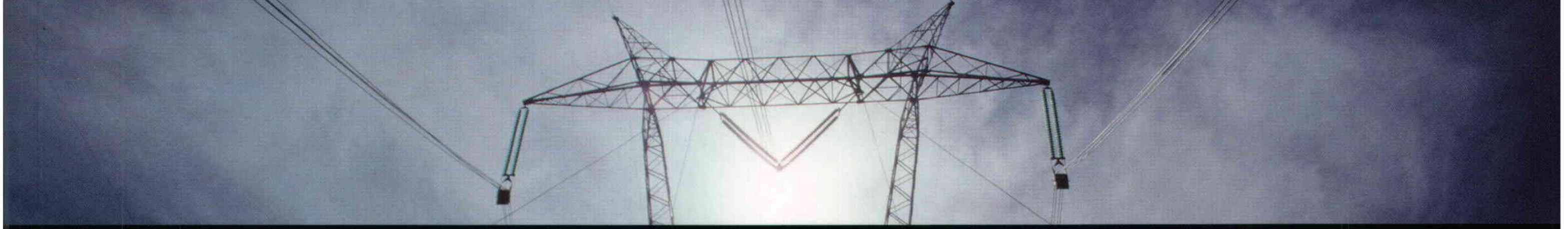
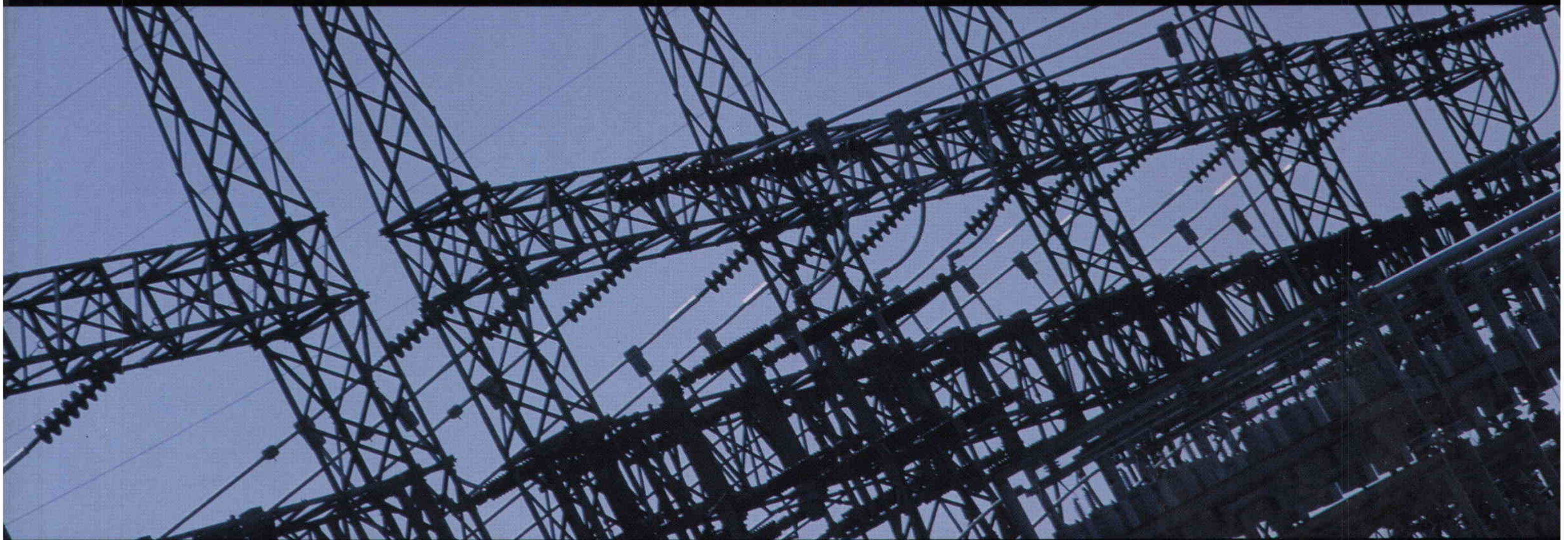
MEGA PROJECTS
HONG KONG AND BEYOND





THE HONG KONG INSTITUTION OF ENGINEERS – ELECTRICAL DIVISION
THE 26TH ANNUAL SYMPOSIUM
23RD OCTOBER 2008

THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 26th Annual Symposium
Thursday
23rd October 2008

MEGA PROJECTS – HONG KONG AND BEYOND

at

Ballroom
Sheraton Hotel
Nathan Road
Kowloon
Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

09.00 Welcome Address

- Ir S.K. Ho
  Chairman, Electrical Division, The HKIE

09.05 Opening Address

- Ir Peter Y.S. Wong
  President, The HKIE

09.10 Keynote Speech

- Mr Ricky W.K. Wong
  Chairman
  Hong Kong Broadband Network Limited

1. Power Generation

09.40 Development of a 2 x 600MW Mega Coal - fired Power Station Project in Guangxi Province, PRC

- Ir Albert S.W. Li, Director - Engineering
- Ir W.Y. Sze, Engineering Manager
  CLP Power Holdings Limited
- Mr K.M. Tam, Station Manager
  CLP Fangchenggang Power Company

10.00 A 1,400MW Independent Power Producer Project in Ratchaburi, Thailand

- Ir C.K. Lau, Power System Development Manager
- Ir P.K. Ho, Senior Project Engineer
- Ir M.S. Ching, Project Engineer
  Associated Technical Services Ltd
  The Hongkong Electric Group

10.20 Discussion

10.40 Coffee Break

2. Construction Projects

11.10 Electrical Services and Vertical Transportation Design for International Commerce Centre

- Ir H.K. Yung, Director
- Ir Albert W.K. To, Director
- Ir Tony C.F. Lau, Associate Director
  J. Roger Preston Ltd, Hong Kong

11.30 Construction of Turnkey Transmission Project at Lower Gulf – Challenges & Achievements

- Mr Johann Reidl, Project Director
  Siemens Limited, Germany
- Mr Volker Knierim, Senior Area Manager
  Sales and Marketing, Energy Sector,
  Siemens Limited, Germany

11.50 2008 Beijing Olympic National Stadium and National Swimming Centre – Electrical and Lighting System Design
2008北京奧運會國家體育場和游泳中心
供配電及照明系統的研究及應用

- Mr B.H. Li, M&E General Manager
- Ms Q. Dong, Head of Electrical Department
  Beijing Branch Office,
  China Construction Design Internatioal, PRC

12.10 Discussion

12.30 Lunch

3. Railway Development

14.15 Railway Development in Hong Kong

- Ir Malcolm Gibson
  Head of Project Engineering
  MTR Corporation Ltd.

14.35 The Express Rail Link – Enhancing the Strategic Position of Hong Kong as the Southern Gateway of China

– Ir Paul P.H. Lo
General Manager -
Express Rail Link/Mainland Projects
MTR Corporation Ltd.

14.55 Discussion

15.15 Coffee Break

4. Technological Advancement

15.45 A Sustainable Energy Solution for Beijing South Station – Combined Heat and Power System

– Ir Barry K.P. Lau
Associate
Ove Arup & Partners Hong Kong Limited

16.05 Wi-Fi Technology and Development in Hong Kong

– Ir Dennis T.K. Cheng
Senior Electronics Engineer
Electrical and Mechanical Services Department
The Government of The HKSAR

16.25 Discussion

16.45 Summing Up

– Ir Gary C.W. Ko
Symposium Chairman
Electrical Division, The HKIE

Closing Address

– Ir K.W. Ho, JP
Director
Electrical & Mechanical Services Department
The Government of The HKSAR

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 contributions to the Symposium :

Speakers / Authors

Mr Ricky W.K. Wong
Ir K.W. Ho, JP
Ir Peter Y.S. Wong
Ir Albert S.W. Li
Ir W.Y. Sze
Mr K.M. Tam
Ir C.K. Lau
Ir P.K. Ho
Ir M.S. Ching
Ir H.K. Yung
Ir Albert W.K. To
Ir Tony C.F. Lau
Mr Johann Reidl
Mr Volker Knierim
Mr B.H. Li
Ms Q. Dong
Ir Malcolm Gibson
Ir Paul P.H. Lo
Ir Barry K.P. Lau
Ir Dennis T.K. Cheng

Sponsors

Siemens Ltd.
CLP Power Hong Kong Ltd.
The Hongkong Electric Co., Ltd.
MK Electric (China) Ltd.
Junefair Engineering Co. Ltd.
Kum Shing Group
The Jardine Engineering Corporation Ltd.
Keystone Electric Wire & Cable Co. Ltd.
Jiangsu Shangshang Cable Group Co. Ltd.
MTR Corporation Ltd.
Mitsubishi Electric (Hong Kong) Ltd.
Greenland Engineering Co., Ltd.
Tyco Electronics Hong Kong Ltd.
Wenden Engineering Service Co., Ltd.
Metrix Engineering Co., Ltd.
Chat Horn Engineering Ltd.
NWS Engineering Group Ltd.
The Hong Kong & Kowloon Electric Trade Association
Hong Kong Electrical Contractors' Association Ltd.

Cover Design of this Booklet by Mr Mark K.H. Lai, New Zone Creative Centre Limited.

26TH ANNUAL SYMPOSIUM ORGANIZING COMMITTEE

Symposium Chairman	**:**	**Ir Gary C.W. Ko**
Members	**:**	**Ir S.K. Ho**
		Ir Simon F.W. Chung
		Ir Geoffrey L. Chan
		Ir Albert W.K. To
		Ir Dr F.C. Chan
		Ir Dr K.M. Leung
		Ir W.S. Tam
		Ir C.L. Wong
		Ir Y.H. Chan
Hon. Secretary and Treasurer	**:**	**Ir Y.K. Chu**

Paper No. 1

DEVELOPMENT OF A 2 X 600MW MEGA COAL - FIRED POWER STATION PROJECT IN GUANGXI PROVINCE, PRC

Speakers : Ir Albert S.W. Li, Director - Engineering
Ir W.Y. Sze, Engineering Manager
CLP Power Holdings Limited
Mr K.M. Tam, Station Manager
CLP Fangchenggang Power Company

DEVELOPMENT OF A 2 X 600MW MEGA COAL - FIRED POWER STATION PROJECT IN GUANGXI PROVINCE, PRC

Ir Albert S.W. Li, Director - Engineering,
Ir W.Y. Sze, Engineering Manager
CLP Power Holdings Limited
Mr K.M. Tam, Station Manager
CLP Fangchenggang Power Company

ABSTRACT

The economy in the People Republic of China (PRC) has been growing at an amazing rate in recent years. This is best reflected by its annual growth in GDP of 11% in year 2007. To support this fast growing pace, mega electricity power projects are being developed in most parts of its coastal developing regions, including Guangxi, which is a province located in the western part of China, close to Vietnam. This set of presentation materials summarizes the development of the Fangchenggang Power Station.

1. THE PROJECT

Founded in 1901 as the China Light & Power Company Limited (CLP) in Hong Kong, the CLP Group has grown from a Hong Kong based power utility into a leading investor and operator in the Asia Pacific's electricity market. To date, CLP owns a portfolio of over 30 generation assets and retail operation. With its long term experience in building power stations in Hong Kong and overseas, CLP is positioned to utilize its in-house expertise to developing power generation projects in PRC. In China, CLP is the largest foreign investor in electricity power generation, owning a total equity capacity of over 4.5GW.

The Fangchenggang Power Station Project is 70% invested by CLP and 30% by Guangxi Water Conservancy & Electric Power Construction Group Co. Phase I of this Project has a generating capacity of 1,200MW, comprising two 600MW coal-fired units. On completion, the electricity power generated from this station will help to ensure a stable power supply, alleviate the power demand of Guangxi and support the coastal industrial development of Guangxi's Beibu Gulf. The total investment of this Project is approximately RMB 4.8 billions.

2. CONTRACT STRATEGY

With the growing demand for power plant equipment , but with the western contractor and equipment suppliers bottlenecked creating challenges in meeting the project deadlines, CLP have adopted a strategy of China sourcing for the equipment supply for the Project. In addition, CLP have also adopted an arrangement of splitting the plant procurement and construction in a number of component supply and erection packages, as against the more conventional way of managing the plant procurement and construction by placing a turnkey Engineering, Procurement and Construction (EPC) contract .The benefit of adopting this approach is that it will allow a better control in terms of managing and execution of the works by the Owners, resulting in a saving of the overall costs for the investment. However, with such approach, it will also give rise to a number of challenges to the project team, demanding special attention given to the adoption of proven plant design, careful selection of equipment suppliers, and most importantly, a need to exercise an effective control of programme and qualities during both the manufacturing and construction stages.

3. STATE-OF-THE-ART TECHNOLOGIES

To sustain the economical operation of a coal-fired project, it is imperative that the design must be engineered to be as flexible as possible in terms of coping with its fuel supply. With CLP's extensive international coal procurement experience, a long-term coal supply contract with an overseas supplier has been secured for the Project. This approach of arranging imported coals to the Project will help to support the Guangxi province to diversifying its source of primary energy.

Currently, climate change is a challenge of global proportions. Recognizing that the conventional fossil fuel business is exposed to the risk of new regulations on greenhouse gas emissions, CLP have taken all the necessary steps to adopt the state-of-the-art technologies in the development of the Project. These included the adoption of the supercritical steam technology, as well as the various other measures on control on coal qualities and implementation of flue gas treatment to reduce the impact on environmental emissions.

4. PROJECT MANAGEMENT

In the course of developing a mega project such as Fangchenggang, CLP have also recognized the need to provide a sustainable and effective arrangement in the operation and maintenance of the plant. The station will therefore be managed with the support from a team of CLP staff, following all the applicable PRC and international procedures and practices.

At CLP, care for people and the community are deeply ingrained corporate values. Throughout the development of the Project, CLP have taken special care to provide a safe and healthy work environment for its employees and contractors. CLP have also participated in the local community programmers to ensure that the Project will set a successful example for a foreign joint venture development of such type of mega investment in China.

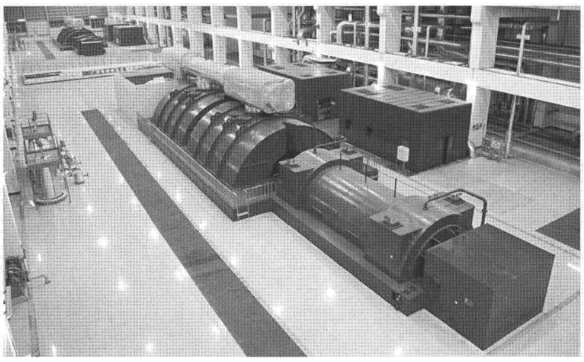
5. CONCLUSION

From an investment prospective, shareholders and senior management for a power development project will be asking for continued performance and cost improvement. Hence, managing CAPEX and equipment - related cost for a high performance level will be the prime objectives for implementing such type of development. The achievement of this objective has been realized by the dedicated effort of the project team throughout the various stages of the project development.

From commencement to completion in April 2008, the Project has taken some 26/30 months' to achieve commercial operation of the two units. This is comparable to a fast track programme of this type in PRC, but is a record broken by the project team for CLP in developing its overseas projects.

Figure 1 Coal Supply

Figure 2 Turbine Hall

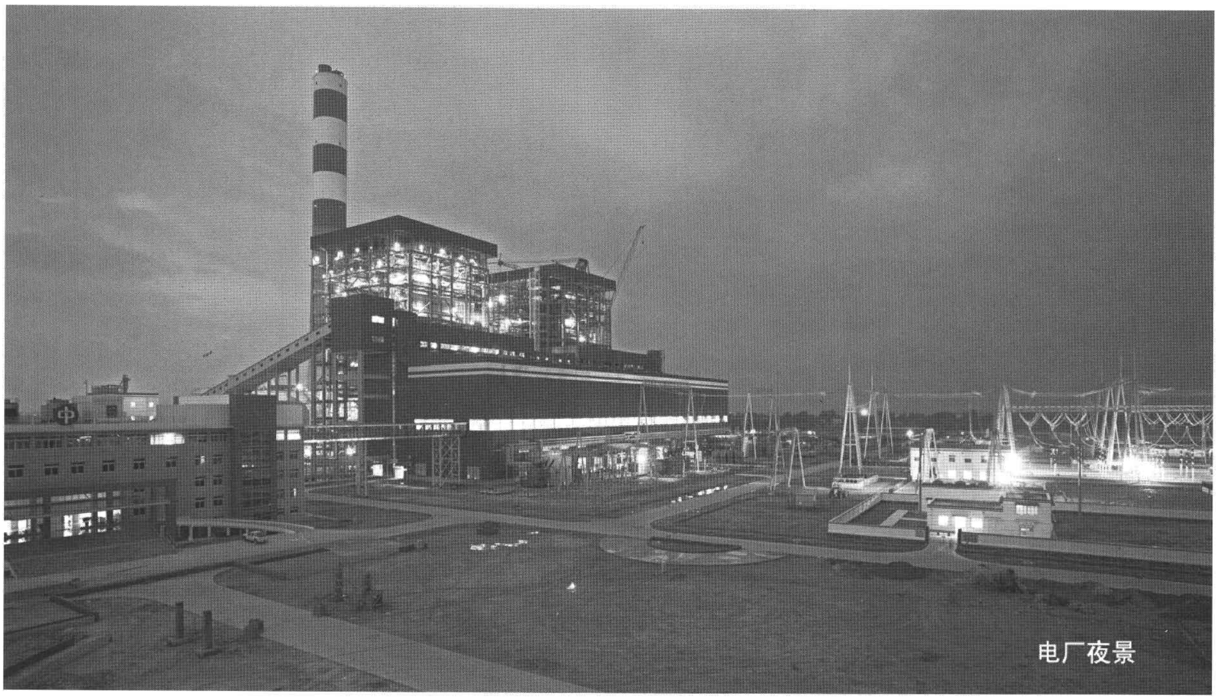


SIEMENS

Paper No. 1

Figure 3 Station Central Control Room

Figure 4 Power Station in Operation



SIEMENS

Paper No. 2

A 1,400MW INDEPENDENT POWER PRODUCER PROJECT IN RATCHABURI, THAILAND

Speakers : Ir C.K. Lau, Power System Development Manager
Ir P.K. Ho, Senior Project Engineer
Ir M.S. Ching, Project Engineer
Associated Technical Services Ltd
The Hongkong Electric Group

A 1,400MW INDEPENDENT POWER PRODUCER PROJECT IN RATCHABURI, THAILAND

Ir C.K. Lau, Power System Development Manager
Ir P.K. Ho, Senior Project Engineer
Ir M.S. Ching, Project Engineer
Associated Technical Services Ltd
The Hongkong Electric Group

ABSTRACT

Located 100km southwest of Bangkok, a new Natural Gas Fired Power Plant comprising 2 x 700MW 2-on-1 combined cycle blocks supplying 1,400MW to the power grid of Thailand via 500kV transmission system has been fully commissioned by June 2008. The power plant is developed under Independent Power Producer (IPP) programme of Electricity Generating Board of Thailand (EGAT). Electricity output will be sold to EGAT under a 25 year Power Purchase Agreement. Hongkong Electric International Limited (HEI) is the largest foreign shareholder of Ratchaburi Power Company Ltd, the plant owner. This paper presents the development of the power plant and shares experience in meeting challenges for the project.

