

## Energy in the Modern World

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The modern society is highly dependant on an adequate supply of energy that is needed for cooking, heating, cooling, lighting, etc. At present most of the energy comes from fossil fuels such as coal, oil and gas. Over the last 25 years, the world demand for energy has grown continuously at a rate of increase of around 2.5 percent per year. This increase in consumption cannot be sustained indefinitely both because of depletion of reserves, and more urgently, because of the environmental impact of burning fossil fuels. At some time in the future the costs of extraction of oil and gas will become so high as to limit their use. Further, there is clear agreement among climate scientists that burning fossil fuels and the consequent emission of  $\text{CO}_2$  into the atmosphere is leading to extensive climate change. Therefore, most governments are taking strenuous efforts to introduce renewable energy sources as these do not produce  $\text{CO}_2$  during their operation and as these will not get depleted like fossil fuel.

The use of renewable energy has an important part to play in the future supply of energy

and in the transition to a more sustainable energy economy. However, renewable energy has its own challenges. In general, the initial capital cost of renewable energy schemes is high and their output depends completely on the resource, and so varies with the strength of the sun and wind.

### The Need for Renewable Energy

Burning fossil fuels lead to local environmental impacts such as air pollution, regional effects such as acid rain as well as the global impact on climate change.

Thermal power stations, internal

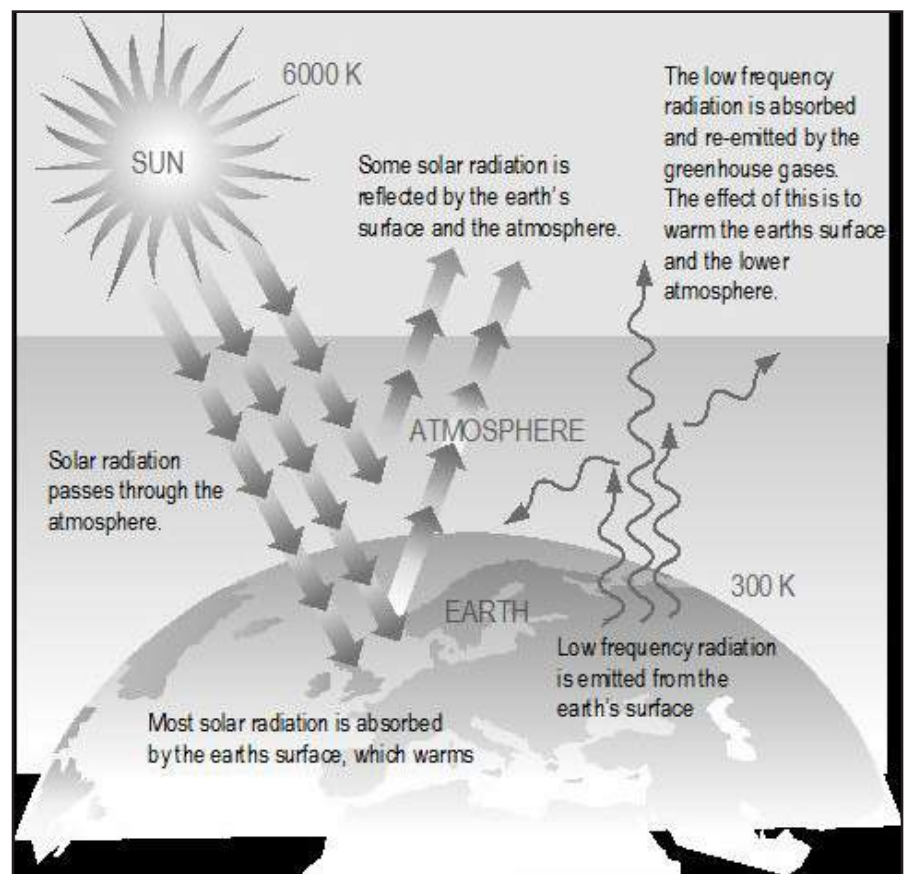


Figure 01 : Simple representation of the Greenhouse effect



**Figure 02 : Wind farm (RichardJones/BusinessVisual Rights Managed)**

combustion engines and building heating systems all produce gaseous emissions and very small particles that can be damaging to environment and human health. Examples of the local consequences of such emissions are the photo-chemical smogs that occur in some large cities, due to vehicle exhausts. Further, burning coal in power stations produces sulphur dioxide ( $\text{SO}_2$ ) and other pollutants that lead to acid rain causing considerable environmental damage, particularly to lakes and forests.

