CHAPTER 1

INTRODUCTION

1.1 GENERATION AND DEPLOYMENT OF POWER

The thirst for energy has been continuously increasing globally due to population explosion, industrial growth and urbanization (Sinha & Chandel 2014). The economic development of a nation is more intimately related to its industrial growth which is the major consumers of energy. The utilization of energy has increased by around 1% in the developed countries and around 5% in the developing countries. The global annual energy consumption is projected as 16.9 TW, and a doubling of this production needs to be planned to meet the energy requirements in the next 40 years (Rezzouk & Mellit 2015). Indu R. Pillai & Rangan (2009) of the total energy requirement, 80% is generated from the firing of fossil fuel. Thus fossil fuels are the chief sources for the power generation. Unfortunately, fossil fuels may get depleted within the next six decades (Ashourian et al. 2013). Grimmer picture is painted by the review of Taghvae et al. (2013) who estimates the exhaustion of oil fuels by the year 2040, coal by 2030 and natural gas by 2060.

Besides, Rezzouk & Mellit (2015) reports that burning of fossil fuels to result in the emission of harmful pollutants, oxides and hydrocarbons into the atmosphere, which causes severe damage to the health. Emission of Carbon Di-oxide (CO₂) results in greenhouse effect, which leads to global warming. Global warming is estimated to increase the temperature of earth surface by 3°C to 6°C within the end of this century. In India, the power
generation is dependent on coal; hence, the emission of CO$_2$ is anticipated to increase in future. The CO$_2$ emission from power generation sector is liable for 38% of the total CO$_2$ emission in India, which shares 4% of total global CO$_2$ emission. However, the good news is that India and China have agreed to reduce the greenhouse emission to 20%-25% by 2020. The greenhouse emission is a major threat to the ecological sustainability that motivates the government agencies, researchers and policies to work towards achieving a solution to produce clean energy at affordable price.

Presently, renewable energy power generation contributes only 17% of the total global energy mix because of the huge difference in cost of generation of energy from renewable energy sources and conventional energy sources. Ashourian, et al. (2013) concludes from their evaluation of the situation that 50% of the global energy need will be harnessed from the renewable energy sources by 2050.

1.2 ENERGY SCENARIO IN INDIA

India holds a third position in energy consumption in the world with a consumption of 5% (Gabrial Anandarajah & Ajay Gambhir 2014). Owing to the fast industrial and economic growth, the power demand has been consistently increasing at the rate of 3.6% per year. The higher rate of consumption of energy is also attributed to India’s population as India is the second most populated country in the world, about 15% of the world population resides in India and it will reach 8 billion by 2025.

According to the prediction of the International Energy Agency (IEA), India will need to generate around 600 to 1200 Giga Watt (GW) extra power before 2050. The expected energy demand has been estimated to be 1392 Terra Watt hour (TWh) with a peak demand of around 218 Giga Watt hour (GWh) in 2016-17, and 1915 TWh with a peak demand of 298 GWh in
2021-22. The growth of population forces demands for food, shelter, clothes, power consumption, etc.

Table 1.1 Power Generation status in India

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Installed Capacity in MW</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>164,635.88</td>
<td>61.51</td>
</tr>
<tr>
<td>Hydro</td>
<td>41,267.43</td>
<td>15.42</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5,780.00</td>
<td>2.16</td>
</tr>
<tr>
<td>Renewable</td>
<td>31,692.14</td>
<td>11.84</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>23,062.15</td>
<td>8.61</td>
</tr>
<tr>
<td>Oil</td>
<td>1,199.75</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Total Power</strong></td>
<td><strong>267,637.35</strong></td>
<td></td>
</tr>
</tbody>
</table>

(Source:https://en.wikipedia.org/wiki/Energy_policy_of_India#Power_Generation_capacity_in_India)

The technological growth in industries will promise the above requirements in accelerated speed. But all industries should be served by its basic and foremost requirement, the electricity to achieve their target and to meet out the requirement. In India, The Central Ministry of Power is accountable for the progress in the power generation. Roughly, the total power generation from various power generation systems is figured out as 267,637.35 Mega Watt (MW) as listed in Table1.1 and illustrated by bar chart in Figure 1.1.

Maximum power is generated through thermal power stations which contribute 61.51% of the energy source. In the global scenario, India holds the fourth position in the production of coal and lignite. The CO₂ emission from thermal power plant is 0.869 Kg/kWh.
The contribution of hydro power generation system is 15.42%; on the contrary, the nuclear power generation is only 2.16%. The renewable power generation is accounted for 11.84%. For sustainable growth of the ecosystem, access to electricity is the key factor.

