

ELECTRO-TECHNOLOGIES

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Summary

The discovery of practical electro-technologies such as electrical generators, motors, and lighting in the last part of the 19th century accelerated economic development through a period of rapid dynamic growth. This first wave of electrification was largely complete by 1940. The next fifty years witnessed a second period of electrification built on diverse range of electro-technologies. Today many question whether the world can sustain the continued increase in pollution level due to fossil fuel combustion and transportation. Recent and ongoing analysis points toward a third wave of electrification as a sound and sane path towards sustainability of social and economic progress. New electro-technologies are now being developed to meet the future demand for electrical energy while satisfying environmental constraints.

This chapter presents a survey of electro-technologies and their status. Electro-technologies used in electric power generation using conventional methods and those using non-conventional methods are described followed by a discussion on advanced energy technologies such as storage system applications and distributed generation systems. Applications of electro-technologies for end use applications are then discussed starting from the basic DC and AC machines to recent advances in electric drives technology using power electronics to improve efficiency. Electro-technologies using plasma are then introduced as a means of improving efficiency in industrial, chemical and metallurgical area. Finally a discussion of recent electro-technologies in transportation in the form of electric vehicles is provided.

1. Introduction

The greatest challenges of the twenty-first century will include conversion of energy to appropriate and environmentally acceptable forms, cost-effective means of transmitting distributing the energy, and efficient use at end-user level. The high quality of life we seek depends upon a healthy environment and sufficient energy to meet our needs and wants.

As the most convenient form of energy, electrical energy has gained an increasing share in the world energy market. Electro-technologies refer to the evolving technologies associated with efficient and effective generation of electricity from other forms of energy and the supporting technologies to transmit, distribute and utilize the generated electrical energy in the most efficient manner while satisfying the environmental concern.

Electricity generation contributes significantly to the supply of energy and therefore plays a major role in the production and control of emissions. About two-thirds of the world's electricity is obtained by fossil fuel combustion, emissions from which can produce urban ozone, bring about acid rain, and contribute to global climate change.

According to the International Energy Agency (IEA), Asia will produce approximately one quarter of the world electricity output by 2010. The largest increase in electric generating power capacity will be in the developing countries, particularly in Asia. IEA predicts that by 2010, China alone will require nearly 280 GW of new generating capacity, which is equivalent to adding a 1000 MW power generation plant to the system every month. It is obvious that such an expansion will have a great impact on the environment.

The deteriorating impact on the environment is already visible. People in many countries around the world continue to suffer from health effects due to the combustion of fossil fuels in equipment lacking environmental control. For example, in some part of the world, winter days are often dark and grey because of suspended particulates exceeding 500 micrograms (μg) per cubic meter, far in excess of the maximum level recommended by the World Health Organisation (WHO). Urban ozone has been linked to respiratory problems and eye irritation and is known to be harmful to many types of trees and crops. Acid rain raises the acidity of streams and lakes, causing harm to fish and invertebrates, and has been blamed for damage to forests and structures. Elevated levels of sulfates and nitrogen oxides in the atmosphere have been linked to respiratory ailments and increased mortality rates in humans. The possibility of global warming from the so-called greenhouse gases (GHG) could cause changes in crop productivity, migration of forest ecosystems, rising sea levels, and the extinction of some endangered species.

Meeting the future demand for electrical energy while satisfying environmental constraints, is certainly one of the most technically challenging and economically important problems facing the world of electro-technologies today.

Recent advancement in power electronics, microprocessors, and information technology has seen new developments of electro-technologies that have a substantial potential for saving electricity by implementing more efficient end-uses of electricity. This can significantly reduce the environmental problems, which to a large extent are associated with the generation of electric power. The saving potential can be more than half of the present electricity consumption. Moreover, since electricity savings are often much cheaper than providing the power, efficient end-use of electricity can play a vital role in future life support systems.

This chapter presents a survey of electro-technologies and their status. Principles of operation and significant applications both current and potential are outlined and assessment is made whenever possible of its potential for sustainable use of electricity. Some of the technologies and processes discussed are still in their infancy and development stages. Some have developed and are developing rapidly; while others show great future promise. Rapid progress is being made in numerous industrial and environmental applications.