1. INTRODUCTION

The economy of Thailand has regained momentum in recent years after the Asian financial crisis in 1997-1998. Increased domestic activities and strong exports achieved an annual GDP growth of about 5-7% in the years of 2002 - 2004.

To support the pace of economic growth, the government of Thailand has been encouraging and promoting the development of power projects in different ways especially on IPP - Independent Power Producer.

As of November 2007, the total installed power generating capacity in Thailand is 28,530.3MW comprising 15,793.6MW (55.4%) from Electricity Generating Board of Thailand's (EGAT's) power plants, 12,097MW (42.4%) from private power producers and 640MW (2.2%) from foreign power purchase. The standard voltage levels of Thailand's transmission system are 500kV, 230kV, 132kV, 115kV, and 69kV at operating frequency of 50Hz.

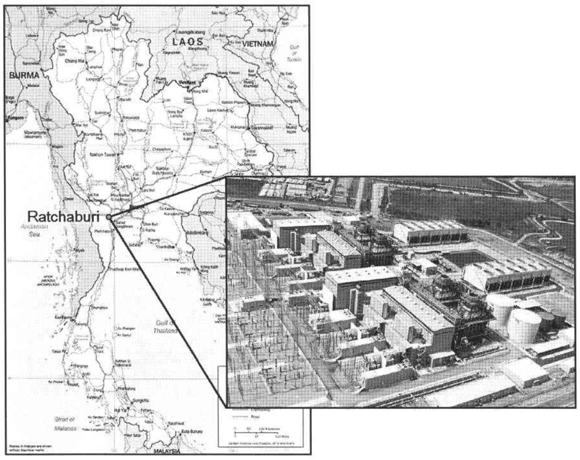
Electricity Generating Authority of Thailand (EGAT), a state enterprise under the Ministry of Energy, is responsible to develop, own and operate not only the national transmission network but several types and different sizes of power plants across the country. EGAT also purchases electric power from private companies and neighboring countries.

In support of the governmental policy, EGAT has been reaching agreements with various Independent Power Producers for the development of power plants.

Hongkong Electric International Limited (HEI), a wholly-owned subsidiary of Hongkong Electric Holdings Ltd.(HEH) was established in 1997 HEI's core business covers investment in power generation, transmission and distribution as well as other energy-related businesses. In 2004, HEI with partners reached an agreement with EGAT for the development of a 1,400MW gas-fired power plant in Ratchaburi under IPP programme.

The new power plant, with an initial investment of US$890 million, is located in the compound of the existing Ratchaburi Power Plant in Ratchaburi Province, the land of the king. Figure 1 shows the site location of the Ratchaburi Power Plant.

Figure 1 Location of Ratchaburi Power Plant



2. PROJECT COMPANY & PROJECT TEAM

Ratchaburi Power Company Limited (RPCL), incorporated in Thailand, is the registered owner of the power plant. RPCL is principally engaged in the development, financing, construction, installation, testing, operation and maintenance of the power generating station.

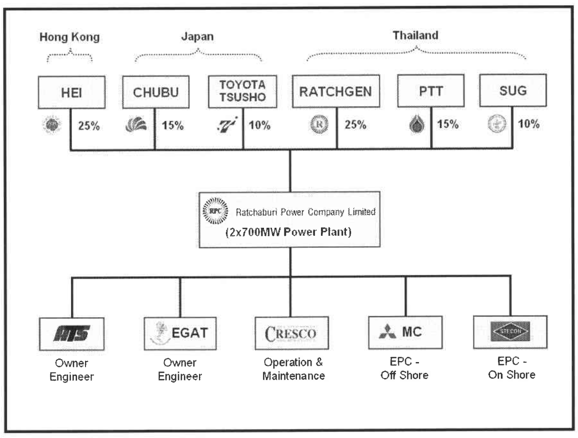
HEI is the largest foreign shareholder (25% stake) of RPCL. Other foreign investors are Chubu Electric Power Co., Inc. (CHUBU) and Toyota Tsusho Corporation (Toyota Tsusho) which take up 15% and 10% respectively. The largest local shareholder is Thailand's Ratchaburi Electricity Generating Holding Public Company Limited (RATCHGEN), with a 25% interest. RATCHGEN is also the largest independent power producer listed in the stock exchange of Thailand as well as the owner of the neighboring existing Ratchaburi Power Plant. Petroleum Authority of Thailand (PTT), the largest petroleum company and the plant's natural gas supplier, has a 15% share of the project. The remaining 10% is owned by Thailand's Saha Union Group (SUG).

Associated Technical Services Limited (ATS), an engineering consultancy arm of HEH, is one of the owner's engineers responsible for technical supports in negotiation of the Power Purchase Agreement (PPA) with EGAT, preparation bidding documents, selection of engineering, procurement and construction (EPC) contractor, overseeing the project implementation in the detailed engineering and construction stages. An engineering team from EGAT is also appointed as owner's engineer focusing on construction management and acting as an advisor on local statutory requirements.

After a long international tendering process, the EPC project was awarded to Mitsubishi Heavy Indurstries, Ltd. (MHI), Mitsubishi Corporation (MC) and Sino-Thai Engineering and Construction Public Company Limited (STECON) in March 2005. MHI design and supply the core facilities of the power plant and orchestrating the overall project. Mitsubishi Corporation and Electric and STECON are handling on shore work including civil, structural and construction work.

Chubu Ratchaburi Electric Services Company Limited (CRESCO), which is owned by CHUBU and RATCHGEN of equal shares, is awarded with the O&M contract responsible to operate and maintenance the Plant in accordance with the requirements of the PPA. A long term service agreement (LTSA) is subcontracted to MC to undertake the gas turbine performance guarantees and full parts warranties. Figure 2 shows the organization of the Project Team.

Figure 2 Organization of Project Team



3. POWER PURCHASE AGREEMENT

Electricity output produced by the 1,400MW power plant will be sold to EGAT under a 25 year take-or-pay Power Purchase Agreement (PPA).

The PPA contains a main body and over 20 schedules to set out the details on facilities development and provision, connection arrangement, provision and purchase of availability and electricity, delivery of electricity, billing and payment, environmental quality, fuels supply, critical dates/milestones, default and termination, securities and liquidated damages, force majeure, dispute resolution, limitation of liability, change-in-law, insurance and indemnities, representations and warranties, equity undertaking, governing law and jurisdiction, etc.

Under the PPA, operating characteristics for the unit and system operating standards such as the dependable capacity, reactive power, primary response, five-minutes and fifteen-responses to system frequency change, fuel switching cycle, loading/de-loading rates, minimum uptime/downtime, start-up/shutdown notice times, etc. are all well defined. In particular, the maximum loading/de-loading rates will be as high as 32MW and the maximum primary/five-minute/fifteen-minute response will be 32MW/72MW/250MW respectively.

Start-up notice time for the whole block from cold mode is 280 minutes while the shut-down notice time for 2-on-1 combined cycle mode is 60 minutes. In case of fuel switching between primary fuel and secondary fuel, it shall be achieved in 65-75 minutes.

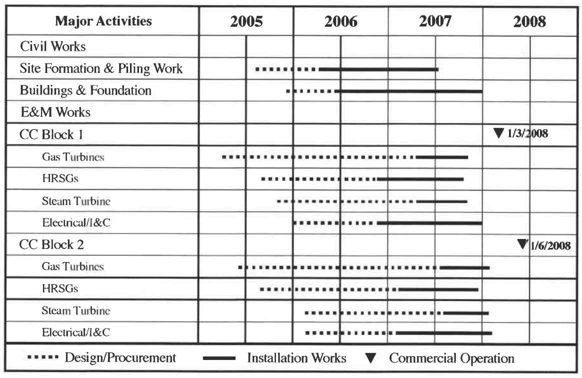
Revenue metering equipments are installed at the 500kV outgoing feeder lines to existing Ratchaburi 3 Switching Station.

In broad terms, payment for the electricity can be divided into two components, namely the availability payment and energy payment. Availability payment in a certain settlement period is based on the availability of the unit with adjustment for deviation of contracted circumstances. On the other hand, energy payment is intended to cover various costs related to operation and maintenance. Adjustment will also be made for meter reconciliation and cover fluctuation in foreign exchange rate.

4. PROJECT PROGRAMME

Figure 3 shows the overall programme of the 2 x 700MW Ratchaburi Power Plant.

Figure 3 Project Programme of the Power Plant



The civil work commenced in early 2006 and the column lifting of first GT building was carried out in September 2006. E&M equipment were progressively delivered to site and installation work was started in the third quarter of 2006. With the 500kV Switchyard initial power receiving carried out in August 2007, testing and commissioning phase of the plant began. After completion of the all acceptance tests, the first block and the second block have started the commercial operations on schedule on 1 March 2008 and 1 June 2008 respectively contributing to ensure safe and reliable supply of electricity for the development of Thailand.

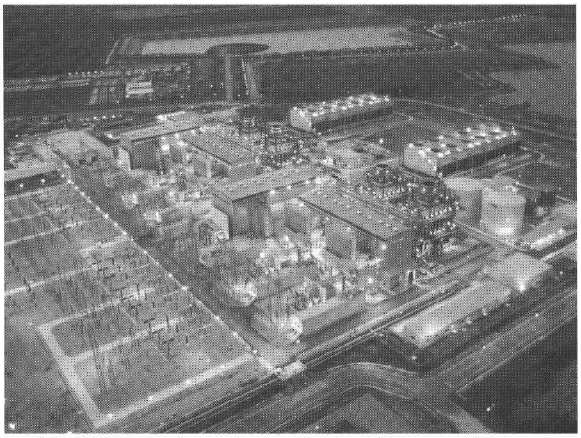
Being one of the largest base-load, low cost generators in Thailand, the 2 x 700MW natural gas fired combined cycle power plant adds about 5% of country's total installed capacity to the grid.

5. PLANT CONFIGURATION

The plant consists of two blocks each of 700MW combined cycle unit in 2-on-1 configuration with an overall efficiency of around 56% on LHV basis. It is designed for dual fuel firing using natural gas as primary fuel and light oil as backup fuel. Net output capacity achieved at site condition is 745MW for gas firing.

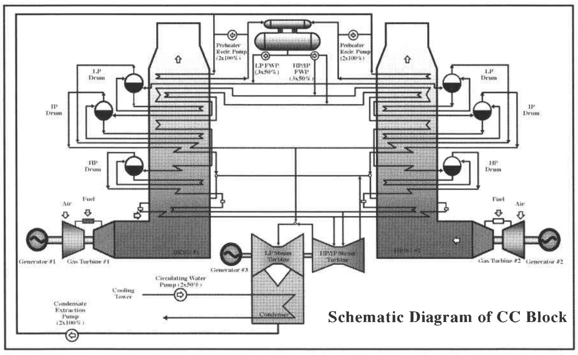
Figure 4 shows the night scene of the completed Ratchaburi Power Plant.

Figure 4 Completed Power Plant



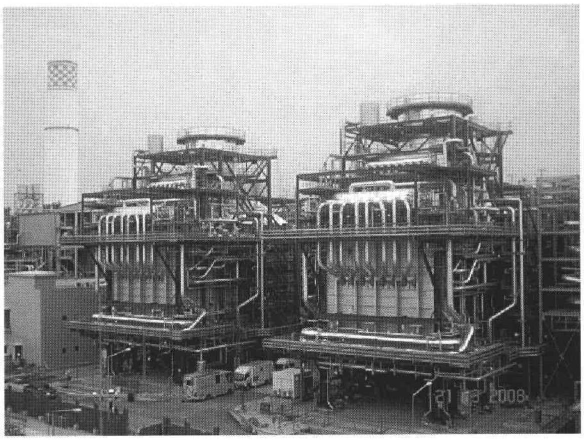
Each block encompass two gas turbines (GT) , two heat recovery steam generators (HRSG), one steam turbine (ST), associated unitized auxiliaries and plant common facilities. Figure 5 shows the Schematic Diagram of a Combined Cycle (CC) Block.

Figure 5 Schematic Diagram of a CC Block



The M701F GTs consists of a 17-stage, high efficiency axial compressor, combustion chamber equipped with 20 Dry Low NOx (DLN) combustors arranged in circular array around the engine, and a 4-stage reaction type turbine. The HRSG is of natural circulation, vertical gas path arrangement, triple pressure with reheat design and without supplementary firing. The steam turbine is of tandem compound double cylinder, triple pressure, reheat, with sliding pressure control and a downward exhaust condenser capable for 100% steam bypass.

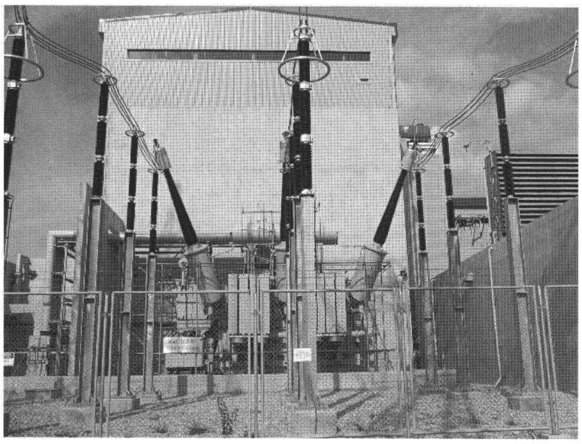
Figure 6 Heat Recovery Steam Generators (HRSG)



6. MAJOR ELECTRICAL EQUIPMENT

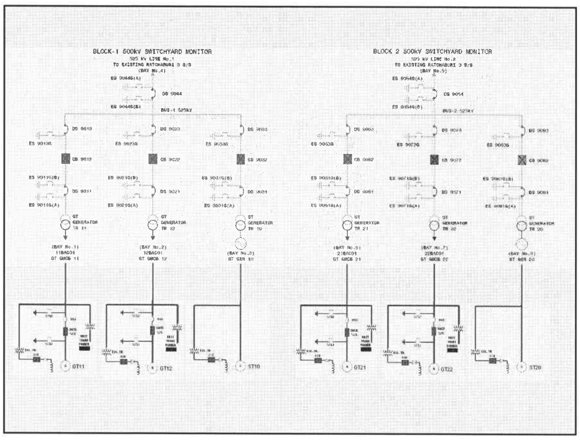
The main electrical equipment includes a plant common 500kV switchyard, six 21kV hydrogen cooled generators, four 22.5kV generator main circuit breakers (GMCB), two 6.6kV static frequency converters (SFC), six 525kV/21kV generator transformers, four 21kV/6.6kV unit transformers, six 21kV/560V excitation transformers, two 380V emergency diesel generators, twenty eight sets of MV/LV switchgears, seventy seven sets of AC/DC distribution boards, twenty four sets of Battery Charger/UPS inverter and other unit/station auxiliaries for power generation.

Figure 7 Steam Turbine Generator Transformer



The GT generator is connected to the generator transformer by means of isolated phase busduct (IPB) through GMCB delivering power to the 500kV switchyard. Power from ST generator is delivered to the switchyard in a similar way except without the GMCB. A key single line diagram is shown in Figure 8.

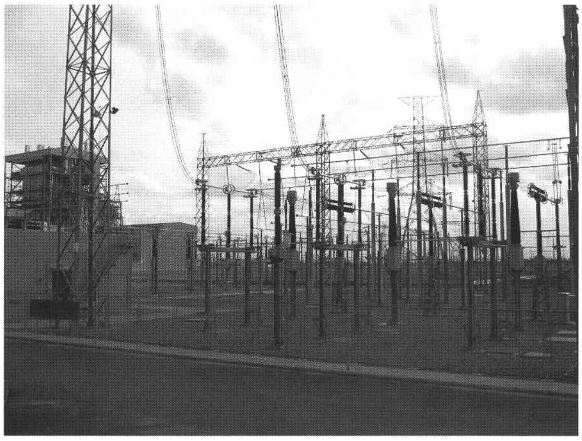
Figure 8 Key Single Line Diagram



The 500kV Open Type Switchyard facilities are supplied by Mitsubishi Electric Corporation. Electricity output from each power block is connected to an individual single 525kV bus group which is then transported to EGAT's existing Ratchaburi 3 Substation via an individual group of 500kV overhead line.