**Table 1.2 Sector wise CO₂ Emission**

<table>
<thead>
<tr>
<th>S. No</th>
<th>Sector Name</th>
<th>CO₂ emission %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electricity and Heat Production</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Transport</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>Industry</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>Commercial &amp; Residential</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Agriculture &amp; Forest</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Other Energy</td>
<td>10</td>
</tr>
</tbody>
</table>

(Source: http://www3.epa.gov/climatechange/ghgemissions/global.html)

The sector wise emission of CO₂ is noted in Table 1.2. From the data, it is evident that the major sources of emission of CO₂ from the use of conventional fuels such as coal for thermal power generation and diesel and petrol for transport.
On the other hand, diesel generator contributes to substantial amount of CO$_2$ emission in commercial and residential buildings, industries and agricultural fields. The rapid economic development and technology has resulted in increase in domestic requirements for energy leading to the ambitious increase in the power generation capacity of India.

The Energy handbook of India 2011 forecasted the demand supply status of India up to XII plan as plotted in Figure 1.2. Use of renewable energy sources (RES) can be envisioned as a viable solution to counteract the effects of CO$_2$ emission.

### 1.3 SIGNIFICANCE OF RENEWABLE ENERGY POWER GENERATION

India has the fourth largest economy and third biggest energy consumer in the world. Within the next few decades, the consumption of energy and the emission of CO$_2$ are expected to drastically increase due to population increase and industrial growth. Based on Copenhagen Accord,
India has to reduce the Green House Gas (GHG) emissions by 20%-25% by the year 2020 from that of 2005 GHG emission level.

As far as Tamil Nadu is concerned, thermal power generation is the major power generation system and uses large amount of coal as fuel, resulting in it being the 14th largest CO$_2$ emitting state in the world (Kumar & Manoharan 2014).

Added to this is the encumbrance arising from the economic and social uplift of the rural community which enhances the life style, but at the same time the increased demand for electricity for these areas becomes inevitable. However, supplying power to remote areas is not viable through grid extension, hence alternate energy sources will have to be used. Generation of power from renewable energy sources will support this proposal.

Renewable power generation have the following characteristics: clean energy, reduced dependence on conventional energy sources, unlimited, eco-friendly, cost-free fuel suppliers and decreased CO$_2$ emission. Several nations have come forward to use renewable energy sources to meet their energy demands and bring down the greenhouse gas emissions and their effects. Further progress in technology, government subsidies and fall in market price are other factors that could contribute to the competitive growth of wind and solar power generation (Nagamani et al. 2015).

1.4 RENEWABLE ENERGY POWER GENERATION IN INDIA

The generation of renewable power in India from various renewable energy sources are specified in Table 1.3 and depicted in Figure 1.3. Among all the renewable energy sources, wind energy has the mammoth share (7349.4MW) in the amount of energy produced, followed by it is the
solar energy (109.26 MW). India holds the pride as the first country for setting a separate Ministry for the Renewable energy sources in the year 1980 itself.

Table 1.3 Renewable Power Generation status in India as on 30.09.2014

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Installed Capacity in GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind power</td>
<td>22.00</td>
</tr>
<tr>
<td>Bagasse Cogeneration</td>
<td>2.69</td>
</tr>
<tr>
<td>Biomass Power</td>
<td>2.09</td>
</tr>
<tr>
<td>Solar Power</td>
<td>2.97</td>
</tr>
<tr>
<td>Small Hydro</td>
<td>3.87</td>
</tr>
<tr>
<td>Waste to power</td>
<td>0.24</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33.86</strong></td>
</tr>
</tbody>
</table>

(Source: Chilakapati Nagamani et al. 2015)

Though wind and solar energy are eco-friendly and naturally accessible, the wind energy speed changes more randomly than solar energy (Khare et al. 2013).

Figure 1.3 Renewable Power Generation status in India as on 30.9.2014
According to the analysis of Shrimali and Tirumalachetty (2013), the Government of India has planned for the generation of 20GW Photovoltaic (PV) power by the year 2022. The Ministry of New Renewable energy sources has planned to generate 15% of power requirement of India through renewable energy sources by 2020.