The structure of the chapter is as follows: Section 2 discusses electro-technologies used for generation and transmission of electricity. Both conventional and non-conventional methods of generating electricity are described. Electro-technologies for transmission and distribution includes both the AC and HVDC transmission, and discusses the

benefits of having distributed generation and energy storage to improving the operation of the power system. Section 3 presents the electro-technologies used in end-use equipment, such as DC machine and induction machine. Means of improving the performance of the end-use electro-technologies using power electronics such as the variable speed drives, switched reluctance motor drives and demand side technologies will also be presented in Section 3. Electro-technologies in transportation in the form of electric vehicles are covered in Section 4. This can help significantly in reducing air pollution and global warming and hence is an indispensable technology for future life support system.

2. Electro-technologies for Generation and Transmission of Electricity

This section will first describe the electro-technologies associated with the generation of electricity followed by electro-technologies associated with the transmission and distribution of electrical energy.

The most traditional way of generating electrical energy is by converting rotational energy to electrical energy using synchronous generators. Two types of synchronous generators will be discussed: cylindrical-rotor generators and salient-pole generators. This is then followed by discussion on how the rotational energy can be obtained. Section 2.2 describes several conventional methods to achieve this. Traditionally steam expansion turbines are used to produce the mechanical energy to drive the synchronous generator. The steam can be obtained from waters heated by combustion of fossil fuels such as coal, oil, gas or nuclear. Another conventional method is to use gravitational energy due to falling water to rotate the synchronous generator. Section 2.2.3 describes the operation of a nuclear generation plant.

Section 2.2.4 discusses newer technologies such as combined cycle gas turbine (CCGT) and cogeneration, which are increasingly being used in newer power plants being built in recent years.

As the continual depletion of fossil fuels such as coal, oil and the increasing level of polluting gasses and particulates are not sustainable, non-conventional electro-technologies to generate electricity are being developed by converting wind, solar and chemical energy to electrical energy. While they are still relatively new, small in ratings and more expensive than the conventional methods of generating electricity, the increasing need to have sustainable use of energy will ensure that these technologies will further developed and researched. Section 2.3.5 covers these non-conventional electro-technologies which include wind generators, photovoltaics and fuel cells.

Another important electro-technology that will be discussed is the use of energy storage in which electrical energy can be stored in the form of non-electrical energy and when electrical energy is required again, the non-electrical energy can be converted back to the electrical energy. This is particularly useful as generated electrical energy cannot be easily stored and hence without storage must be used immediately once generated.

Having discussed the electro-technologies associated with the generation of electricity, the next section will describe electro-technologies associated with power transmission

and distribution of electrical energy.

Two main methods of transmitting electrical energy will be discussed: AC and DC transmission. The most traditional method of transmitting electrical energy efficiently is using AC transmission by transforming the generated electricity into high voltage for transmission using transformers and later transforming it back to lower voltage for distribution and end-use of electricity.

In some countries, the power has to be transmitted over long distances causing severe voltage drop across the AC transmission line. To overcome this problem, HVDC transmission is used. HV DC transmission also allows better control of power flow.

This section will close with a discussion on most recent development to improve power system performance. To reduce losses in transmission and to utilize the excess or small generation at the distribution networks, a distributed generation system has been proposed as the basis of future power systems. Combining this with the emergence of energy storage systems and growing numbers of renewable being installed in transmission and distribution network, a much more reliable and secure power system can be obtained.

2.1. Synchronous Generators

The most commonly used generators for converting mechanical (rotational) to electrical energy in AC power systems are the three-phase synchronous generators operating at 50 Hz or 60 Hz.

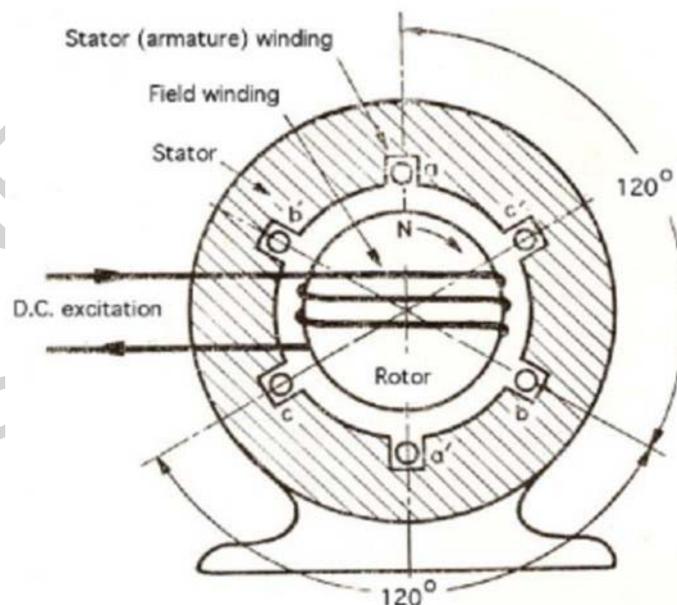


Figure 1: A Schematic Diagram of a synchronous generator

A three-phase synchronous generator consists of two main windings: the stator winding that generates electrical power and the magnetic field excitation winding commonly located in the rotor (the rotating part of the machine). In nearly all synchronous

generators used in a generating station, the magnetic field is established using a DC current in the field excitation winding. Figure 1 shows a schematic diagram of a synchronous generator.

