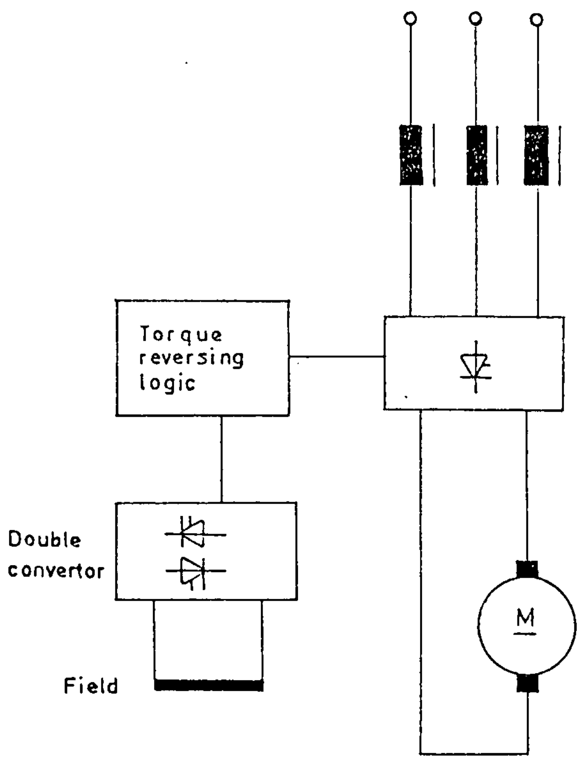


Fig. 6 FIELD REVERSAL

Regenerative drives (D.C. Drives with Armature Reversal)

In some applications when high speed reversing is required, the aforementioned connections for four quadrants operation cannot be applied. The configuration of a regenerative drive is as shown as follows: –

Fig. 7.1 shows the power section of the regenerative drive, which is similar to that of the uni-directional drive, with the exception of using 6 additional anti-parallel thyristors for quadrants II and III operations.

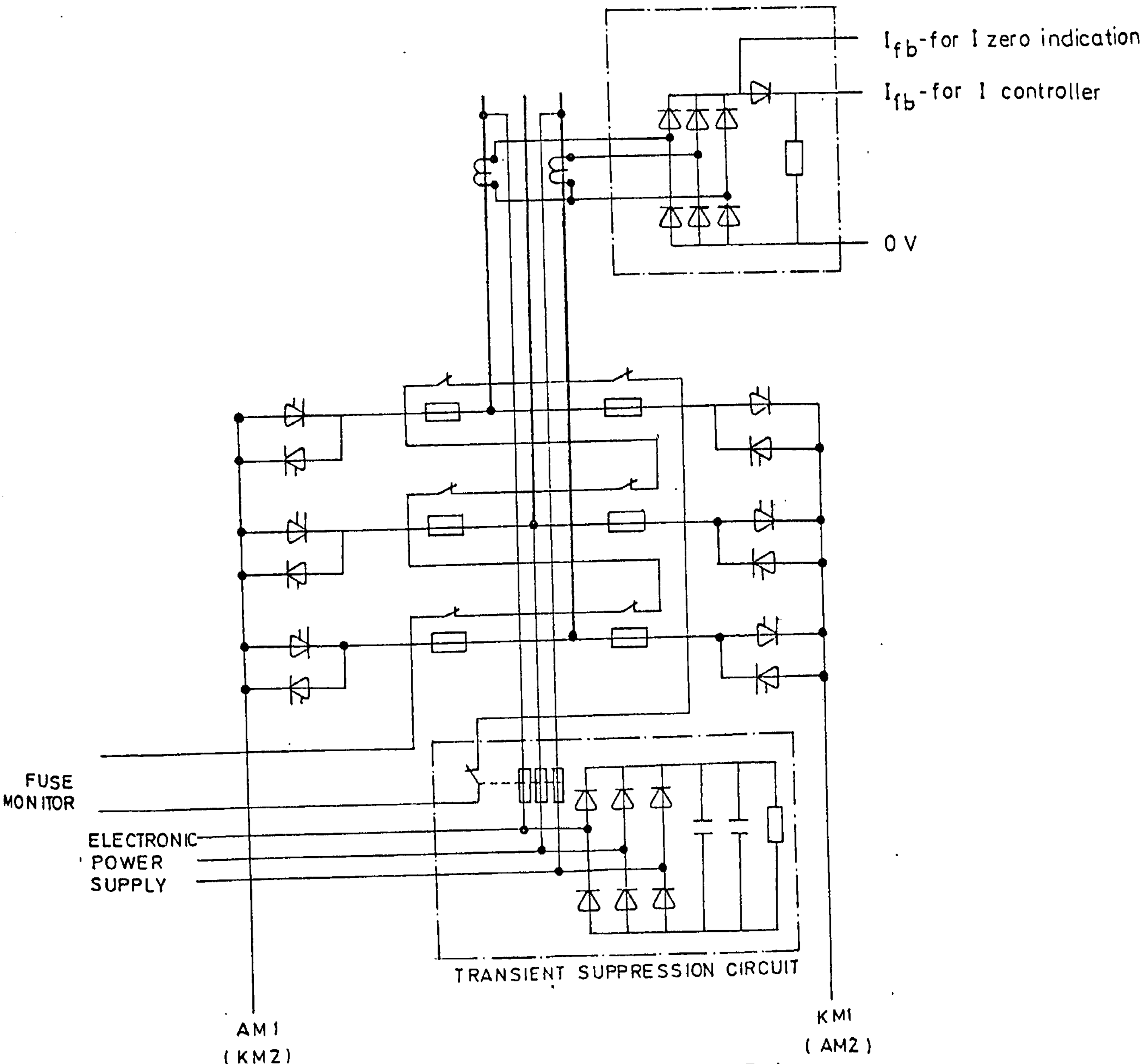


Fig. 7.1 Power Section of Regenerative Drive

The control section of the regenerative drive is as shown in Fig. 7.2.

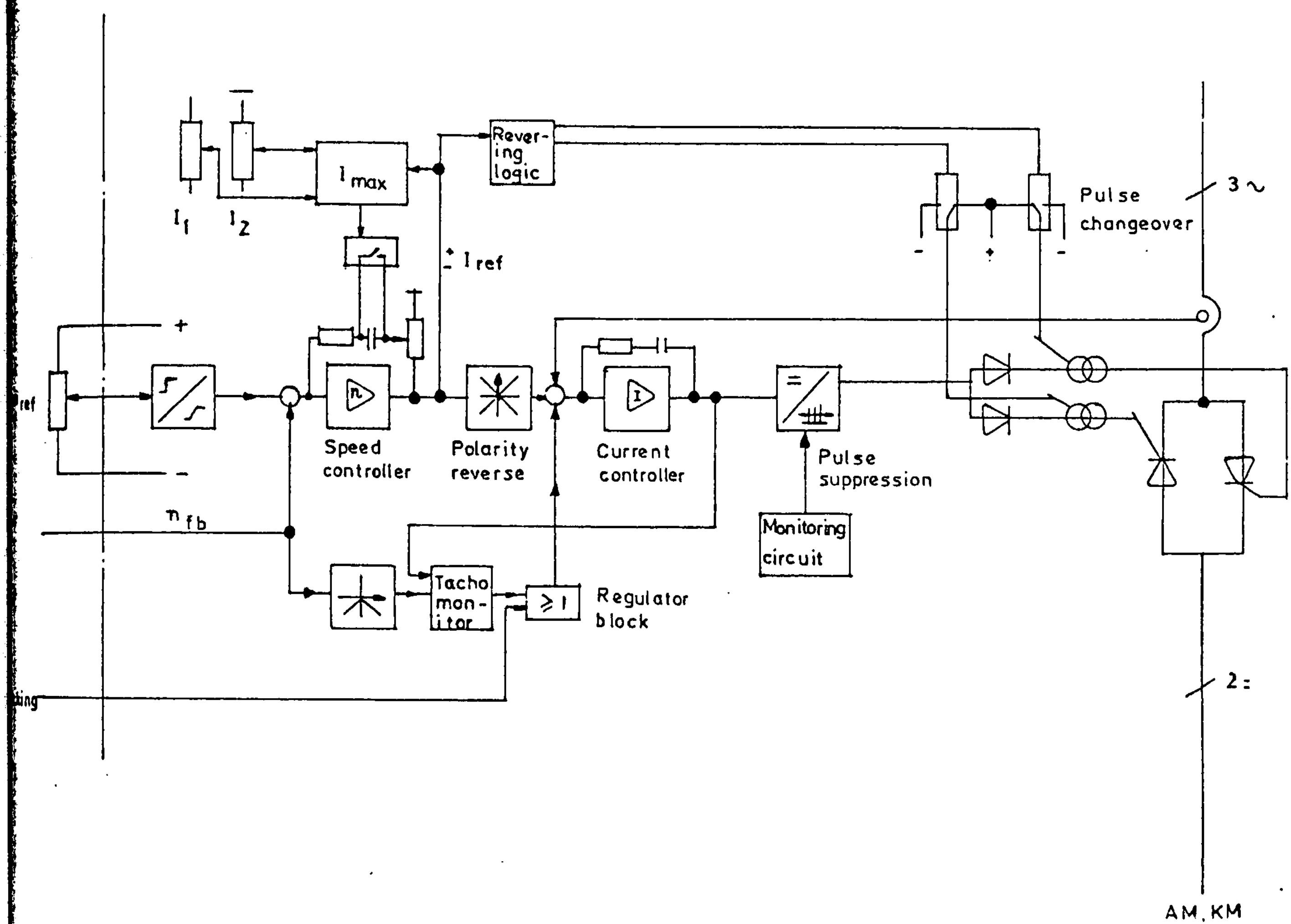


Fig. 7.2 CONTROL CIRCUIT OF REGENERATIVE DRIVE

The possible modes of operation of a D.C. motor fed from a double converter can be illustrated by the torque speed diagram as shown in Fig. 8.

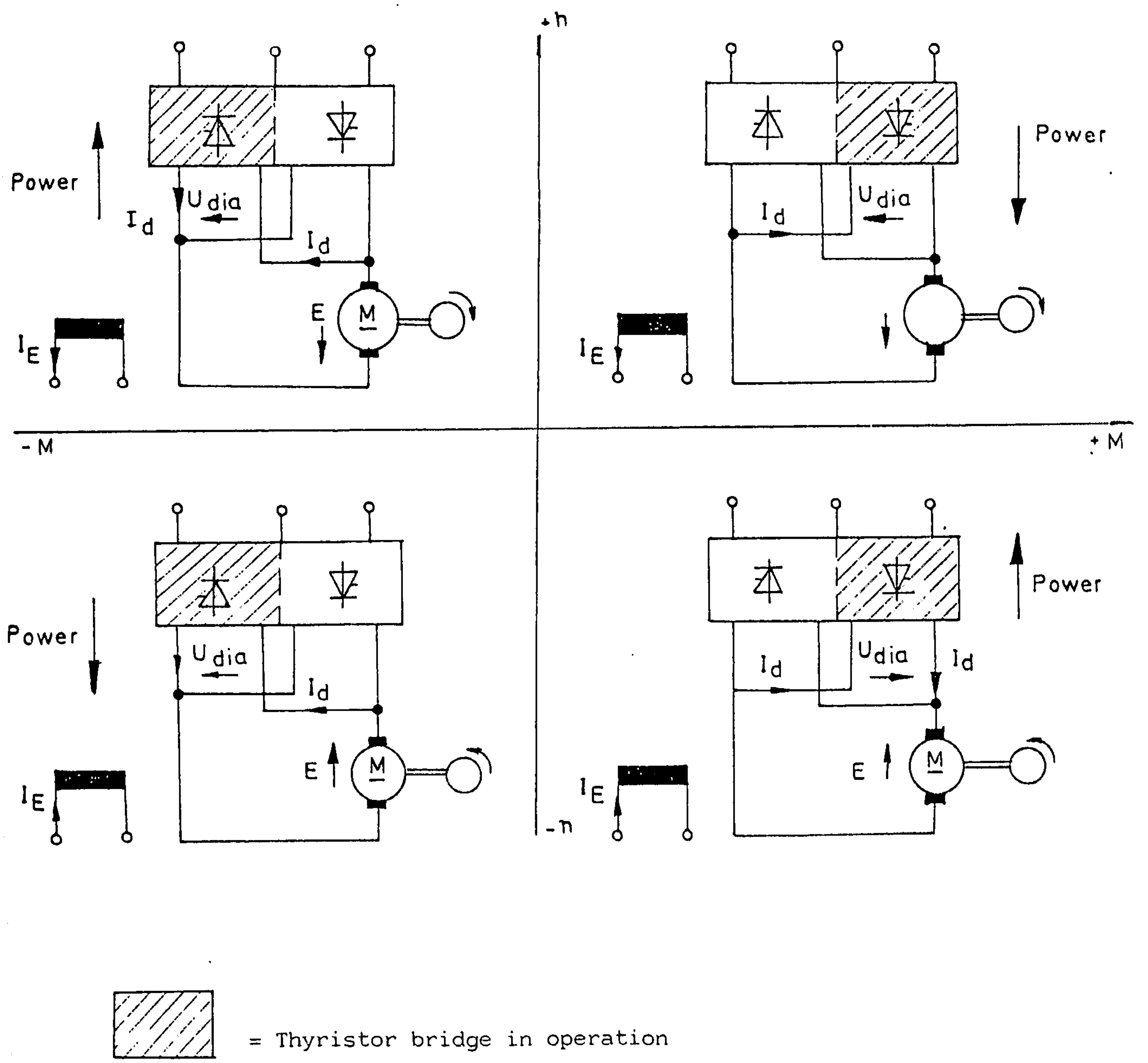


Fig. 8 Four-quadrant Operation

AC Drives

The advantages of A.C. drives over D.C. drives is listed as following:–

- Ruggedness of the A.C. motor
- Low power/weight and power/volume ratio
- Low-inertia rotor
- No maintenance duo to omission of commutator
- Brushless machines enables very high output
- Squirrel-cage induction motors are a particularly economic solution for drives operating in a corrosive environment (same for in hazardous area).

And since the cage motor is the simplest and most rugged of the motors, the desire to use it as a variable-speed drive has always be strong.

There are 2 possible converter system for use with the cage motor:

1. The current-source inverter
2. The voltage-source inverter

The Current Source Inverters

These frequency converters are particularly well suited for individual drives, as shown in the drawing the current source inverter consists of the following (See Fig. 9).

1. Gr – Line-commutated thyristor converter
2. LK – DC Link
3. Wr – Self-commutated static converter
(Normally working in the inverter mode)
4. ASM – Three phase induction motors

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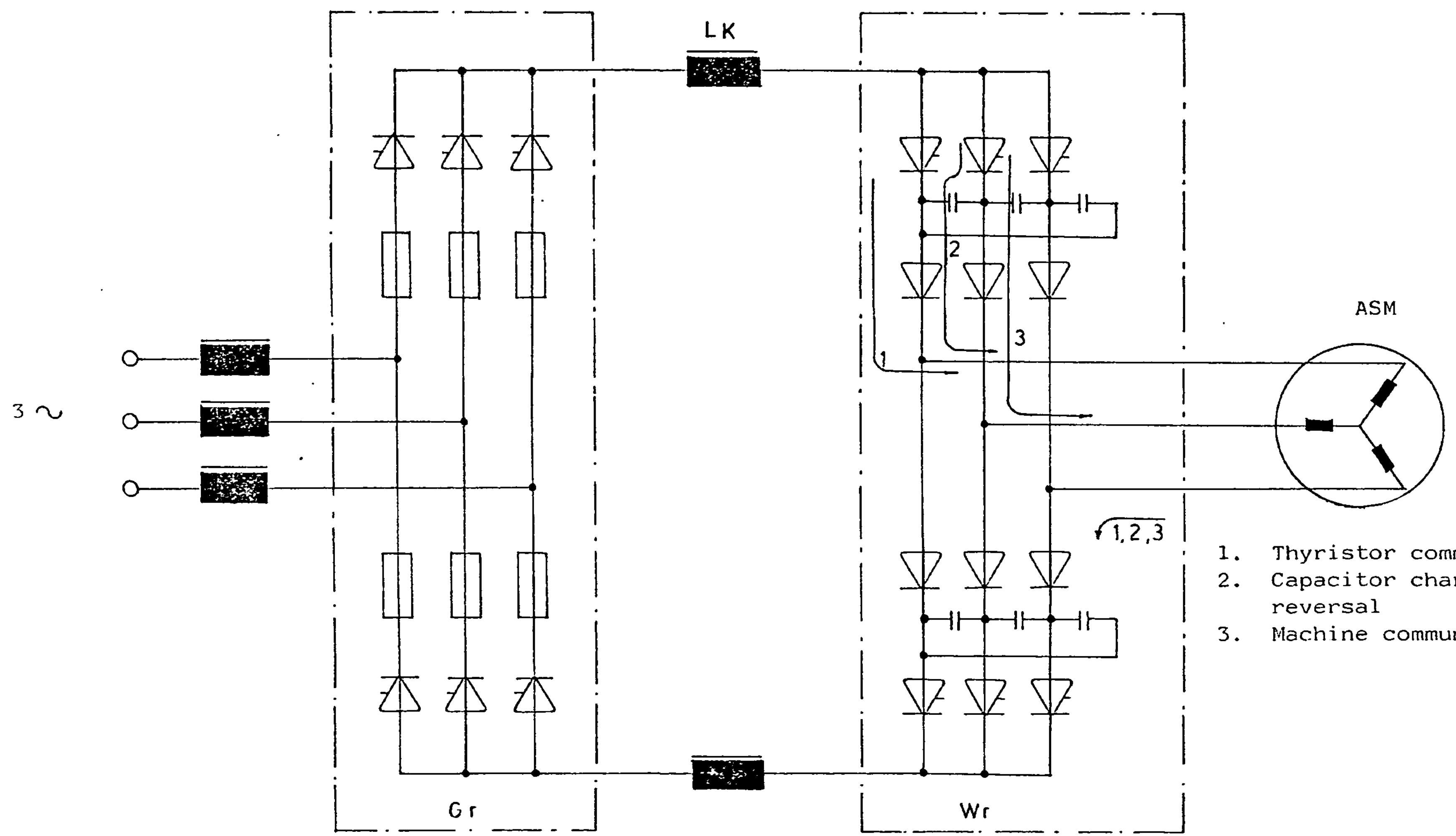

1. Thyristor communtation
2. Capacitor charge reversal
3. Machine communtation

Fig. 9 CURRENT SOURCE INVERTER

The incoming section consists, as in the case of D.C. drives, a six-phase thyristor bridge in series with a 3-phase line-choke. The D.C. link uncouples the A.C. power supply from the 3-phase system for the induction motor.

The inverter switches the controlled direct current behind the D.C. reactor cyclically through the 3-phase of the induction motor. This converter is basically arranged as a 3-phase bridge with six semi-conductor switching circuits which can be turned-off, in accordance with the phase sequence turn-off principles.

The circuit shown in Fig 9 enables the motor to be operated in all four quadrants.

In contact to D.C. drives and to 3-phase motor fed via a voltage source inverter. The current source inverters require no anti-parallel semi-conductor for carrying out a torque reversal and accepting the associated regenerative power. The flow of energy is reversed by reversing the polarity of the D.C. link voltage (as in the case of unidirection drives), with the current direction remaining unaltered. (Fig 10).