Air insulated disconnecting switches are COELME pantograph type and double break type. Circuit breakers are Mitsubishi 550kV Live Tank Gas (SF_6) Circuit Breaker. Because of the isolation of insulating medium (SF_6 gas) from the atmosphere, the insulating capability of this breaker will be very reliable. Circuit breaking is achieved by the two breaks in series per pole and by the intrinsic compactness of the puffer type interrupters. The simplicity of the breaker structure minimizes inspection and maintenance work. Figure 9 shows the 500kV open switchyard.

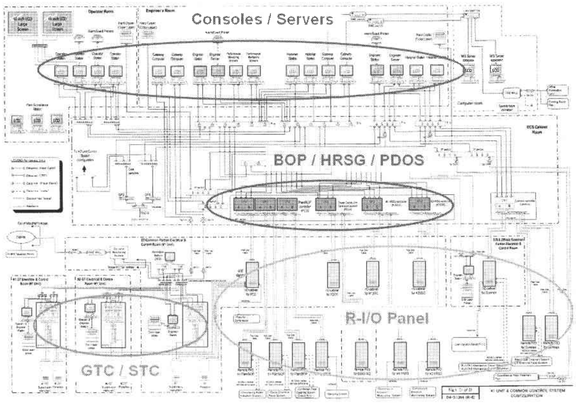
Figure 9 500kV Switchyard



7. MAJOR CONTROL EQUIPMENT

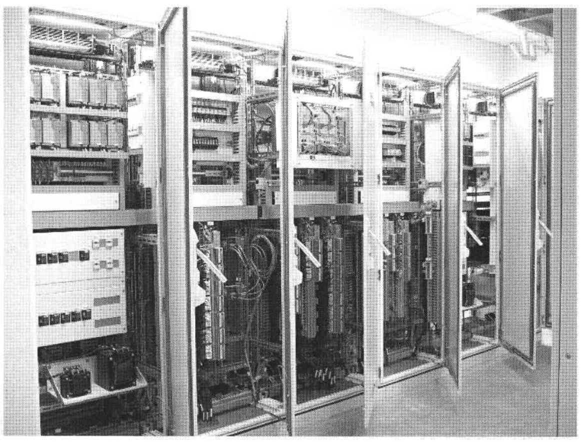
Control system for the plant is designed as an integrated control and monitoring system capable of fully automatic unit startup/ shutdown and loading control under different modes via PC based operator stations in central control room. Redundant configuration in power distribution system, process controller, data communication link and interfacing module is adopted to maximize system reliability and to eliminate the possibility of plant shutdown due to single component failure. The overall Control System Configuration for Block 1 and Common System is shown on Figure 10.

Figure 10 Control System Configuration Diagram



Being the brain and nerve of the plant, the control system is functionally distributed for the plant major processes. The backbone of the plant control system is Ovation Distributed Control System (DCS) by Emerson Process Control, responsible for the control and monitoring of the Heat Recovery Steam Generators (HRSGs), major Power Distribution Operation Systems (PDOSs) and the Balance of Plant (BOP) processes. It interfaces with MHI's state-of-the art Netmation control system via TCP/IP and gateway computers for the control and monitoring of the Gas Turbines (GTs) and Steam Turbines (STs).

Figure 11 DCS Panels



PLCs are utilized for various plant auxiliary processes and linked up with DCS via MODBUS interface for remote control and monitoring in central control room.

8. CHALLENGES

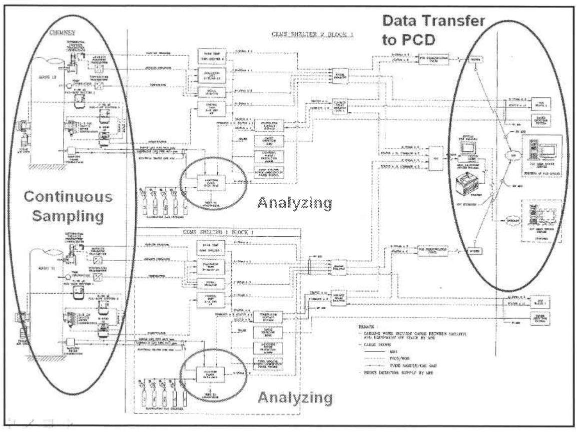
Being the major agreement to protect both the buyer and the seller sides, the route to a final PPA embracing by both parties is no easy task especially to close the gap between the Thailand Authority - EGAT, and the plant owner comprising of different companies with different culture and practices. Not to mention there are a number of challenges in ensuring the relevant PPA requirements to be practicably achieved throughout different stages of the project.

Influenced by the Asian economic crisis, project financing is no easy task. With the unfailing commitment of the project company, the required fund has successfully raised without the necessity of political risk insurance. The financing package has even been voted the "Power Deal of the Year - Asia Pacific" by a renowned international magazine Project Finance International as it set a benchmark pricing for green field power projects in Thailand absent political risk coverage. The financing package had its first drawn down and Notice-to-Proceed to the EPC Contractor in the first February 2006. The short delivery and construction period of 24.5 months from Notice to Proceed order to Commercial Operation of the 1st Block on 1 March 2008 has undoubtedly set a giant barrier to this 2 x 700MW power plant project.

Throughout the course of design and commissioning, the differences in norm and understanding also introduced some hard negotiation among the system operator and the EPC contractor. Extra effort has to be made by the project teams to tackle some optional grid requirements and extended commissioning period. On top of that, the unfavorable weather condition often slows down the work progress.

Gaining social acceptance at the construction stage is one of the major issues faced. Addressing the environmental concerns of the local community, the power plant has installed with Dry Low NOx (DLN) combustion system, water injection control and Continuous Emission Monitoring System (CEMS) conforming to USEPA. Emission data have to be reported to the Pollution Control Department (PCD) of Thailand via telemetric system. Figure 12 shows parts of the CEMS Facilities.

Figure 12 CEMS Facilities



A number of other initiatives have been implemented to promote public understanding and trust. RPCL has committed to setting up a community development fund with one Satang (1/100 of a Thai Baht) per unit of electricity sold, which is the first in Thailand, well before legislation was passed by the Thai Government in December 2007 requiring similar funds be set up by power companies for future projects.

Figure 13 Example of RPCL's Community Building & Environmental Protection Work

RPCL has also been providing support for a number of communities building and environmental protection programmes, benefiting tens of thousands of Thailand residents.

9. CONCLUDING REMARKS

As a green field power generation project, hurdles and challenges are unavoidable. The project has been faced with numerous challenges such as change in project nature, negotiation of the PPA, conclusion of financial arrangement, different challenges during project implementation, coordination with EGAT (the grid owner), coordination with RATCHGEN (the owner of existing neighboring power plant), etc. With the full dedication, strong technical expertise and competency of project owners, construction contracting consortium, and the owner's engineers, the obstacles are always cleared in a professional manner.

The RPLC Power Plant project is successfully contributing to the booming of Thailand economy and electricity demand. Rooted in Hong Kong for over a century as one of the world's most reliable electricity companies, HEH is fully committed to excel in the energy business in Hong Kong and key international markets. Leveraging on the strength and expertise of HEH, plus its own track record of sound and successful investments, HEI will continue to explore more business opportunities including potential investments in the renewable-energy sector. With its pool of experienced professionals in electrical, mechanical and civil engineering, ATS will also continue to offer quality consultancy and engineering services to the power and energy industry globally.

REFERENCES

[1] System Planning Division, Electricity Generating Authority of Thailand, "Thailand Power Development Plan 2007 - 2021", PDP 2007: Revision 1

[2] Web Site of Hong Kong Trade Development Council, http://info.hktdc.com/mktprof/asia/mptha.htm

[3] Associated Technical Services Ltd., Brochure of RPCL 2 x 700MW Gas Fired Power Plant Project in Ratchaburi Province, Thailand

[4] Tso C.W, Kwan Y.L., Wong L., "LNG for Power Generation in Hong Kong", Symposium on Electrical and Mechanical Safety & Energy Efficiency - Engineering a Safer and Greener Future, February 2007

Paper No. 3

ELECTRICAL SERVICES AND VERTICAL TRANSPORTATION DESIGN FOR INTERNATIONAL COMMERCE CENTRE

Speakers : Ir H.K. Yung, Director
Ir Albert W.K. To, Director
Ir Tony C.F. Lau, Associate Director
J. Roger Preston Ltd, Hong Kong

ELECTRICAL SERVICES AND VERTICAL TRANSPORTATION DESIGN FOR INTERNATIONAL COMMERCE CENTRE

Ir H.K. Yung, Director
Ir Albert W.K. To, Director
Ir Tony C.F. Lau, Associate Director
J. Roger Preston Ltd, Hong Kong

Paper No. 3

ABSTRACT

Standing at a height of more than 490 metres with over 100 storeys, the International Commerce Centre (ICC) located on the prime land of the West Kowloon region will be the tallest skyscraper in Hong Kong and the third tallest in the world by 2010. This skyscraper will contain 250,000 square metres of Grade A office space, an observation deck, and the 6-star Ritz Carlton Hotel at the top, and accommodate over 20,000 people combined. The building will utilise seven lift zones, three sky-lobbies and four main mechanical floors to serve the above in the most economical and energy-efficient manner possible.

Being a world-class skyscraper with international tenants including top investment banks and 6-star hotel operators, secure and reliable power supply, and flexible and expedient elevating service pose formidable challenges to all engineers. Some of the engineering solutions to bring these about include:

(i) 100% redundancy 2-N normal supply to minimize down time;
(ii) 100% redundancy generator back-up for critical services to enhance supply availability;
(iii) synchronization of gensets to improve step load capability;
(iv) high-speed double-deck lifts to optimize lift provisions;
(v) predictive lift control system to maximize passenger handling capacity; and
(vi) crowd sensor controls to avoid overcrowding in sky-lobbies during exceptional circumstances.

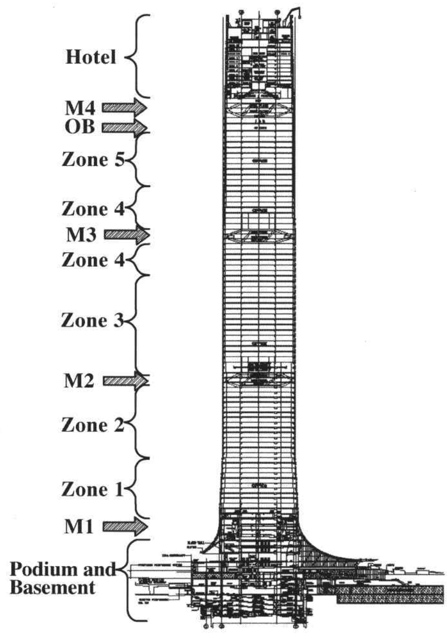
This paper outlines the solutions from both the perspectives of engineering design and site construction.

1. INTRODUCTION

ICC is a 490 metres 109-storey skyscraper with offices from 12/F to 99/F, observation deck and food and beverage (F&B) outlets on 100/F and 101/F and Ritz Carlton Hotel from 102/F to 118/F. Due to the sheer scale of the project, ICC will be completed in four phases. Phase 1 has been completed in Dec 2007 while phases 2, 3 and 4 are respectively scheduled for completion in June 2009, Feb 2010 and Dec 2010.

When the construction of the skyscraper is completed, a total of 25 transformer substations housing a total of 68 pieces of 1.5MVA - 2.0MVA dry type transformers will be installed to meet an overall demand of 80MVA. A total of 88 lifts including 40 double deck lifts will be installed to provide vertical transportation for a total population of over 20,000 people. A secure and reliable power supply and a flexible and expedient elevator services play an important role in sustaining the operation of the skyscraper in good conditions.

Figure 1 Elevation of ICC



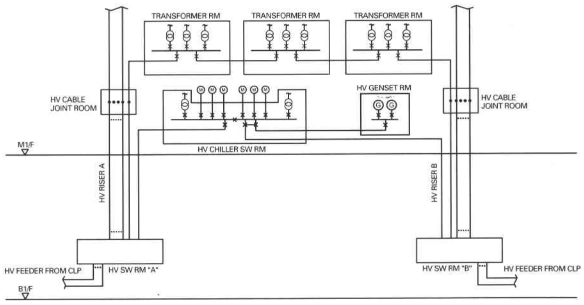
2. MAIN ELECTRICAL SYSTEM

2.1 SERVICE STRATEGY

Reliability, resiliency and redundancy of power supply system are of paramount importance to a world-class skyscraper operating in good conditions all year round. The following strategies have been adopted for ICC to achieve such quality:-

- Dual HV Intake - Currently, the power company is providing power supply from different sub-stations to ICC via diversified routes to ensure HV infeed can be maintained at all time.
- Dual HV Risers - Power company's 11kV cables are running in two independent risers rising through the core of ICC to eliminate the risk of total blackout in case of fire or accidents in one of the risers.
- Cable Joint Rooms - Cable joint rooms strategically located on mechanical floors facilitate extension of power supply in accordance with the site progress and minimize down time in case of cable faults.
- Dual tenant risers - Each tenant floor is served by dual riser LV busduct system feeding from different transformers sources. In case of power failure, it will be possible to changeover the tenant loads to other healthy busduct.
- Reduced loading capacity - Some lightly loaded transformers are deliberately incorporated which can be set free to offer on-the-spot replacement of faulty transformer before permanent replacement is available.
- Redundancy of supply - 2N supplies backed up by generators are provided for some anchor tenants to reduce down time to a minimum.
- Segregation of services - Within the building core, dry and wet trades are segregated from each other thus minimizing the risk of flooding impact. Leakage alarm devices are installed at strategic locations to report leakage for immediate response by the building management.

Figure 2 Simplified HV Supply Schematic



2.2 ABOVE-GROUND TRANSFORMER SUBSTATION

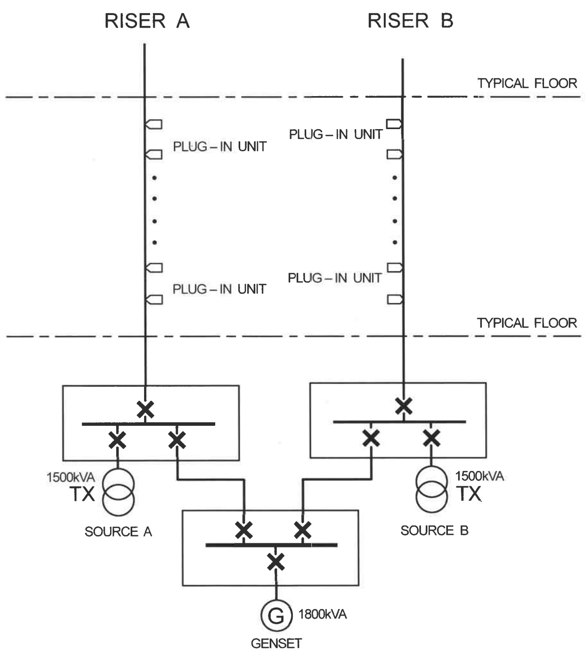
The height of ICC is comparable to the Peak, siting the transformer substations on above ground mechanical floors where the major M&E plant are located is the best way to contain voltage drop and distribute electricity to the plant and tenants. Furthermore, this extremely economical and energy-efficient distribution ties in with the phasing plan of temporary occupation (TOP) ensuring availability of power supply in a timely manner. A 4500kg service lift tailor-made for vertical transportation of the transformers and switchgear of the power company within ICC is provided after consultation with the power company on the requirements of plant delivery.

A total of 25 above-ground substations accommodating a total of 68 transformers of ratings 1.5MVA to 2MVA tailored for ICC will be provided for the whole building when completed in 2010. The loading on the transformers are precisely designed as lightly loaded transformers are deliberately incorporated which can be set free to offer on-the-spot replacement of faulty transformers. This can ensure continual main supply to the tenants before a permanent replacement becomes available.

2.3 2-N POWER SUPPLY

Prior to the moving in of anchor tenants, early consultations with the tenants have been made to determine the power supply that best suit their needs. 2-N power supplies are provided for some of the tenants. Each N of a 2-N supply is fed by substations in different zones to offer 100% cross-back-up to each other. The power distribution infrastructures of each N are totally segregated from each other thus eliminating the risk of single point of failure. Due to the increase in requirement of redundancy of main supply when 2-N power supply is provided, conversion of some of the office floors to plant room floors to accommodate additional transformer substations and main switchrooms is required. The structural strengthening to enhance the floor loading capability, the modification of the facade for additional louvers for plant rooms, the additional EMI shielding to eliminate electro-magnetic interference to tenants and the design of substations tailored to suit the head room and floor loading constraints are challenging tasks of the conversion which need collaboration among the design team, the employer and the power company.