A three-phase winding consists essentially of sets of coils equal to the number of pairs of poles symmetrically distributed around the stator, and each set consists of three groups of coils, which are symmetrically distributed under every pair of poles. Each one of these groups belongs to one of the phases, and all the groups belonging to one phase are connected together, usually in series and occasionally in parallel, to form the phase winding. For the availability of a neutral and because of insulation requirements, the three phase windings are connected in Y (star) for most synchronous generators.

When the rotor of a three-phase synchronous generator is driven by a prime mover, the magnetic flux linking the stator winding coils alternates and an alternating voltage is generated in them. The generated voltages in the three phase windings are equal in magnitude, but are always 120° apart in phase. The frequency of these voltages will depend on the speed of the prime mover and the number of poles of the synchronous generator. For operation at a desired frequency, the choice of the number of poles of a synchronous generator will depend on the speed of the prime mover. For optimal operation, the speeds of the various prime movers depend on their types, and thus the number of poles and the form of construction of synchronous generators will essentially depend on their prime movers.

The two main basic constructions of synchronous generators are cylindrical-rotor (or wound rotor) generators and the salient-pole generators.

2. 1.1. Cylindrical-Rotor Generators

As implied by the name, these generators have cylindrical rotors. The excitation field winding is usually embedded in axial slots. These generators are usually driven by steam or gas turbines. Such turbines operate best at high speeds, usually 3600 (3000) or 1800 (1500) revolutions per minute. At these speeds, the number of poles of a synchronous generator has to be either two or four for 60 (50) Hz operation.

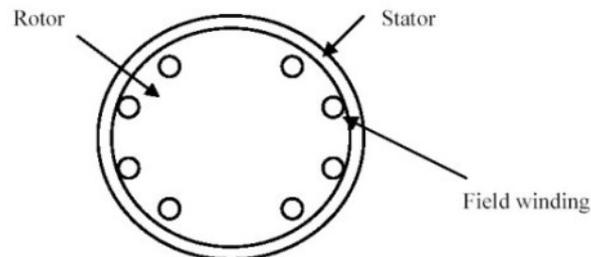


Figure 2: Construction of cylindrical-rotor synchronous machine

2. 1.2. Salient-Pole Generators

In salient-pole generators, the field windings are wound around the poles and connected in series in the salient-pole form. The salient-pole generators are most suited for low

speed operation, in the range of 50 to 1000 revolutions per minute. The prime movers are generally hydraulic turbines or internal combustion engines. A damper winding is usually fitted in slots at the pole surface for synchronous motor starting and for improving the stability of the machine. Figure 3 shows a salient pole construction.

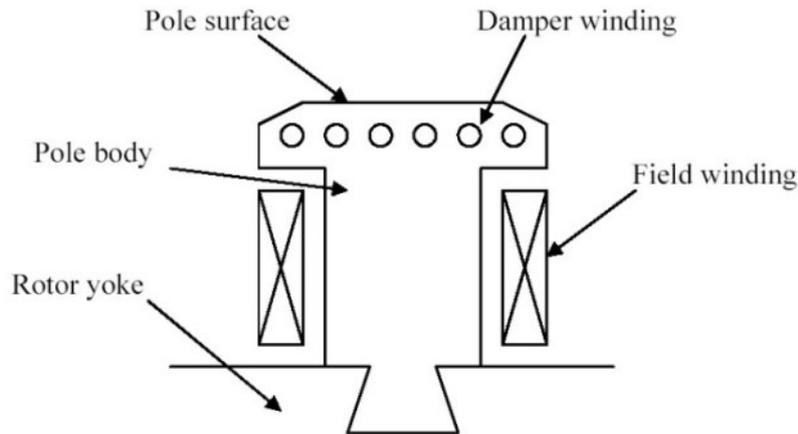


Figure 3: Salient Pole Construction

2.2. Electric Power Generation: Conventional Methods

The mechanical (rotational) energy required in a synchronous generator can be obtained either from high pressure steam generated in a turbine by heating water using combustion of fuels such as coal, oil, gas or nuclear or from gravitational energy of falling water.

