Pearson BTEC Levels 4 and 5 Higher Nationals in Engineering (RQF)

Unit 44: Industrial Power, Electronics and Storage

Unit Workbook 3

in a series of 4 for this unit

Learning Outcome 3

Control Techniques and Power Electronics for Renewable Energy Systems

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Contents

INTRODUCTION

Analysing the control techniques of power electronics for renewable energy systems.

- *Control techniques:*
    - Environmental aspects of electrical energy conversion using power electronics.
    - Introduce design criteria of power converters for renewable energy applications.
    - Analyse and comprehend the various operating modes of wind electrical generators and solar energy systems.
    - Introduce the industrial application of power converters, namely AC to DC, DC to DC and AC to AC converters for renewable energy systems.
    - Explain the recent advancements in power systems using the power electronic systems. Introduction to basic analysis and operation techniques on power electronic systems.
    - Functional analysis of power converters' main topologies.
    - Use of MATLAB/Simulink to model, simulate and analyse the dynamic behaviour of a simple renewable energy system.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose	Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.
Theory	Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.
Example	The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.
Question	Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.
Challenge	You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

3.1 Control Techniques

Most national energy policies worldwide aim at ensuring an energy portfolio that supports a cleaner environment and stronger economy and that strengthens national security by providing a stable, diverse, domestic energy supply. Clean energy is a global and urgent imperative. Renewable generation, especially from wind and solar, and smart grid concepts are critical technologies needed to address global warming and related issues. The key challenge is to reduce the cost of renewable energies to affordable levels. Control and related technologies will be essential for solving these complex problems.

3.1.1 Electrical Energy Conversion and the Environment

Power Electronics is critical to achieving the UK's ambitions for a low-carbon economy. Government targets are for a 34% cut in 1990 CO2 emission levels by 2020, and a greater than 80% cut by 2050 3. To achieve these levels will require action on many fronts but consider the potential of Power Electronics in just one area – motor drives.

Industrial electric motors account for more than 60% of all electrical energy consumption. The application of Power Electronics in their control results in typically a 30-40% reduction in energy used and could be applied in about 50% of applications. In consequence, applying current Power Electronics technology in just this area would directly result in a 9% reduction in all electrical energy consumption – a significant contribution achieved at modest cost as payback on applications tends to be within months rather than several years.

In addition to its targets for the low-carbon economy, the UK Government has also set the target of 15% of all energy generation to come from renewable sources by 2020. This will actually require a more than five-fold increase in renewable electricity generation from 2009, to more than 30% of the total 5. We will need to drastically restructure our national energy portfolio to achieve this transition.

3.1.2 Design Criteria of Power Converters for Renewable Energy Applications

The global electrical energy consumption is still rising and there is a steady demand to increase the power capacity. It is expected that it has to be doubled within 20 years. The production, distribution and use of the energy should be as technological efficient as possible and incentives to save energy at the end-user should also be set up. Deregulation of energy has lowered the investment in larger power plants, which means the need for new electrical power sources may be very high in the near future. Two major technologies will play important roles to solve the future problems. One is to change the electrical power production sources from the conventional, fossil (and short term) based energy sources to renewable energy resources. Another is to use high efficient power electronics in power generation, power transmission/distribution and end-user application. Two of the most emerging renewable energy sources, wind energy and photovoltaic, by means of power electronics are changing from being minor energy sources to be acting as important power sources in the energy system.

In classical power systems, large power generation plants located at adequate geographical places produce most of the power, which is then transferred towards large consumption centres over long distance transmission lines. The system control centres monitor and regulate the power system continuously to ensure the quality of the power, namely frequency and voltage. However, now the overall power system is changing, a large number of dispersed generation (DG) units, including both renewable and non-renewable sources such as wind turbines, wave generators, photovoltaic (PV) generators, small hydro, fuel cells and

gas/steam powered Combined Heat and Power (CHP) stations, are being developed and installed. A wide-spread use of renewable energy sources in distribution networks and a high penetration level will be seen in the near future many places. The main advantages of using renewable energy sources are the elimination of harmful emissions and inexhaustible resources of the primary energy. However, the main disadvantage, apart from the higher costs is the uncontrollability. The availability of renewable energy sources has strong daily and seasonal patterns and the power demand by the consumers could have a very different characteristic. Therefore, it is difficult to operate a power system installed with only renewable generation units due to the characteristic differences and the high uncertainty in the availability of the renewable energy sources.

Some resources;

https://www.youtube.com/watch?v=5uz6xOFWi4A

https://www.youtube.com/watch?v=NoGYYsOkOA8

3.1.3 Renewable Energy Operating Modes.

This section provides an outline and brief description, including fundamentals, of the different renewable energy technologies, wind, solar, bioenergy, hydro and geothermal energy. It provides a general overview of the technologies and their applications.

Electricity generation from wave and tidal energy is not discussed since the technology is mostly at the prototype stage. While these technologies are not fully proven yet, promising research and development is being conducted.

One of the first aspects to consider is the cost of renewable energy technologies. However, this is not an easy question to answer because, as with many energy technologies, many factors affect cost and different sources of information use different criteria for estimating cost. In many cases, the environmental benefits of renewable energy technologies are difficult to gauge in terms of cost savings through less pollution and less damage to the environment. When trying to calculate the cost of these technologies is often best to take a life cycle cost approach, as these technologies often have high up-front capital costs but very low operation and maintenance costs. And of course, there is usually no fuel cost!

Table 3.1 below shows average energy generation costs (in MWh) for a variety of renewable energy technologies in Europe. The table clearly shows that the minimum to average generation costs for these technologies vary widely between different technologies, and within the same technology, according to differences in national markets and resource conditions. This means that one technology can be cheaper in one country than in another.

Table 3.1: Minimum to average generation costs for the main green electricity technologies in Europe

Technology	Range (minimum to average) of electricity generation Technology cost (€/MWh)
Wind onshore	50-80
Small-scale hydro	40-140
Biomass using forestry residues	40-80
Agricultural biogas	60-100
Photovoltaics	> 450

3.2 Wind energy

A wind turbine produces power by converting the force of the wind (kinetic energy) acting on the rotor blades (rotational energy) into torque (turning force or mechanical energy). This rotational energy is used either within a generator to produce electricity or, perhaps less commonly, it is used directly for driving equipment such as milling machines or water pumps (often via conversion to linear motion for piston pumps). Water pumping applications are more common in developing countries. A schematic of a wind energy system is presented in Figure 3.1.

Wind power by its nature is variable (or intermittent), therefore some form of storage or back-up is inevitably involved. This may be through:

a) a connection to an electricity grid system, which may be on a large or small (mini-grid) scale;
b) incorporating other electricity producing energy systems (from conventional generating stations through diesel generators to other renewable energy systems);
c) the use of storage systems such as batteries or, for mechanical systems, storage via water held in a tank.