There is a clear scientific consensus that the earth's climate is being changed by human activity through the emission of greenhouse gases. The main greenhouse gases are carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), nitrous oxides ( $\text{NO}_x$ ) and fluorocarbons. Water vapour also plays a major role in the greenhouse effect. The greenhouse effect is a complicated phenomenon with important impacts of gases and particles in the atmosphere that can both increase or lower the earth's temperature. However, it can be understood simply as the effect of gases in the upper atmosphere absorbing the long wavelength

radiation that is emitted from the earth's surface (Figure 1). The sun is a high temperature source with an effective temperature at its outer surface of around 6000 K. It emits short wavelength (high

frequency) radiation that passes through the earth's atmosphere. This radiation strikes the earth, warming it, and the earth then re-radiates long wavelength (low frequency) radiation from its lower surface temperature. The high frequency radiation from the sun passes through the earth's atmosphere largely unaffected while the concentration of gases in the upper atmosphere leads to absorption of the lower frequency (longer wavelength) radiation. The temperature of the earth

depends on the balance between the incoming high frequency radiation from the sun and the lower frequency radiation re-radiated from the earth's surface. Due to increasing of the concentration of greenhouse gases in the atmosphere, more of the low frequency radiation is trapped and so the temperature of the earth increases. The concentration of existing greenhouse gases in the earth's atmosphere causes the temperature of the earth to be maintained at a level suitable for life, without it the earth would be colder by some 30 °C. By increasing the concentration of greenhouse gases, as we are currently doing, the earth's temperature increases, and the climate is changed. Although an increase in average temperature has significant implications, the consequent effects such as melting of the ice in the Arctic and increases in frequency of extreme weather events are potentially even more serious. Greenhouse gases disperse throughout the earth's atmosphere and so the effect is global.

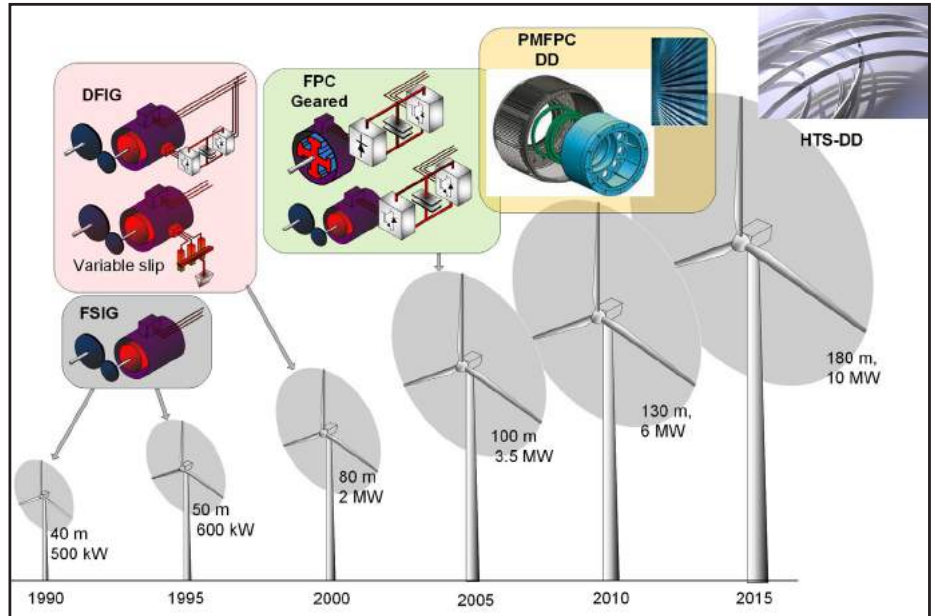


**Figure 03 : Solar photovoltaic farm (RichardJones/BusinessVisual Rights Managed)**

Carbon dioxide is an inevitable product of burning fossil fuels and once emitted it remains in the atmosphere for up to 100 years. It is one of the most important greenhouse gases and many countries have policies to reduce emissions of CO<sub>2</sub>, particularly from electricity generation. By restricting the emission of CO<sub>2</sub> and other greenhouse gases it is hoped to limit the rise in global mean surface temperature rise to 2 °C. A rise of this magnitude with the associated increase in extreme weather events will have important consequences for agriculture and biodiversity. Allowing the continued emission of CO<sub>2</sub> from an electrical power sector that relies predominantly on burning fossil fuels significantly increases the risk of affecting climate change.