The conventional power plants can be categorized into three main types: thermal-generating stations, hydroelectric generating stations and nuclear generating stations. The most common ones are the thermal power stations, which provide the bulk of the electrical energy. About 70% of all power plants are of this type. The hydroelectric and nuclear power stations provide about 25 % of electrical energy produced in the world.

More recently Combined Cycle Cogeneration has been developed to improve the efficiency and reduce emission of pollutants.

2.2.1. Thermal Generating Stations

In a thermal generating station, high-pressure steam at high temperature from the boiler provides the mechanical energy at the steam turbine's shaft to drive an AC generator, which then produces electrical energy. The steam is generated from water heated by the combustion of coal, oil, or natural gas to heat water in a boiler. The temperature can reach up to 600°C and the pressure can go up as high as 30 MN/m². In most thermal generating station, the steam that exhausts from the turbine is directed to a condenser where it is cooled, distilled into water, and returned to the boiler. For this reason, thermal stations need to be located near rivers, lakes, and oceans, where an ample quantity of cooling water is available. Figure 4 shows the schematic diagram of a coal power station.

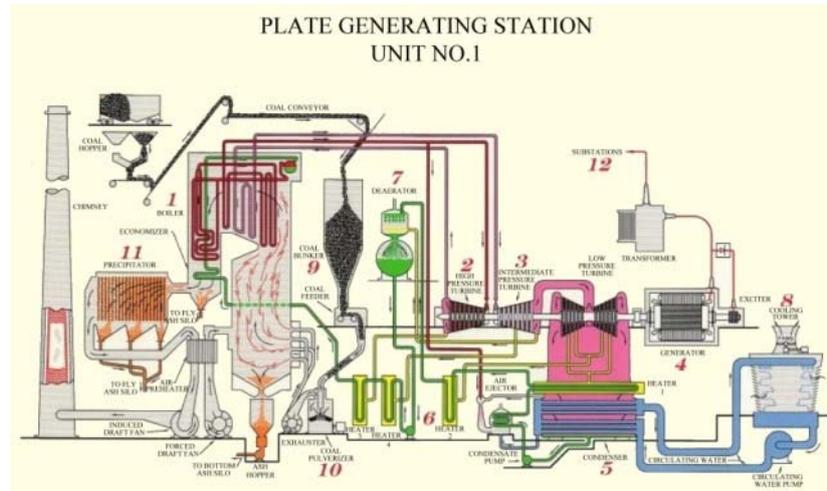


Figure 4: The Schematic Diagram of the operation of a coal power station
 Source: *Grand Island Utilities Department's website* (<http://www.giud.com/>)

Prior to the oil crisis in the 1970's, the most widely used fuel was oil. In recent years coal-powered stations have replaced many oil-fired stations. This, however, resulted in the increased emission of pollutants, and hence more stringent environmental regulations have been placed on coal-powered stations. Now the most acceptable fuel is natural gas, which produces the least atmospheric pollution, and is available in large quantities.

The conversion efficiency of a thermal generating station is always low (typically ranging from 30% to 40%), because of the inherent low efficiency of the steam turbines. To increase the efficiency, combined cycle plants using gas and coal have become more and more attractive because of its high efficiency (more than 50%).

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Bibliography

- B. K. Bose (ed.), (1996) *Power Electronics and Variable Frequency Drives Technology and Applications*, Piscataway, NJ: IEEE Press. [This is a good reference book on variable speed drives with many examples in actual applications]
- D. Sutanto (2000). Feasibility of Introducing Electric Vehicles in Hong Kong. Better Air Quality Motor Vehicle Control & Technology Workshop (BAQ2000), Hong Kong, 18-20 September 2000, Hong Kong Polytechnic University, Hong Kong, pp.1-6. [A reference paper describing the options that are currently being considered in Hong Kong for the use of electric vehicles].
- D. Sutanto, W.R. Lachs (1998). *Battery Energy Storage Systems for Sustainable Energy Development in*

Asia. Electric Power Systems Research No. 44, pp. 61-67. [A reference paper on the benefits of Battery Energy Storage Systems for Asia]

Electric Vehicle Association of the Americas (EVAA) 2001. Frequently Asked Questions About EVs (http://www.evaa.org/evaa/pages/online_store.htm) [A good reference article on understanding electric vehicle basics]

EPRI (1991). Customer Systems Division, Technical Brief: Load Management and the Environment, Report RP2788, Electric Power Res. Inst., 1991. [A good reference on load management technologies with discussions on how to improve environment by using load management]

