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

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.

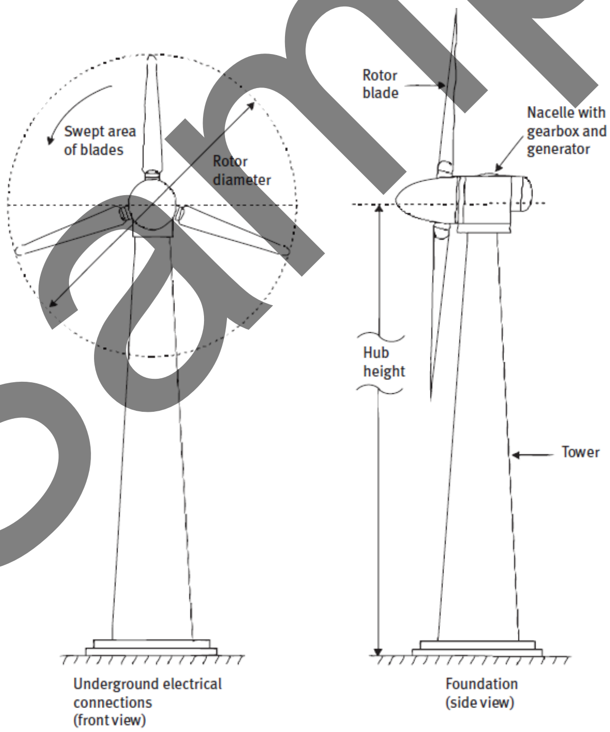

Fig.3.1: Wind energy system schematic

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 $25 - 100\text{W}$ 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.

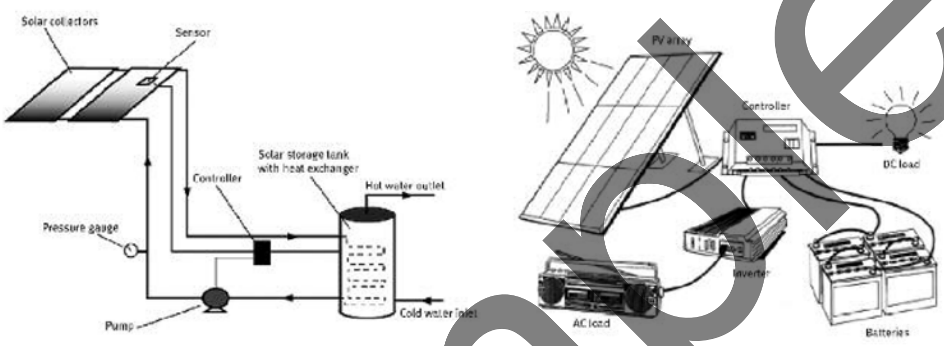

Fig.3.2: Schematic of a typical solar water heating system (left) and a typical PV system (right)

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

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)