So long as the system is designed to have sufficient storage capacity, whether for energy or product (e.g. water pumped), to cover the periods when the supply is unable to meet the full level of demand, then an output is always available. The strengths and weaknesses of this technology are presented in Table 3.2.
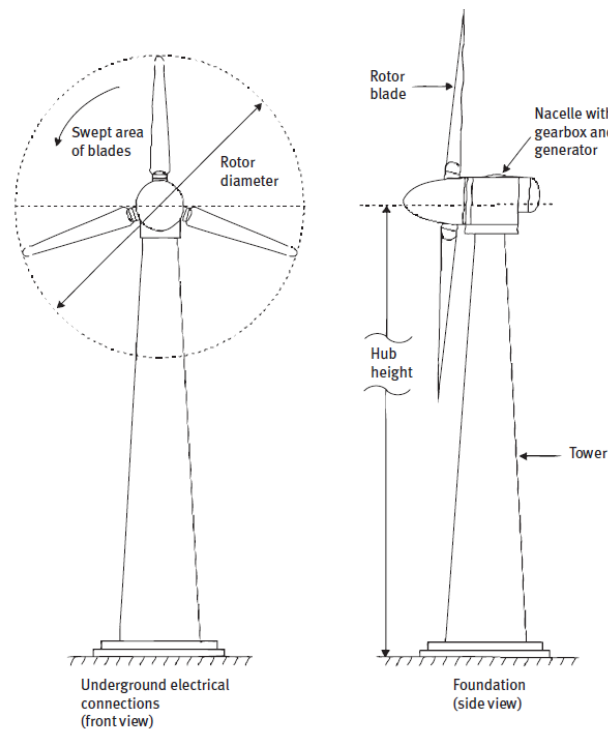

Fig.3.1: Wind energy system schematic

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Table 3.1: Strengths and weaknesses of wind energy systems

Strengths	Weaknesses
Technology is relatively simple and robust with lifetimes of over 15 years without major new investment	Site-specific technology (requires a suitable site)
Automatic operation with low maintenance requirements	Variable power produced therefore storage/back up required.
No fuel required (no additional costs for fuel nor delivery logistics)	High capital/initial investment costs can impede development (especially in developing countries)
Environmental impact low compared with conventional energy sources	Potential market needs to be large enough to support expertise/equipment required for implementation
Mature, well developed, technology in developed countries	Cranage and transport access problems for installation of larger systems in remote areas
The technology can be adapted for complete or part manufacture (e.g. the tower) in developing countries	

Usually wind energy systems are classified in three categories: grid-connected electricity generating, stand-alone electricity generating (often subdivided into battery-based or autonomous diesel, the later having automatic start-up when the wind speed falls, although diesel generators may also be used within stand-alone battery systems) and mechanical systems. Examples of wind power applications are illustrated in Table 3.3.

Table 3.2: Examples of wind power applications and system type

Technology type (electrical/mechanical)	System	Application
Wind power – electrical	Grid connected	Supplementing mains supply
Wind power – electrical	Stand-alone, battery charging	Small home systems Small commercial/community systems Water pumping Telecommunications Navigation aids
Wind power – electrical	Stand-alone, autonomous diesel	Commercial systems Remote settlements Mini-grid systems
Wind power – mechanical	Water pumping	Drinking water supply Irrigation pumping Sea-salt production Dewatering
Wind power – mechanical	Other	Milling grain Driving other, often agricultural machines

3.2.1 Wind turbines generating electricity

Several turbine types exist but presently the most common configuration has become the horizontal axis three bladed turbine (as shown in Fig.3.1 above). The rotor may be positioned up or downwind (although the former is probably the most common). Modern wind turbines vary in size with two market ranges: small units rated at just a few hundred watts up to 50-80 kW in capacity, used mainly for rural and stand-alone power systems; and large units, from 150 kW up to 5 MW in capacity, used for large-scale, grid-connected systems.

3.2.2 Grid-connected wind turbines

Grid-connected wind turbines are certainly having a considerable impact in developed countries and in some developing countries. This is mainly through large-scale installations either on land (on-shore) or in the sea on the continental shelf (off-shore). In addition, in developed countries, more smaller machines are now being grid-connected. These are usually installed to supply power to a private owner already connected to the electricity grid but who wishes to supply at least some of their own power. This principle can be used in developing countries to contribute to a more decentralized grid network and/or to support a weak grid.

Wind turbines do, however, generate electricity intermittently in correlation to the underlying fluctuation of the wind. Because wind turbines do not produce power constantly and at their rated power (which is only achieved at higher wind speeds) capacity factors (i.e. actual annual energy output divided by the theoretical maximum output) are typically between 20 per cent to 30 per cent. One of the principal areas of concerns of wind energy is its variable power output, which can create network problems as the share of intermittent generation on the grid rises.

3.2.3 Stand-alone wind turbines

The most common type of stand-alone small wind electric system involves the use of a wind generator to maintain an adequate level of charge in an electrical storage battery. The battery in turn can provide electricity on demand for electrical applications such as lights, radios, refrigeration, telecommunications, etc., irrespective of whether or not the wind is blowing. A controller is also used to ensure that the batteries are not damaged by overcharging (when surplus energy is dissipated through a dump load) or excessive discharge, usually by sensing low voltage. Loads connected to the battery can either be DC or AC (via an inverter).

Small wind battery charging systems are most commonly rated at between $25 - 100W$ for a 10m/s wind speed and are quite small with a rotor diameter of 50cm to 1m. These systems are suitable for remote settlements in developing countries.

Larger stand-alone systems, incorporating larger wind electricity generators and correspondingly larger battery banks (at an increased cost) are also available, these may include other renewable energy technologies, such as PV, as well as diesel generators to ensure that the batteries are always charged, and that power availability is high.

Less common is the stand-alone system which does not incorporate a battery back. This involves the use of a wind turbine with, at least, a diesel generator, which will automatically supply power when required. This has the advantage of not requiring a battery bank, but the required control systems are complex.

3.2.4 Wind turbines for water pumping

The most common type of a mechanical wind turbine is the wind pump which uses the wind's kinetic energy to lift water. Wind pumps are typically used for water supply (livestock or human settlements), small-scale irrigation or pumping seawater for sea salt production. Here we look at the two main uses which are irrigation and water supply. There are two distinct categories of wind pump, because the technical, operational and economic requirements are generally different for these two end uses. That is not to say that a water supply wind pump cannot be used for irrigation (they quite often are) but irrigation designs are generally unsuitable for water supply duties.

Most water supply wind pumps must be ultra-reliable, to run unattended for most of the time (so they need automatic devices to prevent over-speeding in storms), and they also need the minimum of maintenance and attention and to be capable of pumping water generally from depths of 10m to 100m or more. Irrigation duties on the other hand are seasonal (so the windmill may only be useful for a limited fraction of the year), they involve pumping much larger volumes of water through a low head, and the intrinsic value of the water is low when compared with drinking water. Therefore, any wind pump developed for irrigation has to be as cheap as possible and this requirement tends to override most other considerations.

3.3 Solar energy

Solar energy technologies can be loosely divided into two categories: solar thermal systems. Fig.3.2 shows a solar water heating system and solar electric or photovoltaic (PV) systems.
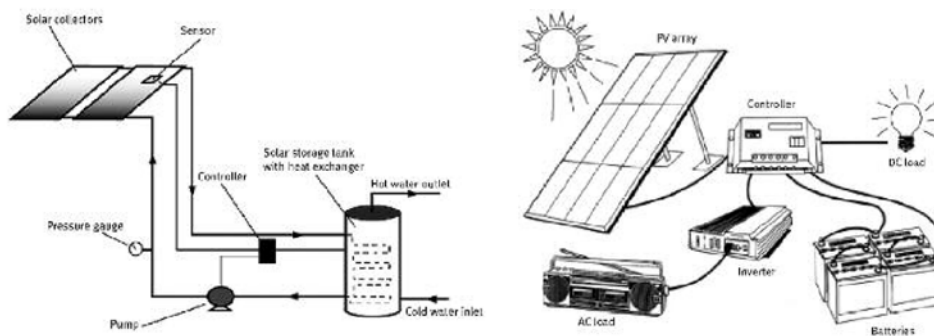

Fig.3.2: Schematic of a typical solar water heating system (left) and a typical PV system (right)

Examples of solar power applications are illustrated in Table 3.4.