**Low Carbon Electricity Generation**

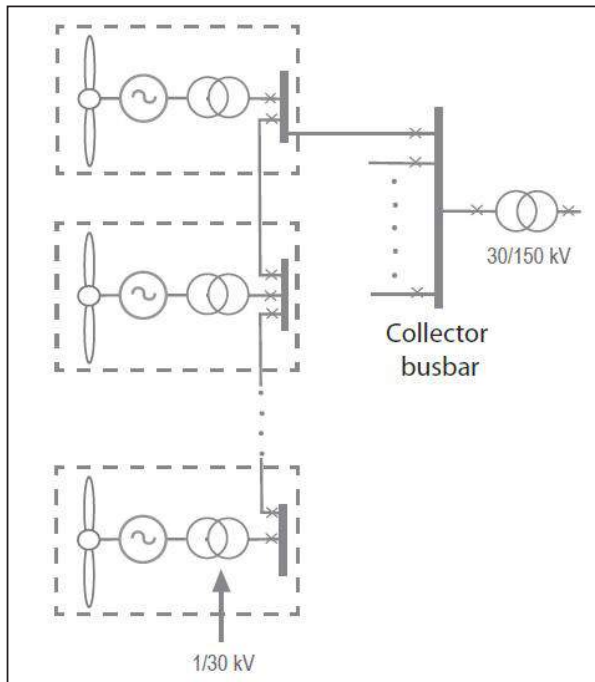
Climate change brought about by the emission of CO<sub>2</sub> from burning fossil fuels is a major driver of



**Figure 04 : Evolution of wind turbine technology**

energy policy in many countries. Thus, alternatives to burning fossil fuel, particularly coal, are needed urgently. The options to generate electricity without emitting CO<sub>2</sub> are restricted to renewable energy, nuclear energy, and fossil fuel generators equipped with carbon capture and storage

fossil fuels are burnt and storing CO<sub>2</sub> underground has the obvious attraction that fairly conventional generating units can continue to be used. This is known as Carbon Capture and Storage (CCS). However, neither the technology for extracting the carbon from fossil fuel or storing the CO<sub>2</sub> has yet been demonstrated at commercial scale.



**Figure 05 : Typical on-shore wind farm connection**

There are those who consider that the generation of electrical energy from nuclear fission is an attractive technology and that nuclear generation should be expanded. However, nuclear generation of electricity has a number of considerable difficulties including high capital costs and continuing uncertainty over the disposal of nuclear waste.

Removing carbon either before or after

Due to limitation of many low carbon technologies, most governments encourage the development of renewable energy generation. As a stimulus of emerging renewable energy technologies, financial mechanisms such as net-metering, feed-in-tariffs, quota requirements, carbon trading or carbon taxes are introduced. Established technologies include wind power, micro-hydro, solar photo-voltaic systems, landfill gas, energy from municipal waste, biomass and geothermal generation. Emerging technologies include tidal stream, wave-power and solar thermal generation.