Figure 3 Simplified 2N-Power Supply Schematic



2.4 EMERGENCY POWER SUPPLY

Four categories of emergency generators are provided in ICC, they are the FSI generators, non-FSI generators, Tenant-dedicated generators and HV generators

a. FSI Generators

Considering the importance of maintaining the integrity and availability of full back up for the fire services installations (FSI) at all times, generators dedicated to the FSI are provided. A total of 13 FSI generators will be installed in generator rooms in above ground mechanical floors to serve :-

- Sprinkler and AFA
- Hose reel/Hydrant system
- Drencher system
- Gas total flooding system
- Audio/Visual Advisory system
- Staircase pressurization system
- Smoke extraction system
- Essential lighting and Exit signs
- Fireman's lifts

b. Non-FSI generator

As ICC is targeted to serve international corporations including top investment bank and 6-star hotel operator who will demand a high resilience of power supply, non-FSI generators are installed to maintain essential services during emergency. A total of 9 non-FSI generators will be installed in generator rooms in above ground mechanical floors to cater for :-

- All essential air-cooled chillers on mechanical floors. These chillers are 100% backed up by generator to ensure the supply of essential chilled water to tenants in case of the failure of the main water-cooled chiller system.
- At least one passenger lifts in each zone and sky-lobbies. Vertical transportation for tenants can be maintained after sequential lift homing of the lifts.
- Base building critical equipment. They are the security system, CCTV system, carpark control systems, sump pump system, emergency broadcast system, building management system and service lifts for delivery of fuel caddies to tenant-dedicated generators.

c. Tenant-dedicated generator

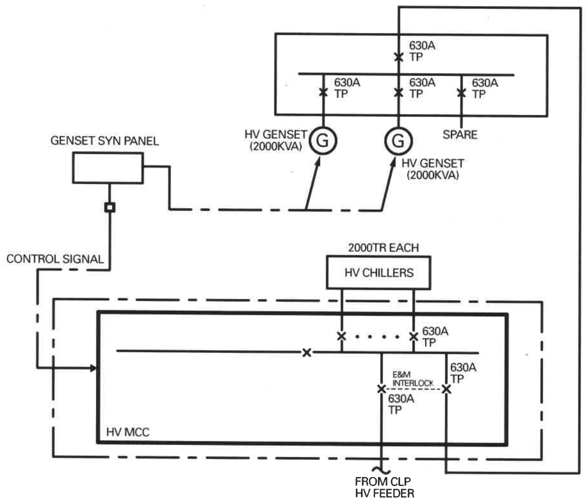
The dedicated generator is designed to suit the requirements specific to the anchor tenants. Currently, a total of 14 non-FSI generators will be provided. In general, the generator is designed to back up:-

- Tenant's UPS systems for their data centres
- Air-cooled chillers dedicated for the tenants
- 2N power supply system.
- Other critical services which require 100% redundancy generator back up

d. HV Generator

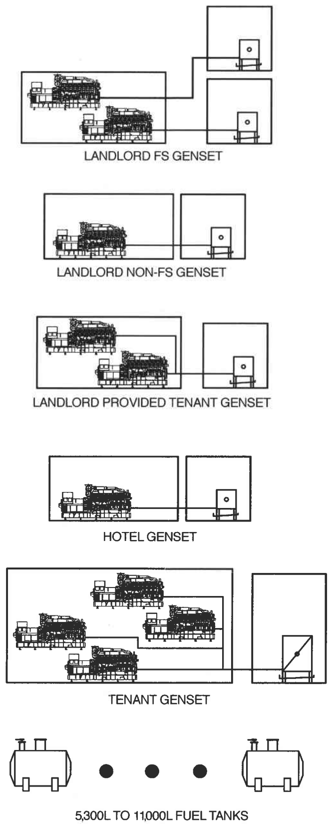
Six11kV chillers each of 2050 cooling tonnes capacity fed by dual 11kV network from different zone substations of the power company are installed in the 1st mechanical floor of ICC. In order to maintain operation of at least one HV chiller under main failure, two 2MVA 11kV generators are provided to back up the HV chiller. The generators will be synchronized before delivering power to the chiller to achieve a higher step load capability and to contain the voltage dip caused by inrush of starting currents. The settings of the protective devices of the MCC of the chillers have been consulted with the power company to avoid nuisance tripping of the devices under generator supply conditions.

Figure 4 Simplified HV Genset Power Supply Schematic



Local fuel tanks dedicated to generators of each category are provided in fuel tank rooms located in the vicinity of generator rooms housing respective generators. The capacities of the local fuel tanks for FSI generators are designed to maintain continuous operation of the FSI generators for at least 6 hours. A bulk fuel tank room which houses 6 bulk fuel tanks of capacities range from 4,500 litres to 11,000 litres is provided on ground floor to facilitate the building management to timely replenish the local fuel tanks whenever required.

Figure 5 Simplified Fuel Supply Arrangement



2.5 LIGHTNING PROTECTION SYSTEM

Being the tallest skyscraper in Hong Kong with unrivaled views in all directions, it will not be surprising for the ICC to attract lightning strikes more than other buildings in Hong Kong. On the roof of the skyscraper, there will be 4 sets of early streamer type lightning arrestors offering lightning protection to the entire building. The arrestors are connected to a number of dedicated re-bar down conductors embedded in 8 mega-columns evenly spread around the building perimeter and finally connected to the lightning earthing pits and earthing grids laid below a 8 metres thick concrete ground slab on the lowest basement. Lightning stroke counters are installed at test points in the basement to record the numbers of lightning strikes attracted by the arrestors at all times.

Along with the lightning protection by the early streamer arrestors, the curtain wall system is also designed as an electrical continuous envelope and bonded to the dedicated re-bar concealed in the mega-columns at every three to four floors interval. The curtain wall system acts as a Faraday cage which can protect ICC from attack of side-flashing by discharging the lightning currents effectively to the lightning earthing pits through the re-bars.

3. VERTICAL TRANSPORTATION SYSTEM

3.1 OVERVIEW

ICC is divided into 5 lift zones for the office and dedicated lift zones for the observation deck/F&B floor above the office floors and the Ritz Carlton Hotel on the top floors of the skyscraper. There are altogether 88 lifts providing vertical transportation for working population over 20,000 peoples and the capacities and speeds of the lifts range from 900kg to 4500kg and 1.5m/s to 9m/s.

Figure 6 Lift and Escalator Provision for ICC

	Type of Lift	Rated Load (Kg)	No. of Passengers	Speed (M/s)	Total nos. of Lift and Escalator
Office	Double Deck	1,600 - 1,800	21+21 - 24+24	3.5 - 9	32
	Single Deck	900 - 1,600	12 - 21	1.5 - 9	30
	Tx Lift	4,500	60	4	1
	Escalator				35
Observation	Double Deck	1,600	21 + 21	9	4
	Single Deck	1,000 - 1,600	13 - 21	1.75	4
Hotel	Double Deck	1,800	24 + 24	9	4
	Single Deck	900 - 2,500	12 - 33	1.6 - 9	13
	Escalator				4

A good lift design plays an important role in achieving a flexible and expedient elevator service. The following outline the key features adopted for ICC.

3.2 SKY-LOBBY APPROACH FOR OFFICE

With a floor areas of 250,000 sqm and 67 office floors, direct transportation between the main lift lobbies and all the local lift zones will be penalized for wasting a lot of lift shaft spaces and reducing the efficiency of the building core drastically. Sky-lobby approach is the best way to overcome such inefficiency.

Paper No. 3

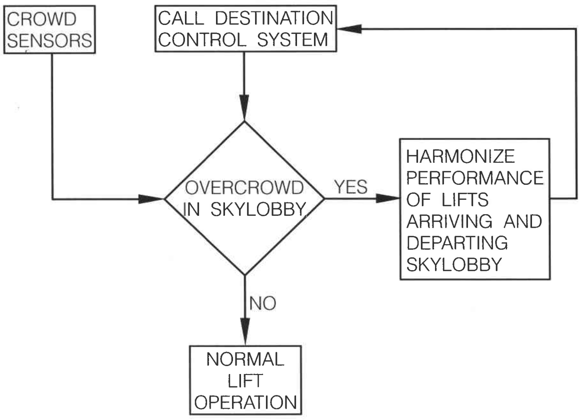
The office floors of ICC is divided into 5 lift zones with two sky-lobbies located at 48F/49F (between lift zone 2 and lift zone 3) and 88/F (between lift zone 4 and lift zone 5).The 1st sky-lobby is served by eight 1800kg/1800kg high speed double-deck shuttle lifts and the 2nd sky-lobby by six 1600kg high speed single deck shuttle lifts. With the introduction of sky-lobbies, lift shaft spaces are saved in the low zones, size of the building core is substantially reduced and more usable floor areas are available for the low zone floors.

3.3 CROWD SENSOR CONTROL

Crowd sensor control function, which prevents passengers from crowding into lobby areas that have lifts of different capacities arriving and departing, is essential to lift installations incorporated with sky-lobby approach.

Under the crowd sensor control, passengers arriving and leaving the sky-lobbies can be closely monitored by the call destination control system and crowd detectors in lobbies. If there are more people arriving than people leaving, the departure trips will be prioritized compared to trips which bring people to sky-lobbies. Thus the transportation of passengers to the sky-lobbies will be reduced until the lobbies are no longer overcrowded.

Figure 7 Crowd Sensor Control Schematic



3.4 DOUBLE-DECK LIFTS

There are altogether 40 double-deck lifts provided for ICC

Office
Local Passenger Lifts – 24 lifts of 1,600kg/ 1,600kg

Shuttle Passenger Lifts – 8 lifts of 1,800kg/ 1,800kg

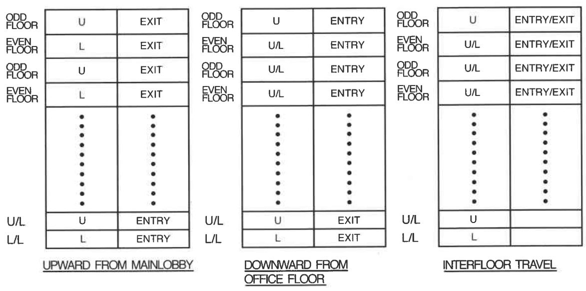
Observation Deck/F&B
Shuttle Passenger Lifts – 4 lifts of 1,600kg/ 1,600kg

Ritz Carlton Hotel
Shuttle Passenger Lifts – 4 lifts of 1,800kg/ 1,800kg

In order to get the maximum efficiency from double-deck lifts, the following considerations have been taken during the design phaseof the project:

- Floor to floor height of sky lobby and destination floors shall be the same
- For upward travel from main lobbies or sky lobbies, the lower car deck will serve even floors and the upper car deck the odd floors. Adequate signage shall be provided to guide tenants/visitors to the correct lobbies.
- Selection of lift control system should best suit the operation of double-deck lifts. (The double-deck lift traffic concept is explained as follows)

Figure 8 Double Deck Lift Traffic Concept



The compact size of the building core of ICC is attributed to the adoption of double deck local passenger lifts and shuttle lifts.

3.5 BUILDING SWAY

Standing at a height of more than 490 metres, ICC will be subject to strong wind effects during typhoon seasons which create a complex oscillation and torsional movement of the building i.e. building sway. The sway might be barely perceptible to occupants but its profound impact on the safety operation of the vertical transportation system must not be underestimated. The roping systems inside lift shafts could be excited to oscillate under the influence of building sway, and in extreme circumstances come to resonance with the sway resulting in severe damages to the installations inside lift shafts.

Lifts with long roping systems are more susceptible to building sway effects. All lifts in ICC that serve floors above the sky lobby are therefore equipped with high wind operation sensors to safeguard the lift installations by means of sway control algorithm.

Figure 9 Sway Control Algorithm

Inputs from high wind sensor	Control function	Functionality	Duration
Level 0: No Building sway	No sway	Normal operation	Min 5 minutes with <300 displacement
Level1: Building displacement >=350mm	Low sway Max speed 5m/s (Speed adjustable)	Speed reduction about 50%, critical zones will not be served anymore	>=3minutes
Level 2: Building displacement >=450mm	Medium sway Max speed 2.5m/s (Speed adjustable)	Further Speed reduction about 25% Critical zones will not be served anymore	>=3minutes
Level 3: Building displacement >=600mm	High sway	Elevator evaculates people to main floor and parks at a pre-defined floor (non-resonant floor)	>=3 minutes

4. CONCLUSION

ICC is a vibrant super high-rise building that never sleeps. Incorporated with a highly reliable and resilient power supply and a state-of-the-art elevator system, ICC is able to operate 24 hours a day, all year round, making it the best choice for headquarters of multinational corporations. No doubt, ICC is ready to meet the challenge of the 21st century and will be an icon of Hong Kong for years to come.

Paper No. 4

CONSTRUCTION OF TURNKEY TRANSMISSION PROJECT AT LOWER GULF – CHALLENGES & ACHIEVEMENTS

Speakers : Mr Johann Reidl, Project Director
Siemens Limited, Germany
Mr Volker Knierim, Senior Area Manager
Sales and Marketing, Energy Sector,
Siemens Limited, Germany

CONSTRUCTION OF TURNKEY TRANSMISSION PROJECT AT LOWER GULF – CHALLENGES & ACHIEVEMENTS

Mr Johann Reidl, Project Director
Siemens Limited, Germany
Mr Volker Knierim, Senior Area Manager
Sales and Marketing, Energy Sector,
Siemens Limited, Germany

ABSTRACT

To meet its growing demand for electricity Qatar plans to spend $ 5.75 bn till 2010. As a result the Qatar General Water & Electricity Corporation Kahramaa conducts the biggest transmission expansion project in the Lower Gulf region. Siemens has been awarded several turnkey contracts to build 62 high voltage substations and to lay 650km of HV cables with total contract volume of approximately 1.5 billion Euros in Qatar, Middle East.

A major challenge in the implementation of these fast track projects is to match advanced technology with aesthetic building design and to deliver in time. The execution of the contracts almost in parallel required a precise time scheduling and resource planning.

New approaches in project management, reporting, controlling and subcontractor management were necessary to assure the handing over of the completed substations to meet time, costs and quality requirements. The project details along with best project management practice will be shared in this paper.

1. PROJECT HIGHLIGHTS

The fast growing economy in the booming region Lower Gulf leads to an upsurge demand for electricity, which is increasing at an annual rate of 12 per cent. The expansion of the electrical transmission network included the construction of 62 substations in the 220kV, 132kV and 66kV level and the laying of approx. 650km HV power cables within 4 years. Following a clear strategy Kahramaa awarded the contracts with full turn-key responsibility to the contractor, including architectural design, civil, electrical and mechanical works, associated High Voltage to Medium Voltage switchgear, power transformer and Protection and Control system as a complete package to the customer.

2. PARTNERSHIP WITH CIVIL CONTRACTORS

Although the contractor is not a civil construction company the management of civil works is understood as core competence for turn-key projects. An effective local set up for the civil parts and transparent contracts with civil companies ensured the permanent control over the civil works, in line with customer's requirement. This approach helped minimizing contractual claims from civil contractors.

In order not to repeat design works for the substation building, typicals were created. They led to a high degree of standardization. Further a compact design was developed, harmonious with the surroundings and saving valuable space. To ensure a clear interface between the civil construction stage and the equipment installation stage, each substation building was clustered in working areas and for the purpose of precise time and manpower planning clear milestones for the achievement of clean room condition were defined.

From the very beginning the liaison with concerned authorities like municipality/urban planning/road department was established and maintained to obtain in advance the necessary certificates or permits, pre-requisite for the smooth execution of the projects.

3. PROJECT ORGANIZATION

The high demands of such mega projects made it necessary to build up a powerful team of experts, able to execute the works without delay. In the peak 250 employees of 12 nationalities were working simultaneously at 35 locations, managing 4,000 people from subcontractors. For each project, headed by an experienced Project team, a dedicated project execution team was built up. Support functions helped the project teams in the areas of vendor coordination, logistics, project planning, safety and health procedure and quality management, common for all projects, as and when required. A coordination team was responsible for a uniform project execution throughout all phases over all projects. This matrix organization created synergy effects and optimized the economic use of the valuable asset human resource. In addition, a helicopter view on the effectiveness of the common function groups and further improvement is observed in the process.

4. RESOURCE PLANNING AND REPORTING

Apart from the above, advanced project management tools which are developed by the contractor for international projects and adopted to these mega projects were strictly followed in all project cycles. Every project work element was documented with the tools and templates regarding the progress plan, execution schedule and resource chart, basis of a transparent and clear reporting system to the Steering Committee, governing body of the entire operation.

5. FINANCIAL AND TECHNICAL CONTRACT CLOSING

After the commissioning of a substation or cable route a concise contract closing is indispensable for the final success of a project. The final site activities like training, handing over of spares and special tools or clearing of snag items are equally important as the final engineering activities as-built drawings or operation & maintenance manuals. New solutions were agreed with customer, for example the handing over of the final documentation in a soft version, avoiding excessive paper copies. Information can be easily retrieved from the database, using a standard internet browser for navigation.

Moreover, trainings were scheduled and carried out to train customer's own resource making them fit for future maintenance and service job, and strategic spare parts lists developed and agreed. In order to stay focused a dedicated Closing team was built up, responsible for the technical and financial close out of projects, after handing over from the project team.

6. CONCLUSION

The enormous economic growth in the Middle East Region in recent years required the execution of big projects. New challenge is to set up multinational project management teams with different cultural background or adequate engineering expertise in the local region. Effective project management tools and transparent reporting systems are a must when implementing mega projects successful.

Only when understanding the customer's requirements and responding quickly to his needs the short execution times of fast track projects can be met.

During the executions of the above contract, the contractor successfully delivered the project in the expected time and quality. This is a key factor for a satisfied customer and subsequent orders. The above experience will be beneficial to similar mega projects in other regions as well.

