# EE3014-POWER ELECTRONICS FOR RENEWABLE ENERGY SYSTEMS

## UNIT I- INTRODUCTION

## 1. 2 ENVIRONMENTAL ASPECTS OF ELECTRIC ENERGY CONVERSION

### Coal as thermal fuel

Coal is the raw fuel that provides 42% of the world‘s electricity. This distinguishes coalas the world‘s primary energy source for electricity generation. The name coal refers to a family of solid, organic fuels with different properties. Coal is mainly composed of elemental carbon and is formed by the conversion of deposited organic material. The lowest grade of coal formedis peat. Under the influence of high pressures and temperatures, the peat is transform into the coal. Using coal to generate power or heat is an old technique. The heat energy of these fuels is converted into mechanical energy by suitable prime movers such as steam engines, steam turbines, internal combustion engines etc.

### Coal mining

There are two types of coal mining, strip mining and underground long wall mining. The environmental impacts from surface versus underground mining are not significantly different. The main difference between these two mining techniques is that the surface mining subsystem results in a higher amount of airborne ammonia emissions due to the production of ammonium nitrate explosives which are used at the mine. Another important difference is that underground mining requires limestone which emits a large amount of particulates during its production. The problematic pollutants in emission of coal based generating plants are Sulfur dioxide ($SO_2$), Nitrogen oxides (NOx), carbon monoxide (CO) and carbon dioxide ($CO_2$) and certain hydrocarbons.

### Oxides of sulphur (SO2)

Most of the sulphur present in the fossil is oxidized to $SO_2$ in the combustion chamber before being emitted by the chimney. In atmosphere it gets further oxidized to $H_2SO_4$ and metallic sulphates which are the major source of concern as these can cause acid rain,

impaired visibility, damage to buildings and vegetation. Sulphate concentrations of 9-20 µg/m3 of air aggravate asthma, lung and heart disease.

## Acidification

Acidification is one of the main problems arising from existing coal power. It takes place during many steps in the life cycle of electricity produced by coal combustion. Pumped mine water contains mud, dissolved sulphate and metal ions. It is also acidic and, therefore, needs tobe neutralizing before being discharged. Drainage water from refuse piles with excavated and residual minerals can be very acidic, particularly if the rocks contain pyrite (ferric sulphide) that undergoes oxidation processes when exposed to the atmosphere. These oxidation processes take place in natural environments, but are greatly accelerated by mining activities, especially when no alkaline rocks are present to neutralize the acid formed.

## Impact on biodiversity

The main environmental effect of electricity produced by coal combustion is probably related to the ubiquitous emission of greenhouse gases. The release to the atmosphere of such gases is larger from coal use than for any other fuel used for generating electricity. It is a general contention that any additional increase of greenhouse gases in the atmosphere will exacerbate global warming. This can lead to rapid changes in local weather conditions and can thus have many and profound influences on biodiversity. Organisms that cannot adapt or migrate successfully under changing climate conditions will be adversely affected.

## ENVIRONMENT IMPACTS OF RENEWABLE ENERGY TECHNOLOGIES

Developing renewable energy technologies that exploit the sun, the wind, and geothermal energy is critical to addressing concerns about climate change and some environmental issues. However, using renewable energy sources will not eliminate all environmental concerns. Although renewable energy sources produce relatively low levels of Green House Gas emissions and conventional air pollution, manufacturing and transporting them will produce some emissions and pollutants. The production of some photovoltaic (PV) cells, for instance, generates toxic substances that may contaminate water resources. Renewable energy installations can also disrupt land use and wildlife habitat, and some technologies consume significant quantities of water.

To develop sound policies, policy makers must understand the relative environmental impacts of alternative energy sources, including how the impacts of renewable energy technologies compare to those of fossil-fuel technologies and to opportunities for improvements

in energy efficiency. Understanding the potential environmental impacts of renewable energy technologies is also essential for identifying and pursuing designs, manufacturing methods, project siting, utility operations, and so on to mitigate or offset these effects.

## Life cycle uses of energy

For renewable energy sources, net energy ratio (NER) is expected to be greater than one, indicating a positive return over the fossil-fuel energy investment. For fossil-fuel and nuclear technologies, NERs are smaller than one and essentially represent the overall life cycle efficiency of the project. NERs are strongly influenced by a number of underlying assumptions, such as plant capacity and life expectancy. For electricity generation from wind and solar energy, the strength of the resource (which will affect the capacity factor of the installed technology) is also a critical assumption. For silicon PV specifically, the NER is highly dependent upon the thickness of the wafer and the efficiency of the cell/module produced. NERs would be significantly higher for waste biomass.