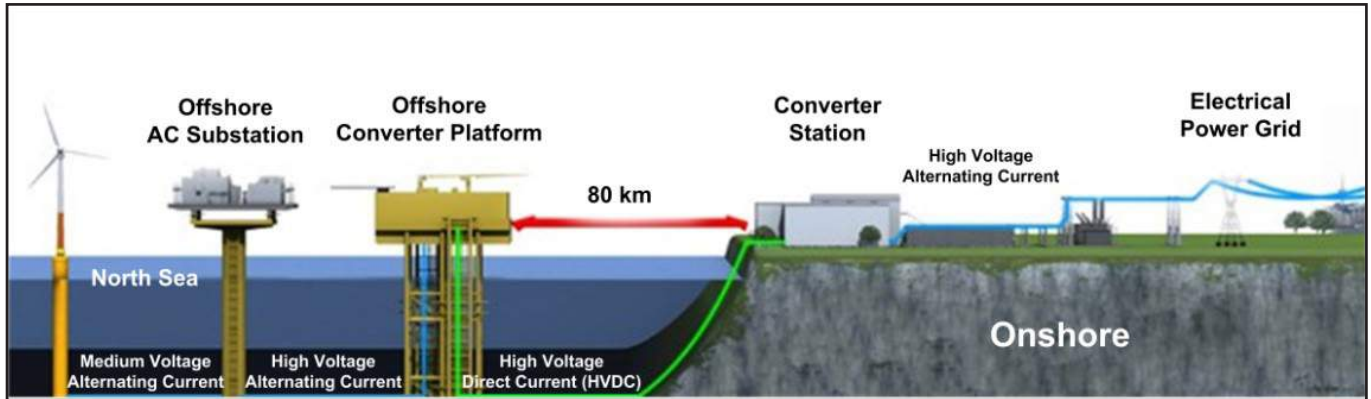


Figure 06 : Offshore wind farm dc connection

Renewable energy sources have a much lower energy density than fossil fuels and so the generation plants are smaller and geographically widely spread. For example, wind farms must be located in windy areas while biomass plants are usually of limited size due to the cost of transporting fuel with relatively low energy density. These smaller plants, typically of less than 50-100 MW in capacity, are then connected into the distribution system. In

many countries the renewable generation plants are not planned by the utility but are developed by entrepreneurs and are not centrally dispatched but generate whenever the energy source is available.

Figures 2 and 3 show a wind and solar energy plant sited on the hills above a former coal mining area of South Wales of the UK. The environmental impact of the schemes are limited and the land continues to be used for grazing

sheep.

**Energy from Wind**

Wind technology is emerging as one of the more cost effective of the Renewables. There are some 597,000 MW of wind turbines installed world-wide. The advantages of wind energy generation are: each wind turbine is comparatively large (up to 5 MW onshore and up to 10 MW offshore). Once planning