Table 3.3: Examples of solar power applications and system type

Technology type (PV/solar thermal)	System	Application
PV (solar electric)	Grid connected	Supplementing mains supply
PV (solar electric)	Stand-alone	Small home systems for lighting, radio, TV, etc. Small commercial/community systems, including health care, schools, etc. Telecommunications Navigation aid Water pumping Commercial systems Remote settlements Mini-grid systems
Solar thermal	Connected to existing water and/or space heating system	Supplementing supply of hot water and/or water and/or space heating provided by the electricity grid or gas network
Solar thermal	Stand-alone	Water heating, i.e. for rural clinics Drying (often agricultural products) Cooking Distillation Cooling

3.3.1 Photovoltaic (PV) systems

Photovoltaic or PV devices convert sun light directly into electrical energy. The amount of energy that can be produced is directly dependent on the sunshine intensity. Thus, for example, PV devices are capable of producing electricity even in winter and even during cloudy weather albeit at a reduced rate. Natural cycles in the context of PV systems thus have three dimensions. As with many other renewable energy technologies, PV has a seasonal variation in potential electricity production with the peak in summer although in principle PV devices operating along the equator have an almost constant exploitable potential throughout the year. Secondly, electricity production varies on a diurnal basis from dawn to dusk peaking during mid-day. Finally, short-term fluctuation of weather conditions, including clouds and rain fall, impact on the inter-hourly amount of electricity that can be harvested. The strengths and weaknesses of this technology are presented in Table 3.5.

Table 3.4: Strengths and weaknesses of PV energy systems

Strengths	Weaknesses
Technology is mature. It has high reliability and long lifetimes (power output warranties from PV panels now commonly for 25 years)	Performance is dependent on sunshine levels and local weather conditions
Automatic operation with very low maintenance requirements	Storage/back-up usually required due to fluctuating nature of sunshine levels / no power production at night
No fuel required (no additional costs for fuel High nor delivery logistics)	High capital/initial investment costs
Modular nature of PV allows for a complete range of system sizes as application dictates	Specific training and infrastructure needs
Environmental impact low compared with conventional energy sources	Energy intensity of silicon production for PV solar cells
The solar system is an easily visible sign of a high level of responsibility, environmental awareness and commitment	Provision for collection of batteries and facilities to recycle batteries are necessary
The user is less affected by rising prices for other energy sources	Use of toxic materials in some PV panels

PV devices use the chemical-electrical interaction between light radiation and a semiconductor to obtain DC electricity. The base material used to make most types of solar cell is silicon (approx. 87%). The main technologies in use today are:

- Mono-crystalline silicon cells. These have a conversion efficiency of 12-15%);
- Poly-crystalline silicon cells (conversion efficiency 11-14%);
- Thin film solar cells (conversion efficiency 5-12%);
- Multiple junction cells (conversion efficiency 20-30%).

The building block of a PV system is a PV cell. Many PV cells are encapsulated together to form a PV panel or module. A PV array, which is the complete power generating unit, consists of any number of PV modules/panels. Depending on their application, the system will also require major components such as a battery bank and battery controller, DC-AC power inverter, auxiliary energy source etc. Individual PV cells typically have a capacity between 5 and $300W$, but systems may have a total installed capacity ranging from $10W$ to $100 \; MW$. The very modular nature of PV panels as building blocks to a PV system gives the sizing of systems an important flexibility.

3.3.2 Solar thermal systems

Solar thermal systems use the sun's power in terms of its thermal or heat energy for heating, drying, evaporation and cooling. Many developing countries have indigenous products such as solar water heaters, solar grain dryers, etc. These are usually local rather than international products, specific to a country or even to a region. The main solar thermal systems employed in developing countries are discussed briefly below.
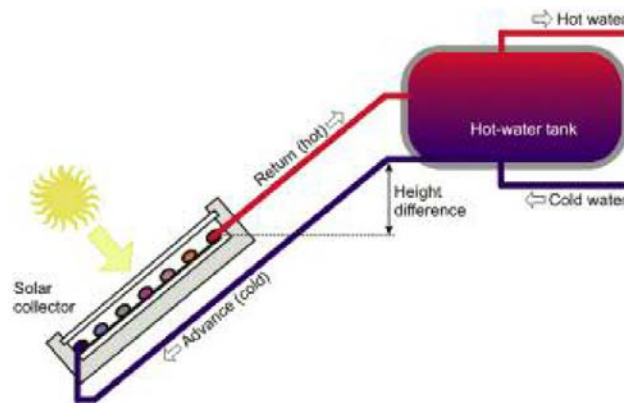

Fig3.3: A thermosiphon solar water heating system

3.3.3 Solar thermal power plants

Solar thermal engines use complex concentrating solar collectors to produce high temperatures. These temperatures are high enough to produce steam, which can be used to drive steam turbines generating electricity.

3.3.4 Solar water heating

Solar water heating systems (see Fig.3.2 above) may be used in rural clinics, hospitals or even schools. The principle of the system is to heat water, usually in a special collector and store it in a tank until required. The cheapest technology available and the simplest to install is a thermosiphon system, an example of which is shown in Fig.3.3.

3.3.5 Solar drying

Solar drying, in the open air, has been used for centuries. Drying may be required to preserve agricultural/food products or as a part of the production process, i.e. timber drying. Solar drying systems are those that use the sun's energy more efficiently than simple open-air drying

3.3.6 Solar cookers

Solar cookers can be important because of the increased scarcity of wood fuel and the problems of deforestation in many developing country regions. Solar cookers can also promote cleaner air where there is a problem with indoor cooking.

3.3.7 Solar distillation

Solar distillation is a solar enhanced distillation process to produce potable water from a saline source. It can be used in areas where, for instance, drinking water is in short supply but brackish water, i.e. containing dissolved salts, is available.

3.3.8 Solar cooling

Several forms of mature technologies are available today for solar-thermally assisted air-conditioning and cooling applications. In particular for centralized systems providing conditioned air and/or chilled water to buildings, all necessary components are commercially available. The great advantage of this solar application, especially in tropical and equatorial countries, is that the daily cooling load profile follows the solar radiation profile (i.e. office buildings).

4.4 Other Renewable Energy Sources

4.4.1 Bioenergy

Bioenergy is a general term that covers energy derived from a wide variety of material of plant or animal origin. Strictly, this includes fossil fuels but, generally, the term is used to mean renewable energy sources such as wood and wood residues, agricultural crops and residues, animal fats, and animal and human wastes, all of which can yield useful fuels either directly or after some form of conversion. There are technologies for bioenergy using liquid and gaseous fuel, as well as traditional applications of direct combustion.

4.4.2 Hydro

Hydropower is the extraction of energy from falling water (from a higher to a lower altitude) when it is made to pass through an energy conversion device, such as a water turbine or a water wheel. A water turbine converts the energy of water into mechanical energy, which in turn is often converted into electrical energy by means of a generator.

Alternatively, hydropower can also be extracted from river currents when a suitable device is placed directly in a river. The devices employed in this case are generally known as river or water current turbines or a "zero head" turbine. Hydropower systems can range from tens of Watts to hundreds of Megawatts.

4.4.3 Geothermal

Geothermal is energy available as heat emitted from within the earth, usually in the form of hot water or steam. Geothermal heat has two sources: the original heat produced from the formation of the earth by gravitational collapse and the heat produced by the radioactive decay of various isotopes. It is very site dependent as the resource needs to be near surface and can be used for heating and power generation purposes. High temperature resources (150°C+) can be used for electricity generation, while low temperature resources (50-150°C) can be used for various direct uses such as district heating and industrial processing. Since the earth's crust is continuously emitting heat towards its surface at a rate of 40 TW, geothermal is in principle an inexhaustible energy source, with the centre of the earth having cooled down by only about 2% over the earth's lifetime of about 4 billion years.

There are no problems of intermittency in the utilization of geothermal energy sources for direct heat applications or for electricity generation. A developed geothermal field provides what is essentially a distributed heat source since the input to a power plant normally consists of the integrated outputs of several wells. Thus, one or more wells may be shut for repairs or maintenance while others produce.