Figure 1 Substation West Bay Super #1

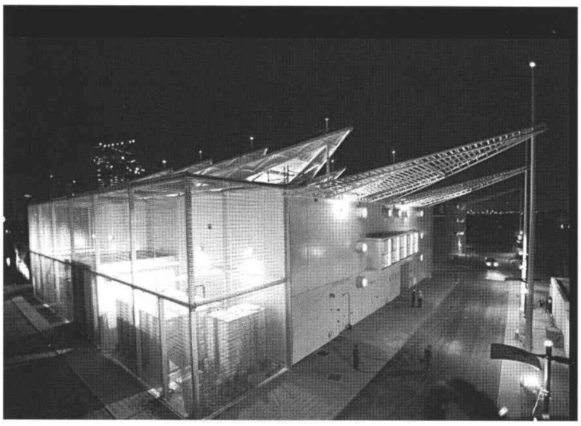


Figure 2 Project Management Tools

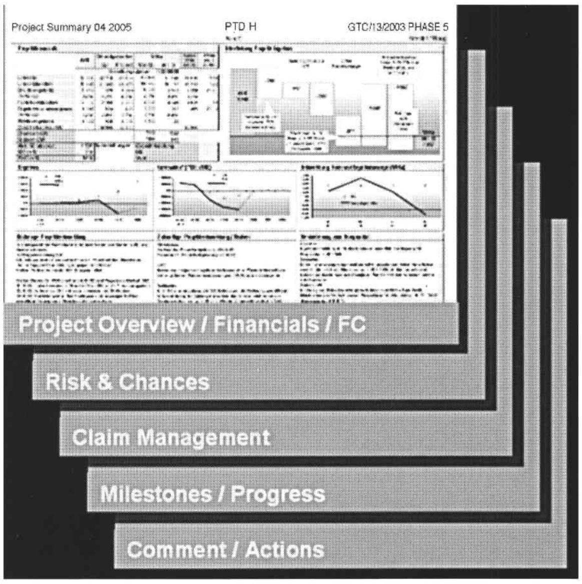
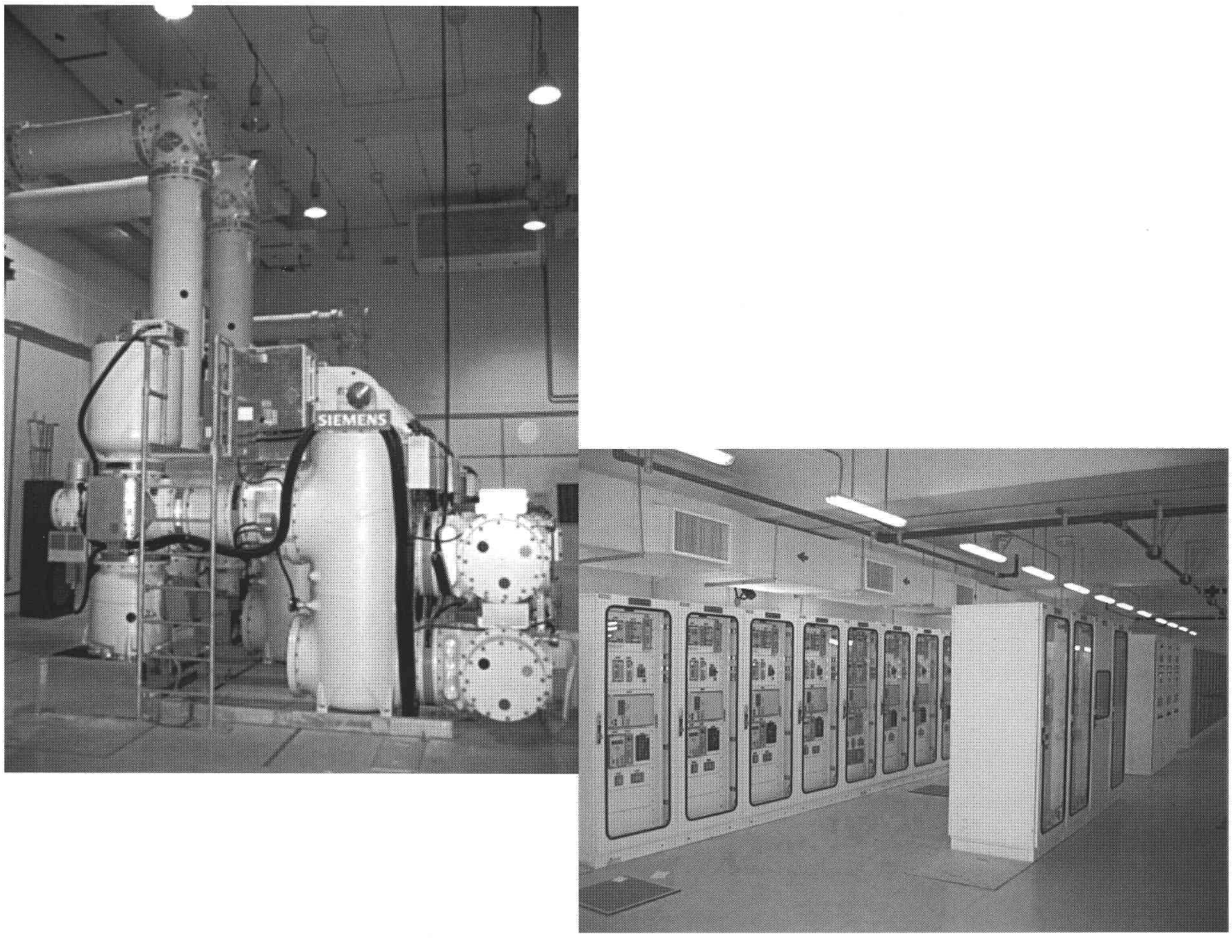


Figure 3 Switchgear & Control Rooms



Paper No. 5

2008 BEIJING OLYMPIC NATIONAL STADIUM AND NATIONAL SWIMMING CENTRE – ELECTRICAL AND LIGHTING SYSTEM DESIGN

2008北京奧運會國家體育場和游泳中心 供配電及照明系統的研究及應用

Speakers : **Mr B.H. Li, M&E General Manager**
Ms Q. Dong, Head of Electrical Department
Beijing Branch Office,
China Construction Design International, PRC

2008 BEIJING OLYMPIC NATIONAL STADIUM AND NATIONAL SWIMMING CENTRE – ELECTRICAL AND LIGHTING SYSTEM DESIGN
2008北京奧運會國家體育場和游泳中心 供配電及照明系統的研究及應用

Mr B.H. Li, M&E General Manager
Ms Q. Dong, Head of Electrical Department
Beijing Branch Office,
China Construction Design International, PRC

Paper No. 5

摘要

第二十九屆夏季奧運會兩個標誌性場館—鳥巢和水立方，其用電設備安裝容量大，其中含有大量的一級負荷中的特別重要負荷，對供電可靠性、連續性要求很高。本文研究、分析了鳥巢和水立方的負荷特點、建築特點，確定鳥巢採用4路10kV市電進線電源，即將上級110kV變電站引來的10kV線路兩兩引入到國家體育場的兩個主變電站，主變電站內設母聯，主變電站之間設單向聯絡。而水立方採用2路10kV 電源至游泳館內主變電站，2路電源分別引自2個上級110kV變電站，主變電站內為單母線分段，設母聯。

本文分析說明了鳥巢、水立方立面照明的理念、實現照明效果的措施和方法，並對照明效果進行評價。

1. 概況

2008年8月8日至24日，在我國首都北京成功的舉行了第29屆夏季奧林匹克運動會，在奧林匹克中心區內，有兩座舉世矚目的場館—國家體育場和國家游泳中心。圖1所示（註），國家體育場，俗稱“鳥巢”，是2008年北京奧運會主體育場，位於奧林匹克公園中心區南部，南鄰北四環路，西鄰中軸路延長線上的景觀路，北辰東路西側。景觀路西側為國家游泳中心，即“水立方”，在這水晶宮般的建築中，每天都有多項世界紀錄被刷新。

國家體育場在奧運會期間有座位9.1萬個，其中固定座位8萬個，臨時座位1.1萬個。與周圍相比，體育場整體抬高6.8m，體育場與周圍為3～6%的緩坡。體育場基座以下有0層和局部地下一層，地上7層。體育場總建築面積約為258,000m²，體育場建築最高點為69.21米，屬特級體育建築。體育場（含熱身場）南北長約887m，東西長約405m。

國家游泳中心屬特級體育建築，在奧運會期間有座位1.7萬個，其中固定座位6,000個，臨時座位1.1萬個。賽時總建築面積8.7萬m²，賽後改造後建築面積9.4萬m²，地下兩層，地上四層，建築物長、寬均為176m，地面上高度31米。建築圍護結構採用雙層聚四氟乙烯(ETFE)薄膜氣枕單元和源於數學界“泡沫”理論的多面體剛架鋼結構組成的牆體和屋面。地下部分為砼結構，樁基礎，地上為多面體剛架鋼結構體系。

2. 國家體育場供配電系統的研究與應用

2.1 設計依據

國家體育場10kV供配電系統的設計執行國家及行業現行規範，滿足奧組委對2008年奧運會的要求和業主方提出的設計大綱及其它設計要求，還要符合北京電力公司的有關規定，參照有關專家的評審意見。具體設計依據有：

- 國家及行業規範；

註：大部份圖示刊印於5.19至5.25頁

- 業主方提供的設計大綱及其它設計要求；
- “國家體育場電氣專業初步設計專家組評審意見”；
- 北京市建築設計研究院的“國家體育場初步設計審查意見（匯報稿）”；
- 北京電力公司“關於國家體育場供電初步設計審核意見的函”2004.4.14；
- 北京電力公司京電營[2004]12號文件“國家體育場供電初步設計第二次審核會會議紀要”2004.5.12。

2.2 負荷統計及計算

見表1。
其中，純消防負荷1,150kW。
考慮同時系數K_T=0.8
總計算負荷 $P_{js}=K_T\times P=0.8\times 18,526=$ 14,820.8kW。

需要說明，表中負荷為2004年6月統計的數據，以後施工圖幾經修改，負荷略有增加。但經過奧運會實際運行，最大負荷不足10,000kW。看來各用電單位所提出的用電負荷容量偏大。

表1 體育場負荷統計

負荷名稱	容量 (kW)	需要系數 (Kx)	計算有功負荷 (kW)	計算無功負荷 (kVar)	功率因數	小計
製冷站	4,560	0.7	3,192	2,145	0.83	3,621kW
空調通風機	715	0.6	429	288	0.83	
純消防進排風機	850				0.83	
生活水及其泵類	400	0.8	320	240	0.8	1,520kW
主場雨水泵	400	0.7	280	210	0.8	
電開水爐	100	0.8	80	0	1	
電鍋爐	400	0.7	280	0	1	
熱力站	300	0.8	240	149	0.85	
純消防水泵	300				0.8	
電拌熱	400	0.8	320	0	1	
電梯扶梯類	1,000	0.2	200	150	0.8	280kW
活動屋頂	400	0.2	80	60	0.8	
場地照明	1,800	0.8	1,440	697	0.9	1,440kW
-1~7F照明插座	4,250	0.5	2,125	1,029	0.9	2,705kW
廣場照明	200	0.8	160	77	0.9	
內立面局部照明	600	0.7	420	203	0.9	
廚房用電	1,000	0.35	350	217	0.85	350kW
熱身場用電	400	0.8	320	155	0.9	320kW
場外臨時媒體預留	2,000	0.7	1,400	868	0.85	3,290kW
場內弱電及媒體	2,700	0.7	1,890	1,171	0.85	
演出及開閉幕式預留	6,000	0.6	3,600	2,231	0.85	3,600kW
體育工藝	2,000	0.7	1,400	1,050	0.8	1,400kW
總計：	**29,625**		**18,526**	**10,940**	**0.86**	**18,526kW**

綜合上述依據，國家體育場10kV供配電系統的核心為：**上一級變電站發生故障時，該站的饋出線路全部失電，其餘上級變電站引來的電源應能保證體育場全部用電負荷的正常運行。而每一路電源所帶負荷不宜超過10,000kVA，最大不得超過12,000kVA。**

2.3 電源電壓

根據我國電力部門的規定，供電電壓等級一般可參照表2確定。

從表2可知，國家體育場的負荷，宜採用35kV電壓供電。但北京地區沒有35kV電

表2 電源電壓的確定

供電電壓等級	用電設備容量	受電變壓器總容量
220V	10kW及以下單相設備	
380V	100kW及以下	50kVA及以下
10kV		100kVA至8,000kVA(含8,000kVA)
35kV		5MVA至40MVA
66kV		15MVA至40MVA
110kV		20MVA至100MVA
220kV		100MVA及以上

源，經與供電部門協商，國家體育場採用10kV電源電壓供電。

電源數量分析見表3。

表3 電源數量比較

供電電源數量	2路	3路	4路
電源共帶負荷總容量(kVA)	20,000	30,000	40,000
一路電源停電，剩餘電源帶負荷情況	帶不了全負荷，要卸載次要負荷	處於臨界點	可以帶全負荷
二路電源停電，剩餘電源帶負荷情況	除應急負荷外，其它負荷均斷電	不能帶全負荷，部分負荷要卸載	可以帶全負荷
系統複雜程度	簡單	較複雜	複雜
是否滿足要求	不滿足	不滿足	滿足

電源數量在5路及以上，系統將變得十分複雜，投資大大增加，而系統可靠性提高甚微，性價比不佳。因此，國家體育場採用4路10kV市電供電。

2.4 變電所的位置

需要綜合考慮諸多因素以確定變電所位置：深入或接近負荷中心，更好的為負荷服務，降低有色金屬損耗和電能損失，除6#變電所低壓供電在300m外，原則上，其它變電所低壓供電半徑在100m以內；還要考慮進出線方便；接近電源側，盡量靠近外牆；便於設備吊裝、運輸方便；避免設在有劇烈振動或有爆炸危險介質的場所；遠離多塵、水霧或有腐蝕性氣體的場所；不應設在廁所、浴室、廚房或其它經常積水場所的正下方，且不宜與上述場所貼鄰。

體育場負荷的最主要特點是建築佔地面積大，負荷較為分散，並且含有特別重要的一級負荷。因此，國家體育場共設8個變電所，參見圖2。

1#變電所： 兼高壓配電，為國家體育場主變電站之一。進線來自安慧變電站及惠翔變電站。1#變電所除為本所四台變壓器供電外，還為2#、4#、7#變電所和6#箱式變電站配電。該變電所主要為1、2、3號核心筒附近的負荷供電。

2#變電所： 進線一路引自1#變電所，另一路引自3#變電所。該變電所主要為4、5、6號核心筒附近的負荷供電。

3#變電所： 為國家體育場另一主變電站。進線來自惠翔變電站及安惠變電站。3#變電所除為本所變壓器供電外，還為2#、4#、5#、8#變電所配電。該變電所主要為7、8、9號核心筒附近的負荷供電。

4#變電所： 進線一路引自1#變電所，另一路引自3#變電所。該變電所主要為10、11、12號核心筒附近的負荷供電。

Paper No. 5

5#變電所： 進線兩路均引自3#變電所。奧運會期間，該變電所主要為開幕式負荷供電。奧運會後，為商業用房提供電源。

6#變電所： 為箱式變電站，為熱身場地提供照明電源。進線兩路均引自1#變電所。

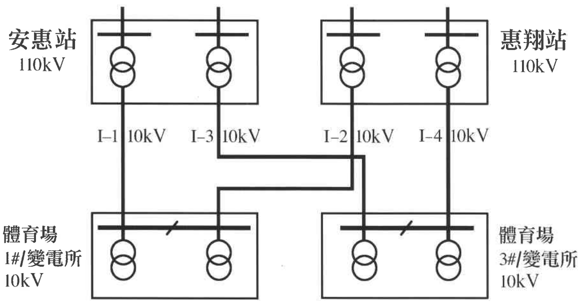
7#變電所： 與1#柴油發電機房相鄰，兩路進線均引自1#變電所。該變電所主要為1#冷凍站負荷供電。

8#變電所： 與2#柴油發電機房相鄰，兩路進線均引自3#變電所。該變電所主要為2#冷凍站負荷供電。

2.5 供配電方案

國家體育場採取四路獨立的10kV電源供電，分別由為本次奧運會新建的安慧110kV變電站、惠祥110kV變電站各提供兩路10kV電源。該四路10kV電源分別兩兩引入國家體育場內部兩座總變電所，各分變電所由總變電所提供電源。即圖2中1號變電所和3號變電所為總變電所，分別簡稱“1號主站”和“3號主站”。參見圖3和圖4。

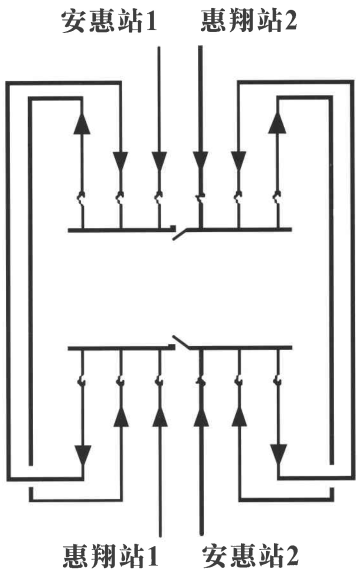
圖4 國家體育場10kV電源關系圖



2.5.1 符合N-2原則的供配電方案

圖5所示，該方案四路電源分別兩兩引入到國家體育場內部兩座主站1#變電所和3#變電所，兩個主站均為單母線分斷方式，兩主站相距較遠，兩主站相對應的母線採用雙向聯絡。1#和3#變電所站內的單母線間的聯絡簡稱“母聯”；1#、3#變電站之間的聯絡簡稱“站聯”。該方案符合N-2原則，即電源兩次故障，也能保證體育場正常供電。該方案在北京已有些應用，並積累了諸多經驗。

圖5 符合N-2原則的供配電方案



(1) **正常時方案分析**

圖6一(1)所示，正常運行時，四路電源分別帶各自母線，母聯和站聯均斷開。1#站兩段母線所帶的負荷均為6,850kVA，3#站內兩段母線的負荷為5,350kVA。該負荷為變壓器的安裝容量，實際負荷要小得多，不大於安裝負荷的50%。

(2) **安惠站故障時方案分析**

假設安惠站由於某種原因故障，例如火災、水災等，該站向體育場提供的兩路電源停止供電，剩餘的惠翔站能否保證體育場正常運行?