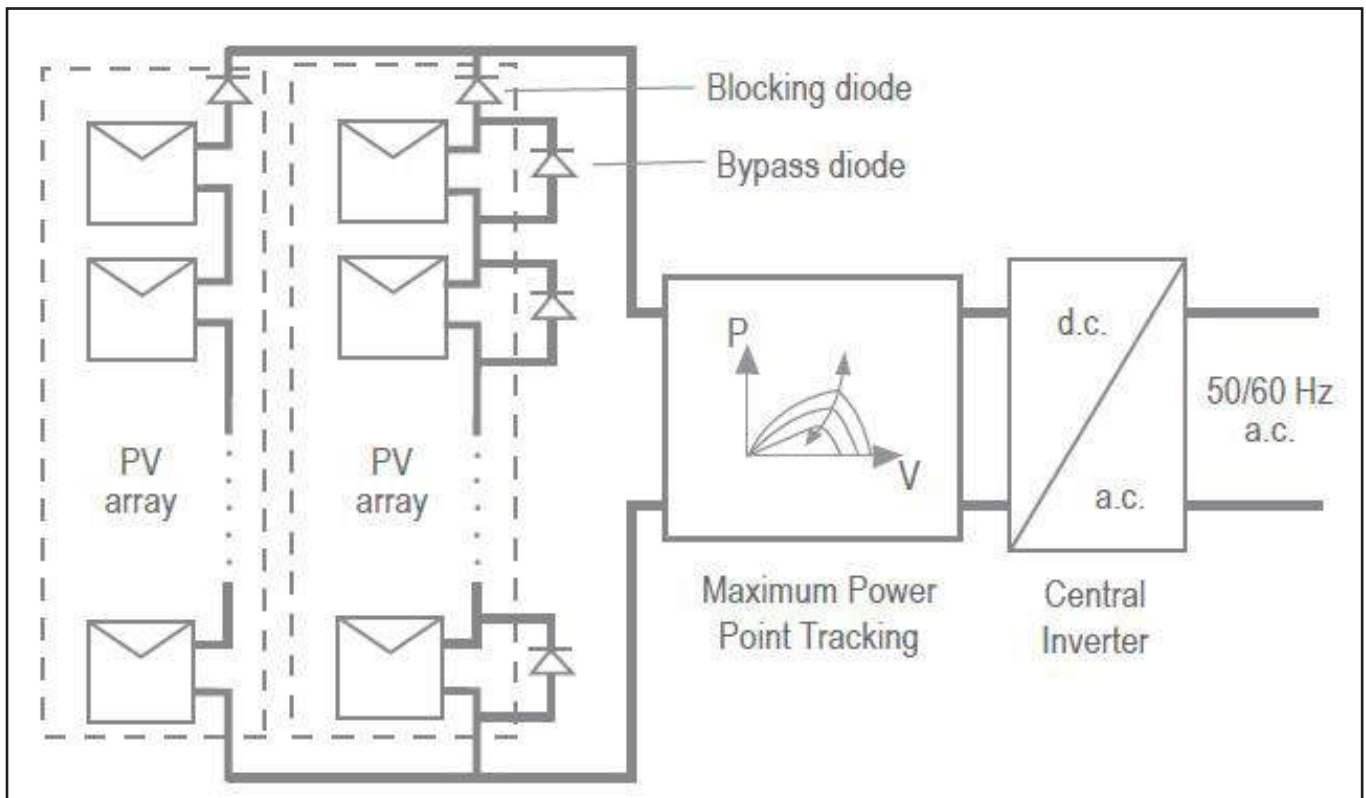


Figure 07 : PV panels connected to a central inverter

permission is obtained, wind farms can be constructed quickly and in high wind speed sites at low cost. Disadvantages are visual impact, of the intermittent energy source.

Depending on the power rating, different wind turbine topologies are used (Figure 4). They can be broadly categorised as fixed speed wind turbines and variable speed wind turbines. In a fixed speed wind turbine, a gearbox is connected in between the low speed shaft and the generator shaft (shown as FSIG). With variable speed operation, it is possible in principle, to increase the energy captured by the aerodynamic rotor. However, it is then necessary to de-couple the speed of the rotor from the frequency of the network through some form of power electronic converter. Variable speed technologies available are, doubly fed induction generator (DFIG), full power converter (FPC) with a gearbox, permanent magnet generator based full power converter direct drive (PMFPC DD), and high temperature superconductor generator based direct drive (HTS DD).

Wind turbines generate at a relatively low voltage, usually below 1000 V. Some larger turbines (>3 MW) use a higher generator voltage, up to around 3-5

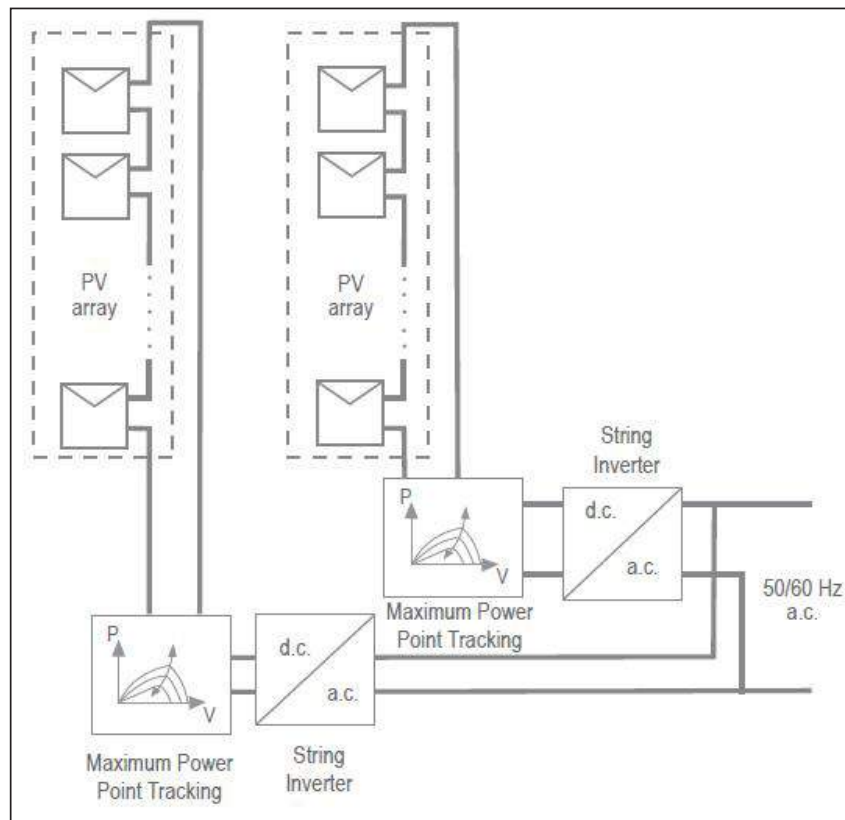
kV. With these generator voltages it is necessary for each turbine to have an individual transformer either within or adjacent to the tower. This increases the voltage for connection to the power collection network, for example to 33 kV. A typical onshore wind farm connection is shown in Figure 5. A number of strings of wind turbines are connected to the collector busbar at 33 kV. A central wind farm transformer steps up the voltage to 132 kV or 220 kV for connection to the public network.