Environmentally, geothermal schemes are relatively benign, but typically do produce a highly corrosive brine which may need special treatment and discharge consents. There is also a possibility of noxious gases, such as hydrogen sulphide, being emitted.

4.5 Control for Renewable Energy and SMART Grids.

Harvesting energy on a large scale is undoubtedly one of the main challenges of our time. Future energy sustainability depends heavily on how the renewable energy problem is addressed in the next few decades.

Although in most power-generating systems, the main source of energy (the fuel) can be manipulated, this is not true for solar and wind energies. The main problems with these energy sources are cost and availability: wind and solar power are not always available where and when needed. Unlike conventional sources of electric power, these renewable sources are not "dispatchable"—the power output cannot be controlled. Daily and seasonal effects and limited predictability result in intermittent generation. Smart grids promise to facilitate the integration of renewable energy and will provide other benefits as well.

Industry must overcome a number of technical issues to deliver renewable energy in significant quantities. Control is one of the key enabling technologies for the deployment of renewable energy systems. Solar and wind power require effective use of advanced control techniques. In addition, smart grids cannot be achieved without extensive use of control technologies at all levels.

Solar and wind power plants exhibit changing dynamics, nonlinearities, and uncertainties—challenges that require advanced control strategies to solve effectively. The use of more efficient control strategies would not only increase the performance of these systems but would increase the number of operational hours of solar and wind plants and thus reduce the cost per kilowatt-hour (KWh) produced.

Both wind and solar have tremendous potential for fulfilling the world's energy needs.

In the case of wind, if conventional onshore wind turbines with 80-m towers were installed on 13% of the earth's surface, the estimated wind power that could be commercially viable is 72 terawatt (TW). That amounts to almost five times the global power consumption in all forms, which currently averages about 15 TW. With capacity that has tripled in the last five years, wind energy is the fastest growing energy source in the world. Using larger wind turbines to convert kinetic energy into electricity has significantly increased the average power output of a wind turbine unit; most major manufacturers have developed large turbines that produce 1.5 to 3.5 megawatts (MW) of electric power, even reaching 5 to 6 MW per turbine in some cases. At the end of 2009, with 159.2 gigawatt (GW) of wind-powered generators worldwide, primarily grouped together to create small wind farms, the global collective capacity was 340 terawatt-hour (TWh) of energy annually, or 2% of global electric energy consumption.

Although wind energy is a clean and renewable source of electric power, many challenges must be addressed. Wind turbines are complex machines, with large flexible structures working under turbulent and unpredictable environmental conditions and are connected to a constantly varying electrical grid with changing voltages, frequency, power flow, and the like. Wind turbines have to adapt to those variations, so their efficiency and reliability depend heavily on the control strategy applied. As wind energy penetration in the grid increases, additional challenges are being revealed: response to grid disturbances, active power control and frequency regulation, reactive power control and voltage regulation, restoration of grid services after power outages, and wind prediction, for example.

Another abundant, sustainable source of energy is the sun. One of the greatest scientific and technological opportunities we face is developing efficient ways to collect, convert, store, and utilize solar energy at an

affordable cost. The solar power reaching the earth's surface is about 86,000 TW. Covering 0.22% of our planet with solar collectors with an efficiency of 8% would be enough to satisfy the current global power consumption. Estimates are that an energy project utilizing concentrating solar power (CSP) technology deployed over an area of approximately 160 x 160 km in the Southwest U.S. could produce enough power for the entire U.S. consumption.

Solar-sourced electricity can be generated either directly using photovoltaic (PV) cells or indirectly by collecting and concentrating the solar power to produce steam, which is then used to drive a turbine to provide the electric power (CSP). Her, we focus on CSP in this section, as control has greater relevance to it.

Concentrating solar thermal systems use optical devices (usually mirrors) and sun-tracking systems to concentrate a large area of sunlight onto a smaller receiving area. The concentrated solar energy is then used as a heat source for a conventional power plant. A wide range of concentrating technologies exists, the main ones being parabolic troughs, solar dishes, linear Fresnel reflectors, and solar power towers. The primary purpose of concentrating solar energy is to produce high temperatures and therefore high thermodynamic efficiencies.

Parabolic trough systems are the most commonly used CSP technology. A parabolic trough consists of a linear parabolic mirror that reflects and concentrates the received solar energy onto a tube (receiver) positioned along the focal line. The heat transfer fluid is pumped through the receiver tube and picks up the heat transferred through the receiver tube walls. The parabolic mirror follows the sun by tracking along a single axis. Linear Fresnel reflectors use various thin mirror strips to concentrate sunlight onto tubes containing heat transfer fluid. Higher concentration can be obtained, and the mirrors are cheaper than parabolic mirrors, but a more complex tracking mechanism is needed.

The main control problems with solar plants are related to sun tracking and control of the thermal variables. Although control of the sun-tracking mechanisms is typically done in an open-loop mode, control of the thermal variables is mainly done in closed loop. Solar plants exhibit changing dynamics, nonlinearities, and uncertainties, characteristics that result in detuned performance with classical PID control. Advanced control strategies that can cope with these issues are needed for better performance and for decreasing the cost per kilowatt-hour generated.

The uncertainty and intermittency of wind and solar generation are major complications that must be addressed before the full potential of these renewables can be reached. The smart grid—an evolution of electricity networks toward greater reliance on communications, computation, and control—promises a solution. The term gained prominence through the U.S. Energy Independence and Security Act (EISA) of 2007, the European Technology Platform for the Electricity Networks of the Future, and similar initiatives across numerous other countries.

The application of advanced digital technologies (i.e., microprocessor-based measurement and control, communications, computing, and information systems) are expected to greatly improve the reliability, security, interoperability, and efficiency of the electrical grid, while reducing environmental impacts and promoting economic growth. Achieving enhanced connectivity and interoperability will require innovation, ingenuity, and different applications, systems, and devices to operate seamlessly with one another, involving the combined use of open system architecture, as an integration platform, and commonly shared technical

standards and protocols for communications and information systems. To realize Smart Grid capabilities, deployments must integrate a vast number of smart devices and systems.

The EU's SmartGrids technology platform summarizes the benefits of smart grids as follows. They:

- Better facilitate the connection and operation of generators of all sizes and technologies;
- Allow consumers to play a part in optimizing the operation of the system;
- Provide consumers with greater information and options for choice of supply;
- Significantly reduce the environmental impact of the whole electricity supply system;
- Maintain or even improve the existing high levels of system reliability, quality and security of supply;
- Maintain and improve the existing services efficiently;
- Foster market integration

The broad spectrum of entities and stakeholders covered by the smart grid is evident from the conceptual model of Fig.3.4. The smart grid further broadens the already highly distributed nature of power systems by extending control to the consumer level. The smart grid can be conceptualized as an extensive cyber-physical system that supports and significantly enhances controllability and responsiveness of highly distributed resources and assets within electric power systems.
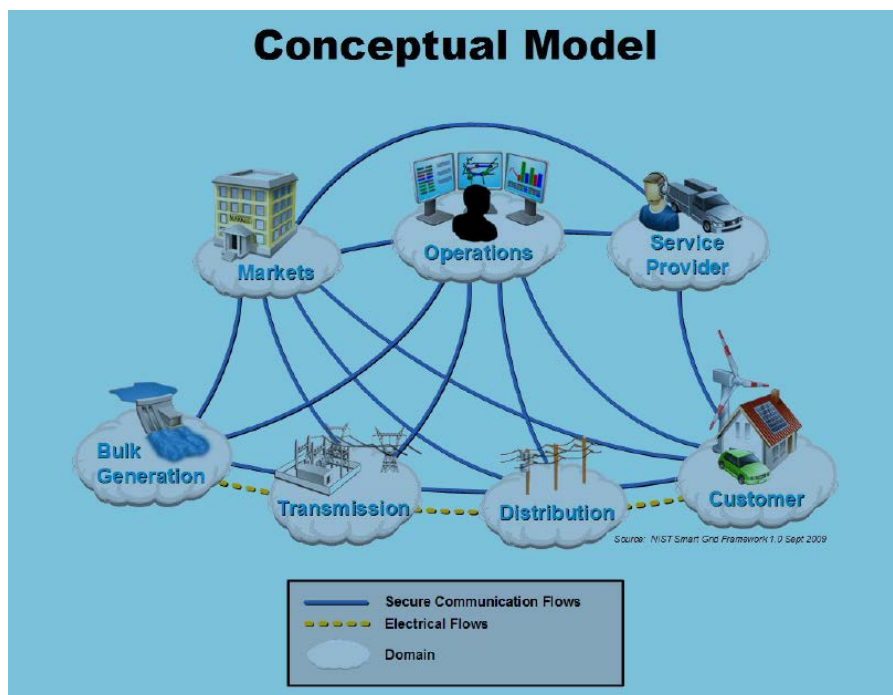