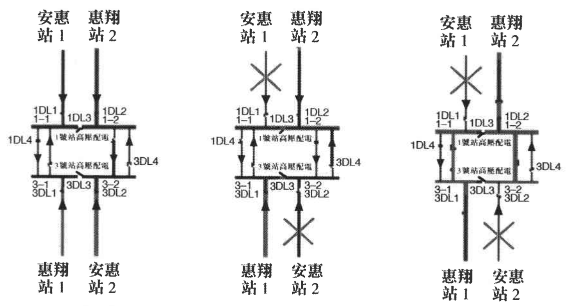
- **第一輪備自投**

圖6一(2)所示，安惠站兩路電源不能供電，此時1#、3#主站內母聯閉合，站聯打開，惠翔站2電源帶1#站內的兩段母線1-2、1-1，此時該電源所帶負荷的安裝容量為13,700kVA，設變壓器的負荷率≦60%，則實際負荷小於8,220kVA；同樣，惠翔站1電源帶3#站內3-1、3-2母線，總安裝容量為10,700kVA，設變壓器的負荷率≦60%，則實際負荷為6,420kVA。**因此，可以得出結論，即當安惠站兩路電源停止供電時，母聯投入後，惠翔站提供的電源可以保證體育場正常運行。**

- **第二輪備自投**

圖6－(3)所示，若第一輪自投失敗，進行第二輪備自投，即投入站聯。此時，惠翔站1電源帶3-1、1-1母線，總安裝容量12,200kVA，變壓器的負荷率≦60%，則實際負荷小於7,320kVA；同樣，惠翔站2帶1-2、3-2母線，總安裝容量12,200kVA，同樣設變壓器的負荷率≦60%，則實際負荷小於7,320kVA。**因此，當安惠站兩路電源停止供電時，站聯投入後，惠翔站提供的電源可以保證體育場正常運行。**

圖6 符合N-2原則的供配電方案故障分析



(1) 正常時 (2) 安惠站故障，第一輪備自投 (3) 安惠站故障 第二輪備投

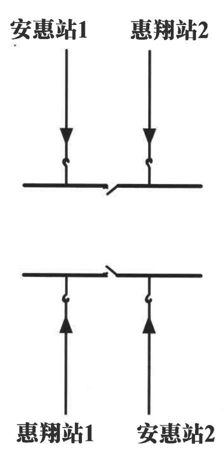
(3) **惠翔站故障時方案分析**

惠翔站兩路電源停電，具有相同的分析結果。

某一路電源停電，是上述分析的一個特例，由於篇幅所限，不再贅述。

結論：符合N-2 原則的供配電系統，當一路或二路電源停止供電時，剩餘的電源可以保證體育場正常運行。

圖7 符合N-1原則的供配電方案



2.5.2 符合N-1原則的供配電方案

圖7所示，該方案四路電源分別兩兩引入到國家體育場內部兩座主站1#變電所和3#變電所，兩個主站均為單母線分段方式，兩主站之間沒有任何聯絡。簡言之，其特點為只有“母聯”，沒有“站聯”。符合N-1原則的方案在全國也有很多的應用，尤其在大中規模的建築中應用較多。

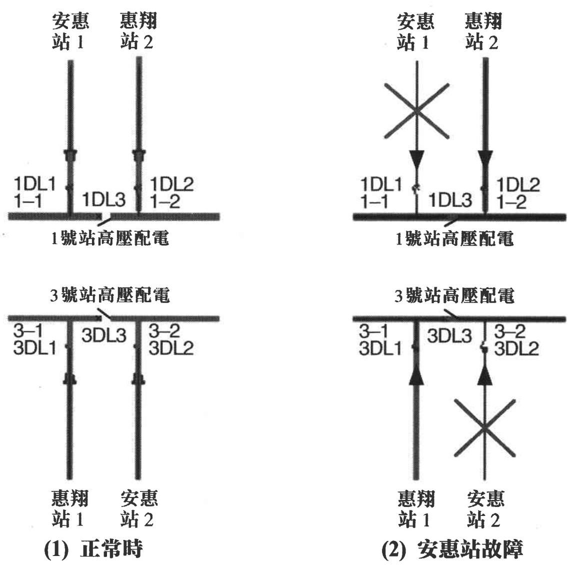
(1) **正常時方案分析**

圖8 ── (1)所示，正常運行時，四路電源分別帶各自母線，母聯均斷開。1#站兩段母線所帶的負荷均為6,850kVA，3#站內兩段母線的負荷均為5,350kVA。該負荷為變壓器的安裝負荷，實際負荷小於安裝負荷的60%。

(2) **安惠站故障時方案分析**

參見圖8── (2)，假設安惠站由於某種原因故障，停止向體育場供電。此時1#、3#主站內母聯閉合，惠翔站2電源帶1#站內的兩段母線1-2、1-1，此時該電源所帶負荷的安裝容量為13,700kVA，由於變壓器的負荷率≦60%，則實際負荷為8,220kVA；同樣，惠翔站1電源帶3#站內3-1、3-2母線，總安裝容量為10,700kVA，同樣，變壓器的負荷率≦60%，則實際負荷為6,420kVA。**因此可以得出，當安惠站兩路電源停止供電時，母聯投入後，惠翔站提供的電源可以保證體育場正常運行。**

圖8 符合N-1原則的供配電方案故障分析



(1) 正常時 (2) 安惠站故障

Paper No. 5

SIEMENS

(3) **惠翔站故障時方案分析**

同樣，惠翔站兩路電源停電具有同樣分析結果，即安惠站提供的電源可以給體育場提供足夠的電源。

一路電源停電是上述分析的特例，不再贅述。

結論：當四路電源中有一路或二路電源停止供電時，母聯投入後，剩餘電源可以保證體育場正常運行。

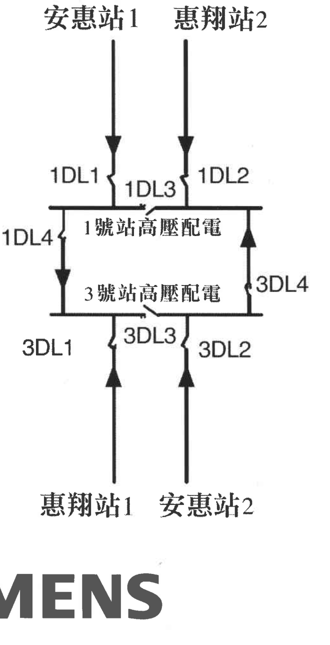
2.5.3 符合N-1.5原則的供配電方案

需要説明，在我國電力部門，只有N-1和N-2原則，沒有N-1.5原則。事實上，本文所説的N-1.5原則是介於N-2與N-1之間，是準N-2原則，功能上能滿足N-2原則的要求。圖9所示，N-1.5原則即有N-2的可靠，又有N-1的簡單。該方案四路電源分別兩兩引入到國家體育場內部兩座主站1#變電所和3#變電所，兩個主站均為單母線分段方式，兩主站相對應的母線採用單向聯絡。兩主站共有四段母線，相鄰兩母線均有聯絡，母聯或站聯。

(1) **正常時方案分析**

圖10 ── (1)所示，正常運行時，四路電源分別帶各自母線，母聯和站聯均斷開。1#站兩段母線所帶的負荷均為6,850kVA，3#站內兩段母線的負荷為5,350kVA。該負荷為變壓器的安裝容量，實際負荷將小於安裝負荷的60%。

圖9 符合N-1.5原則的供配電方案



(2) **安惠站故障時方案分析**

假設安惠站由於某種原因故障（火災、水災等），該站向體育場提供的兩路電源停止供電，剩餘的惠翔站能否保證體育場正常運行?

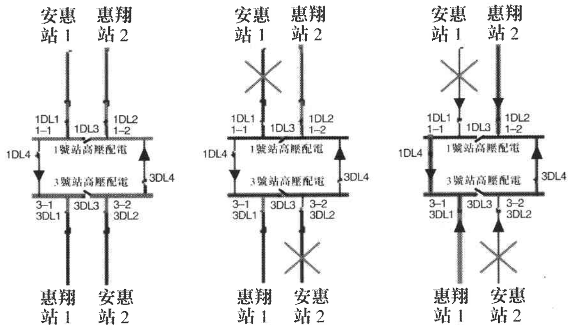
- **第一輪備自投**

圖10 ── (2)所示，安惠站兩路電源不能供電，母聯首先投入，這是第一輪備自投，此時1#、3#主站內母聯閉合，惠翔站2電源帶1#站內的兩段母線1-2、1-1，此時該電源所帶負荷的安裝容量為13,700kVA，設變壓器的負荷率≦60%，則實際負荷為82,200kVA；同樣，惠翔站1電源帶3#站內3-1、3-2母線，總安裝容量為10,700kVA，設變壓器的負荷率≦60%，則實際負荷為6,420kVA。**因此，可以得出，當安惠站兩路電源停止供電時，母聯投入後，剩餘的惠翔站提供的電源可以保證體育場正常運行。**

- **第二輪備投**

圖10 ── (3)所示，若第一輪自投失敗，進行第二輪備自投。此時惠翔站2電源帶3-1、1-1母線，總安裝容量12,200kVA，由於變壓器的負荷率≦60%，則實際負荷不大於7,320kVA；同樣，惠翔站1帶1-2、3-2母線，總安裝容量12,200kVA，同樣設變壓器的負荷率≦60%，則實際負荷為7,320kVA。**因此，當安惠站兩路電源停止供電時，站聯投入後，惠翔站提供的兩路電源可以保證體育場正常運行。**

圖10 符合N-1.5原則的供配電方案故障分析



(1) 正常時　(2) 安惠站故障，第一輪備自投　(3) 安惠站故障 第二輪備投

(3) **惠翔站故障時方案分析**

同樣，惠翔站兩路電源停電具有同樣分析結果，即安惠站提供的電源可以給體育場提供足夠的電源。

一路電源停電是上述分析的特例，不再贅述。

結論：當四路電源中的一路或二路電源停止供電時，母聯或站聯投入後，剩餘電源可以保證體育場正常運行。

2.5.4 供配電方案的比較

上述三個方案均滿足專家提出的，當"上一級站發生故障時，該站的饋出線路全部失電，其餘上級站引來的電源應能保證全部用電負荷的運行。"既然三個方案均滿足要求，那麼哪個方案最優呢?表4為三種方案的比較。

表4 供配電方案的比較

方案	N-2	N-1	N-1.5
可靠性	站內有母聯，站間有站聯，四路電源相互聯絡，系統較可靠。	站內有母聯，站間沒聯絡，四路電源的優勢沒有很好的利用。	站內有母聯，站間有站聯，四路電源相互聯絡，可靠性高。
複雜性	站聯雙向聯絡，線路長，節點多；保護複雜，場內一條10kV回路可能有4個斷路器，保護配合困難；操作複雜。	站聯沒聯絡，系統簡潔；操作簡單。	站聯單向聯絡，線路雖長，但節點比N-2減少，又能充分發揮四路電源的優勢；操作較N-2簡單。
投資	一次投資高，與N-1相比，投資增加至少300萬元。	三個方案中，該方案投資最少。	該方案投資居中。
運行費用	運行、維護費用高。	運行費用最少。	運行費用居中。

2.6 供配電方案的結論

綜上所述，並經專家論證，確定採用符合N-1.5原則的10kV供配電系統方案。該方案充分發揮四路電源的優勢，又簡化了系統，可靠性大大提高。經濟性又較好，是一較合理的供配電方案。目前該系統運行良好，在奧運會之前的多次試驗中體現出可靠性的優勢。

3. 國家游泳中心供配電系統的研究與應用

3.1 設計依據

國家游泳中心供配電系統設計以國家及行業現行規範為依據，按照北京電力公司和市規劃委的有關規定，為滿足設計大綱、奧組委以及國際泳聯相關要求進行設計，具體設計依據為：

- 國家及行業現行規範；
- 業主方提供的奧運工程設計大綱；
- 各市政主管部門對本工程提供的市政條件和要求：

其中包括：北京市規劃委員會《關於國家游泳中心初步設計審查的批復》
—2003年12月17日

北京供電公司關於《國家游泳中心供電方案及內部電氣設計原則審核會會議紀要》 —2004年1月14日

北京供電公司關於《奧運游泳中心內部電氣設計圖紙審核會會議紀要》
—2004年6月2日

北京供電公司關於《北京奧運場館及配套設施配電系統技術規範》
—2006年9月

綜合上述依據，國家游泳中心作為一座特級體育場館，其10kV供配電系統的核心為：**當其中一個上級變電站饋出線路失電時，另一個上級變電站引來的電源應能保證游泳中心全部用電負荷的正常運行。**

3.2 負荷統計及計算

建築物的用電負荷是供配電系統設計的基本依據，而用電負荷的需求集中反映於負荷等級和負荷容量這兩方面。國家游泳中心作為一座近九萬平方米的全ETFE氣枕圍護結構的特級體育場館，其內部負荷類別很多，各類負荷按照供電可靠性及中斷供電在政治、經濟上所造成損失或影響的程度劃分為3個級別，其中包括中斷供電會直接或間接影響賽事和轉播正常進行的一級負荷（包括特別重要一級負荷），中斷供電不影響賽事和轉播正常進行但影響室內環境質量的二級負荷和中斷供電不影響賽事正常進行及室內環境質量的三級負荷。各類負荷容量統計詳見表5。

表中數據是基於各方提出的用電需求進行計算的，與實際運行中有一定差異。奧運會期間實測的最大負荷約4,600kW。這裡實測與設計計算負荷之間存在差距的主要原因在於弱電類負荷實際運行容量偏低，遠低於設計階段所提的需求電量；再有就是由於賽時運營需求發生變化，部分負荷未啟用，如景觀大屏幕和部分空調通風設備等。

3.3 電源電壓

從第2.3節和表2可知，國家游泳中心的負荷在8,000kVA以下，宜採用10kV電壓供電。但究竟採用2路還是3路10kV供電，還需要進一步研究。

表5　游泳中心負荷統計

負荷名稱	容量 (kW)	需要系數 (Kx)	計算有功負荷 (kW)	計算無功負荷 (kVar)	功率因數	小計
普通照明和插座	1,013.00	0.80	810.40	392.49	0.90	
應急照明	200.00	0.90	180.00	87.18	0.90	
廣場照明	16.00	1.00	16.00	9.92	0.85	1,006.40
水處理系統	442.00	0.75	331.50	248.63	0.80	
空調系統	4,179.20	0.75	3,134.40	2,106.33	0.83	
電梯	186.40	0.60	111.84	83.88	0.80	
廚房動力	60.00	0.40	24.00	18.00	0.80	
充氣泵	179.00	0.40	71.60	53.70	0.80	
其他動力	642.00	0.75	481.50	361.13	0.80	4,154.84
體育照明	384.00	1.00	384.00	237.98	0.85	384.00
顯示屏	170.00	0.40	68.00	42.14	0.85	
重要賽事負荷	532.00	0.40	212.80	131.88	0.85	
其他弱電	367.00	0.40	145.20	89.99	0.85	426.00
媒體及攝影工作用電	289.00	0.80	231.20	143.28	0.85	231.20
景觀水泵和照明用電	293.00	0.90	263.70	163.43	0.85	
建築物景觀照明	551.00	0.70	385.70	186.80	0.90	
景觀大屏幕	648.00	0.70	454.00	281.36	0.85	1,103.40
總計	10,201.60		7,305.84	4,638.12	0.84	7,305.84

其中，純消防負荷829kW。

考慮同時系數$K_T=0.8$

總計算負荷$P_{js}=K_T \times P=0.8\times 7,306=5,844.8$kW。

電源數量分析見表6。

表6　電源數量比較

供電電源數量	2路	3路
一路電源停電，剩餘電源帶負荷情況	可帶全負荷	可帶全負荷
二路電源停電，剩餘電源帶負荷情況	負荷均斷電	能帶全負荷
系統複雜程度	簡單	較複雜
是否滿足要求	滿足	滿足

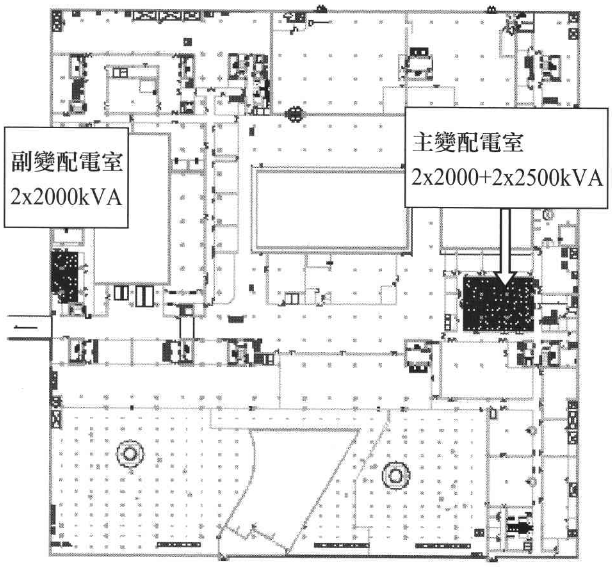
電源數量在3路及以上，系統將變得較為複雜，投資也相應增加，且由於10kV電源只能由附近的2個110kV變電站供電，3路10kV電源不完全獨立，系統可靠性提高甚微，性價比不佳。因此，國家游泳中心採用2路10kV市電供電。