Deployment of renewable energy sources provides the following advantages:

i. Bridging the demand-supply gap without greenhouse effects

ii. Deployment of large unused potential of energy sources

iii. Affording a feasible method for the electrification of remote communities

iv. Uplifting the energy security of the nation

1.5 TYPES OF RENEWABLE ENERGY SOURCES

The various types of renewable energy sources available are charted by Mehmet Bilgili et al. (2015) as in Figure 1.4. India is also blessed with surplus of natural resources such as wind, solar, tidal, geothermal, etc. to supply power for both rural and urban needs.

Though there are many types of renewable energy sources available, the type of source selection depends on the location, accessibility, availability, etc. Among all the energy sources, PV power generation is the most suitable, as power generation of few KW to several MW can be performed by series and parallel connection of solar panels that can be tuned according to the voltage and current requirements. Most regions in the Indian subcontinent are blessed with daily global radiation of 4-7 kWh/m2/day.
1.5.1 Solar Energy

The Direct Normal Irradiance (DNI) of solar energy for a country depends on the geographical location of the country, revolution of earth around sun, tilting angle of rotational axis of the earth, attenuation caused by the suspended particles in the environment.

India receives five trillion MWh solar energy annually and the annual sunshine hours vary between 2300 and 3200 hours. The average clear sunshine day for a year ranges between 250 and 300 days. Theoretical calculations reveal that a total land area of 3000 km$^2$ of PV power generation unit is sufficient to meet the energy needs of India (Kapoor et al. 2014).

1.6 RURAL HOME ENERGY SUPPLY

The International Energy Agency estimates that nearly 1.4 billion people around the world will be denied to access power grid and it will be around 1 billion by 2030 (Tao Ma et al. 2015). Majority of these people reside
in inaccessible areas that could not be accessed by the grid supply. Further, geographic, technical and monetary constraints restrict the extension of the grid supply to these areas.

The growth of a nation is measured by the growth of the rural areas in the nation. For the socio-economic growth of rural people, electricity is highly essential for the lighting their residences, schools, health centers and other public buildings. In India about 18000 villages are yet to be electrified. Further, in some electrified regions also, uncertain condition exists for the stable supply of energy (Nitin Agarwal et al. 2013). According to Nagamani et al. (2015), among the 85% electrified villages in India, the supply will be provided to them only on the basis of the availability of power, though the quality of power is poor and supply irregular.

1.6.1 Diesel Generator

Diesel generators were used for electrification of arid regions. Although the initial investment for diesel generators is less, the running cost of diesel generators to generate power have been found to be exorbitantly high as it involves cost of fuel, fuel transportation and maintenance. In addition, running of diesel generator produces emission of CO$_2$ thus pollutes the atmosphere which in turn increases carbon footprint. The burning of 2 liters of diesel per hour causes an emission of 2.63 kg of CO$_2$ in a 10-15 KVA generator (Sekar & Duraisamy 2013).

Also, incomplete burning of the oil occurs if the load value lies between 40% and 50% resulting in carbon build up, and making the system inefficient. This will increase the maintenance cost of the diesel generator system as stated by Rezzouk & Mellit 2015. The relationship between the load ratio and specific fuel consumption is plotted in Figure 1.5. From the Figure 1.5, it can be shown that for the low values of load ratio, the fuel
consumption is high. The generator operating duration could not be more than 30 minutes when it is operated at full load.

![Graph of Specific fuel consumption against load ratio of Diesel Generator](image)

(Source: Henerica Tazvinga & Tawanda Hove 2010)

**Figure 1.5 Specific fuel consumption against load ratio of Diesel Generator**

Diesel generators can be incorporated with battery and bidirectional converters. The bidirectional converter charges the battery when the generator is operated at loads less than the peak load which in turn increases the efficiency of the diesel generator and avoids the premature failure of the generator. If battery is not integrated with the diesel generator, to protect the diesel generator a dump load can be used to dissipate the excess energy when the load demand is low.

The problems discussed above institutionalize a path way of interest in everyone towards the renewable energy sources viz., solar, wind, tidal, geothermal, etc., for power generations in the past few decades for rural electrification.
1.6.2 PV Power Generation

Renewable energy sources are the excellent substitute for fossil fuels in alleviating the harmful environments effects and balancing the depletion of fossil fuel. The earth’s wind energy potential was found to be five times the total global energy requirement. Likewise, the solar energy received by the earth is 6000 times the present energy requirement of the universe (Rezzouk & Mellit 2015).