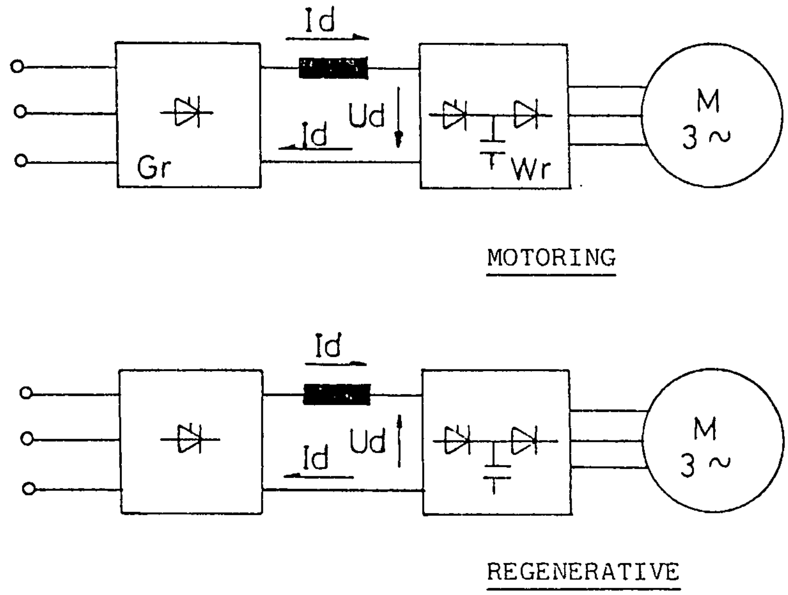

Fig. 10.1 Voltage and Current Condition For Motoring and Regenerative Operation

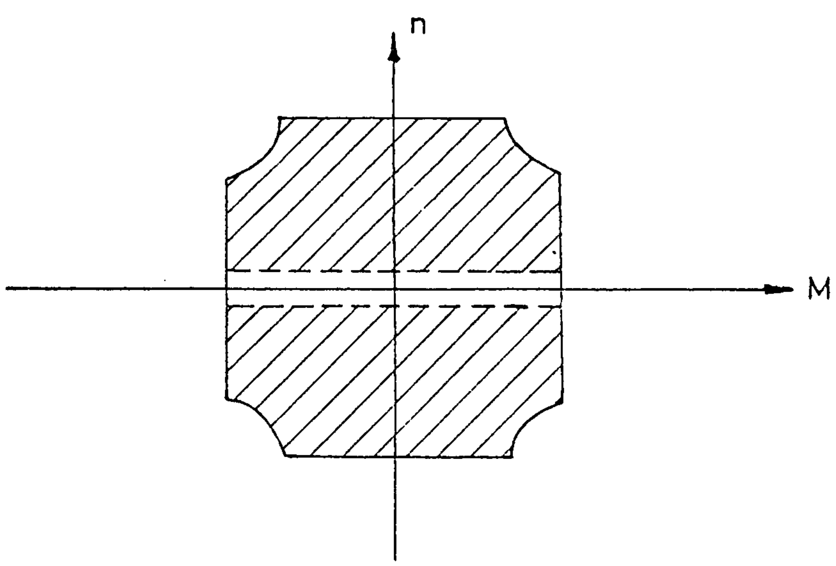

Fig. 10.2 Speed-torque Operating Range Of Current-Converter Drives

The control diagram of the current source inverter is as shown in Fig. 11

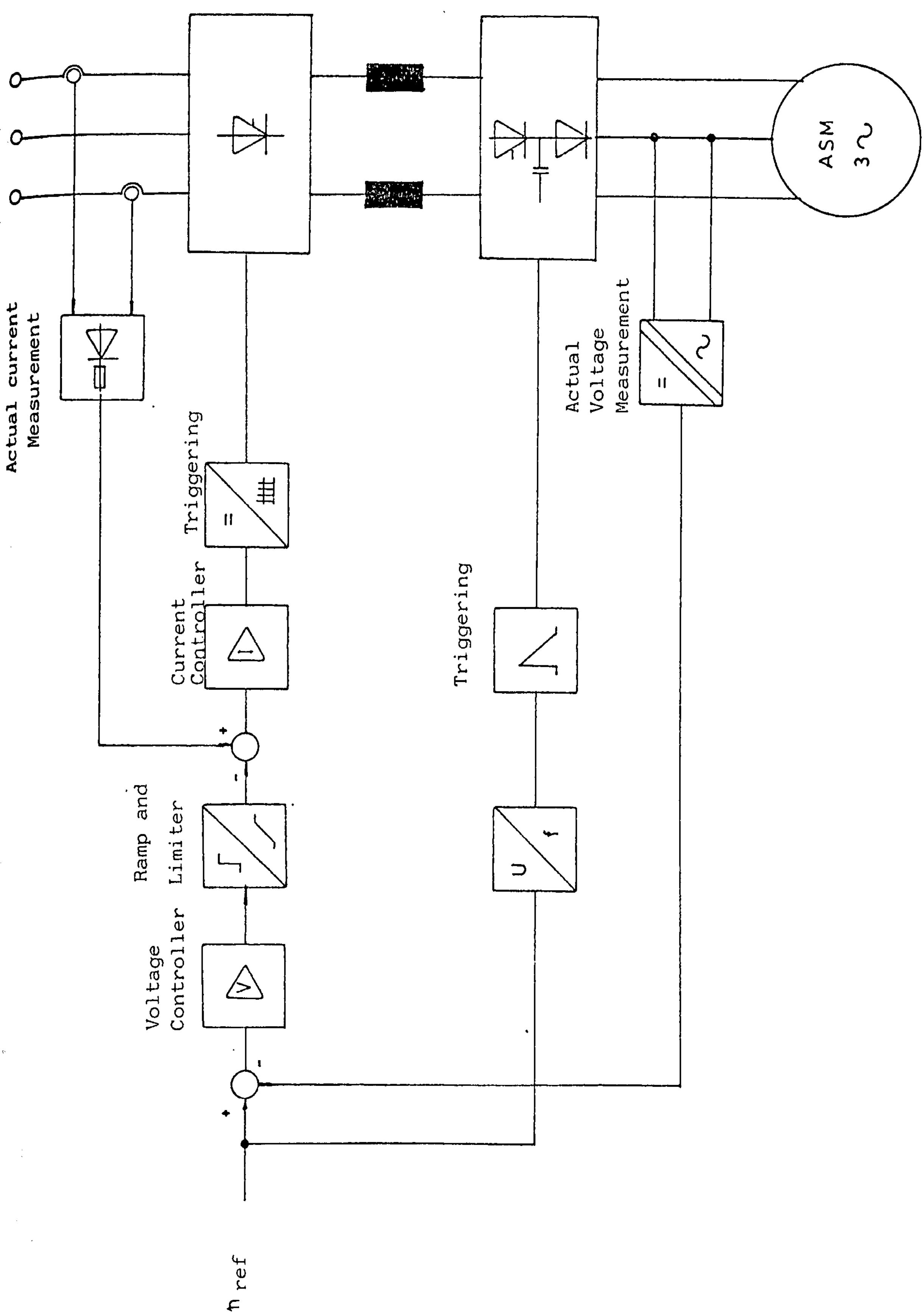

Fig. 11. Voltage - control system for reduced dynamic response requirement

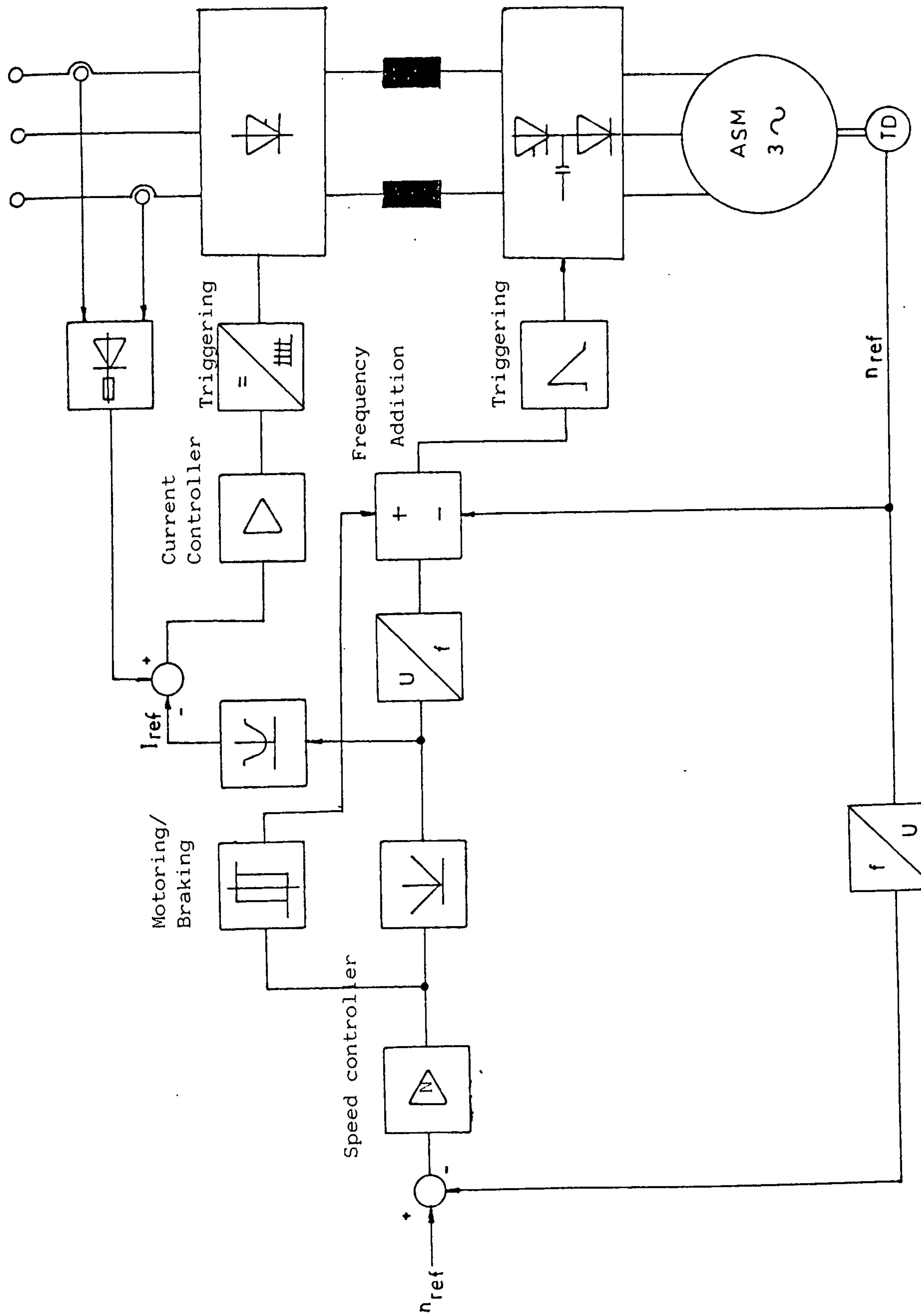

Fig 11.2 Speed-Control System With Speed Measurement

The current source inverter appear as standard package for frequency range 5 -- 135Hz and power range (power at motor shaft with inverter) from 15 to 500KW with input voltage of 380 -- 415V/3 phase, and output power can be up to 660KW with input voltage of 500V/3 phase or up to 1120KW with input voltage of 660/3 phase.

Under special design, the system can give an output power up to 1500KW with output frequency up to 135Hz.

The Voltage – Source Inverters

The system configuration of the voltage-source inverter is as shown in Fig. 12 which consists:–

1. Gr – Diode Rectifier
2. LK – D.C. Link, with reactor and capacitor
3. Wr – Force commutated inverter
4. ASM – Three phase induction motor

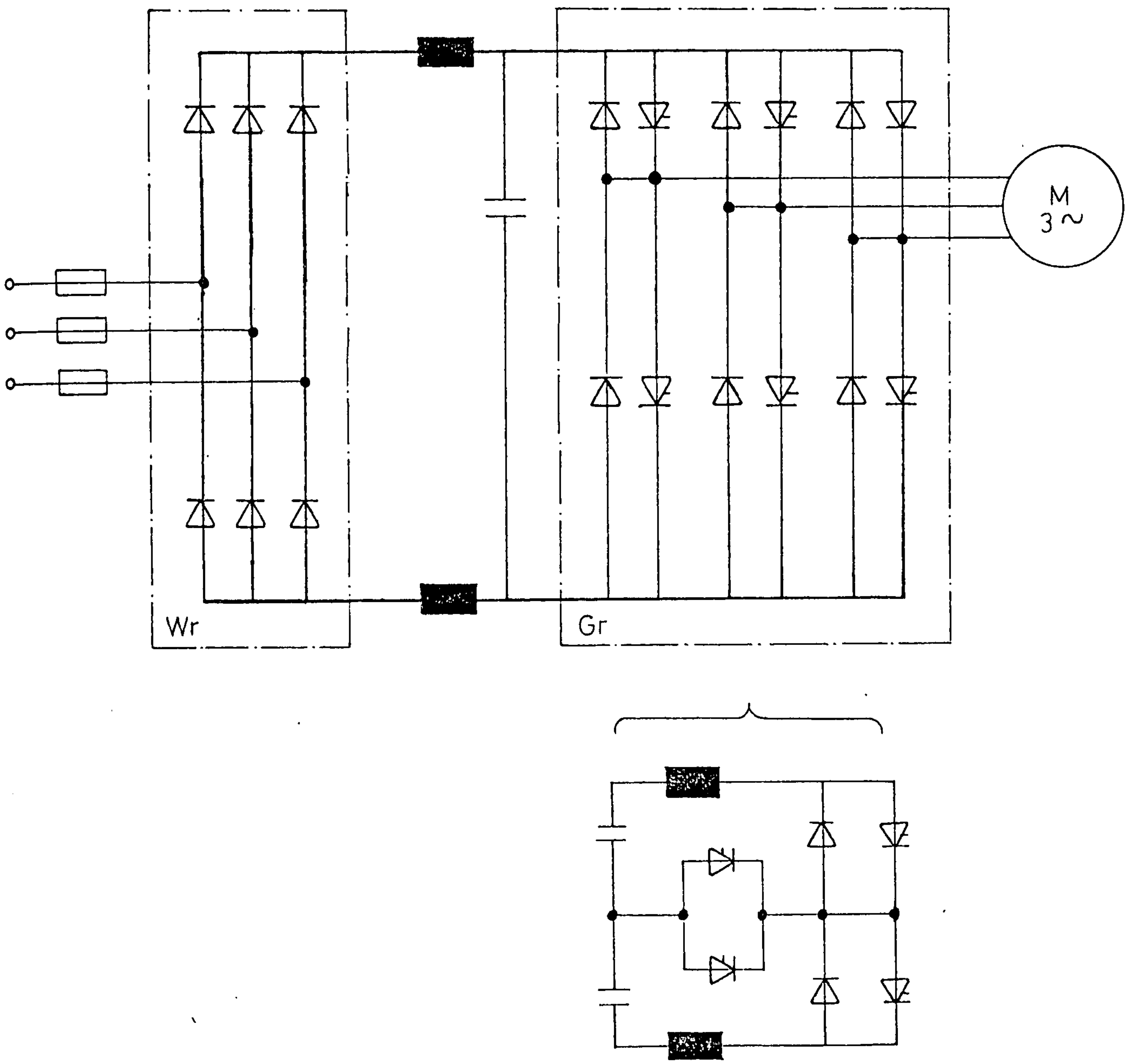

Fig 12 Voltage – Source Inverter

This system has the advantage that the converter almost always draws pure active power from the mains.

The principal according to which the inverter operate in simple, it operates as a change-over switch which connect either to the positive or the negative of the D.C. link in order to generate a variable frequency voltage source.

In order to generate from the constant D.C. Voltage an A.C. Voltage with amplitudes proportional to the frequency, the inverter is controlled by means of Pulse width modulation. Thus it is possible to obtain a good sinusoidal shape for the current. (Fig. 13)

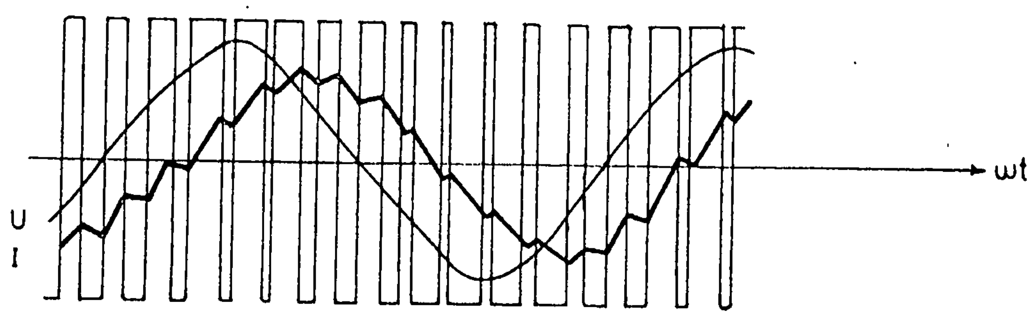

Fig. 13 Pulse Width Modulation

The system shown enables the motor to be operated in two quadrants only (quadrant I and quadrant III i.e. motoring in both direction). Fig. 14.

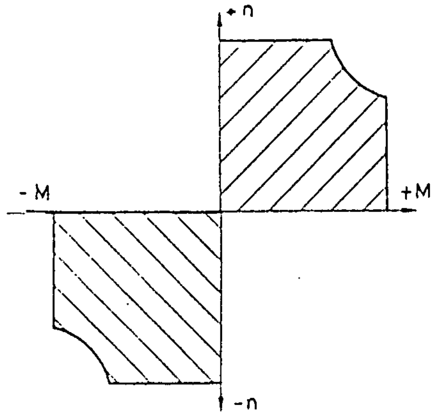

Fig. 14 Duty Diagram of Voltage-Source Inverter with Single Converter

The voltage source inverter can also be possible for four-quadrants operation by means of using double converter in the Rectifier section Fig. 15.

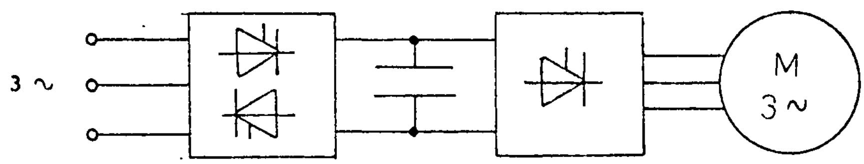

Fig. 15 Voltage-Source Inverter for Four-quadrants Operation

The voltage-source inverters are suitable for connection of more than one drive. See Fig. 16.

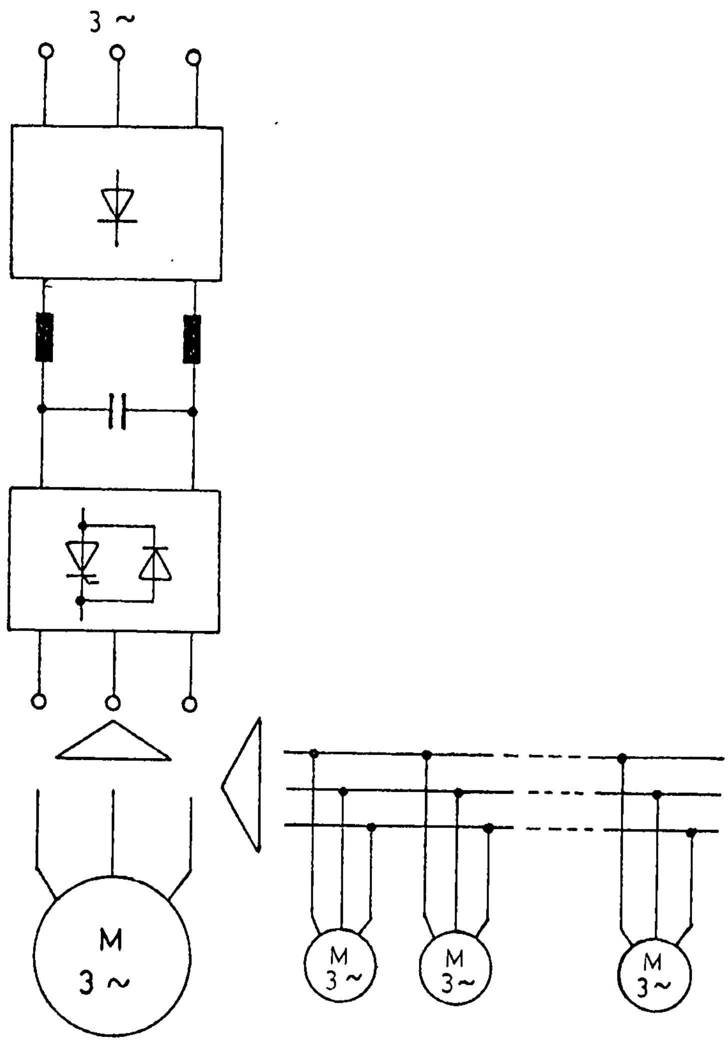

Fig. 16 Application of voltage-source inverter
For Individual/Multiple Drives

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The voltage source inverters appear as standard package for frequency range of 0.5 – 150Hz and power range of 100 – 540KVA with input voltage of 380 – 415V/3 phase and output power can be up to 710KVA with input voltage of 500V/3 phase.

Under special design, this system can give an output power up to 4000KW for one-quadrant or four-quadrants operations.

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In the last two years, we have a new type of voltage source inverter using transistors and microprocessor control. This new frequency converters are more compact, cost-effective and easier to maintain in compare with the type using thyristors. With this series the speed of standard cage motors rated to approximately 145KW can be controlled.

The system configuration of the transistor type voltage-source inverter is as show in Fig. 17.