3.4　變電所的位置

正如第2.4節所述，變配電所設置需要綜合考慮諸多因素。游泳館不像體育場佔地面積那麼大，因此負荷相對比較集中，同時作為特級體育場館，也含有特別重要的一級負荷。

國家游泳中心變配電所設計在滿足規範要求的基礎上，重點考慮負荷容量的大小、供電半徑及大容量設備──製冷機房的設置，共設有一主一副2個10kV變配電所，主、副變配電所分別位於地下二層的東側和西側，詳見圖11。

圖11 B2層變配電所分佈

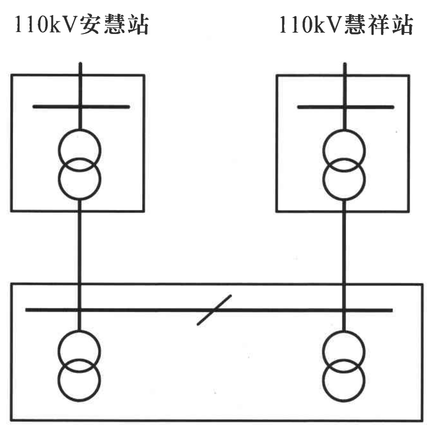


其中主變配電所兼10kV配電，為國家游泳中心主變電站。2路10kV進線來自安慧變電站及慧祥變電站。主變配電室內設有兩組變壓器，一組為就近水處理機房設備和各層照明、插座、通風、弱電機房設備等負荷供電；另一組主要為空調製冷負荷供電。副變配電室內設有一組變壓器為就近水處理機房設備和各層照明、插座、通風、弱電機房設備等負荷供電。根據北京奧運電力標準規定，國家游泳中心變壓器設計負荷率均不超過60%。

3.5　供配電方案

與國家體育場相比，國家游泳中心的建築體量要小很多，負荷量也不足其一半，所以採取2路獨立的10kV電源供電，分別由為本次奧運會新建的安慧110kV變電站、慧祥110kV變電站各提供1路10kV電源。這2路10kV電源先引入國家游泳中心內主變電所，再由主變電所饋出至分變電所。參見圖3和圖12。

圖12 國家游泳中心10kV電源關係圖



Paper No. 5

由圖可見，游泳中心的10kV系統相對比較簡單。考慮10kV系統的運行方式在第2.5.2部分中已有很詳盡的闡述，所以這裡僅作簡要說明。

游泳中心的10kV系統，正常情況下2路10kV電源分列運行，共同承擔全部負荷。當110kV安慧降壓站電源故障時，游泳中心10kV主變電所內相應10kV電源進線斷路器失壓掉閘，母聯斷路器自動合閘，由110kV慧祥降壓站饋出的10kV電源為全部負荷供電，實現N-1運行方式。反之亦然。

3.6 供配電方案的結論

不同建築物的用電要求各不相同，電氣系統也必須有針對性，因項目而異，以滿足不同建築物的特殊要求。國家游泳中心供配電系統接線力求簡潔、安全、可靠，確保奧運會期間場館電力系統的正常運行。

4. 國家體育場立面照明系統的研究與應用

4.1 設計原則

4.1.1 尊重建築師的設計理念

國家體育場建築方案主要由瑞士H & de M建築事務所設計，方案創作之初，提出了晚上鳥巢的效果，即圖13所示的效果剪影。這樣的效果我們並不陌生，中國的窗花具有相似的剪影效果。也就是說，背景亮、前景暗，以此襯托出前景的效果。為了讓晚間的鳥巢有層次感，外側鋼結構柱子的內側被照亮。

紅牆是鳥巢的特色之一，外表面約一半是紅牆。因此，紅牆的照明對剪影效果至關重要。

4.1.2 符合奧林匹克中心區照明規劃的要求

北京奧林匹克中心區照明規劃是鳥巢照明設計的重要原則之一，如圖14所示，鳥巢、水立方及中間的中心廣場為高亮度區，往北面至森林公園分別為中亮度區、低亮度區和最低亮度區。其中，高亮度區內的平均水平照度33*lx*，最小水平照度15*lx*，最高水平照度可達100*lx*。中間廣場中心的照度約100*lx*。

同時，要求國家體育場和國家游泳中心的平均亮度為8-10cd/㎡。

4.1.3 滿足北京市主管部門照明模式的要求

根據北京市市政管委的要求，照明設計至少要求三種照明模式，以滿足重大節日、一般性節日和平常日的照明需要，也可以達到照明節能的目的。

4.1.4 尊重工程現狀

由於工程施工進度較快，而照明設計審批工作比較複雜，周期較長，原先預留、預埋的管線盡量保留，減少不必要的浪費。

4.2 照明的效果

我們確定的照明設計主題為“體現中華傳統文化，弘揚奧林匹克體育精神。”也就是用光表現出中國傳統的文化。因此，在設計時幾個關鍵的場景非常重要。

效果1：剪影。如上所述，其靈感來源於中國民間的窗花。

效果2：金碧輝煌。奧運會是世界範圍內的一大盛事，用紅光、黃光將鳥巢裝扮的金碧輝煌，與奧運盛事非常吻合。

效果3：變化效果。包括“呼吸”效果和“心跳”效果，給國家體育場賦予新的生命。

4.3 立面照明系統的研究

立面照明不包括開幕式照明，本研究包括計算機模擬分析和試驗研究。由於篇幅所限，本文將計算機模擬分析的結果進行總結，重點敍述照明試驗。

4.3.1 立面照明指標的研究

根據照明規劃，結合鳥巢西側的水立方和中心區照明，特制定了鳥巢的照明指標，並標於圖15所示，這些指標通過實際

工程試驗及理論研究得出的。指標反映了鳥巢與水立方照明要協調、匹配。水立方照明不能比鳥巢亮的很多，否則，水立方有“搶了鳥巢風頭”之嫌，消弱了鳥巢的主角地位；同時水立方與鳥巢相比，也不能暗淡無光。

由此，鳥巢的照明指標分解到各個被照部位，見圖16。圖中照明指標不包括開閉幕式的舞台照明，也不包括為了增加喜慶氣氛的其它臨時照明，本指標僅為本建築物永久立面照明指標，請讀者注意。

4.3.2 核心筒洗牆照明的研究

限於篇幅所限，本文重點介紹最重要的洗牆照明。

(1) 光源

圖17為金鹵燈、熒光燈、LED照亮紅牆的效果，通過多次試驗，最後確定採用大功率(1W)LED作為洗牆燈的光源，原因有三：

第一：本照明系統需要調光，LED很容易實現；

第二：北京屬於寒冷地區，冬季氣溫可達零下15℃以下，而夏季氣溫多次超過40℃，立面照明燈具全部屬於室外環境，LED可以滿足此要求；

第三：通過紅、白、黃光LED的等比例配比，對紅牆色彩還原性較好，符合建築師的要求。

(2) 換色材料

正如(1)中所述，燈具的紅光由LED光源提供的。在試驗熒光燈、金鹵燈時，不可避免要用到紅色的換色材料，如濾色片、鍍膜等。通過測試，紅色系列的換色材料造成光的衰減達80~90%，燈具效率大大降低。達到同樣照明效果，如果採用LED，其光效是配有換色裝置的熒光燈、有換色裝置的金鹵燈的3~5倍。

因此，最終決定採用LED，它不需要換色裝置，實現高效、色彩還原性好。

(3) 牆面照明的均勻度

從獲得良好的剪影效果出發，背景的紅牆用均勻照明還是退韻照明呢?

圖18所示，左圖為退韻照明效果，即牆面上照度由上至下逐漸變暗，最小照度與平均照度之比將小於0.05。右圖為均勻照明效果。對於一般的照明，退韻不失為較好的選擇，但是對於剪影效果而言，紅牆照明的目的是作為背景，用於襯托前面的鋼結構，為了鋼結構剪影的表現，背景照明相對均勻可以給人較好的視覺效果。

應該説明，“均勻”明亮的紅牆是相對的，如果紅牆照明非常均勻，剪影效果將會變得呆板。試驗表明，牆面上照明均勻度宜為最小照度與平均照度之比的0.3或更大。

Paper No. 5

(4) 燈具

為了達到效果要求，我們對燈具的配光提出要求，如圖19所示為試驗實測的數據。

Eave=199.75*lx*
Emax=380*lx*
Emin=64*lx*
Emin/Eave=0.32

符合前面的指標要求，試驗效果得到各方的認可和確認。

經過多次修改、完善，最終定型燈具，其主要技術參數如下：

- 鋁制燈體，靜電噴塑處理，外觀顏色黑色/紅色；
- IP65，I類燈具，220V/50Hz；
- 大功率LED；每套總功率60W，20顆白色+20顆紅色+20顆黃色，呈三角形排列，每套燈具總光通量不低於1,190*lm*；透鏡外發光角度45度，正負偏差3度；
- 白色LED色溫3,000-3,600K、60-70*lm*/W；
- 紅色LED波長620-625nm、30-40*lm*/W；
- 黃光LED波長585-590nm、30-40*lm*/W；
- 光衰，30,000h時小於75%；
- 壽命，不小於30,000h。

SIEMENS

4.4 實際效果

剪影效果1：用於平常日，只開啟洗牆燈，外圍鋼結構剪影效果非常明顯。

如圖20所示，上圖為設計時的效果，紅、黑顏色很純，沒有過多的雜色光。但立體感不強，與窗花的效果很接近。

下圖為實際效果，由於室內照明、集散廳照明、景觀照明等的影響，使得實際效果顏色太多，除紅色光外，還有白、藍、綠等光。實際效果打了折扣。

剪影效果2：用於一般性節日，開啟洗牆燈、外圍柱子內側照明、立面與頂部轉接處照明。

參見圖21，上圖為設計效果，由於增加了對外圍鋼結構內側照明，效果比“剪影效果1”更有層次、有深度感，建築物立面由平面變成立體。該效果仍然保持較好的剪影效果，應該說，這種效果是對效果1的延伸和豐富。

下圖為奧運會期間實拍的照片，基本上達到了設計效果的要求。從照片上不難看出，實際效果與設計效果存在一定的差距，主要原因有：

第一：景觀照明對立面照明產生影響，導致“剪影”效果被弱化；

第二：室內照明的影響。主要是三層和四層室內照明、食品零售點照明對立面照明產生負面影響，使得很純粹的紅色增添了不少雜色。

第三：集散廳吊燈也增加了視覺上的雜色光，同時還弱化了紅色背景牆的效果。

第四：中心區的照明、河兩岸的照明對鳥巢產生干擾光，影響鳥巢的照明效果。

剪影效果3：就是在效果2基礎上將頂部膜結構均勻照亮，在此不再用照片說明。

金碧輝煌：圖22這個效果是今年4月新增加的效果，屬於照明的升級版。主要採用紅色光和黃色光，在中國傳統文化中，紅色比較喜慶，而黃色顯示富貴和華麗，紅色和黃色結合顯得非常喜慶，並且將鳥巢裝扮得金碧輝煌。我們可以聯想到，中國的國旗── 五星紅旗也是紅、黃兩色。這種效果主要用於大喜大慶之日。奧運會期間使用這種效果非常貼切，與奧運盛事非常協調。

變化效果：包括“心跳”和“呼吸”，預示著該建築物具有生命力，即用光表現了鳥巢的生命力。變化還包括其它有序的明暗變化，實現這些效果應該歸功於智能照明控制系統。這種效果盡量少用，因為鳥巢畢竟是比較莊重、大氣的建築，具有紳士風度，過多的變化與其身份不相協調。

圖23為國家體育場的總體照明效果，拍攝於奧運會期間的2008.8.12，拍攝地點在鳥巢的東南側、龍形水系的東岸，這是鳥巢最佳拍攝點之一，天空中的浮雲依稀可見，微風輕吹河面，泛起層層漣漪，水中的倒影給鳥巢增添了靈氣。

4.5 效果評價

奧運會期間，筆者對奧林匹克中心區的觀眾及鳥巢周圍觀景的市民進行隨機調查，在127位受訪者中，117位認為鳥巢照明整體效果令人滿意，佔92.1%；10位認為可以接受這樣效果，佔7.9%；沒有人認為不滿意。通過專業的視覺評價，鳥巢照明質量達到優秀等級。評價參照《視覺環境評價方法》GB/T 12454-90，在此基礎上，

結合立面照明的特點從十個方面進行評價，包括立面照明的藝術效果、與環境的協調、與建築物的協調、照明或亮度、照明或亮度分佈、顏色特性、能耗、光影、眩光及光污染、整體印像等。總得分96分（滿分100分）。應該説，鳥巢照明設計非常成功，效果較好。

5. 國家游泳中心立面照明系統的研究與應用

5.1 設計原則

5.1.1 詮釋建築設計理念

國家游泳中心建築方案主要由中建國際設計顧問有限公司(CCDI)、澳大利亞PTW、ARUP組成的設計聯合體創作完成的，建築的核心創意為力圖營造一個以“水”為生命的空間，裡面容納人的各種與水相關的活動，讓人享受水帶來的各種美和快樂。同時，水也是生命之源，因而“水”主題更有著極為豐富的內涵和外延。建築物景觀照明設計就是通過形像化、藝術化的手法表現水的特性以及人們對水的多方位感知情緒，詮釋和豐富建築設計理念。如圖24所示水的神韻。

5.1.2 符合奧林匹克中心區照明規劃要求

如4.1.2中所述，同鳥巢一樣，北京奧林匹克中心區照明規劃也是“水立方”照明設計的重要依據之一。按照規劃要求，水立方為高亮度區，其外表面白場平均亮度為8-10cd/m^2。

5.1.3 適應圍護結構的特殊性和安裝空間的複雜性

國家游泳中心採用了ETFE雙層氣枕全圍護結構以及空間多面體剛架鋼結構體系，既為建築物景觀照明提供了獨特的展示平台，同時也由於膜材及氣枕的特殊光學特性和複雜多變的內部安裝空間，對於照明方式、光源和燈具的選擇以及系統集成化控制等，提出了許多新的難題和挑戰。因此需要構建一個為其專用的建築物景觀照明系統，體現“水立方”的特有形像。

5.1.4 堅持實驗和科研相結合的技術路線

由於國家游泳中心建築結構的創新性特點，其景觀照明缺乏範例可循，從照明方式的選用、光源和燈具的選擇等都不同於常規的景觀照明系統。而是需要從實驗入手，通過大量的實驗和分析研究工作，才使得國家游泳中心的建築物景觀照明系統得以逐漸的明晰和確立。由於這項工作需要大量的科研工作，所以也藉此申報了兩項科研項目—北京市科委的“奧運場館LED照明—LED在國家游泳中心建築物景觀照明上的應用研究”和國家科技部的“半導體照明規模化系統集成技術研究—國家游泳中心大規模LED建築物景觀照明工程研究”。

5.2 方案構思

照明效果以“水”主題為基本設計原則，將照明效果劃分為兩大類—基本場景模式和特殊場景模式。在各種場景模式下，根據場館實際運營需求，進行明暗、色彩和整體形像的變化。

5.2.1 基本場景模式

這一效果早在2003年建築方案設計階段就確定下來。在基本場景模式下，國家游泳中心4個立面和屋面近5萬平方米的外表面整體被有序、均勻照亮，呈現亮度適宜的湖藍色。圖25為建築方案階段的夜景效果圖，意在呈現水泡一般晶瑩透明的整體形像。

5.2.2 特殊場景模式

(1) 節慶煙花場景

配合不同慶典事件的場合、季節轉換及現場互動要求，“水立方”可呈現出不同的“表情”—不同的亮度、不同的顏色和獨特的整體形像。也可為特殊節慶設計煙花般變幻的圖案及色彩，烘托特殊時節或慶典中熱烈歡騰的氣氛。圖26為煙花效果圖。

(2) 金魚游弋場景

以一種幽默有趣的手法創建單隻金魚（金魚為經典的金紅色金魚）游弋於“水泡泡”之間的景像，表現

Paper No. 5

“水立方”這一大型水上運動建築結構設計特點。圖27為金魚游弋效果圖。

5.3 立面照明系統的研究

國家游泳中心建築物景觀照明包括建築物LED景觀照明和LED點陣顯示系統兩部分，是一項膜結構體系與LED固態照明技術結合的超大型景觀照明工程。以下將結合歷次實驗結果，從照明方式、光源和燈具選擇以及系統集成化控制等幾個主要方面作簡要介紹。

5.3.1 照明方式

建築物景觀照明通常採用以下幾種照明方式：

外投光照明、輪廓照明和一般內透光照明。

其中外投光照明需要建築物外表面具有良好的反射率。而國家游泳中心外表面為ETFE氣枕，氣枕由3~5層膜構成，其中有1層為藍色膜材，1層為10%~50%銀色鍍點的無色膜材，其他為無鍍點的無色膜材。根據“國家游泳中心室內光環境課題研究報告”中對氣枕光學特性的研究結果，大部分外立面氣枕的總體透射率在50%以上，而反射率不足25%，透射率遠高於反射率。若採用外投光照明方式則大部分光線會進入室內空間，既會干擾室內空間環境，同時建築物外表面又難以達到所需的亮度要求，勢必造成能源浪費和室內光環境污染，因此不適於採用此種方式照明。