Fig.3.4: Depiction of the smart grid conceptual model

The term smart grid implies that the existing grid is dumb, which is far from true. The current grid structure reflects carefully considered trade-offs between cost and reliability. The responsiveness achievable through smart grid concepts will, however, play a vital role in achieving large-scale integration of new forms of generation and demand. Renewable generation will make an increasingly important contribution to electric energy production into the future. Integration of these highly variable, widely distributed resources will call for new approaches to power system operation and control. Likewise, new types of loads, such as plug-in

electric vehicles and their associated vehicle-to-grid potential, will offer challenges and opportunities. Establishing a cyberinfrastructure that provides ubiquitous sensing and actuation capabilities will be vital to achieving the responsiveness needed for future grid operations. Sensing and actuation will be pointless, though, without appropriate controls.

There are some useful resources here;

1) *Power Electronics in Renewable Energy Systems (Other Resources A3)*
2) *Power Electronics Strategy for Success (Other Resources A3)*
3) *Power Electronics for Renewable Energy Systems Transportation and Industrial Applications (eBooks)*
4) *Power Electronics SFG notes V 1.0 (eBooks)*

4.6 Industrial Application of Power Converters

Power electronics is the application of solid-state electronics to the control and conversion of electric power. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices. The power range is typically from tens of watts to several hundred watts. In industry a common application is the variable speed drive (VSD) that is used to control an induction motor. The power range of VSDs start from a few hundred watts up to tens of megawatts.

The power conversion systems can be classified according to the type of the input and output power

- AC to DC (rectifier)
- DC to AC (inverter)
- DC to DC (DC-to-DC converter)
- AC to AC (AC-to-AC converter)

The capabilities and economy of power electronics system are determined by the active devices that are available. As the ratings of solid-state devices improved in both voltage and current-handling capacity, vacuum devices have been nearly entirely replaced by solid-state devices.

Power electronic devices may be used as switches, or as amplifiers. An ideal switch is either open or closed and so dissipates no power; it withstands an applied voltage and passes no current or passes any amount of current with no voltage drop. Semiconductor devices used as switches can approximate this ideal property and so most power electronic applications rely on switching devices on and off, which makes systems very efficient as very little power is wasted in the switch. By contrast, in the case of the amplifier, the current through the device varies continuously according to a controlled input. The voltage and current at the device terminals follow a load line, and the power dissipation inside the device is large compared with the power delivered to the load.

Several attributes dictate how devices are used. Devices such as diodes conduct when a forward voltage is applied and have no external control of the start of conduction. Power devices such as silicon-controlled rectifiers and thyristors (as well as the mercury valve and thyratron) allow control of the start of conduction but rely on periodic reversal of current flow to turn them off. Devices such as gate turn-off thyristors, BJT

and MOSFET transistors provide full switching control and can be turned on or off without regard to the current flow through them. Transistor devices also allow proportional amplification, but this is rarely used for systems rated more than a few hundred watts. The control input characteristics of a device also greatly affect design; sometimes the control input is at a very high voltage with respect to ground and must be driven by an isolated source.

As efficiency is at a premium in a power electronic converter, the losses that a power electronic device generates should be as low as possible.

Devices vary in switching speed. Some diodes and thyristors are suited for relatively slow speed and are useful for power frequency switching and control; certain thyristors are useful at a few kilohertz. Devices such as MOSFETS and BJTs can switch at tens of kilohertz up to a few megahertz in power applications, but with decreasing power levels. Vacuum tube devices dominate high power (hundreds of kilowatts) at very high frequency (hundreds or thousands of megahertz) applications. Faster switching devices minimize energy lost in the transitions from on to off and back but may create problems with radiated electromagnetic interference. Gate drive (or equivalent) circuits must be designed to supply sufficient drive current to achieve the full switching speed possible with a device. A device without sufficient drive to switch rapidly may be destroyed by excess heating.

Practical devices have non-zero voltage drop and dissipate power when on and take some time to pass through an active region until they reach the "on" or "off" state. These losses are a significant part of the total lost power in a converter.

Power handling and dissipation of devices is also a critical factor in design. Power electronic devices may have to dissipate tens or hundreds of watts of waste heat, even switching as efficiently as possible between conducting and non-conducting states. In the switching mode, the power controlled is much larger than the power dissipated in the switch. The forward voltage drop in the conducting state translates into heat that must be dissipated. High power semiconductors require specialized heat sinks or active cooling systems to manage their junction temperature; exotic semiconductors such as silicon carbide have an advantage over straight silicon in this respect, and germanium, once the main-stay of solid-state electronics is now little used due to its unfavourable high temperature properties.

Semiconductor devices exist with ratings up to a few kilovolts in a single device. Where very high voltage must be controlled, multiple devices must be used in series, with networks to equalize voltage across all devices. Again, switching speed is a critical factor since the slowest-switching device will have to withstand a disproportionate share of the overall voltage. Mercury valves were once available with ratings to 100 kV in a single unit, simplifying their application in HVDC systems.

The current rating of a semiconductor device is limited by the heat generated within the dies and the heat developed in the resistance of the interconnecting leads. Semiconductor devices must be designed so that current is evenly distributed within the device across its internal junctions (or channels); once a "hot spot" develops, breakdown effects can rapidly destroy the device. Certain SCRs are available with current ratings to 3000 amperes in a single unit.

4.6.1 DC-AC converters (inverters)

DC to AC converters produce an AC output waveform from a DC source. Applications include adjustable speed drives (ASD), uninterruptible power supplies (UPS), Flexible AC transmission systems (FACTS), voltage compensators, and photovoltaic inverters. Topologies for these converters can be separated into two distinct categories: voltage source inverters and current source inverters. Voltage source inverters (VSIs) are named so because the independently controlled output is a voltage waveform. Similarly, current source inverters (CSIs) are distinct in that the controlled AC output is a current waveform.

DC to AC power conversion is the result of power switching devices, which are commonly fully controllable semiconductor power switches. The output waveforms are therefore made up of discrete values, producing fast transitions rather than smooth ones. For some applications, even a rough approximation of the sinusoidal waveform of AC power is adequate. Where a near sinusoidal waveform is required, the switching devices are operated much faster than the desired output frequency, and the time they spend in either state is controlled so the averaged output is nearly sinusoidal. Common modulation techniques include the carrier-based technique, or Pulse-width modulation, space-vector technique, and the selective-harmonic technique.

Voltage source inverters have practical uses in both single-phase and three-phase applications. Single-phase VSIs utilize half-bridge and full-bridge configurations, and are widely used for power supplies, single-phase UPSs, and elaborate high-power topologies when used in multicell configurations. Three-phase VSIs are used in applications that require sinusoidal voltage waveforms, such as ASDs, UPSs, and some types of FACTS devices such as the STATCOM. They are also used in applications where arbitrary voltages are required as in the case of active power filters and voltage compensators.