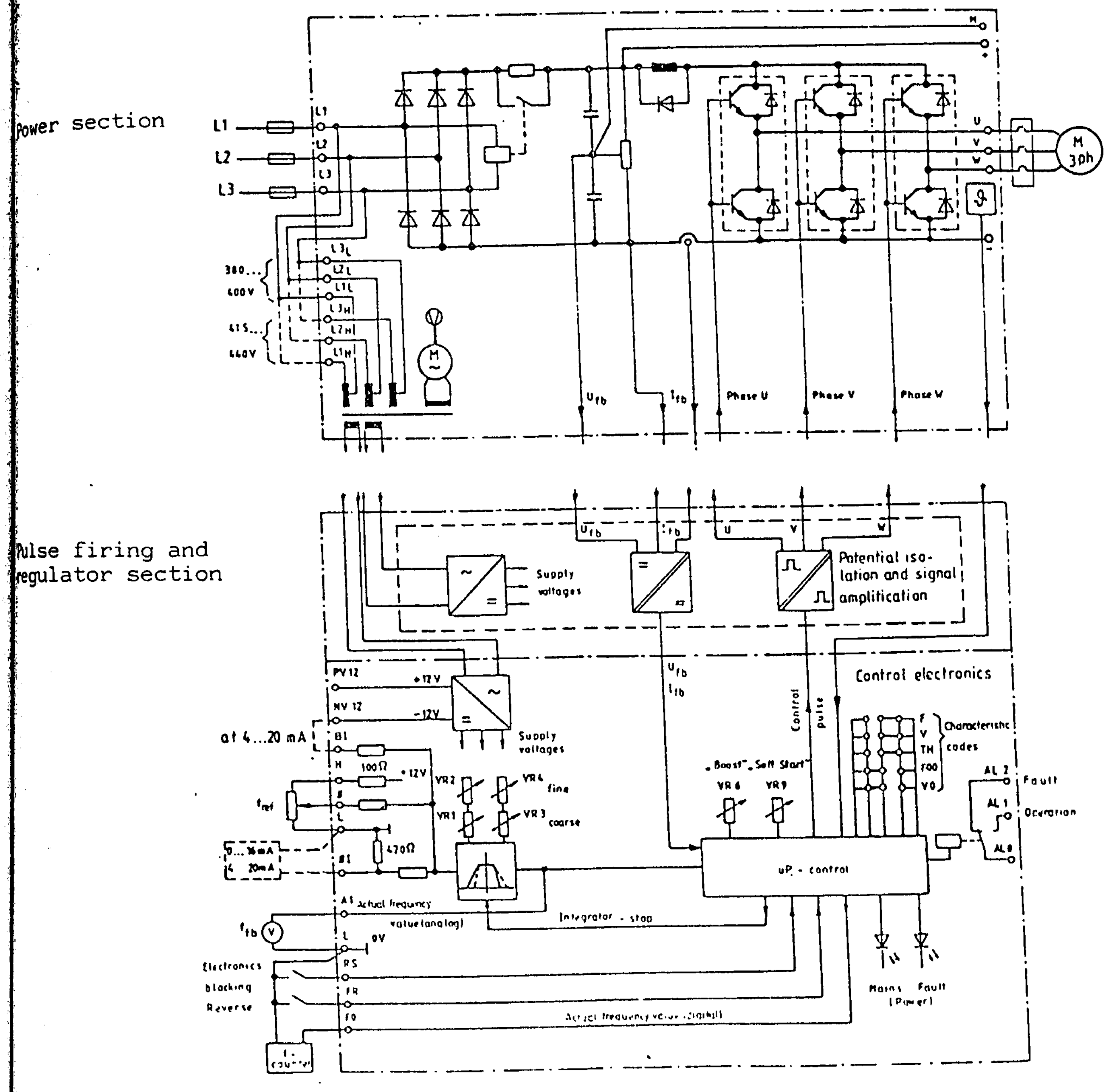


Fig. 17 Voltage-Source Inverters Using Power Transistors

By using transistors and micro-processor, this new series of inverters have a higher system efficiency and better current waveform in compare with the thyristor type.

Slip Energy Recovery System (Sub-Synchronous Converter Cascade)

The method of controlling the speed of a wound rotor induction motor by varying an external resistance in the rotor circuit of that machine has been known for a long time. The load characteristics of a wound-rotor motor with variable rotor resistance is as shown in Fig. 18.

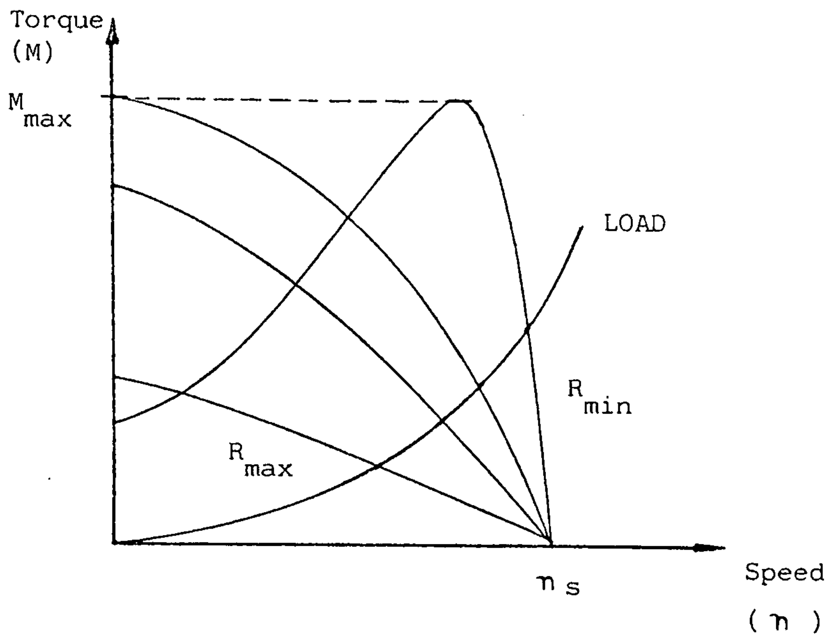


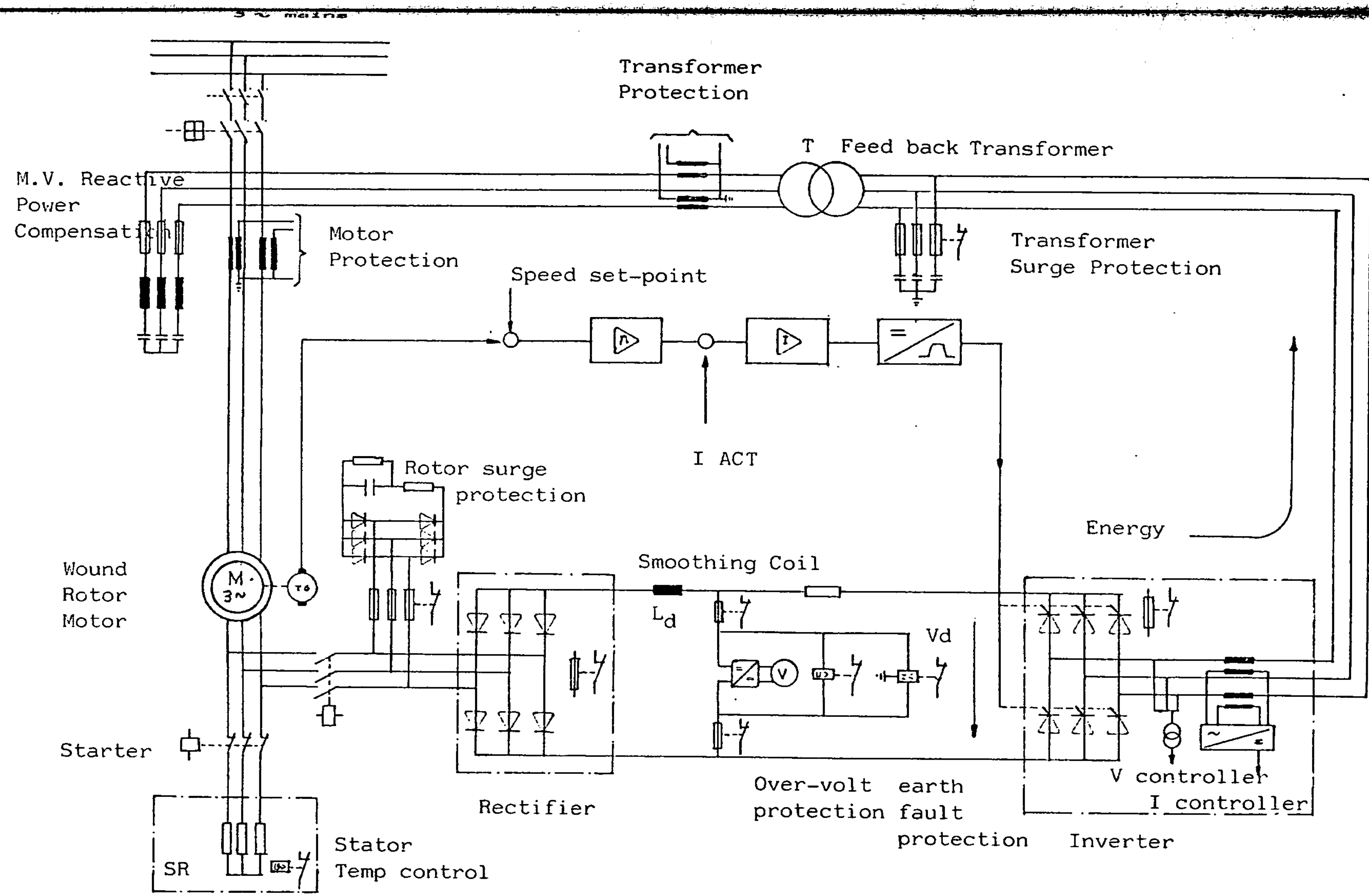
Fig 18 Load Characteristics

The major drawback of this method is that the power loss in the resistors increases considerably with decreasing speed, which has a direct effect on the efficiency of the drive.

The sub-synchronous converter cascade returns the slip energy, reduced by the cascade losses to the supplying system (or to some other system).

From this, only the mechanical power output plus the power dissipated in the cascade drive is drawn from the supply system.

Fig. 19 shows the basic configuration of a simple sub-synchronous static converter cascade.



I ACT: Actual Current

Fig. 19 CONFIGURATION OF A SIMPLE CASCADE-DRIVE

This drive system is mainly used with M.V. motors with output ratings between 1 and 20MW.

The drive system comprises:

M – Wound-rotor induction machine of conventional design (Account must be taken, however, of losses due to the skin effect-caused by the high rotor frequency in the lower speed range and by current harmonics.

SR – The starting resistor of running up the drive to the lower limit of speed range.

Gr – The six-pulse non-controlled rectifier bridge.

Ld – The reactor in the D.C. link.

WR – The six-pulse line-communtantated inverter in bridge circuit.

T – The feedback transformer of conventional design (3 winding transformer for a 12-pulse system).

The advantage of the subsynchronous converter cascade is that only the slip power has to be handled by the converter. The converter rating is thus determined by the speed control range and this gives a low cost drive the additionally with a very high efficiency.

This system has to be custom design in accordance with:–

- The system voltage
- Motor rating
- Speed control range
- Maximum rotor voltage
- Harmonic requirement
- Application

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The operating range of the sub-synchronous converter cascade is as show in Fig. 20.

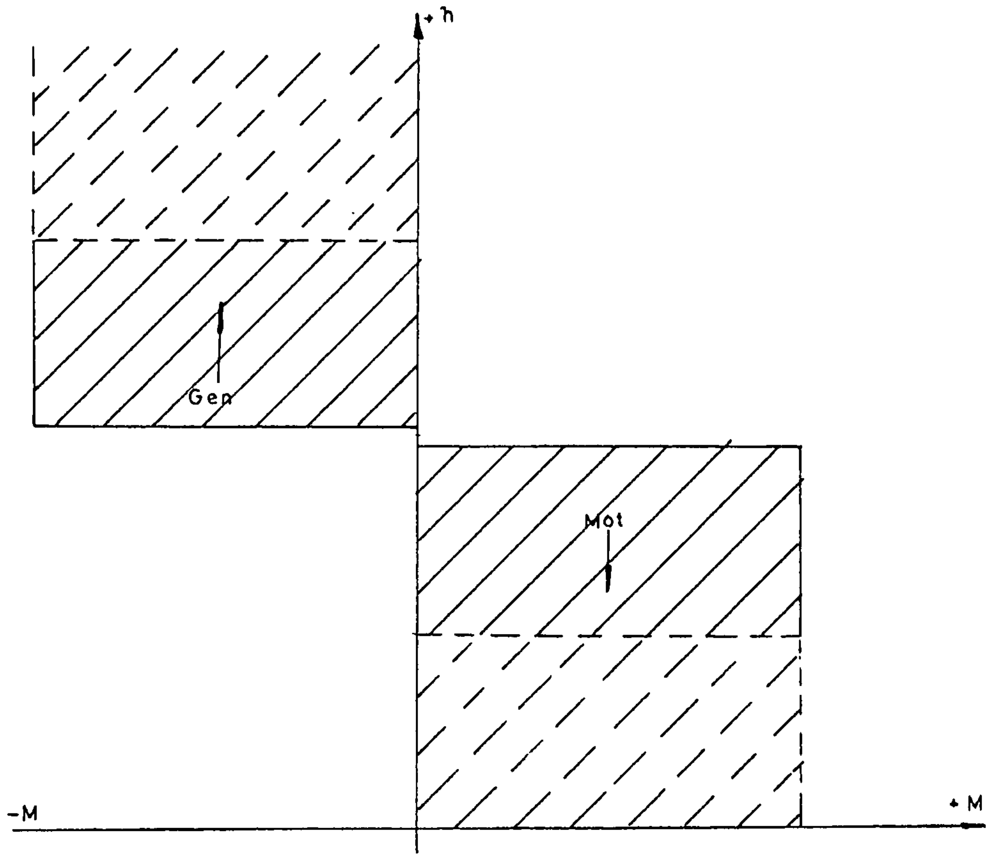


Fig 20 Operating Range Of Sub-Synchronous Converter Cascade

Summary

D.C. Drives without Torque Reversal

Typical speed range : $N_{min}/N_{max} = 1 : 100$

Typical power range : 1 .... 6000kW

Voltage : 1500V D.C.

Machine : D.C. shunt motor

Characteristic Properties

- Suitable for two-quadrant operation
- No torque reversal possible

Options

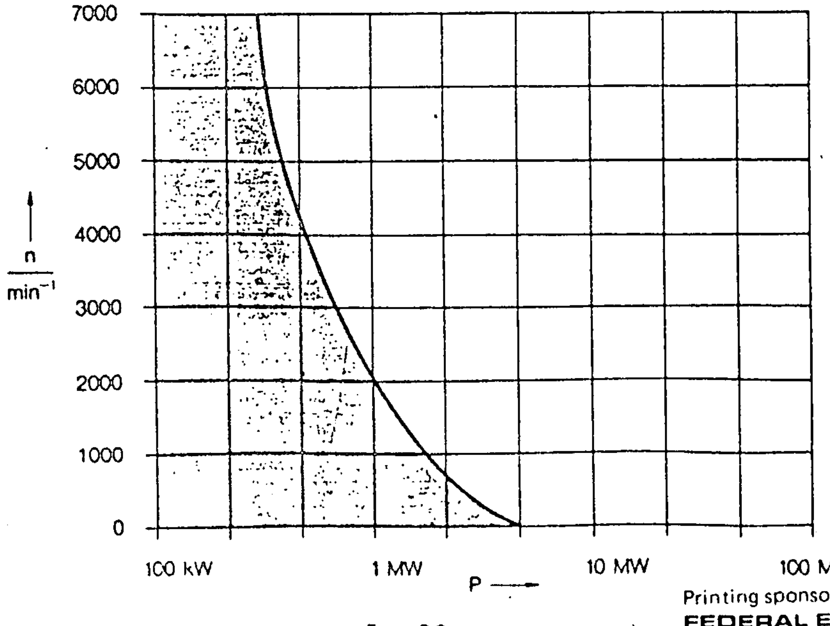
- Braking via armature resistance
- Twelve-pulse armature-circuit converter for high power to reduce the reactions on the supply system.
- Two converter sections with sequential control to improve the power factor at high outputs.
- Output can be increased by using double or triple machines.

Preferred fields of application

Continuously running drives e.g.

- fans
- pumps
- extruders
- kneaders

Power Range



D.C. Drives with Field Reversal

Typical speed range : N_{min}/N_{max} = 1 : 100

Typical power range : 1 .... 6000kW

Voltage : 1500V D.C.

Machine : D.C. shunt motor

Characteristic properties

- Suitable for four-quadrant operation i.e. driving and braking in either direction.
- When the torque is reversed, there is a torqueless interval of 0.5 .... 3s.
- Time to reverse the torque from $+M_N$ to $-M_N$: 1 .... 4s.

Options

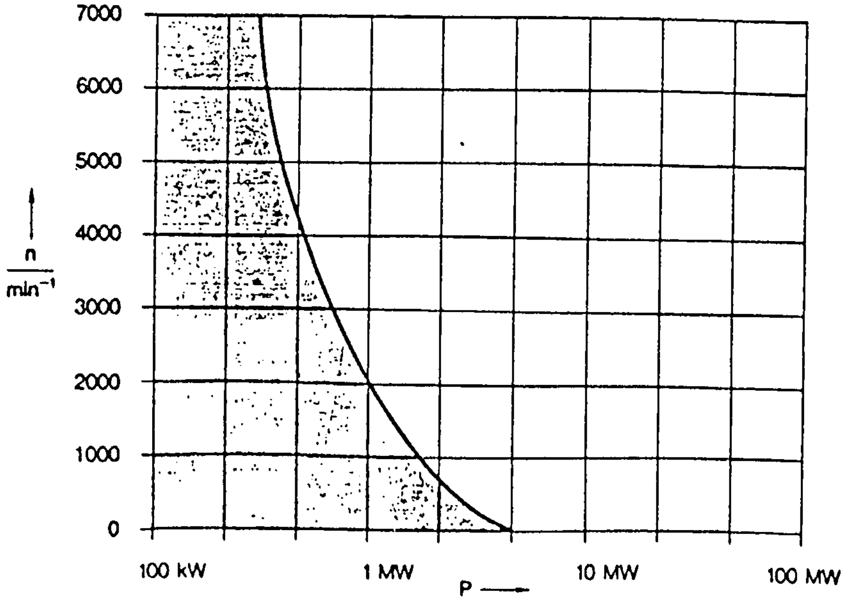
- Twelve pulse armature-circuit converter for high power to reduce the reactions on the supply system.
- Two converter sections with sequential control to improve the power factor at high outputs.
- Output can be increased by using double or triple machines.

Preferred fields of application

Drives for continuous operation, e.g.

- Continuous rolling mills
- Pipe drawing machines
- Balancing stands

Power Range



D.C. Drives with Armature Reversal

Typical speed range : N_{min}/N_{max} = 1 : 100

Typical power range : 1 .... 6000kW

Voltage : 1500V D.C.

Machine : D.C. shunt motor

Characteristic properties

- Suitable for four-quadrant operation, i.e. driving and braking in all four quadrants.
- When the torque is reversed, the torqueless interval is negligible.
- Fast control response in all four quadrants.

Options

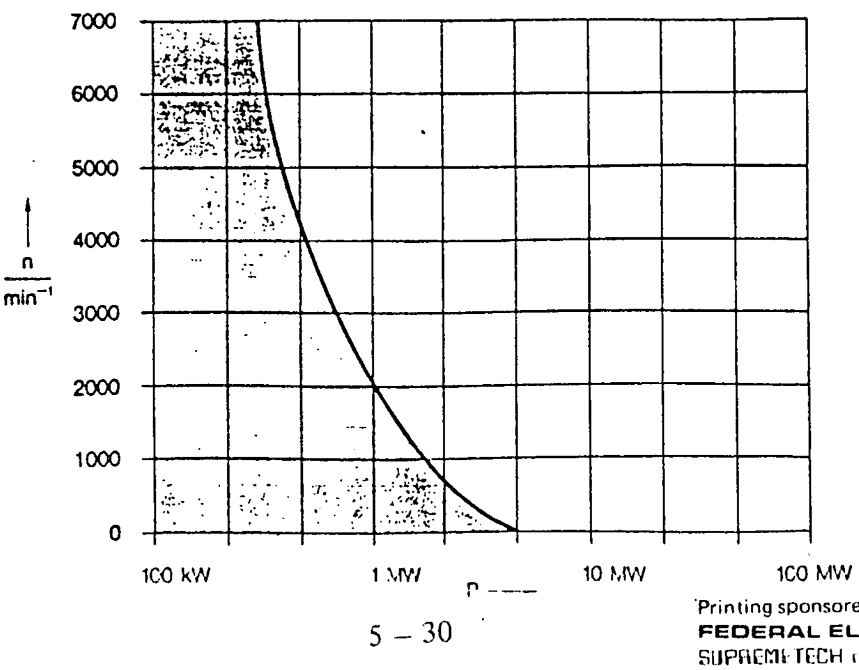
- Twelve-pulse armature converter for high output power to reduce reactions on the supply system.
- Output can be increased by using double or triple machines.
- Depending on the mode of operation, the armature-circuit converters may have to be equipped asymmetrically.