輪廓照明方式則比較簡單，形成場景卻較單調呆板，難以表現國家游泳中心豐富的“水主題”設計內涵，不能產生建築物外表面被整體均勻而有序照亮的效果。此外，由圖28可見，氣枕弧面及其纖細的框架均難以支持輪廓照明燈具的安裝，且表面佈線會大大破壞建築物立面效果，因此也不適用於國家游泳中心。

一般內透光照明方式是利用安裝在建築物室內的燈具，透過建築物外表面形成一定照明效果，來表現建築物的整體形像。一般適用於有大面積玻璃幕牆或透明玻璃牆、玻璃窗的建築物以及膜材類外圍護結構的建築物。而國家游泳中心外圍護結構為雙層氣枕，圖29所示為氣枕空腔。其中立面內外兩層氣枕間空腔軸距為3.472m，屋面和天花兩層氣枕間空腔軸距為7.211m；若採用一般內透光照明方式，安裝在室內燈具投射出的光線需透過2層氣枕6~8層膜（其中有2層膜有10%~50%的銀色鍍點）及3~7米的空腔到達室外，損失較多，燈具光通利用率很低。而國家游泳中心為全ETFE雙層氣枕外圍護結構，外表面總面積將近5萬平方米，要將其全部照亮，其造價和電費也會相當高，因此也不適於本建築物照明。

但若將燈具安裝在兩層氣枕之間，則可充分利用單層氣枕透光率較高的特性，同時大大縮短燈具向外部透光的路徑，提高燈具光通的利用率。

綜合考慮上述因素，國家游泳中心建築物景觀照明方式採用一種新型照明方式—空腔內透光照明方式。即將燈具安裝在靠近外層氣枕的鋼結構框架上，燈具投射光線直接集中透射於外層氣枕表面上，均勻照亮建築物表面，使其呈現晶瑩的水體形像。採用這種照明方式進行的多次照明實驗均達到良好的照明效果。圖30為2006年現場實驗實景。

5.3.2 光源和燈具選擇

由於兩層氣枕之間有許多鋼結構杆件(見圖31~32)，空間複雜，檢修維護條件差，適宜安裝尺寸較小和壽命長的光源和燈具。

在這樣的條件下，比較適合的只有熒光燈與LED燈兩種光源。因此我們重點對這兩種光源進行技術經濟比較。

LED壽命長，達5萬小時，是T5管的2.5倍；LED不含汞，低輻射，廢棄物可回收，有利於環保；LED發光體小，光分佈易於控制，通過一次、二次光學設計，採用合適的光學透鏡使光投射到需要的部位；LED易於集成，集計算機、網絡通訊、圖像處理等技術為一體，可在線編程，適時創新；LED可納秒級快速響應，瞬時場景變換；更主要的是LED色彩豐富，利用三基色原理，可形成256×256×256種顏色，形成豐富多彩的照明場景。此外LED燈體外形可以按需加工，易於與不同規格氣枕的邊長尺寸配合。

採用熒光燈，由於安裝位置的限制，且其發光體尺寸較大，無法利用透鏡只能利用反射器來進行配光，控光效果較差，難以將燈具光線均勻投射到不規則氣枕的表面；且熒光燈尺寸固定不易與不規則氣枕的邊長尺寸配合；此外熒光燈是氣體放電燈，響應速度較慢，無法實現場景快速變換，不利於場景設計；再者，熒光燈在寒冷的冬季光效不到額定光效的一半，且啟動困難。經過現場實驗對比（見圖33~34），LED光源和燈具成為體現國家游泳中心“水”主題豐富內涵的首選產品。

5.3.3 LED光源的功率

LED固態照明技術經過近十年的發展，由低功率低光效逐漸向高功率高光效發展，1W功率型LED也作為新一代照明光源逐步發展成熟，並進入小規模的應用。傳統1W以下小功率LED由於大多採用環氧樹脂封裝，散熱差，壽命較低，實際工程中，大多利用其較高的光源表面亮度和RGB多彩色特點應用於製作顯示屏、燈飾和輪廓照明等以光源為主要觀察對像的場所。當用作以輸出光通為主的投光燈具時，則需要光源有較高的光效和盡量少的數量。因為所需的光源數量越多，相應的驅動電路也就越複雜，系統整體穩定性就越差；此外光源數量多，也會使準確控光會變得非常困難，同時燈具體積也增大，不易安裝於複雜的空間。國家游泳中心建築外表面近乎5萬平方米，要將其全部均勻照亮，若採用普通小功率LED，其使用數量將十分巨大，不利於系統的穩定性和日後的運營和維護；此外也難以滿足將膜體均勻照亮對光源及燈具配光、混光距離的特殊要求。因此，國家游泳中心建築物景觀照明工程最終確定採用1W功率型LED作為照明光源，並對LED芯片和封裝工藝主要技術參數進行嚴格要求，詳情如下：

— 主波長：R：622～629nm，G：520～525nm，B：465～470nm
— 額定工作電流：I_f = 350mA
— 峰值電流：R、G：I_f ≧500mA；B：既要滿足正常情況下亮度要求，又要滿足特殊情況下短時的亮度要求
— 單管光通量：在25℃下，350mA穩定工作，R：≧35 ***lm***；G≧60***lm***；B≧15***lm***
— PN結至封裝底座的熱阻：R≦12℃/W；G、B≦10 ℃/W
— 封裝用硅膠：折射率＞1.5，透光率≧98%(400-800nm)
— 使用壽命：≧50,000小時 時，光衰應小於初始值的30%。

5.3.4 LED光源RGB功率比

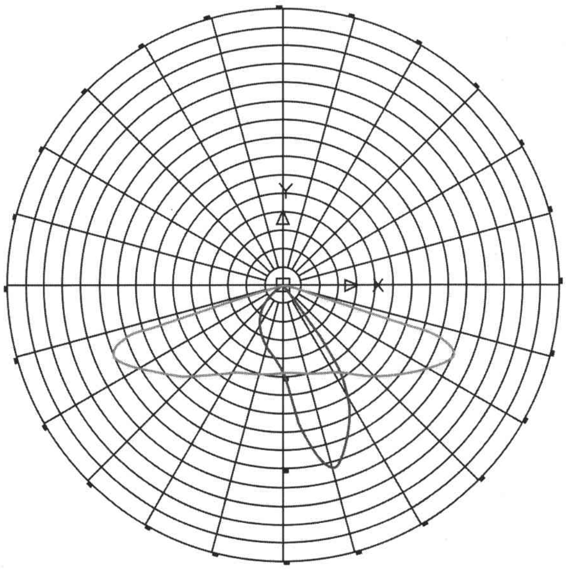
在通常白平衡情況下，RGB的亮度比（光通量）為3：6：1。由於1W藍光LED的光通量不到1W紅光或1W綠光LED光通量的一半，而國家游泳中心的主題色為湖藍色，因此藍光LED所佔比重要相應高一些。經過多次現場實驗和專家論證最終確定RGB光源的功率比R：G：B為1：1：2。實踐證明這一功率比非常成功展示了國家游泳中心的湖藍色主題場景（詳見後面的照明效果實景），此場景下的RGB功率比（即灰度級比）為 0:101:255。

Paper No. 5

5.3.5 燈具

由於建築物外表面為15%弧度的ETFE氣枕，且透光率較高，為了不明顯看到發光光源，同時使空腔內燈具投射出的光線盡量均勻分佈於氣枕表面而盡量少投向內部，理想的燈具配光曲線應如圖35所示。但由於LED燈具光學器件以對稱性透鏡為主，不對稱性透鏡造價較高，最終的工程實施中仍舊採用了對稱性透鏡。這樣一來，使得氣枕表面亮度均勻度和燈具光通利用率都有所降低，某些部位的光源仍可較明顯的出現在近距離視野當中。

圖35 燈具配光曲線



SIEMENS

為確保上萬隻LED燈具的質量和減少日後的運營維護費用，我們對“水立方”景觀照明燈具的主要技術參數提出嚴格要求，詳情如下：

— 輸入電壓：DC24V
— 整體光衰：10,000小時不超過10%(光輸出維持率達90%以上)，30,000小時光衰不超過30%(光輸出維持達70%以上)。
— 透鏡：選用光學級PMMA (acrylic、光學玻璃)，透光比：≧85%，黃化率：30,000h後≦5%。
— 燈具效率：≧80%（即燈具輸出光通量不小於封裝芯片輸出光通量的80%）。
— 使用壽命：≧30,000小時
— 燈具材質和外形：壓鑄鋁，銀灰色
— 外殼防護等級：IP55
— 光源組成：採用1W功率型LED，以1紅+1綠+2藍為1組，有2組8W和4組16W兩種燈具。

5.3.6 燈具佈置

由於外層氣枕透射率較高，如何選擇燈具在空腔中的安裝位置，在均勻照亮建築物外表面的同時，避免從建築物外面和室內直接而明顯的看到發光光源是需要首先解決的問題。這個問題隨著現場實驗的進展逐步明晰，並最終確定下來。

“水立方”建築物景觀照明現場實驗從2006年8月2日開始，到2007年10月份結束，歷時一年多，共進行二十多次現場實驗和測試。最早參加實驗提供燈具和設備安裝的是北京海蘭齊力照明公司，正是在他們的大力支持下，使得燈具佈置方案在早期（2006年8月2日~5日）的實驗中就確定下來。之後陸續加入照明實驗的還有上海廣茂達、南京漢德森、河北立德、大連路明、上海藍寶、北京利亞德等多家公司。

實驗一開始將燈具佈置在氣枕的四周(見圖36)，但光源明顯可見照明效果很不理想。之後經過對實際視點視距進行仔細分析後，確定為沿氣枕下部邊框佈置燈具，效果改善不少(見圖37)。

此後又進行了多次的調整和改進，終於實現了較理想的照明效果(見圖38~39)。

現場實驗燈具安裝見圖40~41，工程實施後最終的燈具安裝見圖42。

根據以上對於立面照明佈燈方式的研究，屋面LED燈具的佈置也重點考慮奧林匹克中心區景觀塔所在位置為主視點，將燈具佈置在氣枕東北側的鋼結構邊框上。

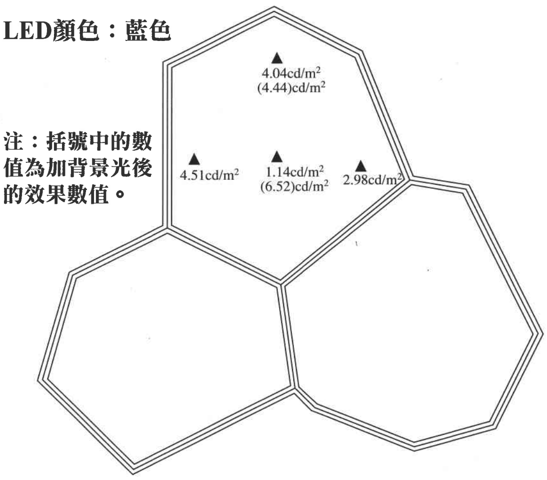
5.3.7 電源驅動系統的效率

由於LED光源的正向工作電壓是直流且不到5V，要使LED光源正常工作，220V交流電源需要經過專用的電源和驅動系統為其供電。國內市場上此類產品的轉化效率通常在60%以下，有的甚至不到50%，大大降低了LED照明的效率。對於國家游泳中心如此龐大的LED立面照明系統，如此低的系統效率當然是不能接受，需要對系統設備的採購提出了更嚴格的要求。經過對國際市場上知名主流產品的調查和研究，最終確定採用24V PWM 恆流驅動進行調光控制，實現0～100%數字調光；並要求從交流電源至芯片(AC/DC-DC/DC)的電功率效率大於75%。工程實施完成後達到了這一要求。

5.3.8 亮度和功率密度指標

對於如此大面積ETFE膜結構和大規模LED景觀照明工程，如何建立和確定其表面亮度和功率密度指標是工程實施前必須解決的問題。為此進行了多批次的現場實驗實測和視覺評價工作。

圖43 功率密度實驗實測結果



2006年8月2日晚“水立方”樣版膜夜景照明亮度值

圖43實驗條件為，現場氣枕鍍點率46%，光源安裝功率密度6W/m²，且光源安裝功

率是按照RGB為1:1:1功率比配置的，而最終的光源RGB功率比為1:1:2，即RGBB。根據現場實驗結果，同時考慮中心區景觀照明規劃的要求，結合技術改進方案，氣枕外表面亮度指標最終確定為：

四個立面照明在平常白場時（在重大節日或活動時）平均亮度指標＞8cd/m²，在純藍色模式（紅、綠不亮）時立面平均亮度指標為＞2.5cd/m²，達到最大白場亮度的光源安裝功率密度不宜超過8W/m²，實際安裝功率密度10W/m²。"水立方"屋面照明在重大節日和活動時平均亮度指標＞7cd/m²，在純藍色模式（紅、綠不亮）時平均亮度指標為＞2cd/m²，達到最大白場亮度的光源安裝功率密度不宜超過6W/m²，實際安裝功率密度8W/m²。

實測氣枕外表面亮度均達到了設計要求，同時光源安裝功率密度也提高了將近25%。如前所述，若對燈具的光度特性進行優化，則光源安裝功率密度還可以適當降低。

5.3.9 超大規模LED照明系統的集成控制

國家游泳中心立面照明控制系統控制點數達幾萬個，且每個點均要實現RGB三基色256級灰度級的單獨控制，是迄今為止世界上單體建築最為龐大的LED照明控制系統。如此龐大的照明控制系統對場景編輯和效果影響最大的就是控制系統的響應速度，通過對國內外主流LED控制產品的了解和調研，我們對控制系統提出非常嚴格的要求，即LED燈具控制器可以控制每套燈具的每一組RGB LED芯片，每組單色LED芯片的亮度可以256灰度級連續平滑調制，變化速度不小於24幀/秒，同步延時小於25ms。工程實施後雖然受造價影響，LED燈具控制器僅控制到每一套燈具，但即使這樣總控制點數也超過了3.5萬個，同時系統響應速度也達到了設計要求的指標。

此外考慮與未來互聯網網絡和奧林匹克中心景觀照明控制系統的兼容性，系統網絡層協議要求採用IPV6。同時還要求與點陣顯示系統、東南入口大廳及泡泡吧照明、護城河及南廣場水景照明等其他控制系統保持聯動，以創建更富震撼力的場景效果。

5.3.10 LED點陣顯示系統

為實現場館賽後的良好運營，在南立面設置2,000m²視頻效果顯示裝置。起初考慮在南廣場設置激光投影裝置，將視頻圖像投影在南立面約50~100m²氣枕表面。後來由於此部分投影裝置造價過高和成像效果不佳沒有採用。此後從2006年11月份就開始進行在南立面氣枕空腔內部設置LED點陣顯示屏的實驗，圖44為現場300mm²氣枕點陣實驗照片。此次實驗中，點陣像素間距均為等間距，分別為8cm、10cm和12cm。像素間距如何兼顧建築效果和成像清晰度成為此項工程主要難題之一。由於南立面的寬高比例為176:31，為了獲得最大的水平線數，同時兼顧對南立面室內效果的影響，經與專家組研究確定，點陣像素間距垂直方向為6cm，水平方向則為8cm。

5.4 實際效果

5.4.1 基本場景模式

湖藍色主題場景實際效果見圖45，該照片於2008年5月27日攝於水立方西側的摩根大廈頂層。

實景圖與效果圖的差異多在於拍攝照片的色差和實際的視覺評價效果。雖然單個氣枕表面亮度的均勻性與實驗有一定差距，但對整體效果的影響不大。這一點雖然在實驗期間就有預料，但實際效果比預想的還要好一些。屋面局部暗區受屋面通風設施影響，使整體效果不夠完美。

5.4.2 特殊場景模式

(1) 多彩變幻

奧運會期間的多彩變幻"魔方"，實際效果見圖46。

由於LED豐富的色彩和瞬息萬變的色彩，水立方的表情豐富多彩。煙花效果圖的設想也是完全可以實現的，只是受時間和人力所限，目前僅完成了初步的場景編輯。可見，國家游泳中心建築物立面照明系統為場景設計提供了潛力巨大的硬件平台，在賽後可以盡情發揮想像力，進行更專業的場景編輯，創建更加奇異的夜景形像，為場館的賽後運營發揮更大的作用。

(2) **點陣與LED照明相結合**

圖47為點陣實景圖片，效果比較理想，沒有出現之前擔心因水平和垂直像素間距而引起的成像變形問題。畫面內容受信號源限制，未出現方案階段的紅色金魚。上述照片均是在外立面燈光同時亮著情況下拍攝的，可見點陣顯示系統可以較好的與建築物景觀照明效果協調和融合，通過二者的聯動控制可以創建豐富多彩的場景模式，實現更富感染力和衝擊力的視覺效果。

5.5 效果評價

奧運會期間，筆者從立面照明的藝術效果、與環境和建築物的協調性、亮度和顏色的適宜程度、是否節能、光影變化的滿意度、眩光及光污染和整體印像等10個方面，對奧林匹克中心區的觀眾及水立方周圍觀景的121位受訪者進行隨機調查，水立方建築物景觀照明綜合得分93（滿分為100分）。可見，大多數觀眾對於水立方立面照明是比較認可和滿意的。

6 結論

奧運會已經結束了，鳥巢、水立方給世界留下了深刻的印像，其供配電系統也經受了奧運的考驗，系統運行良好，達到了設計要求。

鳥巢、水立方的立面照明同樣成功、精彩，現在已經成為旅遊景點之一。夜晚，有眾多市民和遊客到此觀景，深受人們的喜愛。