## Local and regional air pollution

Most renewable energy technologies have much lower life cycle emissions of conventional air pollutants than conventional coal and natural gas plants. One exception is electricity generation from biomass, which can produce significant NOx, particulate matter, and hazardous air pollutants, such as polycyclic aromatic hydrocarbons (PAHs). Although biomass has lower nitrogen content than fossil fuels, a substantial quantity of NOx is formed whenever high-temperature combustion occurs in air, through oxidation of atmospheric nitrogen ($N_2$) at high temperatures. Although direct emissions of NOx and SOx are expected to be low for geothermal power plants, flash and dry-steam geothermal facilities can produce significant quantities of hydrogen sulfide ($H_2S$) from geothermal reservoirs, unless steps are taken to decrease it.

## Land and water use

The amount of land used is a rough substitute for other impacts of new development, including impacts on ecosystems, cultural and historical resources, scenery, and agricultural land. When the impacts on land use are measured simply by the surface area they occupy during their life cycle, some renewable energy technologies appear to have heavy land-use requirements. However, this approach does not take into account the intensity of land use or whether the technology allows for simultaneous use of land for other purposes. Whereas coal- fired power plants fully occupy the sites where they are constructed, small-scale PV installations

may be placed on rooftops where they cause little or no interference with the primary use of the land for commercial or residential buildings. Thus, smaller scale or distributed solar technologies may have less of an impact on land use and habitat loss than large-scale, central station plants. Land-use concerns may also be addressed by deploying renewable energy systems on previously developed sites, rather than in undeveloped areas.

Water is a scarce resource in large portions. Recent global circulation model projections suggest that, if climate change proceeds as expected, under current business-as-usual scenarios, freshwater supplies will become even scarcer in some parts of the world. Electricity production using thermoelectric technologies requires vast amounts of water, primarily for cooling. In is about 43 percent of existing thermoelectric generating capacity uses once-through cooling, 42 percent uses re-circulating wet towers, 14 percent uses re-circulating cooling ponds, and 1 percent uses dry cooling. Water use by power plants is characterized by withdrawals and consumption. Although consumption is sometimes emphasized over withdrawals, the latter is important, because power plant operation may be constrained by the amount of water available for withdrawal and power plant uses may compete with other demands for water. Furthermore, water returns can be significant sources of thermal pollution and may include discharges of chemical pollutants, such as chlorine or other biocides used in cooling towers.

## ENVIRONMENT IMPACTS OF DIFFERENT RENEWABLE ENERGY SOURCES

All energy sources have some impact on our environment. Fossil fuels—coal, oil, and natural gas—do substantially more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions. However, renewable sources such as wind, solar, geothermal, biomass, and hydropower *also* have environmental impacts, some of which are significant. The exact type and intensity of environmental impacts varies depending on the specific technology used, the geographic location, and a number of other factors. By understanding the current and potential environmental issues associated with each renewable energy source, we can takes steps to effectively avoid or minimize these impacts as they become a larger portion of our electric supply.

### Environmental impacts of wind energy

***Land use***

The land use impact of wind power facilities varies substantially depending on the site: wind turbines placed in flat areas typically use more land than those located in hilly areas. However, wind turbines do not occupy all of this land; they must be spaced approximately 5 to 10 rotor diameters apart (a rotor diameter is the diameter of the wind turbine blades). Thus, the turbines themselves and the surrounding infrastructure (including roads and transmission lines) occupy a small portion of the total area of a wind facility. Offshore wind facilities, require larger amounts of space because the turbines and blades are bigger than their land-based counterparts.

### *Wildlife and habitat*

The impact of wind turbines on wildlife, most notably on birds and bats, has been widely document and studied. A recent survey founded evidence of bird and bat deaths from collisions with wind turbines and due to changes in air pressure caused by the spinning turbines, as well as from habitat disruption. Offshore wind turbines can have similar impacts on marine birds, but as with onshore wind turbines, the bird deaths associated with offshore wind are minimal. Wind farms located offshore will also impact fish and other marine wildlife.

### *Public health and community*

Sound and visual impact are the two main public health and community concerns associated with operating wind turbines. Most of the sound generated by wind turbines is aerodynamic, caused by the movement of turbine blades through the air. There is also mechanical sound generated by the turbine itself. Overall sound levels depend on turbine design and wind speed. Some people living close to wind facilities have complained about sound and vibration issues. Under certain lighting conditions, wind turbines can create an effect known as shadow flicker. This annoyance can be minimized with careful siting, planting trees or installing window sunshades, or curtailing wind turbine operations when certain lighting conditions exist.