Preferred fields of application

High-speed reversing, e.g.

- Reversing rolling mills
- Pipe push benches
- Main drives of continuous rolling mills
- Stretch-reducing mills
- Coilers, winders
- Test rigs

Power Range



Current-source Inverter

Typical basic

Frequency	:	5 .... 135Hz
Typical speed range	:	N_{min}/N_{max} 1 : 20
Typical power range	:	15 .... 1500kW
Machine	:	Three-phase cage induction motor

Characteristic Properties

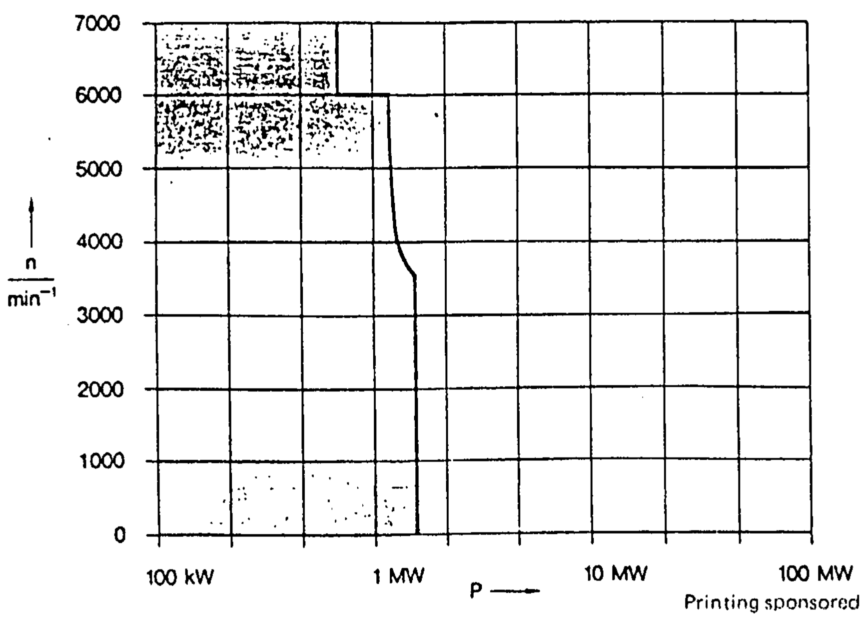
- Suitable for four-quadrant operation
- Preferably single drives
- Starting with full torque
- Steady-state operation at very low speed not possible

Preferred fields of application

Continuously running drives, e.g.

- Pumps
- Extruders
- Blowers
- Fans
- Agitators
- Centrifuges
- Conveyor belts
- Screw-type conveyors
- Kneaders

Power Range



Voltage-source Inverter

Typical basic

Frequency : 0 .... 150Hz

Typical speed range : N_{min}/N_{max} = 1 : 200

Typical power range : 1 .... 4000kW
(One-quadrant operation)
80 .... 4000kW
(Four-quadrant operation)

Machine : three-phase cage induction motor
three-phase reluctance motor
three-phase synchronous motor

Characteristic Properties

- Suitable for four-quadrant operation (with double converter)
- Full torque and steady-state operation even at standstill and very low speeds
- Formation of busbars with controlled frequency and controlled voltage is possible.
- Output voltage with high fundamental content (due to pulse-width modulation)
- Motor currents sinusoidal with low harmonic content
- High control response possible

Options

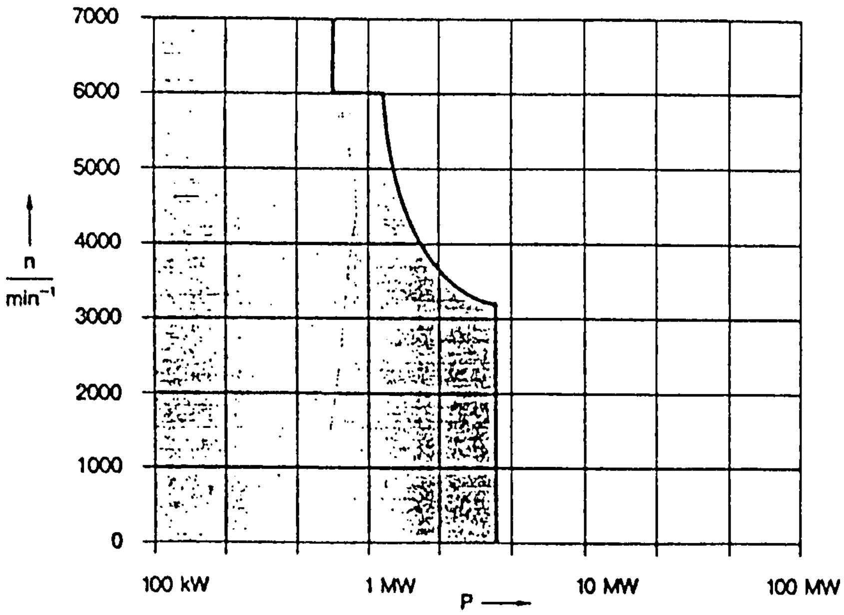
- Two-quadrant operation possible without braking, with diode bridge as feeding converter
- Common D.C. link for several individually controlled inverters and motors
- Additional electronics to obtain a control response comparable with that obtained with D.C. drives

Preferred fields of application

Universally applicable, hitherto preferred for

- Synthetic fibre production
- Roller tables
- Test rigs
- Three-phase locomotives
- Coking plant vehicles
- Magnetic levitation railways
- Positioning drives

Power Range



Slip Energy Recovery System
(Sub-Synchronous Converter Cascade)

Frequencies :

Stator Mains frequency f_N
Rotor 3Hz .... f_N (depending on speed range)

Typical speed ranges :

n_{min}/n_{max} 1:1.2 .... 1:2 .... 1:20
(as motor)

n_{min}/n_{max} 1.2:1 .... 2:1 .... 3:1
(as generator)

Typical power range : 800 .... 25000kW

Machine : Wound-rotor induction motor

Options

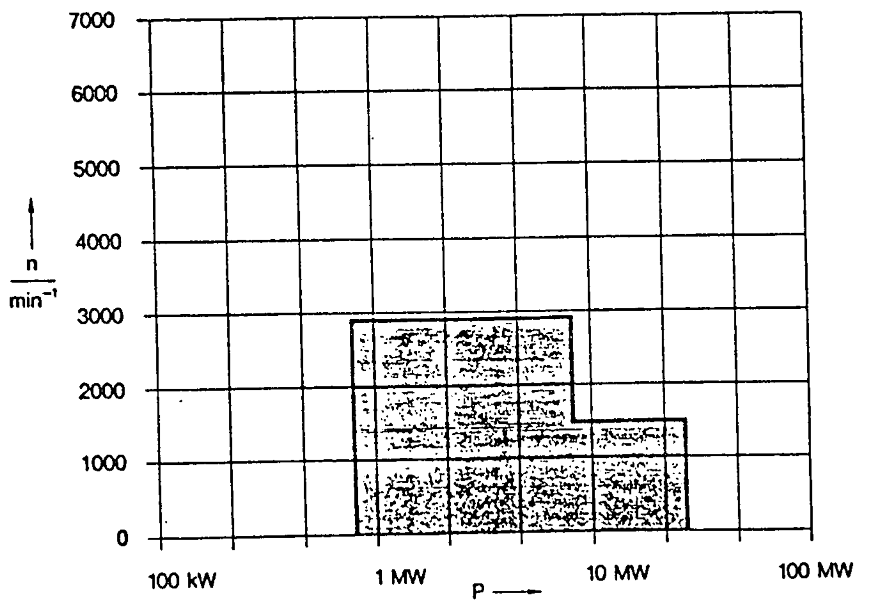
- Switchable Cascade with 6/12 Pulse feedback
- Model insensitive to supply disturbances
- Twelve-pulse inverter to reduce reactions on the supply system
- Inverter with sequential control to improve the power factor
- Twelve-pulse rectifier (machine with two rotor winding systems) for very high outputs
- Emergency or short-circuit operation

Preferred fields of application

Continuously running drives. e.g.

- Pumps
- Compressors
- Wind tunnels
- Blowers
- Bucket-wheel drives for Large Excavators
- Test rigs, load machines
- Crushers

Power Range



— Notes & Questions —

Paper No. 6

Factory Built Assemblies of L.V. Switchgear and Controlgear

Speaker: Mr. A Horton, Chief Engineer,
Federal Electric Ltd.

FACTORY BUILT ASSEMBLIES OF L.V. SWITCHGEAR AND CONTROLGEAR

"Low Voltage Switchgear and Control Gear Assemblies" is the title of the recently revised International Specification IEC439 Part 1, formerly known as "Factory Built Assemblies of Switchgear and Controlgear" – the words "Factory Built" have been omitted in the new edition because this revised version is intended to cover both the initial manufacturer supplying a completed assembly which will be known as a TYPE TESTED ASSEMBLY (TTA), and a customer finished or site assembled unit which will be known as a PARTIAL TYPE TESTED ASSEMBLY (PTTA) and contained within this specification are tested requirements for both types of construction.

So what is an assembly of low voltage switchgear and controlgear? – It can be any assmbly of one or more items of electrical switchgear and/or controlgear with or without an enclosure having a rated voltage not exceeding 1000 Volts ac at a frequency not exceeding 1000Hz or dc voltages up to 1500 Volts.

These assemblies can range from:

1. A single item in a metal or insulated box.
2. A combination of various pieces of ancilliary equipment in a wall mounted enclosure.
3. A busbar chamber supplied loose or together with fuse/switch combinations or miniature circuit-breaker boards, again loose items to be assembled as a wall mounted composite unit, or together with a metal frame or back plate.
4. An assembly of busbar trunking.
5. A desk or pedestal assembly of controlgear.
6. A panelboard arrangement of moulded case circuit-breakers in a wall mounted or free standing steel enclosure.
7. A main or sub-main switchboard containing a main incoming air circuit-breaker, a set of current carrying busbars and several outgoing air circuit-breakers and moulded case circuit-breakers.
8. A packaged sub station.

So you can see this specification covers a very wide variety and range of different assemblies and the emphasis is on "assemblies" which are defined in this specification as "A combination of one or more low voltage switching devices together with associated control, measuring, signalling, protective, regulating equipment etc. completely assembled under the responsibility of the manufacturer with all the internal electrical and mechanical interconnections and sturctural parts. The components of the assembly may be electro-mechanical or electronic and for various reasons such as transport or production, certain steps of assembly may be made in a place outisde the factory of the manufacturer."

This specification does not cover the requirements for individual pieces of electrical switchgear or controlgear, reference for these should be made to the appropriate product specifications; it does however cover assemblies intended for use in ships, rail vehicles, machine tool equipment, hoist equipment and in explosive atmospheres.

It can be seen from this that certain classifications of assemblies are required, namely:

Classification according to:

1. The external design, a selection of which has already been mentioned.

2. The place of installation, this can vary from an outdoor installation at –25°C, to an indoor installation at +40°C with a continuous relative humidity of 50% at the maximum temperature, although higher values can be permitted for short periods. This range of ambient temperatures is generally covered in a standard design with added protective means for lower or higher values such as:

   a) Larger busbar and conductor sizes when the ambient is higher than 40°C and perhaps special insulation.

   b) Special anti fungicidal coatings for cut edges of insulation materials, at higher humidity and ambient levels.

   c) Special insulating materials for ambients below –25°C.

   d) Special preparations and finishing for steel enclosures at higher and lower values or ambient temperature.

   e) Special ventilation or heaters to prevent harmful condensation within the assembly.

3. Classification according to mobility – whether the assembly is fixed to a wall or floor, or whether the assembly is designed so that it can be readily moved from one place to another.

4. Classification according to the degree of protection provided by the assembly against contact with live parts, ingress of solid bodies and ingress of liquids, whether the assembly should be a bolted construction, a welded construction, drip proof or whether proof. All the necessary requirements and tests are specified in IEC publication 529 and with these tests a classification is given to te assembly. Generally IP30 or IP40 is an acceptable level for most assemblies but for special arrangements, up to IP68 may be required. Two tables are provided below as guidance to these classifications.

5. Classification according to the method of mounting – either fixed assemblies or removable assemblies (withdrawable to a fixed position on plug-in), which can be sub-divided as follows:–

   a) A fixed assembly or part of any assembly should only have the main circuit connections established or broken when the whole assembly is dead, generally the removal or installation of fixed parts requires the use of a tool.

   b) A removable assembly or part of an assembly should be such that the electrical connections or equipment can be safely disconnected or connected to the main circuit whilst this circuit is live and that creepage and clearance distances are maintained in the various positions of withdrawable gear. An example would be air circuit-breaker which could have a connected position, test position, disconnected position and also removed or isolated position.

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First characteristic Numeral	Degree of protection	
	Short Description	Definition
0	Non Protected	No special protection
1	Protected against solid objects greater than 50mm	A large surface of the body such as a hand (but no protection against deliberate access). Solid objects exceeding 50mm in diameter.
2	Protected against solid objects greater than 12mm diameter	Fingers or similar objects not exceeding 80mm in length. Solid objects exceeding 12mm dia.
3	Protected against solid objects greater than 2.5mm diameter	Tools, wires etc. of diameter or thickness greater than 2.5mm. Solid objects exceeding 2.5mm dia.
4	Protected against solid objects greater than 1.0mm diameter	Wires or strips of thickness 1.0mm. Solid objects exceeding 1.0mm diameter.
5	Dust-protected	Ingress of dust is not totally prevented but dust does not enter in sufficient quantity to interfere with satisfactory operation of the equipment.
6	Dust-tight	No ingress of dust.

TABLE 1
Degrees of Protection Indicated by the First Characteristic Numeral

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Second characteristic Numeral	Degree of protection	
	Short Description	Definition (see clause 4)
0	Non Protected	No special protection
1	Protected against dripping	Dripping water (vertically falling drops) shall have no harmful effect.
2	Protected against dripping	Vertically dripping water shall have no harmful effect when the enclosure is tilted at any angle up to 15° from its normal position.
3	Protected against spraying water	Water falling as a spray at an angle up to 60° from the vertical shall have no harmful effect.
4	Protected against splashing water	Water splashed against the enclosure from any direction shall have no harmful effect.
5	Protected against water jets	Water projected by a nozzle against the enclosure from any direction shall have no harmful effect.
6	Protected against heavy seas	Water from heavy seas or water projected in powerful jets shall not enter the enclosure in harmful quantities.
7	Protected against the effects of immersion	Ingress of water in a harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time.
8	Protected against submersion	The equipment is suitable for continuous submersion in water under conditions which shall be specified by the manufacturer **Note:** Normally this will mean that the equipment is hermetically sealed, however with certain types of equipment it can mean that water can enter but only in such a manner that it produces no harmful effects.

TABLE 2
Degrees of Protection Indicated by the Second Characteristic Numeral

The final classification is according to the measure for the protection of persons which are contained in IEC publication 364-4-41 and are:–

1) **Protection by Insulation of Live Parts** – an example of this is a main busbar completely covered in a high temperature resoftening PVC sheath.

2) **Protection by Barriers or Enclosures** – an example of this is a busbar chamber where the steel enclosure would have a degree of protection of at least IP40 and a warning label would be prominantly displayed on the front surface stating 'ISOLATE BEFORE REMOVING COVER'.

Another example is a Fuse Switch unit mounted behind a door whereby the door cannot be opened with the switch in the 'ON' position and the switch cannot be closed with the door open – an overide is generally provided for use by authorised personnel – this design would contain a shield to ensure the line side conductors cannot be touched while the door is open.

A further example is live conductors behind a steel barrier and where access is only available to change a lamp bulb, change a control fuse or reset a timer, and access to the conductors would require the use of a tool and again a warning label is prominently displayed.

3) **Protection by Obstacles** – This is generally for open type assemblies and a guard rail which is firmly fixed would be placed to eliminate the possibility of unintentional contact with live parts – another method would be to install the assembly behind a locked door where only skilled authorised personnel would be allowed to enter.

4) **Protection by Placing out of Reach** – Again this would be an open type assembly and would generally be wall mounted and placed at least 2.5 metres up from floor level.

5) **Protection Against Indirect Contact** – IEC 364-4-41 contains five basic protective measures, the most important and most widely used is: Earthed Equipotential Bonding and Automatic Disconnection of the Supply and the requirements to be complied with are:

a) Electrical continuity between the exposed conductive parts of the assembly and the protective circuits of the installation, this means that all major metalwork should be bonded to the earth bar provided. Small items such as screws, rivets, nameplates and any item smaller than 50mm X 50mm can be excluded. For doors, lids and cover plates the usual screwed connections or hinges are considered sufficient provided that no electrical equipment is connected to them unless the hinge or sliding contact is specifically designed to carry the maximum fault current that could flow in that part of the assembly and the size is based on the cross sectional area of the supply lead to the equipment attached to the door or cover etc. Precautions should be taken to ensure that withdrawable equipment such as air circuit-breakers retain good conductivity between the metal supporting surface and the protective circuit from the connected position through to the test position inclusively.

b) Handles, wheels and all manual operating means that are normally grasped by the hand during operation should be made of, or covered with, insulating material rated for the maximum insulation voltage of the assembly or at least of the equipment being operated.

c) Continuity of the protective circuits should be maintained at all times and the removal of a piece of equipment from the assembly should not impair this – if continuity is interrupted by means of a plug and socket device, then the live conductors should be interrupted first with continuity last and on replacing the continuity must be established first. The only other means of interruption permitted shall be links between sections of assemblies and test links which should only be accessible to authorised personnel. In addition a separate terminal of adequate size shall be provided for the outgoing protective conductor of each circuit and if the enclosure of the assembly is of a conducting material such as steel then means must be provided to ensure continuity between this enclosure and metal sheathing of cables and also to steel conduits or steel trunking if these are used to carry cables. In addition metal parts such as gland plates must be bonded to both enclosure and conduit/trunking. The size of the protective conductors to ensure adequate strength against thermal stresses can be as per the chart below or calculated from the formula.

$$SP = \sqrt{\frac{I^2 t}{K}}$$

where: Sp = CSA of cable.

I = The fault current that could flow in the protective conductor.

t = Operating time of protective device.

K = Factor dependant on the material of the protective conductor such as PVC covered copper conductors would be K = 143, with a minimum cross sectional area of $2.5mm^2$.

Cross-sectional area of phase conductors	Minimum cross-sectional area of the corresponding protective conductor
S (mm^2)	S_p(mm^2)
$S \leqslant 16$	S
$16 < S \geqslant 35$	16
$S > 35$	$\frac{S}{2}$

Note: These values only apply when the material of the protective conductor is the same as the associated phase conductor.

Another method of protection against indirect contact is:

Protection by Total Insulation – This is also known as Double Insulation, or protection by use of Class II equipment, and should carry the symbol of a square within a square. The insulating material must be capable of withstanding both the mechanical and electrical stresses to which it is liable to be subjected, be resistant to ageing, and flame resistant, and should give a degree of protection of at least IP40.

A protective conductor terminal or terminals can be provided within the enclosure but must be clearly identified and should be insulated from other live parts and conductive parts in the same manner as live parts.

Exposed conductive parts within the assembly must not be connected to the main protective terminal. If doors or lids are provided and can be opened or removed without the use of a tool then an obstacle of insulation material must be provided to afford protection against unintentional contact, not only with accessible live parts but with exposed conductive parts which may be accessible with the door open, this obstacle must not be removed without the use of a tool.

Coupled with "Protection for Personnel" is "Accessibility for Maintenance" which means that the type of personnel who will service or maintain the assembly will determine whether the functional units within the assembly can be safely inspected, tested, or removed while the circuits are live. Also the need for restricting the passage of foreign objects from one section or unit to another while inspecting, testing or maintenance is being carried out. A method for ensuring safety is "Separation by Barriers or Partitions" and in this specification four forms of assemblies are recognised.

1. **Form 1** – Having no separation or partitions: With this type of assembly it is not recommended that maintenance or servicing or inspection be carried out with the assembly live and usually a label is fixed to the front cover warning of the danger.

2. **Form 2** – Where the main busbars only are separated from the functional units – here we would expect only inspection to the carried out.