An offshore wind farm can be connected to the onshore network through an ac or a dc submarine

80 km, dc transmission (Figure 6) becomes cost effective. Above around 100 km and 50 MW only dc transmission is possible due to the high reactive power generated by the capacitance of ac cables. For wind farms larger than 200 MW, dc is attractive as fewer cables are needed to connect the wind farm to shore and so multiple cables crossing a beach can be avoided.

**Solar Energy**

Energy from sun strikes the earth as packets of light energy, termed photons. There are two main methods of converting sunlight into electricity. Heat in sunlight can produce and drive a steam turbine to produce electricity. However, the most common technique is direct conversion of solar energy into electricity which is called Photovoltaic energy (PV). When designing a PV system, detail consideration should be given to solar resource at the site, conversion equipment – solar modules, energy storage equipment – battery, system control and loads or end – user equipment.



**Figure 08 : String of PV panels connected to a number of string inverters**

cable. The choice of ac or dc depends on the distance to shore and the power of the wind farm. For cable route lengths above

A photovoltaic cell is a device that converts energy from the sun to dc electricity by the photovoltaic effect. The cell is formed by a p-n

junction. When the junction is exposed to light, dc electricity is produced from the junction. An individual cell produces an open circuit voltage of about 0.6 V. Therefore, in practical applications a number of cells are connected in series to obtain higher open circuit voltage. The short circuit current can be increased by connecting a number of cells in parallel to form a higher power and larger module. The module is the basic building block of a PV array. PV arrays are formed by connecting strings of modules in different formations. Commonly used topologies are strings connected in parallel to a central inverter, strings connected through multiple inverters, and individual modules connected through micro-inverters.

The connection of a PV array into a central inverter is shown in Figure 7. Each PV string is connected in parallel through a blocking diode. These diodes are used to prevent reverse current flowing from one string into another. Even though the central inverter connection can be cost effective, the lifetime of the central inverter is often less than that of the PV modules thus requiring its replacement at least once over the life of the solar array, adding significant cost.

Figure 8 shows the use of string inverters. Each string of modules is connected through a dc/ac converter, which allows the Maximum Power Point of each PV string to be optimized. The PV system can be expanded easily by installing additional strings of modules and their own inverters. PV modules can also be connected such that each PV panel has a

micro-inverter of 150-300 W. The micro-inverters convert dc to ac from each module and their output is connected in parallel to form an array. Even though this scheme is attractive in terms of performance (unlike the other scheme the performance does not depend on the poorest module), the main disadvantage of this scheme is high cost.

### Smart Grid

Modern electrical power systems, which have been developed over the last 70 years, feed electrical power generated by large central generators up through generator transformers to a high voltage interconnected transmission network. The transmission system is used to transport the electrical power, sometimes over considerable distances, and it is then extracted and passed down through a series of distribution transformers to final circuits for delivery to the customers.

From around 1990 there has been a revival of interest in connecting renewable generation to the electrical power network, which demands some degree of integration, automation and control. Electrical energy supplies that are low or zero-carbon, secure and not dependent on imported fossil fuel require demand side initiatives that include energy transactions, demand response which enables loads, and distributed energy resources to provide capacity, peak shaving and other ancillary services. In addition, services such as customer billing, management of customer equipment, and energy information, and customer empowerment are

now being developed by a variety of potential providers. Delivering these services from the demand side requires communication and information technologies that are open and flexible.

Recently, the name “Smart Grid” has become common to describe this future power network. The concept is gaining a lot of traction as a means of decarbonising the power sector, allowing more renewable energy to be connected, maximising utilisation of transmission networks that have plenty of redundancy/capacity, and enabling customer participation to improve power system efficiency, security and operation. It is anticipated that with the realisation of the Smart Grid, it is possible to operate the power system with a high proportion of renewable generation.

Note : Some information are extracted from one of author's books “Renewable Energy Engineering”, Cambridge University Press.



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