### *Water use*

There is no water impact associated with the operation of wind turbines. As in all manufacturing processes, some water is used to manufacture steel and cement for wind turbines.

### *Life-cycle global warming emissions*

While there are no global warming emissions associated with operating wind turbines, there are emissions associated with other stages of a wind turbine‘s life-cycle, including materials production, materials transportation, on-site construction and assembly, operation and maintenance, and decommissioning and dismantlement. Estimates of total global warming emissions depend on a number of factors, including wind speed, percent of time the wind is blowing, and the material composition of the wind turbine.

## Environmental impacts of solar energy systems

### *Land use*

Depending on their location, larger utility-scale solar facilities can raise concerns about land degradation and habitat loss. Total land area requirements vary depending on the technology, the topography of the site, and the intensity of the solar resource. Estimates for utility-scale PV systems range from 3.5 to 10 acres per megawatt, while estimates for concentrated solar power (CSP) facilities are between 4 and 16.5 acres per megawatt. Smaller scale solar PV arrays, which can be built on homes or commercial buildings, also have minimal land use impact.

### *Water use*

Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, some water is used to manufacture solar PV components. Concentrating solar thermal plants (CSP), like all thermal electric plants, require water for cooling. Water use depends on the plant design, plant location, and the type of cooling system. CSP plants that use wet-recirculation technology with cooling towers withdraw between 600 and 650 gallons of water per megawatt-hour of electricity produced. CSP plants with once-through cooling technology have higher levels of water withdrawal, but lower total water consumption (because water is not lost as steam). Dry-cooling technology can reduce water use at CSP plants by approximately 90 percent. However, the exchanges to these water savings are higher costsand lower efficiencies.

### *Hazardous materials*

The PV cell manufacturing process includes a number of hazardous materials, most of which are used to clean and purify the semiconductor surface. These chemicals, similar to those used in the general semiconductor industry, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, tri-chloroethane and acetone. The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of silicon wafer. Workers also face risks associated with inhaling silicon dust. Thus, PV manufactures must follow the rules to ensure that workers are not harmed by exposure to these chemicals and that manufacturing waste products are disposed of properly.

### *Life-cycle global warming emissions*

While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation,

maintenance, and decommissioning and dismantlement. Most estimates of life-cycle emissions for photovoltaic systems are between
0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour.

## Environmental impacts of geothermal energy systems

### *Water quality and use*

Geothermal power plants can have impacts on both water quality and consumption. Hot water pumped from underground reservoirs often contains high levels of sulfur, salt, and other minerals. Most geothermal facilities have closed-loop water systems, in which extracted water is pumped directly, back into the geothermal reservoir after it has been used for heat or electricityproduction. In such systems, the water is contained within steel well casings cemented to thesurrounding rock. Water is also used by geothermal plants for cooling and re-injection.Depending on the cooling technology used, geothermal plants can require between 1,700 and4,000 gallons of water per megawatt-hour. However, most geothermal plants can use either geothermal fluid or freshwater for cooling; the use of geothermal fluids rather than freshwater clearly reduces the plants overall water impact.

### *Air emissions*

The distinction between open- and closed-loop systems is important with respect to air emissions. In closed-loop systems, gases removed from the well are not exposed to the atmosphere and are injected back into the ground after giving up their heat, so air emissions are minimal. In contrast, open-loop systems emit hydrogen sulfide, carbon dioxide, ammonia, methane, and boron. Hydrogen sulfide, which has a distinctive ―rotten egg‖ smell, is the most common emission. Once in the atmosphere, hydrogen sulfide changes into sulfur dioxide ($SO_2$). This contributes to the formation of small acidic particulates that can be absorbed by the bloodstream and cause heart and lung disease. Sulfur dioxide also causes acid rain, which damages crops, forests, and soils, and acidifies lakes and streams. However, $SO_2$ emissions from geothermal plants are approximately 30 times lower per megawatt-hour than from coal plants.

Some geothermal plants also produce small amounts of mercury emissions, which must be mitigated using mercury filter technology. Scrubbers can reduce air emissions, but they produce a watery sludge composed of the captured materials, including sulfur, vanadium, silica

compounds, chlorides, arsenic, mercury, nickel, and other heavy metals. This toxic sludge often must be disposed of at hazardous waste sites.

### *Land use*

The amount of land required by a geothermal plant varies depending on the properties of the resource reservoir, the amount of power capacity, the type of energy conversion system, the type of cooling system, the arrangement of wells and piping systems, and the substation and auxiliary building needs. The Geysers, the largest geothermal plant in the world, has a capacity of approximately 1,517 megawatts and the area of the plant is approximately 78 square kilometers, which translates to approximately 13 acres per megawatt. Like the Geysers, many geothermal sites are located in remote and sensitive ecological areas, so project developers must take this into account in their planning processes.