3. **Form 3** – Where the busbars are separated from the functional units and each functional unit is separated from one another, but the outgoing terminals need not be separated from the busbars. This form generally implies the use of draw out type functional units and both maintenance and inspection and test can be carried out but not removal of complete circuits.

4. **Form 4** – Would be as Form 3 above but also the outgoing terminals would be separated from each other and with this type of assembly whole circuits could be removed and replaced while the rest of the assembly remained live.

Associated with separation and barriers is the limitation of fault gasses which could be contained within a compartment and which would not impair the safe operation of an adjacent unit – here special testing may be required. This brings us to one of the main considerations as in the specification testing is divided into two categories.

1. **Type Testing** – Is intended to verify a particular design of assembly and is generally carried out on a sample which is representative of that design:– An example is the short circuit strength of busbar systems for switchboards, where two sections of a standard construction are tested together with the interconnections which are normally fitted to couple the sections together.

   Three tests would be carried out:

   a) A 3 Phase test at 50kA generally for 1 or 3 seconds.

   b) A Phase and Neutral Test at 60% of 50kA again for 1 or 3 seconds – this value is the minimum and if there are discharge lamp circuits in the assembly, then this test should be at the same current value as the 3 Phase Test.

   c) A Phase to Earth Test to verify the effectiveness of the protective circuit – generally this test would be between the highest current rated functional unit and the earth bar at the single phase current value being derived from the 3 phase short-circuit strength of the functional unit, such as a test at 29kA, this being $\sqrt{3}$ of 50kA for the operating time of the overcurrent device in the functional unit.

   From these tests, carried out on a standard range of busbar sizes, generally from 400 Amps up to 3000 Amps, together with tests on interconnections to functional units, it is possible to form the basis for an unlimited range of different assemblies, so long as the basic parameters remain the same. Such parameters would be busbar supports being set at no greater distance than the tested values, or interconnections not being changed from solid to flexible conductors or reduced in cross section.

2. **Routine Testing** – Is intended to be carried out on all assemblies and is a check to detect faults in materials and workmanship. These tests are generally visual inspection, electrical operation of the various components ,where possible – dielectric testing, checking of the protective measures provided and continuity tests of the protective circuit. Some of these tests may be carried out on site if necessary.

No	Characteristics to be checked	TTA	PTTA
1	Temperature rise limits	Verification of temperature rise limits by test (type test)	Verification of temperature rise limits by test or extrapolation from type-tested assemblies.
2	Dielectric properties	Verification of dielectric properties by test (type test)	Verification of dielectric properties by test or verification of insulation resistance.
3	Short-circuit strength	Verification of the short-circuit strength by test (type test)	Verification of the short-circuit strength by test or by extrapolation from similar type-tested arrangements.
4a	Effectiveness of the protective circuit Effective connection between the exposed conductive parts of the assembly and the protective circuit	Verification of the effective connection between the exposed conductive parts of the assembly and the protective circuit by resistance measurement (type test)	Verification of the effective connection between the exposed conductive parts of the assembly and the protective circuit by inspection or by resistance measurement.
4b	Short-circuit strength of the protective circuit	Verification of the short-circuit strength of the protective circuit by test (type test)	Verification of the short-circuit strength of the protective circuit by test or appropriate design and arrangement of the protective conductor.
5	Clearances and creepage distances	Verification of clearances and distances (type test)	Verification of clearances and creepage distances.
6	Mechanical Operation	Verification of mechanical operation (type test)	Verification of mechanical operation.
7	Degree of protection	Verification of degree of protection (type test)	Verification of degree of protection
8	Wiring, electrical operation	Inspection of the assembly including inspection of wiring and, if necessary, electrical operation test (routine test)	Inspection of the assembly including inspection of wiring and, if necessary, electrical operation test.
9	Insulation	Dielectric test (routine test)	Dielectric test or verification of insulation resistance.
10	Protective measures	Checking of protective measures and of the electrical continuity of the protective circuit (routine test)	Checking of protective measures.
11	Insulation resistance		Verification of insulation resistance.

TABLE 3
List of Verifications and Tests to be Performed on TTA and PTTA

It should be noted that this specification does not require verification of the short-circuit strength for assemblies having a prospective short-circuit current not exceeding 10kA or for assemblies protected by a current limiting device having a peak cut off current not exceeding 15kA or for auxiliary circuits connected to a transformer having a maximum of 10kVA with a secondary voltage of not less than 110 Volts.

Some additional testing may be required for combined equipment such as combinations of fuses and circuit breakers where the fuse is used as back up protection.

In view of the wide ranging nature of this specification it is essential that the specifier and the purchaser detail precisely what they require and understand what is being offered to them by a manufacturer with regard to the various classifications, forms of segregation, special requirements, short circuit requirements and installation and site conditions. The following is a guide to these requirements.

1. System supply voltage and frequency.

2. Busbar rating.

3. Prospective short circuit current at the supply entry and the through fault capacity requirements together with the withstand time.

4. Type of construction, whether open or enclosed, floor or wall mounting.

5. Degree of protection required against ingress of solid bodies or liquid.

6. Place of installation together with any special site conditions – ambient etc.

7. Fixed or mobile type of assembly.

8. Type of functional units – fixed or withdrawable.

9. Accessibility for maintainance – form 1, 2, 3 or 4.

10. Degree of personal protection – direct contact or indirect contact, or both.

11. Available access – whether front side or rear.

12. Type of system such as TT – TN etc.

13. Any special earthing arrangements.

14. Distribution of outgoing circuit conductors.

All the above items are important to the design engineer so that he can offer the most practical and compact layout, and above all, conform and meet all the requirements for safety of personnel discussed in this paper.

From the points already discussed it becomes obvious that the type of personnel operating, servicing and maintaining equipment to this specification must be skilled in electrical engineering, so if these assemblies or some types of these assemblies are to be used and operated by unskilled personnel then additional requirements for safety are needed and to this end assemblies such as miniature circuit-breaker distribution boards, consumer units and fuse boards are subjected, not only to the requirements of this part of IEC 439, but additional requirement to another part which will ensure the safety of such unskilled personnel. These additional parts of the specification are being considered by various International Technical working parties and will be issued in the near future.

Finally it should be realised that all the requirements discussed in this paper relate to the International Specification IEC 439 Part 1. The British Specification BS 5486 Part 1 will be revised to line up with the IEC but it is expected that the National Appendix – "Guide to the Fault Withstand Capability of FBA's" will be retained. This guide recognised three classes, 1, 2, and 3 and so far as short-ciruit withstand capability is concerned the guide is well understood. This is an important difference between IEC and BS and in Britain, has been used for many years as a basis for the design of large assemblies such as switchboards and will continue to do so for the forseeable future.

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— Notes & Questions —

3. OPERATION & CONTROL

Paper No. 7

Growth of Reactive Power Compensation for Transmission and Industrial Purposes using Thyristors

Author: Mr. R.J. Prizeman, Regional Manager,
Reactive Compensation Department,
ASEA Transmission.

(Speaker: Mr. Albert Chik, General Manager,
ASEA.)

GROWTH OF REACTIVE POWER COMPENSATION FOR TRANSMISSION AND INDUSTRIAL PURPOSES USING THYRISTORS

Abstract

When a transmission line is operating at the maximum capacity then any increase in the power demand from the load centre can result in additional lines that would be required to transmit the larger amount of power that is required. In many countries, it is very difficult and costly to obtain rights of way to install new transmission lines, and perhaps impossible. This together with the very high costs and the long construction time for building new lines has lead to an enormous increase in the interest shown by utilities to implement series capacitors and thyristor controlled shunt compensation in their networks. Both these concepts are utilising highly reliable power electronics such as thyristors and zinc oxide resistors and they are today well proven and accepted by utilities all over the world. The rapid growth in installations of thyristor-controlled compensators (SVC) and series capacitors now in operation is indicative of the acceptance of these methods of compensation. SVC and series capacitors are today both very important tools in the process of improving the performance of transmission networks. Often a combination of series capacitors and SVC is the best solution when utilizing a transmission system in the most efficient method.

Introduction

Since the first commercial use of electricity the necessity for reliable transmission and distribution of electrical energy has been a major influence in the developments in technology and equipment that has been undertaken within the electric power industry.

The energy crisis in 1973 during which the price of oil almost tripled was responsible for focusing the world attention towards energy conservation and also initiated a debate on environmental quality factors.

The energy crisis also drew attention to other energy sources such as hydro and coal in order to reduce the dependency of oil fired power plants, which often were located close to the load areas. It became more economical to utilise less expensive sources of power such as hydropower and coal which were located remote from the load centres.

If we compare the cost of transporting electric energy to other forms of energy transport, it is obvious that for hydropower sources it is necessary to transmit this power over often very long transmission lines. But even in the case of coal transport it is often found more economical to site the electric generation at the coal source and also transmit electric energy to the load areas over power lines.

These factors have had a marked influence on the trends of electric power transmission over the past 10 years. The power utilities requested inexpensive equipment and sytem solutions that can be put on line quickly to increase the power transfer, reduce the transmission losses and improve the reliability in power systems. All these aspects were considered in which to avoid building additional generating capacity and transmission lines.

This decade will be characterised by the improvement in utilisation of the existing transmission networks and with a growing need for network interconnections coupled with more accurate control of the complete network. The regional and international trade with electric power to be transmitted over transmission lines will grow because of the great economical benefits that are to be obtained due to low cost generation available from hour to hour. To meet these new trends the efficiency of power transmission systems must be improved through a more sophisticated control of the active and reactive power flows. An improved transmission capacity in existing lines can be achieved which is of significant importance not only because of the economical benefits but also because of the environmental criteria imposed on many power utilities.

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Series Capacitors

Series Capacitors in transmission systems compensate the line reactance to a certain degree. The length of the line virtually becomes shorter. One can say that the generation source comes closer to the load.

Series compensation in EHV power systems was introduced almost 40 years ago. Today there is more than 40,000 Mvar of installed reactive power in the world utilising series compensation.

The principle for different types of protective schemes is therefore well proven and installations of series capacitors have demonstrated a very high degree of reliability and good performance over the years. Many of the installations have been undertaken on a turnkey contract basis involving very stringent requirements in both mechanical and electrical performance.

A utility located on the west coast of the USA required a turnkey delivery on the two series capacitors of each 740 Mvar with zinc-oxide protection, the withstand requirement of seismic acceleration was 0.4 g. The delivery time from signing of contract to completion of commissioning was less than 14 months for that particular contract. The current on the 500kV line could be increased from 1800 A to 2700 A. The customer indicated the value of the improvement of the power transfer to US$50,000 per day.

In Sweden, the majority of power is generated from hydropower stations located in the north while the large load centres are located in the south. The power transmission capability has been doubled by utilising series capacitors in the 400kV system. The cost of the compensated transmission lines is approximately 10% of the cost of the transmission lines.

Similar examples can be mentioned from many other places in the world such as Argentina, Mexico, Venezuela, Canada and Turkey. Significant savings have been achieved by selecting series capacitors instead of building more lines. The time for installation of a series capacitor can be as short as 12-14 months while a long EHV-line normally will take a much longer period to construct.

Series capacitors can provide a suitable solution when it is found necessary to improve the existing characteristics of a transmission line.

Series capacitors are today furnished with non-linear zinc oxide resistors to provide immediately responding static protection for the capacitors but also other protection schemes exist depending upon re-insertion time required. For unusual faults with long duration and/or high currents a fast protective device operates and protects the zinc oxide resistors as well as the capacitors.

Therefore, series capacitors are now established today as a concept which forms part of the line, with the same reliability and maintenance requirements as for any other part of the line.

The benefits with series capacitors can be summarised as follows:

- An economical alternative in which to increase the power transfer capacity.
- Fast project implementation time compared to additional overhead lines.
- Reduce the system losses and thereby improve the economy.
- Improve the system stability, voltage regulation and reactive power balance.
- Optimise the load sharing between parallel lines.

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Static Var Compensator

The Static Var Compensator (SVC) operates as a shunt device on the network. The SVC can immediately and accurately inject or absorb reactive power to or from a power system. The word "static" relates to the fact that a Static Var Compensator utilises the power thyristor which is a static semiconductor. The thyristor can be described as a switch which operates instantly and due to the. absence of mechanical parts will not suffer any wear that is associated with mechanical components. The power thyristor in itself is a revolution in power electronics and can be compared with the revolution created by the integrated circuit for computers.

Today reactive power of approximately 26.000 Mvar is controlled by power thyristors in SVC systems installed in power transmission and distribution networks all over the world.

In contrast to Series Capacitors, the SVC is controllable. A change in the control signal gives a preset and determined change in the Mvar output from the SVC. The speed of response for example from 100 Mvar leading to 100 Mvar lagging is within a cycle and can be reversed in the coming half period and the repeated an infinite number of times if required. The control system can operate symmetrically on all 3 phases or on each phase individually depending on the application.

The SVC is also built up of proven standard components and which are in operation in many other power applications. The design and applications is flexible and modifications can be easily performed in the control electronics to adapt to new system requirements if necessary.

The major components in an SVC are:

- . Thyristor valves (Air or water cooled and with a suitable triggering system)
- Air-core reactors
- Capacitor banks
- Control system
- Power transformer, or a tertiary winding to an existing transformer (for HV and EHV systems)

The SVC also has built-in facilities to control other reactive power devices to obtain an optimum reactive power control of the system.

The size of the SVC and the range of leading and lagging dynamic control capacity is determined by studies based on the system requirements. There is hardly any technical limit on how big an SVC can be and for example there is a single system of 600 Mvar (±300 Mvar) which is at present the biggest SVC installation in the world.

A control system of an SVC can perform:

- Voltage control
- System oscillation damping control
- Reactive power control

A micro-computer can be added to the SVC and operate with different tasks and also different priority levels. For instance, fine control of voltage during normal operation or control of extreme voltage values, or damping of power oscillations when needed to maintain the operation of the transmission line and avoid tripping.

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Reactive power control is normally not used in transmission systems but it has an extremely important application in the control of reactive power and voltage fluctuations in the steel industries which employ electric are furnaces and rolling mills. These distrubances can be reflected into distribution networks. SVC is also employed to compensate single phase loads such as trains so that negative phase sequence voltage in the supply network can be compensated. Therefore the SVC solution should not be overlooked by the utilities when supplying power to the above applications.

In transmission systems an SVC is installed for the following applications:

- Improve transient stability
- Damping of power oscillations
- Voltage control

The improved damping and improvement of transient stability achieved by an SVC will mean that the transmission system can be operated with a higher power transfer without jeopardizing the system stability. Typical values for power transfer increase is 1-2 MW/1 Mvar installed SVC.

Voltage control provided by the SVC will prevent voltage collapse during extreme conditions at weak points in the network.

The SVC is very reliable. For example in an installation in USA for the AEP system has been operating without any fault since it was placed into commercial operation in 1981.

Some examples of SVC installations in HV and EHV systems are interesting to mention:

- Voltage control, preventing of voltage collapse

A SVC installation of 250 Mvar (±125 Mvar) comprising Thyristor Switched Capacitors (TSC) and Thyristor Controlled Reactors (TCR) as well as 4 X 50 Mvar breaker-switched capacitor banks was comissioned 1981 in the AEP 138kV – substation in Beaver Creek, Kentucky USA. The SVC, now the first of its kind in the world, was to take care of large voltage fluctuations and prevent voltage collapse resulting long outages in the area around Beaver Creek. Since then there has been 70-80 disturbances in the network that the SVC has handled properly and the 138kV system remained in operation without trouble.

The SVC keeps the voltage free from fluctuation in the Beaver Creek area in which previously there was a ±6- 8% load swing which put a strain on customer's equipment. The load now varies only half a volt within 115V.

Initially it was intended to "buy time" with the SVC to catch up with a delay in building a 735kV transmission line to reinforce the 138kV – system. Tody the load growth profile has changed and the small investment of the SVC in MUS$8 has lead to a total reconsideration of the schedule for the 735kV line which was estimated to cost more than MUS$100. It has been mentioned that the SVC returned the investment cost after the big outage it prevented.

- Increase of power transfer and voltage control of 420kV sea cables.

In 1981 an SVC was commissioned of 0–360 Mvar inductive at Hasle Substation for Nve, Norway. The background for selecting the SVC are as follows:

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To increase the power transfer capability between Norway and Sweden it has decided to install an 11.5 km long, 420kV, sea cable including 40 km overhead line across the Oslofiord between Tviten and Hasle substations. The reactive power generated in the cable and the connecting overhead line was 355 Mvar. To avoid a dangerous voltage rise during switching and at low load it was necessary to install reactors to absorb the reactive power. Since the cable was located in a heavy load area it was desirable to exploit the reactive power generated in the cables during heavy load when a large amount of energy was transmitted from the water power stations in Western Norway to Eastern Norway and also exported to Sweden. Due to the breaker times required the solution with fixed breaker connected reactor was not found advisable.

Furthermore, Hasle substation is an important point for the transmission link between Sweden and Norway and is automatic in maintaing the voltage level after large disturbances was responsible for the power transfer capability.

System studies proved that a fixed reactor of 160 Mvar in Tviten and two thyristor controlled reactors of each 180 Mvar in Hasle connected to two different busbars was the best solution. In this arrangement it is possible to operate the two halves jointly or independently allowing one thyristor controlled reactor to operate as a continuously conducting line reactor at disturbances in the cable supply to draw maximum Mvar at the moment the line is re-energised while the other thyristor controlled reactor could continue to regulate on the 420kV busbar. When the fault is cleared they automatically continue on joint operation to regulate on the 420kV busbar.

The experience has now shown that the power transfer capability over the line could be increased by some 300 MW with this SVC installation which now has been operating efficiently since it was commissioned.

The increased power transfer capability has made it possible to increase Norway's export of inexpensive water power to Sweden. For example when at a certain period there is a difference in production costs of US$0.20 between Sweden and Norway this means a profit of almost US$150.000 per day. This profit is normally shared so that both the buying and selling utility benefit economically.

– Stability and voltage control in Hydro-Quebec 735kV

A project for four Static Var Compensators of 445 Mvar each (–115/+330) was required to stabilise the voltage during normal operating conditions and to maintain the stability of the system during disturbances in the power transmission network from the hydropower stations along La Grande Riviere. The total generated power is at present 10.000 MW (which will be further extended) and it will be transmitted over five 735kV lines of 1000km towards the Montreal district. The cost for the Static Var Compensators has to be compared with the cost of building an extra 735kV line and installing synchronous condensers. The difference in costs were substantial to the advantages gained from the SVC solution.

Conclusion

Power electronics utilising modern material, components and system theory which has a development potential has together with increasing popularity of reactive power concepts with respect to SVC and Series Compensation resulted in favourable development of the costs. However, the costs of equipment involved with other methods adopted to increase power capacity ahs not developed so favourabley in comparison. It is noticeable that SVC and Series Compensation has established themselves as attractive alternative in optimising power transmission systems.

It is natural that when a transmission system expands it will involve new substations while it is not initially obvious that reactive compensation by SVC and series capacitors will be required. The traditional planning in many instances has been to equip a transmission network with line reactors for low load application. When the system load has increased it has been found necessary to install shunt capacitor banks until eventually operating load complications result in the installation of a synchronous condenser.

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The developments are fragmented due to the various factors of a system over an operating time period which were not anticipated initially.

Today, however, the synchronous condenser is replaced with the Static Var Compensator which are often purchase at a late stage when the utilities reach a point when a dynamic device is required. The SVC is more economical and reliable than a synchronous condenser. However, it is normal that the utility has already invested in shunt reactors and shunt capacitor banks of which the function to a high degree could have been taken over by the SVC initially.

When planning a new system the SVC and the series capacitors should be incorporated into the overall requirements from the onset in order that immediate and ultimate demands on the system can be accommodated. Line reactance is compensated with series capacitors to bring the two ends of the line closer to each other. The initial low load requirements shall be compensated with a thyristor controlled reactor which can then be expanded with thyristor switched capacitors which can be increased with the load growth.

The fragmented development of the SVC is economical as well as a convenient solution in which the utility is able to incorporate control of the system into both initial the ultimate requirements. It will provide a completely flexible and economic solution.