Most districts of Tamil Nadu get adequate solar radiation for power generation. But the wind velocity is insufficient for power generation in Erode, Namakkal, Salem and Karur districts. Hence PV power generation systems can be used as an eco friendly power generation system. As per the review of Chetan Singh Solanki (2011) PV power generation may be any one of the following type:

- Stand alone PV System (not connected to grid)
- Grid-connected PV System (connected to grid)
- Hybrid PV System (contains additional source other than PV)

The Standalone PV Power System has the following subdivisions:

- Unregulated Standalone System with DC load
- Regulated Standalone System with DC load
- Regulated Standalone System with Battery and DC load
- Regulated Standalone System with Battery, DC load and AC load
- Regulated Hybrid System with AC and DC load
1.6.2.1 Unregulated Standalone System with DC load

Figure 1.6 Block diagram of Unregulated Standalone System with DC load

The PV panels are directly connected to load. The voltage and current of PV panel varies based on sunshine condition and load characteristics. Since there is no energy storage, night time load operation is not possible. Unregulated stand alone PV systems as in Figure 1.6 are suitable for purely DC loads, DC fan or DC pump.

1.6.2.2 Regulated Standalone System with DC Load

It is similar to unregulated PV system. A power electronic interface block (voltage/current regulator or MPPT circuit) is inserted between PV panel and load as illustrated in Figure 1.7 to improve the performance of the solar PV system. This configuration is suitable for DC fan.

Figure 1.7 Block diagram of Regulated Standalone System with DC load
1.6.2.3 Regulated Standalone System with Battery and DC Load

This type of configuration in Figure 1.8 is suitable for the night time operation of the load such as lighting applications because of the usage of storage batteries to store energy for night time operation.

![Block diagram of Regulated Standalone System with Battery and DC load](image)

Figure 1.8 Block diagram of Regulated Standalone System with Battery and DC load

A charge controller is necessary to prevent the overcharging and deep discharging of the batteries. The optimization of PV source utilization can be carried out by MPPT circuit. The electronic controller circuit incorporates both charge controller and MPPT circuit. This configuration is suitable for running DC fan, lightning and other DC appliances.

1.6.2.4 Regulated Standalone System with Battery, AC and DC load

![Block diagram of Regulated Standalone System with Battery, AC and DC load](image)

Figure 1.9 Block diagram of Regulated Standalone System with Battery, AC and DC load
In this configuration Figure 1.9 an AC load is also connected to the system. The DC power supplied by PV source and battery will be converted into AC by a DC to AC converter. This configuration is suitable for domestic and commercial applications.

1.6.2.5 Regulated Hybrid System with AC and DC load

In addition to PV sources, auxiliary sources such as diesel generator, wind or biomass can be used to increase the reliability and to make the system economical. In hybrid system configurations, a diesel generator is a good option for non sunshine hours. This configuration of Figure 1.10 is suitable for all type of loads.

![Block diagram of Regulated Hybrid System with AC and DC load](image)

The major problem with standalone PV power generation system is the uncertainty in the output voltage generated by the system. The variation of solar radiation and the variation in the surrounding temperature vary the output of the PV system. Further during night time we cannot get the PV power due to the absence of solar radiation. In order to provide reliable output large storage devices must be incorporated with the PV power generation system to meet the load requirements all over the day.
To get rid of the above problems formation hybrid power generation systems by integrating conventional energy sources with non-conventional energy sources offers a fruitful solution for the supply of power to isolated communities where the grid extension is not viable.

1.7 TYPES OF HYBRID POWER GENERATION SYSTEM

The selection of the sources for the hybrid power generation for a particular location is decided by the load demand of the consumer, geographical location of the site, energy requirement variation according to seasonal variations, availability of the energy source based on seasonal variation, storage device cost and cost of distribution. The types of hybrid power generation systems are listed below based on the sources combined and storage system usage (Khelif, et al. 2012).

- PV-Diesel
- PV- Battery- Diesel
- PV-Wind-Battery
- PV-Wind-Diesel
- PV-Wind-Battery-Diesel
- PV-Wind
- PV-Wind-Diesel-Micro hydro electric turbine
- PV-Wind-Fuel cell
1.8 BENEFITS OF HYBRID POWER GENERATION SYSTEM

- Less noise and CO₂ emission from hybrid system reduces the environmental effects.
- No fuel cost as solar energy is free and abundant.
- Reduced spend on purchase of spare parts as the running time of diesel generator is limited resulting in reduced wear and tear.
- Sustainable energy supply
- Effective usage of fallow lands for PV plant erection
- Easy extension of PV system based on increase in load requirement
- Optimizing the size of PV panel, battery and generator supports to get the required output.
- Continuous supply of power to consumers.
- Less maintenance requirements compared to standalone diesel generator power systems (Suresh Kumar & Manoharan 2014).