Current source inverters are used to produce an AC output current from a DC current supply. This type of inverter is practical for three-phase applications in which high-quality voltage waveforms are required.

A relatively new class of inverters, called multilevel inverters, has gained widespread interest. Normal operation of CSIs and VSIs can be classified as two-level inverters, due to the fact that power switches connect to either the positive or to the negative DC bus. If more than two voltage levels were available to the inverter output terminals, the AC output could better approximate a sine wave. It is for this reason that multilevel inverters, although more complex and costly, offer higher performance.

Each inverter type differs in the DC links used, and in whether or not they require freewheeling diodes. Either can be made to operate in square-wave or pulse-width modulation (PWM) mode, depending on its intended usage. Square-wave mode offers simplicity, while PWM can be implemented several different ways and produces higher quality waveforms.

Voltage Source Inverters (VSI) feed the output inverter section from an approximately constant-voltage source.

The desired quality of the current output waveform determines which modulation technique needs to be selected for a given application. The output of a VSI is composed of discrete values. In order to obtain a smooth current waveform, the loads need to be inductive at the select harmonic frequencies. Without some sort of inductive filtering between the source and load, a capacitive load will cause the load to receive a choppy current waveform, with large and frequent current spikes.

There are three main types of VSIs:

- Single-phase half-bridge inverter
- Single-phase full-bridge inverter
- Three-phase voltage source inverter

Single-phase half-bridge inverter: The single-phase voltage source half-bridge inverters are meant for lower voltage applications and are commonly used in power supplies. Fig.3.5 shows the circuit schematic of this inverter.
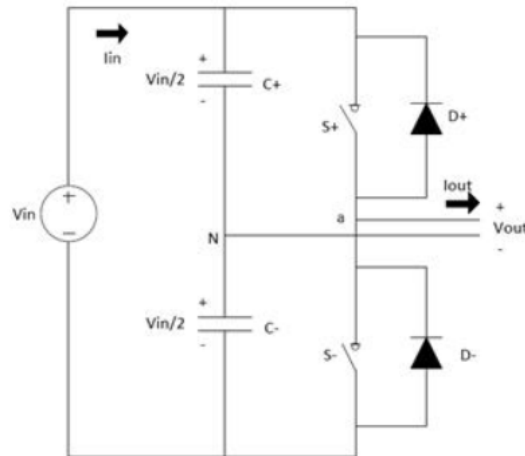

Fig.3.5: Single-Phase Half-Bridge Voltage Source Inverter

Low-order current harmonics get injected back to the source voltage by the operation of the inverter. This means that two large capacitors are needed for filtering purposes in this design. As Figure 6 illustrates, only one switch can be on at time in each leg of the inverter. If both switches in a leg were on at the same time, the DC source will be shorted out.

Inverters can use several modulation techniques to control their switching schemes.

Single-phase full-bridge inverter: The full-bridge inverter is similar to the half bridge-inverter, but it has an additional leg to connect the neutral point to the load. Fig.3.6 shows the circuit schematic of the single-phase voltage source full-bridge inverter.
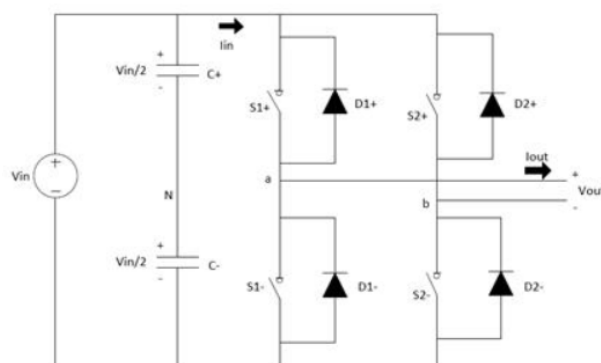

Fig.3.6: Single-Phase Voltage Source Full-Bridge Inverter

To avoid shorting out the voltage source, S1+ and S1- cannot be on at the same time, and S2+ and S2- also cannot be on at the same time. Any modulating technique used for the full-bridge configuration should have either the top or the bottom switch of each leg on at any given time.

Three-phase voltage source inverter: Single-phase VSIs are used primarily for low power range applications, while three-phase VSIs cover both medium and high-power range applications. Fig.3.7 shows the circuit schematic for a three-phase VSI.
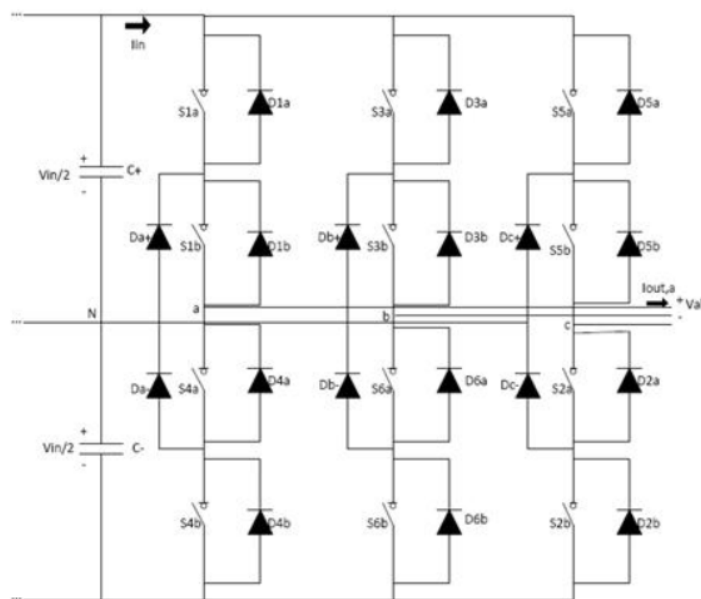

Fig.3.7: Three-Phase Voltage Source Inverter Circuit Schematic

Switches in any of the three legs of the inverter cannot be switched off simultaneously due to this resulting in the voltages being dependent on the respective line current's polarity. The only way to control the load voltage is by changing the input DC voltage.

Current source inverters: Current source inverters convert DC current into an AC current waveform. In applications requiring sinusoidal AC waveforms, magnitude, frequency, and phase should all be controlled. CSIs have high changes in current overtime, so capacitors are commonly employed on the AC side, while inductors are commonly employed on the DC side. Due to the absence of freewheeling diodes, the power circuit is reduced in size and weight, and tends to be more reliable than VSIs. Although single-phase topologies are possible, three-phase CSIs are more practical. (Fig.3.8).
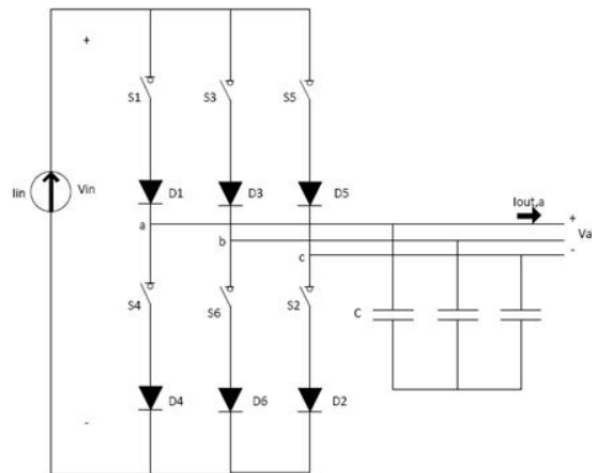
Fig3.8: Three-Phase Current Source Inverter