### *Life-cycle global warming emissions*

In open-loop geothermal systems, approximately 10 percent of the air emissions are carbon dioxide and a smaller amount of emissions are methane, a more potent global warming gas. Estimates of global warming emissions for open-loop systems are approximately 0.1 pounds of carbon dioxide equivalent per kilowatt-hour. In closed-loop systems, these gases are not released into the atmosphere, but there are a still some emissions associated with plant construction and surrounding infrastructure. Enhanced geothermal systems, which require energy to drill and pump water into hot rock reservoirs, have life-cycle global warming emission of approximately 0.2 pounds of carbon dioxide equivalent per kilowatt-hour. To put this into context, estimates of life-cycle global warming emissions for natural gas generated electricity are between 0.6 and 2 pounds of carbon dioxide equivalent per kilowatt-hour and estimates for coal-generated electricity are 1.4 and 3.6 pounds of carbon dioxide equivalent per kilowatt-hour.

## Environmental impacts of hydroelectric energy systems

### *Land use*

The size of the reservoir created by a hydroelectric project can vary widely, depending largely on the size of the hydroelectric generators and the topography of the land. Hydroelectric plants in flat areas tend to require much more land than those in hilly areas or canyons where deeper reservoirs can hold more volume of water in a smaller space. Flooding land for a hydroelectric reservoir has an extreme environmental impact: it destroys forest, wildlife habitat, agricultural land, and scenic lands.

### *Wildlife impacts*

Dammed reservoirs are used for multiple purposes, such as agricultural irrigation, flood control, and recreation, so not all wildlife impacts associated with dams can be directly attributed to hydroelectric power. However, hydroelectric facilities can still have a major impact on aquatic ecosystems. For example, though there are a variety of methods to minimize the impact including fish ladders and in-take screens), fish and other organisms can be injured and killed by turbine blades. Apart from direct contact, there can also be wildlife impacts both within the dammed reservoirs and downstream from the facility. Reservoir water is usually more stagnant than normal river water. As a result, the reservoir will have higher than normal amounts of sediments and nutrients, which can cultivate an excess of algae and other aquatic weeds. These weeds can crowd out other river animal and plant-life, and they must be controlled through manual harvesting or by introducing fish that eat these plants. In addition, water is lost through evaporation in dammed reservoirs at a much higher rate than in flowing rivers.

### *Life-cycle global warming emissions*

Global warming emissions are produced during the installation and dismantling of hydroelectric power plants, but recent research suggests that emissions during a facility‘s operation can also be significant. Such emissions vary greatly depending on the size of the reservoir and the nature of the land that was flooded by the reservoir. Small run-of-the-river plants emit between 0.01 and 0.03 pounds of carbon dioxide equivalent per kilowatt-hour. Life- cycle emissions from large-scale hydroelectric plants built in semi-arid regions are also modest: approximately 0.06 pounds of carbon dioxide equivalent per kilowatt-hour. However, estimates for life-cycle global warming emissions from hydroelectric plants built in tropical areas are much higher. After the area is flooded, the vegetation and soil in these areas decomposes and releases both carbon dioxide and methane. The exact amount of emissions depends greatly on site-specific characteristics. However, current estimates suggest that life-cycle emissions can be over 0.5 pounds of carbon dioxide equivalent per kilowatt-hour.

## Environmental IMPACTS of Biomass energy systems

### *Deforestation and land degradation*

Biomass comprising traditional fuels constitutes about 50% of energy consumption in developing countries. Deforestation leading to soil erosion, risks of floods, desertification on account of clearing of forests and woodlands for agriculture and livestock, and so on, are the common concerns of environmentalists at macro levels. At a micro level, the concerns range from non-suitability of forest soils for agricultural purposes, health problems due to smoke

caused by burning of fuel-wood, loss in soil fertility due to use of agricultural residues and so on. Even a shift towards non-wood biomass fuels creates direct competition with animals that rely upon crop remains and the plants for food. Imbalance between the demand and production of fuel-wood is reported to be one of the primary factors responsible for forest depletion. The increasing use of fuel-wood for meeting the domestic and industrial needs of both rural and urban areas has contributed to forest decline. The environmental impacts of urban fuel-wood consumption have been severe due to commercial exploitation of fuel-wood for charcoal production. The demand for charcoal in urban areas has spread deforestation, which begins atthe surrounding areas of urban centres and moving outwards.