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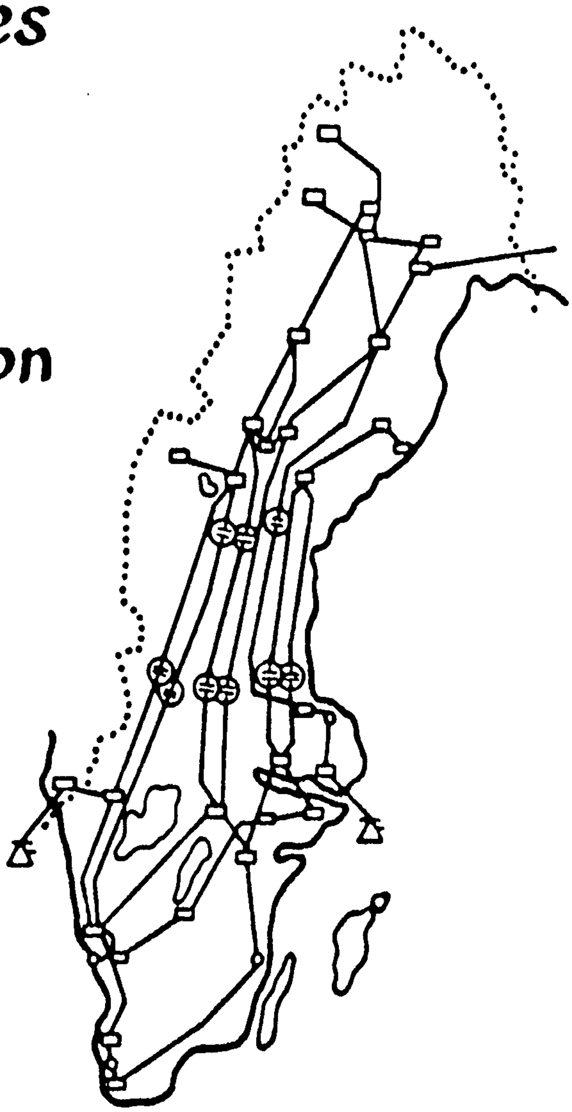
Series Compensation

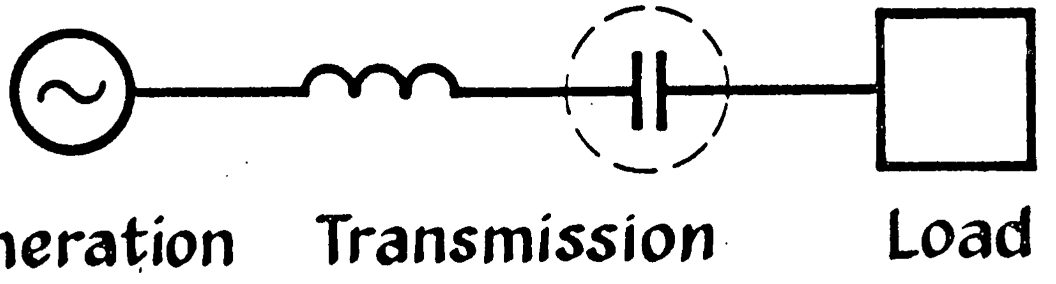
In Sweden the 400 kV system transmits 100% more power by series compensation of the power lines

⊜ Series compensation

⧋ SVS



Series Compensation



Increases transmission capability

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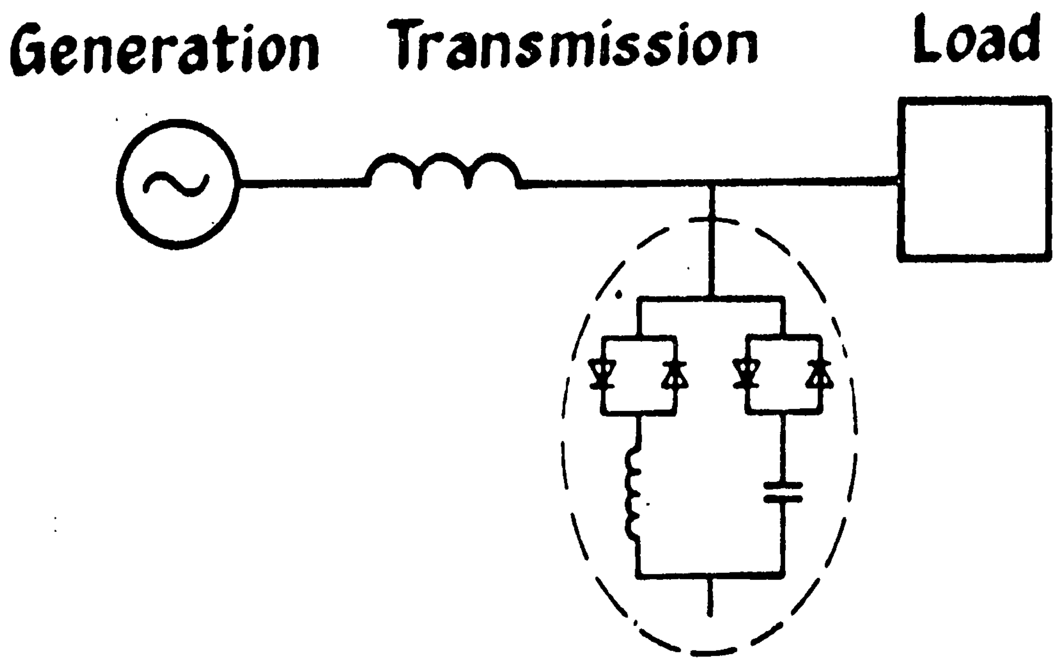
Shunt Compensation



- Increases transmission capability
- Increases load productivity

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— Notes & Questions —

Paper No. 8

Selected Stability Problems in Power System, Excitations Control and Stabilizers

Speaker: Dr. Bayer Wolfgang, Sen. Technical Manager, Siemens.

SELECTED STABILITY PROBLEMS IN POWER SYSTEM, EXCITATIONS CONTROL AND STABILIZERS

Synopsis

The power system in the Federal Republic of Germany (FRG) is compartively densely meshed, has a high load density and is integrated in the West European Grid (UCPTE Network). Calculations and measurements approximately ten years ago showed an increasing tendency towards weakly damped and even undamped power oscillations in parts of the power system. Based on extensive calculations and trials, the Kraftwerk Union AG and Siemens developed a power system stabilizer (PSS). 25 units PSS of this type are in use in the Federal Republic of Germany and 50 units are in use all over the world for stabilizing operation of large turbogenerator units, problems of power oscillation were thus eliminated.

The following points are presented on the basis of examples:

- Experience and difficulties in solving practical stability problems.
- Combined use of PSS and fast valving.
- Mutual influence between turbogenerators with and without PSS operating in parallel.
- Use of PSS and static compensators for damping oscillations.
- Influence of non-linear load characteristics.
- Future tasks.

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— Notes & Questions —

4. Electrical Installation

Paper No. 9

Fire Performance Cable and its impact on the FOC Rules and 15th IEE Wiring Regulations

Speaker: Mr. R. Getgood, BSc, CEng, MIEE,
Resident Manager, Pirelli General Cables.

FIRE PERFORMANCE CABLES AND ITS IMPACT ON THE F.O.C. RULES AND 15TH I.E.E. WIRING REGULATIONS

Electric cables rarely cause fires. The concern of manufacturers and users is the behaviour of cables when exposed to fires started by external causes. Cables designed to have special performance characteristics when exposed to fire are known as Fire Performance Cables.

The amount of information available in International Standards and manufacturers' catalogues regarding the fire performance of cables has increased greatly in recent years but there is still little guidance available to the design engineer concerning the situations in which the use of fire performance cables is desirable.

There is, of course, no substitute for compliance with the rules for good building design. These rules must include:

- the control of fire hazards in the building
- the prevention of fire spread within the building
- the provision of safe means of escape

The characteristics required of the ideal fire performance cable to enable it to make its contribution to those safety rules are these:–

1. It does not contribute to the spread of fire, i.e. it is flame retardant.
2. It does not emit excessive smoke, because smoke hinders fire fighting and escape.
3. It does not emit corrosive or toxic gases, because these gases harm equipment and people.
4. It continues to operate for a specific time without electrical failure, to maintain essential plant and services in operation.

The design engineers has to decide which combination of these characteristics he requires in any particular situation. Unfortunately, the common PVC cable is particularly poor at meeting most of these requirements.

Flame retardance

One of the earliest internationally recognised test standards for determining the fire characteristics of electric cables was BS4066 "Tests on Electric Cables under Fire Conditions", first published in 1969. This gives a method of test for flame retardance of a single cable.

The test involves applying a flame to the cable and measuring the length over which the fire damage extends after the flame has been removed and the cable has extinguished itself. This length is then a measure of the flame retardance of the cable. The shorter the length of cable which has been burnt, the more flame retardant is the cable.

BS4066 is still valid and has been adopted by the International Electro-Technical Commission (IEC) and published as their IEC 332 Part 1.

Note that the test relates to a single cable and a cable passing the test is entitled to be called flame retardant. Despite the generally poor performance of ordinary PVC cables in a fire, most good quality PVC wires in fact will pass the IEC 332 Part 1 test.

Unfortunately, when cable, even flame retardant cables, are bunched or grouped together and ignited, the mutual heating between them and the large volume of combustible material present can result in an intensive self-propagating fire.

Therefore, in 1982 the IEC 332 specification was expanded to include tests on groups or bunches of cables. This expanded specification is known as IEC 332 Part 3.

IEC 332 Part 3 includes three degrees of severity of test, representing increasing volumes of combustible material present. The severest is Category A and a cable meeting IEC 332 Part 3 Category A is entitled to be known as a "reduced propagation" or "RP" cable. Special PVCs have been developed to meet this standard and you will find cables manufactured with them marketed under the trade name "X-Flam RP15". (The significance of the figure "15" will be explained later).

X-Flam RP15 cables should be considered by design engineers for any situation where numbers of people have to evacuate a building safely and without panic. The applies to most public buildings, hotels, department stores, theatres, discos, etc. A particularly important example is hospital buildings where patients may not be able to move themselves and the longest possible time must be secured for their evacuation by others.

Smoke emission

Smoke is possibly the worst danger from the public point of view because smoke causes panic, makes evacuation difficult and hinders the operation of the fire services in locating the seat of a fire.

All PVC cables given off large volumes of smoke when burning and it is not possible to greatly alter this characteristic by changing the chemical formulation of the PVC. Nevertheless, considerable advantage is achieved by the use of reduced propagation (RP) cables because the amount of combustible material burned is limited so that the smoke output is proportionately less.

There are some special situations such as underground vaults and mass transit railways where it is essential to limit smoke emission almost to zero and specially developed compounds such as EVA have to be used in cable construction instead of PVC.

Toxic and corrosive gas emission

The dense smoke given off by burning PVC can cause death by toxic poisoning and structural damage by acid corrosion.

Considering the corrosion aspect, burning PVC evolves as much as 30% by weight of hydrochloric acid gas and there have been occasions when a small fire involving PVC has caused corrosion damage far in excess of the damage caused by the fire itself.

For example, in a telephone exchange in London some years ago, a small fire occurred in a garbage bin which contained some PVC cable ends. The fire caused damage to the value of less than £200 but, later, electronic equipment to the value of £50,000 had to be replaced due to the onset of corrosion damage.

The corrossion was the result wholly of the burning of the small quantity of PVC cables.

So with buildings containing sensitive equipment, in computer suites and communications rooms for example, consideration must be given to reducing acid gas emission.

As a minimum, reduced propagation (RP) cables to limit the spread of fire and therefore the quantity of acid gas evolved should be chosen. Further improvement is achieved by using RP cables in which the acid gas emission is reduced by half to about 15% by additional refinement of the PVC formulation. These are the cables known as "X-Flam RP15".

Cables using materials in their construction which do not give off any toxic or acid fumes should be used where there is risk to life. These cables do not contain PVC and are known as LSOH or Low Smoke Zero Halogen cables. The material EVA, used for its low smoke properties, also has excellent low halogen properties and is frequently used for LSOH cables.

Legislation is being discussed in U.K. at present which, if introduced, would require the use of low smoke, zero halogen cables for all the internal wiring of buildings. Leading cable manufacturers are ready for this development with a complete range of LSOH designs of building wires for both surface and conduit installations.

Fire resistance

The performance characteristics described so far are all physical ones and have no bearing on whether or not a cable survives electrically in a fire. Where a cable has to continue to function electrically in a fire it is known as a fire resistant cable.

There are two ways of achieving this in practice:

- by using a material for the insulation which is unchanged by fire, i.e. a fireproof insulation

- by using an insulating material which does burn in a fire but whose oxide is also an insulator

A well-known example of the first principle is mineral insulated cable or MICC.

However, MICC is unpopular with users, not only because of the high cost, but also because of the difficulties of installation of maintaining moisture resistant terminations, and the problem of low IR readings when moisture does get in. Also, MICC is electrically weak and not suitable for use on circuits subject to voltage impulses. Because of this, some cable manufacturers have introduced designs which do not require special installation techniques or moisture sealing. The installed cost of these cables can be considerably less than for MICC. One particular well known design is FP200.

This development has been helped by the introduction, in 1970 of IEC standard 331, which defines the length of time for which a fire resistant cable must survive in the fire at full rated voltage and the maximum fire temperature.

The temperature chosen is 750°C, which is the temperature of a typical building contents fire, and the length of time selected is 3 hours.

More recently, a new British Standard, BS6387: 1983, has been published which incorporates a wider range of tests including temperatures up to 1000°C (representing petrochemical fires), and tests with vibration and water spray impingeing on the cables which more closely simulate the fire conditions under which the cables may have to operate in practice.

BS6387 will form the basis of a new edition of IEC 331 to be known as IEC 331 Part 2, which will be published shortly.

Fire resistant cables are essential for all circuits which must remain in operation during a fire to ensure continuity of supply to essential equipment such as stand-by generators, water pumps, firemen's lifts and automatic shutdown systems as well as smoke detection and fire alarm circuits, emergency lighting, public address, telephone and security installations.

"Add On" Fire resistance

This refers to methods claimed to add fire resistance to cables during or after installation such as by a sprayed-on fire resistant coating or by drawing ordinary PVC wires into conduits buried in the structural concrete.

Design engineers should not be deceived. The best that can be said for such methods is that the fire resistance will most likely be greater than if the cables were not thus treated. Note that the degree of fire resistance is totally undefineable as an installation cannot be tested for fire resistance after completion.

The idea that pulling PVC wires into buried conduits imparts fire resistance predates the invention of the modern, economical, fire resistant cable and it is surprising that one of the recognised codes of practice on this subject, the Rules of the Fire Offices Committee of UK Insurance Companies for fire alarm circuits, still accepts it.

However, the FOC is thought to have been impressed recently by arguments that the fire resistance of a circuit must be the responsibility of the designer and not left to the judgement of the installation contractor. Only then can the security of a circuit be guaranteed in defined terms.

Discussions are currently taking place between the FOC, the IEE and cable manufacturers and it is likely that the outcome will be the withdrawal of the FOC approval of PVC wires in buried conduit.

Design engineers should take note of IEE Wiring Regulations 15th Edition Clause 563-2 which states:

> "Circuits of safety services shall not pass through locations exposed to fire risk unless the wiring systems used are fire resistant".

The only way of ensuring compliance with this clause is to use tested and certified fire resistant cables.

Fire performance cables – when are they necessary?

Professional design engineers today face increasing public criticism if weaknesses in their designs are revealed by any failure of the system to operate properly.

The design engineer therefore is continually faced with the problem of assessing the degree of risk against the cost of eliminating it.

There is a multiplicity of choices open to the design engineer where fire performance of cables is concerned. They can be summed up as follows:

1. Flame retardance is an inherent property of most good quality PVC wires when used singly or in single circuits. To be sure, specify cables to IEC 332 Part 1.

2. Flame retardance is not a property of groups or bunches of PVC cables. For these circumstances, specify reduced propagation (X-Flam RP15) cables to IEC 332 Part 3 Category A. A bonus will be reduced smoke and acid gas emission.

3. If the need is for the lowest possible smoke and acid gas emission, specify LSOH, – Low Smoke Zero Halogen – cables.

4. Where sustained operation of plant throughout a fire is required, specify fire resistant cables to IEC 331 as a minimum or to BS6387 for enhanced security.

Any combination of these characteristics can be achieved by correct cable choice but, for particularly sensitive situations, for example for control circuits on underground mass transit railways, in power stations and for high security circuits on offshore oil platforms and military installations, specify the complete package – fire resistant, reduced propagation, low smoke and zero halogen.

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— Notes & Questions —

Paper No. 10

The Application of Residual Current Circuit Breakers

Speaker: Mr. J. Rickwood, BSc(Eng), CEng, MIEE, Company Standards Engineer, Crabtree Electrical Industries Ltd.

Earth Fault Protection

One of the aspects of electrical distribution practice, or "Installation Engineering" that has received particular attention in the last few years has been that of earth fault protection with Residual Current Circuit Breakers (rccb's) receiving special prominence. These devices have seen many developments, and there are more to come.

It has long been a requirement of "Wiring Rules" such as those formulated by the IEC (IEC Publication 364) or the highly regarded IEE Wiring Regulations (now into their 15th Edition) that final circuits shall have protection aginst short circuit, over load, and earth fault. The first two are easy to recognise being excessive current flow in the conductors, but earth faults may not be so easily detected. Their magnitudes can be well below the rated currents of their circuits and need particular devices to recognise them.

The simplest approach is to ensure that all metal work in an installation is bonded together and to the earth point of the source so that any fault current to the metal work has a low resistant path back to the supply. It then becomes a current of sufficient magnitude to operate the overcurrent protection which may be either a fuse or mcb. The IEE Wiring Regulations (15th Edition) contain tables showing the maximum value of earth fault loop impedance to achieve this, but it may not always be practical to obtain low enough values to ensure operation of the overcurrent protection devices in a time sufficient to give shock risk protection.

The characteristics of any miniature circuit-breaker are such that compliance with the IEE tables will also give thermal protection to the circuit protective conductor. However, for some ratings of fuse, lower loop impedance than those required for shock risk protection alone are necessary in order to give this thermal protection. Taking this into account the following tables have been derived from the IEE Regulations to indicate the appropriate maximum earth fault loop impedance.

TABLE 1

Maximum Loop Impedance to meet IEE Wiring Regulations for socket outlet circuits.

DEVICE		5A	15A	20A	30A	45A
Type 1 mcb	(BS 3871)	12.0	4.0	3.0	2.0	1.33
Rewireable Fuse	(BS 3036)	9.6	2.7	1.8	1.1	0.6
House Service Fuse	(BS 1361)	11.4	3.4	1.8	1.2	0.6
Type 2 mcb	(BS 3871)	6.8	2.3	1.7	1.1	0.75
Type 3 mcb	(BS 3871)	4.8	1.6	1.2	0.8	0.53
DEVICE		6A	10A	16A	20A	32A
Type 1 mcb	(BS 3871)	10.0	6.0	3.75	3.0	1.87
HRC Fuse	(BS 88)	8.7	5.3	2.8	1.8	1.1
Type 2 mcb	(BS 3871)	5.67	3.4	2.12	1.7	1.06
Type 3 mcb	(BS 3871)	4.0	2.4	1.5	1.2	0.75

Impedance Values in Ohms.

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TABLE 2

Maximum Loop Impedance to meet IEE Wiring Regulations for Fixed Equipment.

DEVICE		5A	15A	20A	30A	45A
Type 1 mcb	(BS 3871)	12.0	4.0	3.0	2.0	1.33
Rewireable Fuse	(BS 3036)	20.0	5.6	3.4	2.5	1.4
House Service Fuse	(BS 1361)	17.0	5.3	2.5	1.5	0.65
Type 2 mcb	(BS 3871)	6.8	2.3	1.7	1.1	0.75
Type 3 mcb	(BS 3871)	4.8	1.6	1.2	0.8	0.53
DEVICE		6A	10A	16A	20A	32A
Type 1 mcb	(BS 3871)	10.0	6.0	3.75	3.0	1.87
HRC Fuse	(BS 88)	13.0	7.7	4.4	2.2	1.4
Type 2 mcb	(BS 3871)	5.67	3.4	2.12	1.7	1.06
Type 3 mcb	(BS 3871)	4.0	2.4	1.5	1.2	0.75

Impedance Values in Ohms.

Table 1 provides fault clearance in 0.4 secs. and Table 2 provides fault clearnace in 5 secs. Earth leakage circuit breakers will clear in less than 40 mS under these circumstances and so offer the facility of detecting and clearing a fault more rapidly than other devices, and without the fault reaching overcurrent proportions. They can also offer many other advantages.

Strictly speaking the term, "Earth Leakage Breaker" covers two entirely different types. The first form was the Fault Voltage operated unit which measures the voltage between metal work and earth and trips out if that voltage is excessive (i.e. greater than 40). This type is susceptible to nisance tripping by responding to faults imported from other installations and its effectiveness can be severly reduced by parallel earth parths on the installation, needing much care in the installation of such devices. None of these problems arise with the current operated form or Residual Current Circuit Breaker (rccb) and use of the voltage operated type is now no longer recognised by the IEE Wiring Regulations.