G. F. Caruso (1996). The Asia-Pacific Region in the IEA's World Energy Outlook and Sustainable Energy Development. Keynote Paper, Proc. Int. Symp. on Sustainable Energy Development in Asia, Hong Kong, 8-10 May 1996, pp. 1.1-1.4. [This paper provides the IEA's outlook for Sustainable energy development in Asia-Pacific]

G. P. Shultz, Transformers and Motors, Indianapolis: Sams, 1989 [A comprehensive reference text on the subject]

Glover/Sarma. (1989) Power System Analysis and Design. [A very good textbook for learning power system analysis. The introduction gives good summary of the history of the electric power system].

Grigsby, L.L.(1998) The Electric Power Engineering Handbook [A comprehensive reference textbook on the subject. It is very useful for those who wants to know more about any aspects of power engineering]

IEEE History Center (2000) http://www.ieee.org/organizations/history_center/. [A very good website to learn about the history of electrical engineering and the institution]

J. E. Miller (ed.), (1988) Switched Reluctance Motor Drives, Ventura, CA: Intertec Commun. [An excellent introductory text for the subject]

J. Hindmarsh (1991). Electrical Machines and their Applications, 4th ed., Oxford: Pergamon. [A good textbook on Electrical Machines with complete description on all types of machines]

L. Y. Chan, C. Y. Chan and Y. Qin (1999) The effect of commuting microenvironment on commuter exposures to vehicular emission in Hong Kong. *Atmospheric Environment*, Volume 33, Issue 11 , 1777-1787. [This paper discussed the effect of air pollution due to cars in Hong Kong].

M. D. Levine et al (1995), Electricity end-use efficiency: Experience with technologies, markets, and policies throughout the world, *Energy Int. J.*, 20 (1): 37-61. [A practical resource manual for end-use efficiency. It is very useful for those interested to investigate this topic]

Nicholas P. Cheremisinoff (1996). Electrotechnology: Industrial and Environmental Applications. Noyes Publications, NJ, USA. [This books provides survey and status of various electrotechnologies with many useful diagrams and tables]

P. Kundur (1994). Power System Stability and Control, New York: McGraw-Hill. [A very comprehensive reference book on power system engineering]

R. Robbins (1997). DC will continue as viable drives technology option. *Drives Control*, Mar 1997, pp: 60-61. [An excellent paper discussing the pro and con of the use of AC or DC motors in variable speed drives]

S. Rahman, A. de Castro, Environmental impacts of electricity generation: A global perspective, *IEEE Trans. Energy Convers.*, 10: 307-314, 1991. [A comprehensive paper reviewing various topics in the subject]

T. W. Keelin, C. W. Gellings (1986). Impact of Demand-Side Management on Future Customer Electricity Demand, EPRI EM-4815-SR, Palo Alto, CA: Electric Power Research Institute. [A report by EPRI Describing the state of the art of Demand-side management]

W. Leonhard (1996) Control of Electrical Drives. 2nd ed., Berlin: Springer Verlag. [An excellent textbook on Variable Drives written from the control perspective]

W.R. Lachs, D. Sutanto & G. Ledwich (1995). Distribution Control with Battery Energy Storage Systems. Distribution 2000 Conference Brisbane, Australia, 14-17th November 1995, pp. 253-261 [A reference paper describing how Battery Energy Storage Systems can help distribution system]

Wiley Encyclopedia of Electrical and Electronics Engineering Online. [A good reference for many aspects of aspects of electrical and electronics applications, from which several articles have been abstracted. It contains short articles describing the current state of technology]

“Wind Energy Bibliography” http://www.nrel.gov/research/wind/wind_bib.html [A very useful resource on wind energy with hundreds of references to almost any topics on wind energy]

Biographical Sketch

Danny Sutanto received his B.Eng. and Ph.D. from the University of Western Australia in 1978 and 1981 respectively. Following his graduation he joined GEC Projects, Australia as a Power System Analyst. In 1982 he joined the School of Electrical Engineering at the University of New South Wales. Since 1996, he has been with the Hong Kong Polytechnic University where he is now a Professor in Electrical Engineering. He is a Senior Member of IEEE and is currently the IEEE PES Region 10 Regional Director. From July 2002 to December 2002 he was a Visiting Professor at the School of Electrical Engineering and Telecommunications at the University of New South Wales in Sydney, Australia. His research interest includes power system analysis, power system economics, voltage stability and power electronics.