### *Loss of soil nutrients*

Agricultural residues constitute an important source of energy in rural areas of developing countries when left on fields improves the fertility of the soil. The use of agricultural residues for energy would thus be an issue if it reduces the fertility of the soil. It is important to note that all residues do not have the same effect on the soil. Some residues such as corncobs, rice husk, jute sticks, cotton stock, coffee pruning, and coconut shells do not decompose easily and have potential as energy sources. The choice of agricultural residues thus has an impact on the environment. Cattle dung, similarly, though it is a fertilizer, loses its value as fertilizer if burnt or left under the sun for a few days. The two categories of residues from agriculture sector are crop residue and cattle dung. Currently crop residue of cereals is largely used as food and woody residues are used as fuel. Burning of woody crop residue may not lead to any significant loss of nutrients to soil. Burning of cattle dung as fuel leads to loss of organic matter and other nutrients affecting crop production.

## Environmental impacts of tidal energy systems

### *Understanding environmental impacts*

In spite of the many benefits of exploiting tidal power, there are negative impacts, aswell. For example, the risk to the marine environment and marine mammals is largely unknown.In order to operate tidal power stations appropriately and analyze the potential contribution tidalpower can make in terms of renewable energy, we must better understand the environmentalimpacts of this technology. One important mention is the difference between environmentaleffects and environmental impacts. On one hand, environmental effects refer to the wide range of potential interactions between tidal energy equipment and the marine ecosystems. On theother hand, environmental impacts are those particular effects that we know for sure will cause deleterious ecological alterations.

### *Environmental impacts of Tidal energy*

In many ways, the environmental impacts of harnessing tidal power are similar to thoseof offshore wind power generation. Several assessments over the past few years have identified the following potential environmental impacts. These indirect ecological impacts would result from lengthy installation of offshore renewable energy projects.

- Changing of substrates, sediment transit and deposition;
- Alteration of waves and sea currents;
- Noise pollution during installation and operation;
- Alteration of ecosystems for regional organisms;

- Emission of harmful electromagnetic fields;
- Intrusion upon animal migrations; and
- Potential strikes by any moving parts of the tidal system.

### Environmental impacts of Hydrogen-based energy systems

There is increasing interest in the role that hydrogen-based energy systems may play in the future, especially in the transport sector. They appear to be an attractive alternative to current fossil fuel-based energy systems in the future, since these have been proven to affect climate due to greenhouse gasses emissions. However, any future hydrogen-based economy would need to assess the possible global environmental impacts of such alternative energy production. Emissions of hydrogen lead to increased burdens of methane and ozone and hence to an increase in global warming. Therefore, hydrogen can be considered as an indirect greenhouse gas withthe potential to increase global warming. The scientists have estimated that the potential effects on climate from hydrogen-based energy systems would be much lower than those from fossil fuel-based energy systems. However, such impacts will depend on the rate of hydrogen leakage during its synthesis, storage and use. The researchers have calculated that a global hydrogen economy with a leakage rate of 1% of the produced hydrogen would produce a climate impact of 0.6% of the fossil fuel system it replaces. If the leakage rate was 10%, then the climate impact would be 6% of that of the fossil fuel system.

## Environmental Impacts of Hydrokinetic Energy systems

Hydrokinetic energy, which includes wave and tidal power, encompasses an array of energy technologies, many of which are still in the experimental stages or in the early stages of deployment. While actual impacts of large-scale operations have not been observed, a range of potential impacts can be projected. For example, wave energy installations can require large expanses of ocean space, which could compete with other uses—such as fishing and shipping— and cause damage to marine life and habitats. Some tidal energy technologies are located at the mouths of ecologically-sensitive estuary systems, which could cause changes in hydrology and salinity that negatively impact animal and plant life.

## Greenhouse gas emissions (GHG)

Compared to fossil-fuel-based electricity generation, renewable energy technologies offer a major advantage in lower emissions of $CO_2$ and other GHGs. In addition, all forms of renewable electricity production are expected to have significantly lower life cycle GHG emissions than electricity production from conventional coal and natural gas plants. Renewable energy would have less of an advantage if carbon capture and sequestration were included with fossil-fuel power plants, or if energy storage systems, such as battery energy storage, compressed air energy storage, or pumped hydro storage, were included as part of renewable energy systems. GHG emissions for some renewable technologies are difficult to estimate. For example, emissions from bio-power vary, depending on which feedstock is used and the assumptions about their production. Most $CO_2$ emission ($CO_2e$) values for bio-power range from 15 to 52 g $CO_2e$/kWh for biomass derived from cultivated feed-stocks, excluding emissions associated with initial land conversion. If carbon capture and storage were added to bio-power systems, there would also be large reductions in $CO_2e$ values.

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