Multilevel inverters: A relatively new class called multilevel inverters has gained widespread interest. Normal operation of CSIs and VSIs can be classified as two-level inverters because the power switches connect to either the positive or the negative DC bus. If more than two voltage levels were available to the inverter output terminals, the AC output could better approximate a sine wave. For this reason, multilevel inverters, although more complex and costly, offer higher performance. A three-level neutral-clamped inverter is shown in Fig.3.9.
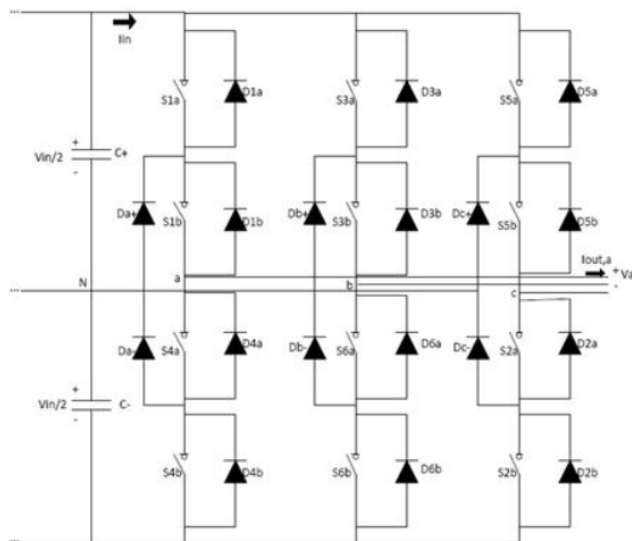

Fig.3.9: Three-Level Neutral-Clamped Inverter

Control methods for a three-level inverter only allow two switches of the four switches in each leg to simultaneously change conduction states. This allows smooth commutation and avoids shoot through by only selecting valid states. It may also be noted that since the DC bus voltage is shared the voltage ratings can be less than a two-level counterpart.

Carrier-based and space-vector modulation techniques are used for multilevel topologies.

3.6.2 AC-AC converters

Converting AC power to AC power allows control of the voltage, frequency, and phase of the waveform applied to a load from a supplied AC system. The two main categories that can be used to separate the types of converters are whether the frequency of the waveform is changed. AC/AC converter that don't allow the user to modify the frequencies are known as AC Voltage Controllers, or AC Regulators. AC converters that allow the user to change the frequency are simply referred to as frequency converters for AC to AC conversion. Under frequency converters there are three different types of converters that are typically used: cyclo-converter, matrix converter, DC link converter (aka AC/DC/AC converter).

The purpose of an AC Voltage Controller, or AC Regulator, is to vary the RMS voltage across the load while at a constant frequency. Three control methods that are generally accepted are ON/OFF Control, Phase-Angle Control, and Pulse Width Modulation AC Chopper Control (PWM AC Chopper Control). All three of these methods can be implemented not only in single-phase circuits, but three-phase circuits as well.

ON/OFF Control: Typically used for heating loads or speed control of motors, this control method involves turning the switch on for n integral cycles and turning the switch off for m integral cycles. Because turning the switches on and off causes undesirable harmonics to be created, the switches are turned on and off during zero-voltage and zero-current conditions (zero-crossing), effectively reducing the distortion.

Phase-Angle Control: Various circuits exist to implement a phase-angle control on different waveforms, such as half-wave or full-wave voltage control. The power electronic components that are typically used are diodes, SCRs, and Triacs. With the use of these components, the user can delay the firing angle in a wave which will only cause part of the wave to be in output.

PWM AC Chopper Control: The other two control methods often have poor harmonics, output current quality, and input power factor. In order to improve these values PWM can be used instead of the other methods. What PWM AC Chopper does is have switches that turn on and off several times within alternate half-cycles of input voltage.

Matrix converters and cyclo-converters: Cyclo-converters are widely used in industry for ac to ac conversion, because they are able to be used in high-power applications. They are commutated direct frequency converters that are synchronised by a supply line. The cyclo-converters output voltage waveforms have complex harmonics with the higher order harmonics being filtered by the machine inductance. Causing the machine current to have fewer harmonics, while the remaining harmonics causes losses and torque pulsations. Note that in a cyclo-converter, unlike other converters, there are no inductors or capacitors, i.e. no storage devices. For this reason, the instantaneous input power and the output power are equal.

Single-Phase to Single-Phase Cyclo-converters: Single-Phase to Single-Phase Cyclo-converters started drawing more interest recently[when?] because of the decrease in both size and price of the power electronics switches. The single-phase high frequency ac voltage can be either sinusoidal or trapezoidal. These might be zero voltage intervals for control purpose or zero voltage commutation.

Three-Phase to Single-Phase Cyclo-converters: There are two kinds of three-phase to single-phase cyclo-converters: 3ϕ to 1ϕ half wave cyclo-converters and 3ϕ to 1ϕ bridge cyclo-converters. Both positive and negative converters can generate voltage at either polarity, resulting in the positive converter only supplying positive current, and the negative converter only supplying negative current.

With recent device advances, newer forms of cyclo-converters are being developed, such as matrix converters. The first change that is first noticed is that matrix converters utilize bi-directional, bipolar

switches. A single phase to a single-phase matrix converter consists of a matrix of 9 switches connecting the three input phases to the tree output phase. Any input phase and output phase can be connected together at any time without connecting any two switches from the same phase at the same time; otherwise this will cause a short circuit of the input phases. Matrix converters are lighter, more compact and versatile than other converter solutions. As a result, they are able to achieve higher levels of integration, higher temperature operation, broad output frequency and natural bi-directional power flow suitable to regenerate energy back to the utility.

The matrix converters are subdivided into two types: direct and indirect converters. A direct matrix converter with three-phase input and three-phase output, the switches in a matrix converter must be bi-directional, that is, they must be able to block voltages of either polarity and to conduct current in either direction. This switching strategy permits the highest possible output voltage and reduces the reactive line-side current. Therefore, the power flow through the converter is reversible. Because of its commutation problem and complex control keep it from being broadly utilized in industry.

Indirect matrix converters have the same functionality, but uses separate input and output sections that are connected through a DC link without storage elements. The design includes a four-quadrant current source rectifier and a voltage source inverter. The input section consists of bi-directional bipolar switches. The commutation strategy can be applied by changing the switching state of the input section while the output section is in a freewheeling mode. This commutation algorithm is significantly less complexity and higher reliability as compared to a conventional direct matrix converter.

DC link converters: DC Link Converters, also referred to as AC/DC/AC converters, convert an AC input to an AC output with the use of a DC link in the middle. Meaning that the power in the converter is converted to DC from AC with the use of a rectifier, and then it is converted back to AC from DC with the use of an inverter. The end result is an output with a lower voltage and variable (higher or lower) frequency. Due to their wide area of application, the AC/DC/AC converters are the most common contemporary solution. Other advantages to AC/DC/AC converters is that they are stable in overload and no-load conditions, as well as they can be disengaged from a load without damage.

Hybrid matrix converter: Hybrid matrix converters are relatively new for AC/AC converters. These converters combine the AC/DC/AC design with the matrix converter design. Multiple types of hybrid converters have been developed in this new category, an example being a converter that uses uni-directional switches and two converter stages without the dc-link; without the capacitors or inductors needed for a dc-link, the weight and size of the converter is reduced. Two sub-categories exist from the hybrid converters, named hybrid direct matrix converter (HDMC) and hybrid indirect matrix converter (HIMC). HDMC convert the voltage and current in one stage, while the HIMC utilizes separate stages, like the AC/DC/AC converter, but without the use of an intermediate storage element.

3.6.3 Applications of AC-AC Converters

Below is a list of common applications that each converter is used in.

AC Voltage Controller: Lighting Control; Domestic and Industrial Heating; Speed Control of Fan, Pump or Hoist Drives, Soft Starting of Induction Motors, Static AC Switches (Temperature Control, Transformer Tap Changing, etc.)

Cyclo-converter: High-Power Low-Speed Reversible AC Motor Drives; Constant Frequency Power Supply with Variable Input Frequency; Controllable VAR Generators for Power Factor Correction; AC System Interties Linking Two Independent Power Systems.