Principle of Operation of rccb's

In a single phase rccb the load current of the circuit is fed through two equal and opposing coils wound on a common transformer core. When the phase and neutral currents are balanced as they should be on a healthy circuit they produce equal and opposing fluxes in the transformer core hence there is no resultant voltage generated on a detector coil also would on the core. If however more current flows in the phase conductor than in the neutral conductor as a result of some of the currrent returning via earth, an out of balance fluex will be produed which will be sensed by the detector coil. This can then be arranged to trip a circuit-breaker mechanism.

In the earliest forms the detector coil was connected directly to a trip coil on a circuit breaker mechanism and in this basic form sensitivities of 500 milli amps. were easily attained. However much higher orders of sensitivity (i.e. lower tripping currents) are now desireable and can be obtained by amplifying in some way the output from the detector coil ofthe current balance transformer (which will be considerably lower for lower tripping currents) so as to obtain enough power to trip the circuit breaker mechanism. The usual method relices on using the output from the detector coil to nulify a weak magnetic field in a specially designed trip mechanism.

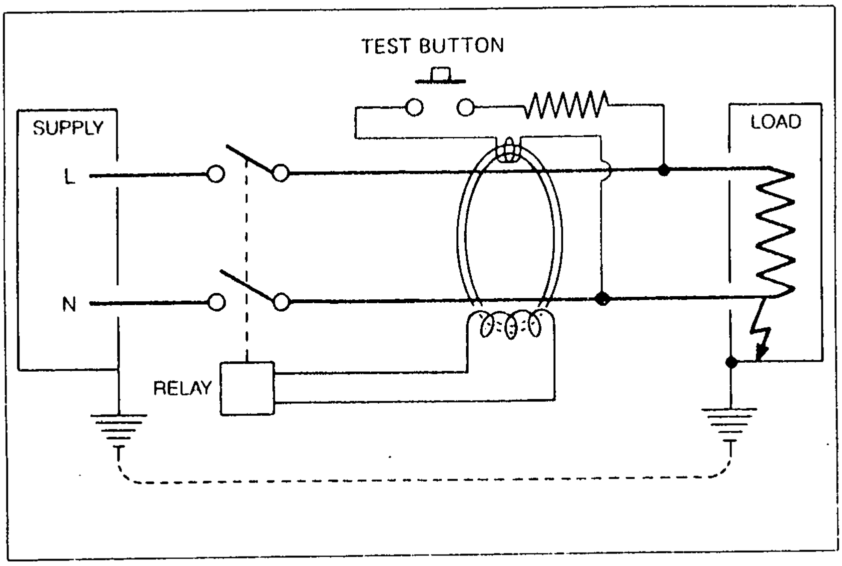

Fig.1 Principle of 'Residual Current Circuit-Breaker'.

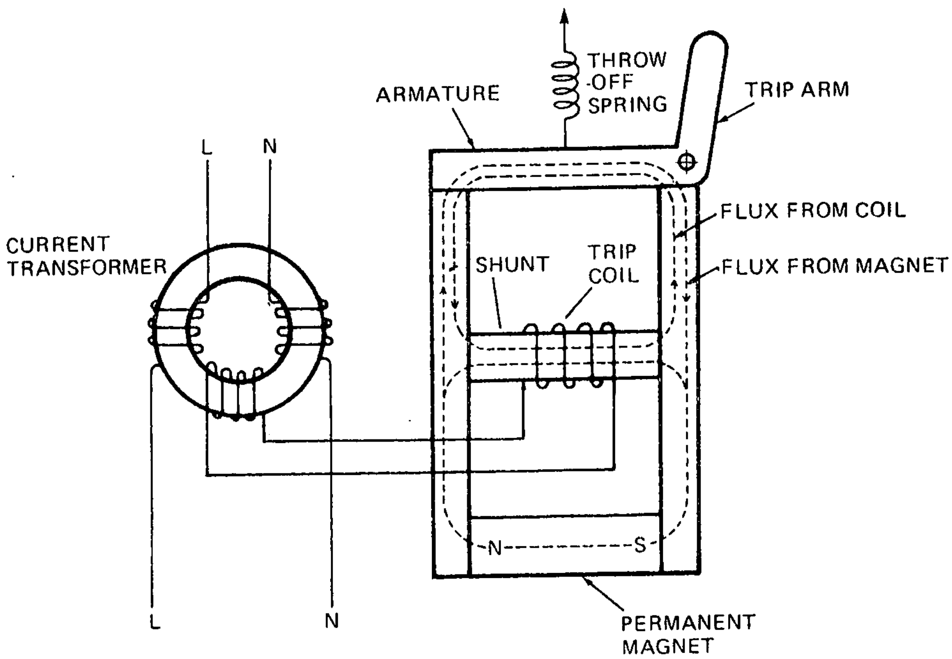

Fig.2 Principle of 'Polarised' Relay.

The main path of the magnetic flux from the permanent magnet is through a shunt, which is so arranged that only a weak magnetic flux continues through the armature. This weak flux has just sufficient force to retain the armature against the effects of a throw off spring. By applying the output from the detector coil to the trip coil a second flux is produced which passes through the armature in opposition on that from the permanent magnet. These two fluexes will cancel out en-abling the throw off spring to move the armature and cause the trip arm to operate the tripping mechanism of the circuit-breaker. This principle can be used to provide a range of rccb's with different sensitivities and the same physical size simply by using different numbers of turns on the coil. The normal sensitivities offered vary between 1 amp. and 30mA.

An alternative method is to use an electronic or solid state power amplifier. This method has the advantage of providing considerably more power to ensure more positive operating of the circuit breakers as it often uses the main supply itself as the tripping power. Sensitivities of 30mA or better can be achieved in this way.

Although the principle has been described in terms of single phase units it also applies to three phase and neutral breakers. In this case the transformer used has four main windings, one for each of the three phases and one for the neutral, in addition to the detector coil. The residual current in the neutral will automatically compensate for any unbalance loading in the individual phases.

Selection of rccb's

The basic requirement for an rccb giving indirect shock risk protection is that the earth fault loop impedance multiplied by the sensitivity of the unit should not exceed 50.

Initially the most popular sensitivity was 300mA as this gives a high level of fire risk protection coupled with shock risk protection in the presence of earth loop impedance not exceeding 166 Ohms. For increased levels of protection 100mA sensitive units are available whcih give even higher levels of fire risk protection and shock risk protection on earth fault loops of up to 500 Ohms.

TABLE 3

Maximum Loop Impedance for r.c.c.b. Protection.

RCCB Nominal Sensitivity mA	1000	500	300	100	30
Max. Loop Impedance Ohms.	50	100	166	500	1666

It may be throught that to get the ultimate in protection it is necessary to get the lowest possible tripping current but as sensitivities are increased other problems may be introduced, namely "nuisance tripping" again. Long lengths of cable can exhibit charging inrush currents of sufficient values to trip very sensitive units and some pieces of equipment may produce a standing leakage current which is quite harmless in itself but would cause such devices to operate. Modern wiring regulations draw a distinction between "earth fault" currents and "earth leakage" currents, the difference being that an earth fault current is one that has arisen from a failure of some part of the installation whereas an earth leakage current is a current which flows to earth in a circuit which is intrinsically sound.

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30mA is generally accepted as the maximum current that the human body can withstand continuously without damage to the heart, and 10mA is the maximum current before muscles become immobilized. Rccb's are available with such sensitivities, but wiring regulations insist that protection against direct contact be given by either insulating live parts, or containing them behind barriers or enclosures, or even placing them out of reach. Rccb's cannot be used in place of such methods but they can be used to give additional protection in high risk situations, e.g. poor earthing, flexible cables etc.

In fact the IEE Wiring Regulations insist on rccb protection on socket outlets intended to supply portable equipment out of doors, and also on installations where the protective circuit does not involve a continuous metal path back to the source (i.e. TT and IT systems).

Continuous Development

Now that rccb's based on the simple concepts have been in use for many years, experience has indicated applications where an even wider range of protection can be provided by improvements to the basic design. The development of a world wide (IEC) standard for rccb's has been hampered as it tries to include requirements to cover these improvements as they occur.

The Effect of D.C.

Some appliances that may be supplied through rccb's include semi conductor rectifiers which could, under fault conditions, produce a d.c. fault current. It is argued that not only would such a fault not be detected by the core balance transformer in an rccb but it could saturate the transformer and so prevent it detecting an a.c. fault. In practice there are no recorded fatalities resulting from the failure of an rccb due to the presence of d.c. fault current and it is not suggested that existing types of rccb's are inadequate and need replacing. However, IEC will shortly be publishing a classification of rccb's according to their behaviour in the presence of a d.c fault. Three different classes will be recognised.

Type A.C. This covers the first generation of rccb's designed to trip on pure a.c. faults and having no criteria for the performance of the rccb in presence of a d.c. fault component.

Type A - These are the latest designs which will respond not only to a pure a.c. fault but also will trip in the presence of a pulsating d.c. wave form. Their performance is verified by means of a fault current derived from half wave rectified a.c. together with a d.c. current of 25% of the rated current. The breaker must trip below its rated current on pure a.c. and below 1.4 times its rated tripping current on the pulsating d.c. wave form.

Type B – This class is intended for rccb's which will respond to the presence of pure d.c. but the test parameters are still under consideration.

Breakers of both type A.C. and type A are now available and it is felt that Type A will cover any type of fault likely to be encountered in domestic premises. The IEC standard for rccb's will cover both types A and A.C. In preparing this classification the IEC has sought to acknowledge improvements in design rather than necessities in practice.

Double Earthing

It is also argued that the presence of a neutral to earth fault on the load side of an rccb on a T.N. system would also inhibit its operation. Such a fault would effectively short out the neutral winding on the core balance transformer since on a T.N. system the supply neutral is effectively at earth potential. Again no hazard to users arises from these circumstances except in the prevention of operation of the rccb's should a second fault occur. The presence of such a neutral earth fault would be readily detected by the recommended periodic use of the test button. Such neutral earth faults as have occurred have been due to incorrect installation work rather than a fault developing upon the installation at a later date. Nevertheless it is possible to provide sensing arrangements in electronic types of rccb to detect this extemely rare fault condition although the increase in cost does not warrant their use in general applications.

Nuisance Tripping

One of the criticisms raised against the fault voltage operated device was its susceptibility to nuisance tripping. Operation on harmless transient surges can indeed cause great inconvenience. For this reason a test has been developed to check the response of an rccb in the presence of a surge and such a test will be included in the eventual IEC standard.

Solid State Devices

The use of solid state or electronic devices in rccb's can bring both advantages and disadvantages. Amongst the advantages are included the ability to manufacture a rccb that will respond in the presence of d.c., and also the manufacture of an rccb that will respond in the presence of a neutral to earth fault. Amongst the disadvantages, is the reliance on a power supply to achieve tripping under fault conditions. It has to be borne in mind that the mains voltage may be considerably reduced during fault operations whilst absence of a neutral connection could remove detection leaving a shock risk possibility from the remaining phase connection. However it must be remembered that a rccb should never be used as the sole means of shock risk protection and as far as shock risk is concerned it will only be called on to give protection where other methods such as insulation, placing out of reach, barriers or enclosures have been defeated. The reduction of mains voltage implies a very high fault current has occurred which, if large enough to severely affect the line voltage will have been large enough to operate overcurrent protection! It could be that wiring rules will apply restrictions on the use of mains powered devices to further ensure that they are not used as the sole means of protection.

The Price of Popularity

Many people, now realising the advantages that Residual Current Circuit Breakers can give, are calling for their use in an ever increasing number which itself could introduce a problem if two or more rccb's are connected in series. Discrimination could then be a problem since an rccb does not of itself limit the fault current and two rccb's placed in series will trip out together if the fault current exceeds the rated tripping current of both of them. To avoid this lack of discrimination and yet enable both main and branch circuits to have rccb protection, rccb's with integral time delays are being introduced. In this manner an rccb supplying others could be chosen of a type having a time delay of sufficient magnitude to let the remaining breakers operate first and still operate itself if the fault persists for a dangerous length of time.

In Practice

There is no doubt that may installations will continue to rely on the overcurrent protection to give earth leakage protection to its circuits as well, but the use of rccb's offer an even safer installation and there are many ways in which they can be applied.

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One way is to have an rccb integral with a socket outlet (Fig. 3) which has the advantage that it localises any disconnection. It is suitable as an addition to an installation but it would be expensive to treat every socket outlet this way.

Similar units are available for commercial applications in either metalclad or decorative finishes, or alternatively, for industrial installations with various types of socket outlets.

An alternative to the protected socket outlet is to have a whole section of an installation protected by using an rccb as a section breaker, or in domestic premises, as the main incoming switch or isolator in a consumer unit. The possible problem here is that an earth fault disconnects everything, even the lighting, which could introduce further hazards although another approach is to have an rccb controlling only that section of busbar feeding socket outlets and the like where the majority of faults are likely to occur (Fig. 4). The result is an economic use of materials with a high degree of integrity on lighting circuits.

Yet another alternative is the use of a combined mcb/rccb providing both overcurrent and earth leakage protection in the same unit (Fig. 5). This can be fitted to both existing and new installations to provide individual circuit protection.

The number of varients of rccb's now available from British Manufacturers and being developed will ensure that somewhere there is the solution for your earth leakage problem.

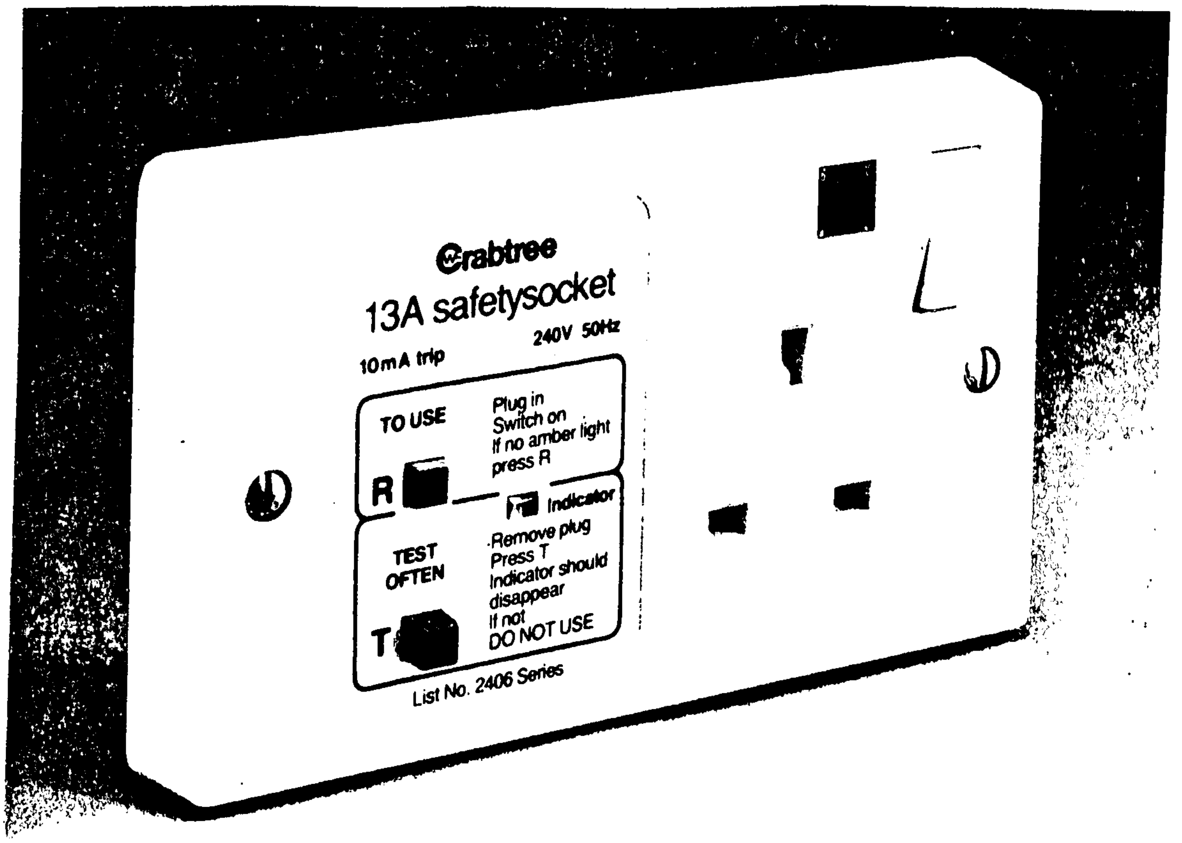

Fig. 3 - Residual Current Protected Socket Outlet.

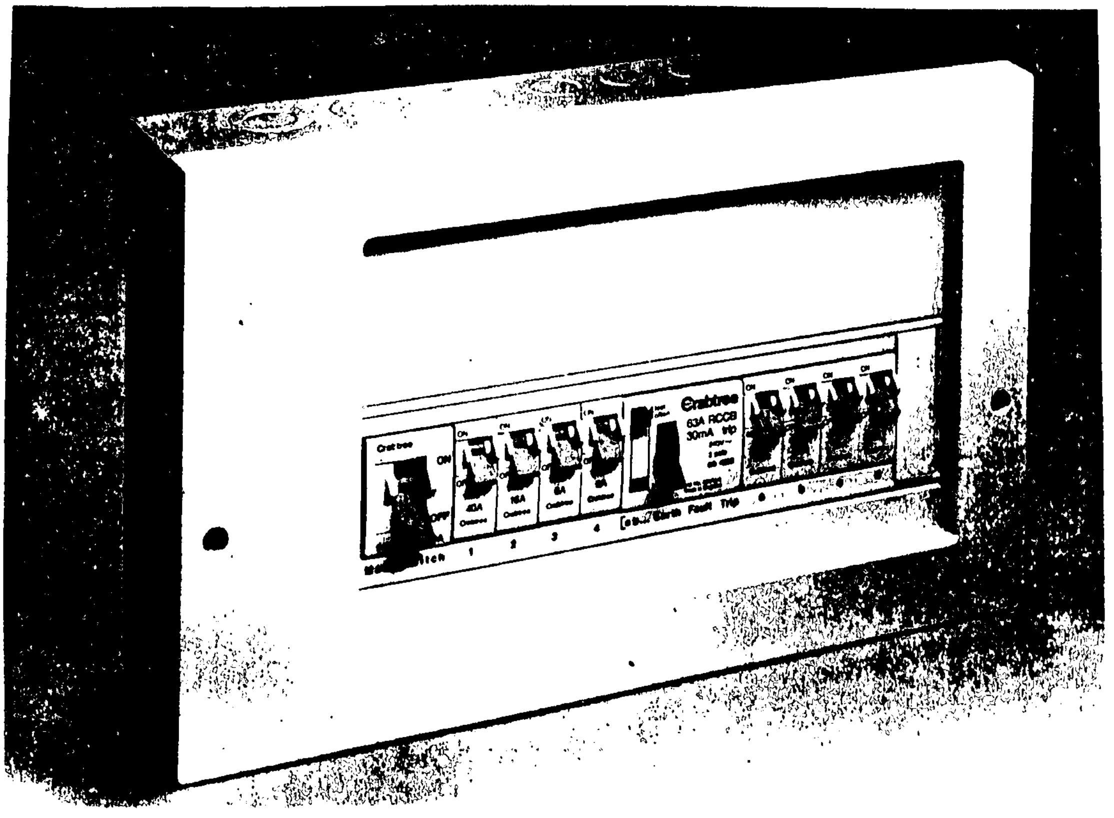

Fig. 4 - Split Load Consumer Unit.