1.9 COMPONENTS OF HYBRID POWER GENERATION SYSTEM

A PV diesel hybrid power generation system has been known to provide an optimum solution for the rural home energy management. The various components of the system are illustrated in Figure 1.11. Some of them are enumerated below:

- PV array
- DC-DC converter with Maximum Power Point Tracking (MPPT) control
- Battery
- Bidirectional converter
- Diesel generator

(Source: A.Kelif et al. 2012)

**Figure 1.11** Block diagram of Hybrid PV-Diesel Power Generation System with Battery storage

The hybrid system realized by the integration of renewable energy source, diesel generator, batteries and inverters have been found to afford continuous supply of AC current to schools, clinics, resorts, national parks, research centers for wild animals, farms and residential buildings in rural and remote areas. The hybrid system helps to reduce the energy consumption ratings of generator and battery.

### 1.10 PROBLEM STATEMENT

Design of PV/diesel/battery hybrid system with fuzzy logic control energy management for electrification of remote areas in India incorporating appropriate converter with optimal MPPT technique and inverter with suitable PWM technique along with battery storage.
1.11 OBJECTIVE OF THE THESIS

To investigate the global future energy need and the challenges for power generation using fossil fuels.

To understand the basics of existing renewable energy sources, DC-DC converter topologies, Maximum Power point Tracking (MPPT) techniques, Pulse Width Modulation (PWM) techniques for H-bridge inverter control.

To simulate, analyze and validate the performance of boost converter, interleaved boost converter (IBC), IBC with MPPT technique, Perturb and Observe (P&O), Fuzzy, P&O Fuzzy MPPT techniques, H-bridge inverter with unipolar and bipolar PWM techniques.

To develop a simulation model of standalone PV-Diesel hybrid power generation system and study the energy management system. The concept of management of energy is based on load variation using fuzzy logic control that studies the harvesting of solar energy for power generation and minimization of the operating time of diesel generator. Thus the reduced burning of fossil fuel (diesel) causes lesser emission of CO₂ thereby reducing environmental pollution.

1.12 ORGANIZATION OF THE THESIS

This thesis is organized into seven chapters covering the complete research work as represented in Figure 1.12.
Figure 1.12 Organizational Flow Chart

Chapter 1 includes an introduction about the power generation and deployment, power generation status of India, CO$_2$ emission from various power generating systems, significance of renewable power generation, renewable power generation status in India, types of renewable energy
sources, problems in rural electrification, need for hybrid power generation, advantages of hybrid system, components of hybrid power generation systems, problem statement and objectives of the thesis.

Chapter 2 presents the literature survey on the PV diesel hybrid system design and energy management, PV panel performance comparison, DC-DC converters, H-bridge inverters and MPPT techniques for PV systems.

Chapter 3 provides the country wise PV power generation, worldwide PV power generation, PV cell operating principle and characteristics, types of PV panels, comparison of PV panels I-V characteristics, and analyzing I-V and P-V characteristics of the PV cell using solar simulator under varying illumination and temperature.

Chapter 4 discusses the types of DC-DC converters and analyses the boost converter performance and IBC performance using Matrix Laboratory (MATLAB) simulation and hardware implementation. It also deals with the need for MPPT, conventional and non-conventional MPPT techniques, simulation and comparison of P&O, and Fuzzy and P&O Fuzzy MPPT techniques.

Chapter 5 presents the analysis of the performance of H-bridge inverter which was implemented using unipolar and bipolar PWM techniques. The observations on MATLAB simulation used hardware implementation are discussed. The results of Hex-bridge inverter simulation have been presented for 3-phase system.

Chapter 6 deals with the load estimation, design, cost comparison, simulation and energy management of the single phase PV-Diesel Hybrid system with battery storage using Fuzzy Logic Control (FLC). The simulation results of three-phase system have been discussed.
Chapter 7 summarizes the significant research findings and draws a conclusion based on the results. The scope of the future investigations that could guide other researchers has been elaborated.

1.12 SUMMARY

In this chapter an introduction about the power generation and deployment, power generation status of India, CO$_2$ emission issues, importance of renewable power generation, types of renewable energy sources, problems in rural electrification, need for hybrid power generation, advantages of hybrid system, components of hybrid power generation systems, objectives of the thesis and thesis organization were discussed.