Matrix Converter: Currently the application of matrix converters is limited due to non-availability of bilateral monolithic switches capable of operating at high frequency, complex control law implementation, commutation and other reasons. With these developments, matrix converters could replace cycloconverters in many areas.

DC Link: Can be used for individual or multiple load applications of machine building and construction.

4.6.4 Simulations of power electronic systems

Power electronic circuits are simulated using computer simulation programs such as PLECS, PSIM and MATLAB/Simulink. Circuits are simulated before they are produced to test how the circuits respond under certain conditions. Also, creating a simulation is both cheaper and faster than creating a prototype to use for testing.

4.6.5 Applications

Applications of power electronics range in size from a switched mode power supply in an AC adapter, battery chargers, audio amplifiers, fluorescent lamp ballasts, through variable frequency drives and DC motor drives used to operate pumps, fans, and manufacturing machinery, up to gigawatt-scale high voltage direct current power transmission systems used to interconnect electrical grids. Power electronic systems are found in virtually every electronic device. For example:

DC/DC converters are used in most mobile devices (mobile phones, PDA etc.) to maintain the voltage at a fixed value whatever the voltage level of the battery is. These converters are also used for electronic isolation and power factor correction. A power optimizer is a type of DC/DC converter developed to maximize the energy harvest from solar photovoltaic or wind turbine systems.

AC/DC converters (rectifiers) are used every time an electronic device is connected to the mains (computer, television etc.). These may simply change AC to DC or can also change the voltage level as part of their operation.

AC/AC converters are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency 50 Hz and 60 Hz power grids.

DC/AC converters (inverters) are used primarily in UPS or renewable energy systems or emergency lighting systems. Mains power charges the DC battery. If the mains fails, an inverter produces AC electricity at mains voltage from the DC battery. Solar inverter, both smaller string and larger central inverters, as well as solar micro-inverter are used in photovoltaics as a component of a PV system.

Motor drives are found in pumps, blowers, and mill drives for textile, paper, cement and other such facilities. Drives may be used for power conversion and for motion control. For AC motors, applications include variable-frequency drives, motor soft starters and excitation systems.

In hybrid electric vehicles (HEVs), power electronics are used in two formats: series hybrid and parallel hybrid. The difference between a series hybrid and a parallel hybrid is the relationship of the electric motor to the internal combustion engine (ICE). Devices used in electric vehicles consist mostly of DC/DC converters

for battery charging and dc/ac converters to power the propulsion motor. Electric trains use power electronic devices to obtain power, as well as for vector control using pulse width modulation (PWM) rectifiers. The trains obtain their power from power lines. Another new usage for power electronics is in elevator systems. These systems may use thyristors, inverters, permanent magnet motors, or various hybrid systems that incorporate PWM systems and standard motors.

4.6.6 Inverters

In general, inverters are utilized in applications requiring direct conversion of electrical energy from DC to AC or indirect conversion from AC to AC. DC to AC conversion is useful for many fields, including power conditioning, harmonic compensation, motor drives, and renewable energy grid-integration.

In power systems it is often desired to eliminate harmonic content found in line currents. VSIs can be used as active power filters to provide this compensation. Based on measured line currents and voltages, a control system determines reference current signals for each phase. This is fed back through an outer loop and subtracted from actual current signals to create current signals for an inner loop to the inverter. These signals then cause the inverter to generate output currents that compensate for the harmonic content. This configuration requires no real power consumption, as it is fully fed by the line; the DC link is simply a capacitor that is kept at a constant voltage by the control system. In this configuration, output currents are in phase with line voltages to produce a unity power factor. Conversely, VAR compensation is possible in a similar configuration where output currents lead line voltages to improve the overall power factor.

In facilities that require energy at all times, such as hospitals and airports, UPS systems are utilized. In a standby system, an inverter is brought online when the normally supplying grid is interrupted. Power is instantaneously drawn from onsite batteries and converted into usable AC voltage by the VSI, until grid power is restored, or until backup generators are brought online. In an online UPS system, a rectifier-DC-link-inverter is used to protect the load from transients and harmonic content. A battery in parallel with the DC-link is kept fully charged by the output in case the grid power is interrupted, while the output of the inverter is fed through a low pass filter to the load. High power quality and independence from disturbances is achieved.

Various AC motor drives have been developed for speed, torque, and position control of AC motors. These drives can be categorized as low-performance or as high-performance, based on whether they are scalar-controlled or vector-controlled, respectively. In scalar-controlled drives, fundamental stator current, or voltage frequency and amplitude, are the only controllable quantities. Therefore, these drives are employed in applications where high-quality control is not required, such as fans and compressors. On the other hand, vector-controlled drives allow for instantaneous current and voltage values to be controlled continuously. This high performance is necessary for applications such as elevators and electric cars.

Inverters are also vital to many renewable energy applications. In photovoltaic purposes, the inverter, which is usually a PWM VSI, gets fed by the DC electrical energy output of a photovoltaic module or array. The inverter then converts this into an AC voltage to be interfaced with either a load or the utility grid. Inverters may also be employed in other renewable systems, such as wind turbines. In these applications, the turbine speed usually varies causing changes in voltage frequency and sometimes in the magnitude. In this case, the generated voltage can be rectified and then inverted to stabilize frequency and magnitude.

4.7 Smart grid

A smart grid is a modernized electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

Electric power generated by wind turbines and hydroelectric turbines by using induction generators can cause variances in the frequency at which power is generated. Power electronic devices are utilized in these systems to convert the generated ac voltages into high-voltage direct current (HVDC). The HVDC power can be more easily converted into three phase power that is coherent with the power associated to the existing power grid. Through these devices, the power delivered by these systems is cleaner and has a higher associated power factor. Wind power systems optimum torque is obtained either through a gearbox or direct drive technologies that can reduce the size of the power electronics device.

Electric power can be generated through photovoltaic cells by using power electronic devices. The produced power is usually then transformed by solar inverters. Inverters are divided into three different types: central, module-integrated and string. Central converters can be connected either in parallel or in series on the DC side of the system. For photovoltaic "farms", a single central converter is used for the entire system. Module-integrated converters are connected in series on either the DC or AC side. Normally several modules are used within a photovoltaic system, since the system requires these converters on both DC and AC terminals. A string converter is used in a system that utilizes photovoltaic cells that are facing different directions. It is used to convert the power generated to each string, or line, in which the photovoltaic cells are interacting.

Power electronics can be used to help utilities adapt to the rapid increase in distributed residential/ commercial solar power generation. Germany and parts of Hawaii, California and New Jersey require costly studies to be conducted before approving new solar installations. Relatively small-scale ground- or pole-mounted devices create the potential for a distributed control infrastructure to monitor and manage the flow of power. Traditional electromechanical systems, such as capacitor banks or voltage regulators at substations, can take minutes to adjust voltage and can be distant from the solar installations where the problems originate. If voltage on a neighbourhood circuit goes too high, it can endanger utility crews and cause damage to both utility and customer equipment. Further, a grid fault causes photovoltaic generators to shut down immediately, spiking demand for grid power. Smart grid-based regulators are more controllable than far more numerous consumer devices.

In another approach, a group of 16 western utilities called the Western Electric Industry Leaders called for mandatory use of "smart inverters". These devices convert DC to household AC and can also help with power quality. Such devices could eliminate the need for expensive utility equipment upgrades at a much lower total cost.

Recent Advancements in Power Systems Electronics

There are some useful resources here;

1) http://www.powerelectronics.com/
2) https://phys.org/news/2015-04-team-electrical-power-renewable-energy.html
3) Power-Electronics-for-Renewable-Energy-Systems-Transportation-and-Industrial-Applications (eBook)
4) Power Electronics SFG notes V 1.0 (eBook)