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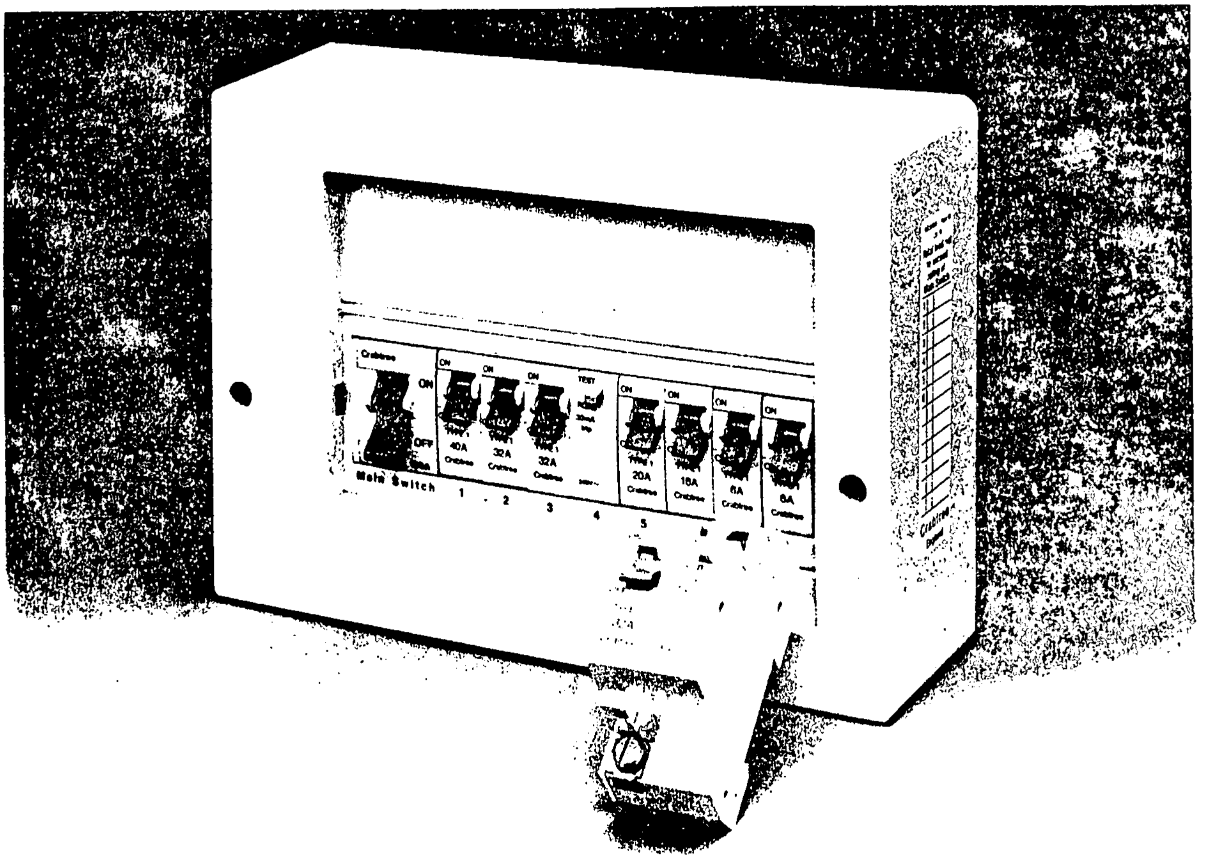

Fig. 5 - Combined mcb/rccb.

— Notes & Questions —

Paper No. 11

Proposed Code of Practice for the Wiring of Fixed Installation in Buildings

Speakers: Mr. H.N. Chan, BSc, MSc, MHKIE, CEng, MIEE, Sen. E&M Engineer, EMSD.
Mr. S.K. She, MSc, MHKIE, CEng, MIEE, E&M Engineer, EMSD.

PROPOSED CODE OF PRACTICE FOR THE WIRING OF FIXED INSTALLATIONS IN BUILDINGS

Introduction

In a symposium on 'Management and Implementation of Electrical Safety in Hong Kong' organised by the Hong Kong Institution of Engineers two years ago, a paper was presented describing the general structure and principles of the new Electricity Bill which was under consideration by the Government.

As mentioned in that paper, under the new Electricity Bill, the Governor-in-Council will be empowered to make regulations governing the safe use and supply of electricity. One of the proposed regulations is the Regulations for the Wiring of Fixed Installations in Buildings and Premises (WIRING REGULATIONS). The WIRING REGULATIONS set out the minimum safety requirements which all future fixed electrical installations must comply with. These minimum requirements relate to all safety aspects of electrical work carried out on fixed installations. The WIRING REGULATIONS are based on consultation with the concerned parties (such as the Supply Companies, electrical trade and industry), the existing Supply Rules of the Supply Companies; and the current requirements of the Institution of the Electrical Engineers Wiring Regulations with modifications to suit the local conditions where necessary. Although the IEE Wiring Regulationsare largely based on the British Standards, our WIRING REGULATIONS have been written in such a way that the statutory requirements are general and not restrictive in nature, i.e. they will not preclude installations meeting other national or international standards.

Because the WIRING REGULATIONS are written in such a way, it is necessary to produce a Code of Practice (the CODE) to give detail technical guidelines on how the statutory requirements of the WIRING REGULATIONS can be met. An electrical installation which complies with the CODE is deemed to satisfy the requirements of the WIRING REGULATIONS. It must be stressed, however, that the new legislation will not preclude other means of achieveing these requirements. The CODE therefore is not part of the statutory requirements and will not have the same force of law. Nevertheless, failure to observe it will constitute strong evidence of guilt in the event of a prosecution being brought under any relevant provision of the new legislation.

Now, I would like to give more details of the CODE including its contents and implementation.

Contents of the CODE

General Structure

The numbering system of the CODE corresponds to that of the WIRING REGULATIONS. As there are 24 regulations in the WIRING REGULATIONS, correspondingly 24 codes are required in the CODE. However, 2 additional codes are also included to describe the general workmanship and examples of application, making a total of 26 codes in the CODE.

Sections of the Code

The CODE is divided into 4 main sections as follows:–

(a) General

This section covers:–

(i) definitions of the technical terms used in the CODE;

(ii) the types of installations to which the CODE applies. The CODE applies to all low and high voltage fixed installations in buildings and premises, except for the following:

- electrical installations belonging to organisations exempted under the WIRING REGULATIONS, such as installations belonging to the Government, Housing Department, MTRC, KCRC and Supply Companies etc.;

- electrical installations contined in an forming part of a mobil unit such as air-craft, motor vehicles and sea-going vessels since the CODE is intended for fixed installations in buildings and premises only;

(iii) general safety practices relating to all aspects of electrical work including workmanship, materials, design, construction, installation and safe access to facilitate operation, inspection, testing and maintenance of electrical equipment.

(b) Practices to be followed in the construction of electrical installations

This section covers:–

(i) segregation of different types of circuits, circuit arrangements, circuit capability to carry the maximum demand,

(ii) effective means of isolation, switching, overcurrent and earth leakage protection;

(iii) practices to be followed in the construction of installation which are subject to adverse environmental conditions such as high ambient temperapture, corrosive atmosphere, exposure to weather or in surroundings susceptible to risk of fire or explosion;

(iv) construction of overhead lines.

(c) Practices and Procedures to be followed in the operation and testing of electrical installatins

This section covers:–

(i) safe operation and maintenance procedures including display of labels and notices and other safety precautions;

(ii) safe practices in carrying out inspection, testing, alteration or addition to electrical installation.

(d) General workmanship and examples of application

This section covers:–

(i) general workmanship in the installation of conduits, trunking, cables, conductors and making of joints and terminations.

(ii) examples of typical applications of the CODE.

Implementation

The CODE, the main BILL, the REGULATIONS FOR THE REGISTRATION OF ELECTRICAL CONTRACTORS AND WORKERS and the WIRING REGULATIONS, have all been circulated twice to the concerned parties for comments. Draft drafting instructions for the Bill and these Regulations, will be shortly submitted to the Law Draftsman.

After the Bill and the Regulations are enacted, the Director of Electrical and Mechanical Services (the Director) will issue the CODE for guidance to the electrical contractors and workers. At that time, the registration of the electrical workers and contractors will commence which is schedule to take 18 months to complete. Thereafter all new electrical installations will be required to meet the requirements of the WIRING REGULATIONS.

Since the CODE is not part of the statutory requirements, it is capable of being updated by the Director as and when necessary, without having to amend the Ordinance or its regulations.

Examples of typical applications of the CODE

As mentioned above, the technical requirements of the WIRING REGULATIONS will be general and the CODE will give guidelines on how these requirements can be met. The following examples illustrate how the CODE can be applied to meet the statutory requirements:–

Example (a) Access and working space

Reg. 4 of the WIRING REGULATIONS states that all electrical equipment requiring operation, maintenance or attention shall be so installed as to provide adequate and safe means of access and working space for such activities.

To give guidelines on the requirements of safe access and working space, Code 4 (see Annex 1) provides the dimensions of clearance spaces for various types of electrical equipment such as switch-gear and meters under various circumstances.

Example (b) Final circuit arrangements

Relating to the provision of adequate numbers of socket outlets so as to obviate the abuse use of adaptors, Reg. 6 prescribes some arrangements of the final circuits as follows:–

(i) a 5A radial circuit connecting not more than four adjacent 5A socket outlets,

(ii) a 15A radial circuit connecting not more than two adjacent 15A socket outlets, and

(iii) a radial/ring circuit connecting unlimited number of 13A socket outlets.

To provide more details on these circuit arrangements for compliance with the WIRING REGULATIONS as a whole, Code 6 (see Annex 2) describes the dimensions of these socket outlets, the types of protective devices to be used and the accepted practice of circuit arrangements. Code 26 (see Annex 3) also recommends the minimum numbers of socket outlets in dwellings to be 3 in kitchen and bedroom and 4 in living room etc.

Example (c) Breaking capacities

Reg. 9 states that every circuit shall be protected against overcurrent by devices which are of adequate breaking capacity.

To give guidelines on the requirements of adequate breaking capacities, Code 9 (see Annex 4) lists minimum breaking capacities of protective devices required at various supply conditions such as supply directly taken from a transformer within the premises, supply tapped from rising mains, supply taken from the Supply Company's service box or overhead line.

Example (d) Protection against earth fault current

Reg. 11 prescribes that where metalwork is earthed, the circuits concerned shall be protected against the persistence of earth fault currents.

To give guidelines no how to protect circuits against the persistence of earth fault currents, Code 11 describes the methods of earthing for this purpose. In this connection, instead of recommending in a formula to select the size of protective conductors (as recommended in the IEE Wiring Regulations) which is difficult to use, Code 11 provides tables (see Annex 5) giving the minimum cross-sectional areas of copper or aluminium protective conductors for circuits protected by fuses, MCBs, moulded case circuit breakers and circuit breakers for easy reference. This Code also tabulates (see Annex 6) the acceptable maximum earth fault impedances for circuits of various current ratings and protected by the above protective devices for easy reference.

Example (e) Overhead lines

Reg. 16 states that low voltage overhead lines shall be properly designed, constructed, installed and maintained so as to prevent danger.

To give guidelines on the proper design etc, Code 16 (see Annex 7) spells out the acceptable installation practices regarding the line support, joints, service connection, installation of poles, stay wires, carrier wires and earthing etc.

Example (f) Display of labells and notices

Reg. 18 prescribes the display of various warning notices for switchrooms, substations and electrical equipment on which work is being carried out etc., to warn public the existence of danger and to safeguard those people working on the equipment.

To provide more details on these, Code 18 (see Annex 8) descibes the minimum dimensions of these notices, the acceptable forms of these notices such as engraved plastic boards, the recommended locations for fixing these notices etc.

Example (g) Inspection and Testing

Reg. 20 prescribes that every electrical installation on completion be inspected and tested, and reg. 21 prescribes that owners of categorised installation (i.e. places of public entertainment etc.) shall arrange their installations to be inspected and tested.

To give guidelines for an electrical installation to comply with the WIRING REGULATIONS, Code 20 details the inspection and testing procedures and provides the check-list (Annex 9) of items to be inspected and tested.

Example (h) Safety Precautions

Reg. 22 states that a registered electrical worker shall ensure that all safety procedures are taken for electrical wiring work carried out by him or under his supervision.

To give guidelines on safe procedures, Code 22 recommends certain safety precaution, such as:—

(i) screening of other conductive parts whilst working on energised parts;

(ii) locking off of incomplete parts of an installation prior to connection of supply to other parts (the completed parts) of the installation;

(iii) disconnection from the supply or positive isolation with the isolating device locked off prior to commencement of a major alternation, and

(iv) use of a non-conductive or insulated ladder on electrical wiring work.

Conclusion

The CODE is based on the most up-to-date international standards and practices. It is hoped that if electrical installations are made in compliance with the CODE, public safety can be enhanced as far as reasonably practicable.

In light of technological advance and the further development in the field of electrical engineering, it is anticipated that the CODE will be updated whenever necessary to keep it in line with the latest technology. For this purpose, the inputs from the concerned parties such as the Supply Companies, electrical trade and industry and yourselves will continue to play an important part in the future revision of the CODE.

Annex 1 – Extract from Code 4

(2) Clearance space

(a) A minimum clearance space of 450 mm for the full width and in front of meters or of all low voltage switchgear having a rating not exceeding 100 amperes such as consumer units and isolation switches, should be provided.

(b) A minimum clearance space of 900 mm for the full width and in front of meters or of all low voltage control panels and switchgear, such as switchboards, distribution panels, and motor control centres with secure footing, having a rating exceeding 100 amperes should be provided.

(c) A minimum clearance space of 450 mm is required behind or by the side of such equipment where access from behind or the side is required for connection and maintenance purposes.

(d) Clearance space is not required behind or by the side of such equipment where there are no renewable parts such as fuses or switches or no parts or connections which require access from the back or from the side concerned.

(e) The clearance space in front of the equipment referred to in subparagraph (b) should be increased to at least 1400 mm for such electrical equipment operating at high voltage.

Annex 2 – Extract from Code 6

6G Final Circuits Using 5A or 15A Socket Outlets to requirements prescribed in appendix 2

(1) 15A socket outlets

(a) Radial final circuit should be used.

(b) A maximum of two 15A socket outlets installed immediately adjacent to one another may be provided in a radial final circuit protected by a 15A high breaking capacity (HBC) fuse or 15A miniature circuit breaker (MCB).

(2) 5A socket outlets

(a) Where more than one 5A socket outlet is provided in a circuit, the socket outlets should be arranged in a gang or installed immediately adjacent to one another.

(b) A maximum of four 5A socket outlets arranged or installed in accordance with sub-paragraph (a) is allowed.

(c) These socket outlets may be fed by–

(i) a radial final circuit protected by a 5A HBC fuse or 5A miniature circuit breaker; or

(ii) a 5A fused spur from a radial final circuit feeding only one 15A socket outlet which is protected by a 15A HBC fuse or 15A miniature circuit breaker and the 15A socket outlet is immediately adjacent to the 5A socket outlet(s).

Annex 3 – Extract from Code 26

Table 26(2) Minimum number of socket outlets in dwellings

Location	Maximum floor area in sq. meter served by a socket outlet for the total floor area of the dwelling not exceeding 100 sq. meter	Maximum floor area in sq. meter served by a socket outlet for the total floor area of the dwelling exceeding 100 sq. meter	Minimum No. of sockets
Kitchen	1.2	2.4	3
Living/Dining Room	2.5	5	4
Bedroom	3	6	3
Store	-	-	1
Utility Room	-	-	3

Note : A twin outlet is regarded as 2 outlets.

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9C Breaking Capacities of Overcurrent Devices for Protection Against Short Circuits in Low Voltage Installations

(a) The breaking capacities of protective devices against short circuits in compliance with Table 9(1) are generally acceptable.

Table 9(1)

Breaking capacities of protective devices

Types of supply to which the protective devices are connected	Current rating of Back-up fuses(if provided) to BS 88	minimum breaking capacities of the Protective devices
(i) Supply directly taken from the transformer within the premises in which the installation is situated.	-	40 kA
(ii) Supply tapped from rising mains	not exceeding 160A	4.5 kA (with back-up fuses)
	exceeding 160A but not exceeding 400A	23 kA (with back-up fuses)
	no back-up fuses fitted	not less than the prospective short circuit current shown at Table 9(2)
(iii) Supply taken from Supply Company's service box or overhead line	not exceeding 160A	4.5 kA
	exceeding 160A but not exceeding 400A	18 kA

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Table 11(3)- applicable to CPC for circuits protected by HBC fuses to BS 88 part 2

Fuse Rating in amperes		6	10	16	20	32	50	60	80	100	160	200	250	315	400
Minimum cross-sectional area (sq. mm) of CPC for 5 sec. disconnection	Copper	1	1	1	1.5	2.5	4	6	10	10	16	25	25	35	50
	Aluminium	16	16	16	16	16	16	16	16	16	25	35	50	50	70
Minimum cross-sectional area (sq. mm) of CPC for 0.4 sec. disconnection	Copper	1	1	1	1	1	2.5	4	4	6	10	10	16	25	25

Table 11(4)- applicable to protective CPC for circuit protected by HBC fuses to BS1361

Fuse Rating in amperes		5	15	20	30	45	60	80	100
Minimum cross-sectional area (sq.mm) of CPC for 5 sec. disconnection	Copper	1	1	1.5	2.5	4	10	10	16
	aluminium	16	16	16	16	16	16	16	25
Minimum cross-sectional area (sq. mm) of CPC for 0.4 sec. disconnection	Copper	1	1	1	1	2.5	4	6	10

Annex 6 – Extract from Code 11

(2) Maximum permissible earth fault loop impedance

(a) The maximum permissible earth fault loop impedance (Zs) to achieve automatic disconnection within 0.4 second by the protective device in the event of an earth fault for paragraph (1) in compliance with Tables 11(9), 11(10) and 11(11) are acceptable.

TABLE 11(9)

Maximum earth fault loop impedance for 0.4 sec. disconnection when the circuit is protected by HBC Fuses to BS88 Part 2

Fuse Rating (A)	6	10	16	20	32	50
Zs (ohm)	7.2	4.4	2.3	1.5	0.9	0.5

TABLE 11(10)

Maximum earth fault loop impedance for 0.4 sec. disconnection when the circuit is protected by fuses to BS 1361

Fuse Rating (A)	5	15	20	30	45
Zs (ohm)	9.4	2.8	1.5	1.0	0.5

Annex 7 – Extract from Code 16

Code 16 LOW VOLTAGE OVERHEAD LINE INSTALLATIONS

16A General

Hard-drawn copper or solid aluminum PVC insulated PVC sheatehed armoured or non-armoured single or multi-core or bunched cables, suspended on carrier wires, are acceptable for low voltage overhead line installations.

16B Installation of Overhead Lines

(a) Cables for overhead lines should be supported on insulators if fixed to metallic pole.

(b) The cables should be attached to the carrier wire by self-retaining nylon fasteners of suitabe size and strength and evenly spaced at approximately 450 mm intervals.

16C Joint of Overhead Lines

(a) Mid-span joints in overhead lines are not acceptable.

(b) Straight joint, if any, should be made at the pole and should be properly designed, installed and insulated from the pole.

16D Service Connection to Building

(a) Where overhead lines enter into a building, the cables should be taken into the building through a swan-neck conduit of adequate size fitted with bushes or bellmouth.

Annex 8 – Extract from Code 18

Code 18 DISPLAY OF LABELS AND NOTICES

18A Warning Notice for Substations

"DANGER-SUBSTATION, UNAUTHORISED ENTRY PROHIBITED (Chinese Translation)" in letters and characters each not less than 50 mm high either painted on the outside of the door of the substation, or engraved on plastic boards permanently fixed on the outside of the door of the substation, is acceptable.

18B Warning Notice for Switchrooms

"DANGER-ELECTRICITY, UNAUTHORISED ENTRY PROHIBITED (Chinese Translation)" in letters and characters each not less than 50 mm high either painted on the outside of the door of the switchroom or engraved on plastic boards permanently fixed on the outside of the door of the switchroom, is acceptable.

18C Warning Notice for Distribution Boards

"DANGER – (Chinese Translation)" in red letters and characters each not less than 50 mm high, displayed at or near each of the distribution board is acceptable.

18D Warning Notice for Connection of Earthing Conductor and Main Bonding Conductor

"DO NOT REMOVE (Chinese Translation)" in letters and characters each not less than 5 mm high to be fixed at or near the point of connection of every earthing conductor to an earth electrode, and at or near the point of main bonding conductor.

Annex 9 – Extract from Code 20

Check-list No. 1 – New L.V. Installation and Periodic Testing for L.V. installations connected before 1.1.85.

(a) Switchboards, circuit breakers and main switches	**Tested by/Date** (N/A if not applicable)
(i) No visible damage to impair safety.	______
(ii) Safe access provided.	______
(iii) Every circuit breaker, main switch and fuse holder(s) provided with correct and durable rating labels giving their ratings.	______
(iv) Every circuit breaker and main switch provided with a durable identification label.	______
(v) An up-to-date schematic diagram displayed to show the main distribution system.	______
(vi) Copper link of adequate size installed in neutral circuit.	______
(vii) All accessible live parts screened with insulating plate or earthed metal.	______
(viii) The overcurrent and earth fault protection characteristics of all circuit breakers verified with secondary injection test instruments where appropriate.	______
(ix) Lowest insulation resistance being __________ Mohms (not less than 1 Mohms) measured between phases and phases to Earth.	______
(x) All exposed conductive parts effectively earthed with a maximum earth fault loop impedance being________ohms.	______