Czech Technical University Prague

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Diploma Thesis

Utilization of Renewable Energy Sources in Microgrid

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DIPLOMA THESIS ASSIGNMENT

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Guidelines:

1. General review on renewable energy sources ?
2. Characterize basic RES type (principles, advantages, disadvantages ...)
3. Rules and standards for connection of RES to distribution network
4. A case study for selected type of RES (photovoltaic)

Bibliography/Sources:

[1] Nikos Hatziargyriou: More microgrids
[2] Energy world outlook 2016
[3] Distribution network code
[4] eVlivy application manual

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Valid until the end of the winter semester of academic year 2017/2018

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Prague, February 20, 2017

Declaration

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In Prague on___________________________

Acknowledgement

Foremost, my first thanks go to God for giving me the strength, Knowledge to finish my thesis work. Also, I would like to express my sincere gratitude to my supervisor Ing. Frantisek Vybiralik, CSc. for his guidance, motivation and proper fundamental technical knowledge support to make my thesis a success. I would like to thank doc. Ing. Jan Kyncl for his devoted advice and help during my whole study.

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Využití obnovitelných zdrojů energie v mikrosítích

Abstrakt

Využití solární energie je jednou z nejoblíbenějších technologií výroby energie mezi několika typy obnovitelných zdrojů energie. Dva obnovitelné zdroje energie, které jsou v současných mikrosítích využívány, jsou v této práci teoreticky diskutovány. Dále je názorně předveden dopad obnovitelných zdrojů energie na mikrosítě a struktura mikrosítí. Součástí této práce je rovněž komplexní simulační analýza distribuční soustavy středního (22 kV) a nízkého napětí (400 V) provedená pomocí softwaru eVlivy před a po připojení PVPPs do distribuční soustavy Středočeského kraje. Analýza zatížení soustavy a napěťový profil v každém uzlu distribuční soustavy středního a nízkého napětí jsou zobrazeny graficky.

Klíčová slova: Solární Energie, Obnovitelné zdroje Energie, Větrná energie, Mikrosítě, Profil napětí, Fotovoltaické Systémy, Větrná Turbína, Distribuční soustava vysokého a nízkého napětí, Ztráty energie, Vliv PVPP

Utilization of Renewable Energy Sources in Microgrid

Abstract

Solar Power utilization is the one of the most popular power production technology among the several types of renewable energy sources. There are two types of renewable energy sources like solar energy and wind energy utilization in Microgrid structure has been described theoretically. Impact of renewable energy sources on Microgrid and structure of Microgrid has been presented in detail. This master thesis presents a comprehensive simulation analysis of medium voltage distribution line 22kV and low voltage line (400 V) with the help simulation software eVlivy before and after connection of PVPPs into the distribution system in Central Bohemian Region. The load flow analysis and voltage profile at each node of medium and low voltage distribution system has been characterized graphically.

Keywords: Solar power, Renewable energy sources, Wind Energy generation, Microgrid, Voltage Profile, Photovoltaic system, Wind Turbine, Medium and Low distribution system, Power losses, Impact of PVPP

Table of Content

References

List of Abbreviation

IEA	International Energy Agency
RES	Renewable Energy Sources
PV	Photovoltaic
DC	Direct Current
AC	Alternating Current
MPPT	Maximum Power Point Tracking
GE	General Electric Company
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
WTG	Wind Turbine Generator
MG	Microgrid
MV	Medium Voltage
LV	Low Voltage
DG	Distributed Generation
CHP	Combined Heat and Pump
PCC	Point of Common Coupling
DOD	Department of Defense
DES	Distributed Energy Sources
PWM	Pulse Width Modulation
CERTS	Consortium for Electric Reliability Technology Solutions
IPP	Independent Power Producer
DA	Distribution Automation
PVPP	Photovoltaic Power Plant
OH	Overhead

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1. Introduction

Today Energy Production and supply is based on Fossil Fuel and Nuclear power plants which are non-sustainable and Nonrenewable. It has major disadvantages and environmental problem. Nuclear power is also based on limited source which having high risk of disposal process of uranium. Renewable energy sources utilization led the world to growth based on environmental and human life. [1]- [3]

Electricity Utilization will increase the demand of energy now and upcoming years. During recent year, alternative energy sources deployment has demand for energy production and utilization due to rapid increase of fossil fuel price and environment consequences of carbon emission. Carbon dioxide is responsible for Green House effect in Environment. Globally concerning things to reduce the carbon emission. Renewable energy Deployment and supporting technological Invention become the policies to reduce the carbon emission. Renewable energy sources having less possibility of risk and disaster, due to this advantage it become desirable as fuel compare to nuclear power plant. [4]- [6]

Many countries worldwide have planned to use renewable energy source for generation of power. Energy security, economic impact and carbon dioxide emission reduction become a primary motivator that support the renewable energy technology growth. IEA (International Energy Agency) indicates two global trends which support the application of renewable energy sources as medium level. [7] First, renewable electricity technology grows up, total supply of energy is increased from 1500GW in 2011 to 2200 GW in 2017. Second, recent year high fossil fuel use which led the renewable technology as competitive on cost basis. Based on IEA report, if financing, CO2emission level and fossil fuel price is going to increase then application of alternative energy sources is favorable.

1.1 Renewable Energy Scope and supplies

World's 18% final energy consumption use renewable energy by different supplies like Biomass, large hydro power and new renewable sources like (Modern

Biomass,Solar,Geothermal and biofuel). In some regions biomass become more efficient source about 13% represent growth. [7]

Most important Renewable energy sources like Biomass provides about 45 EJ and Nuclear power (26EJ) and Hydropower(28EJ) which supplied Current Global energy with much smaller contributions.

Utilization of renewable energy sources reduces the carbon emission, clean the air. These sources are important part of overall sustainable development. Renewable energy sources can help progress the competitiveness of productions over the long period and have a positive impact on regional development and employment. Renewable energies will provide a more diversified, balanced, and stable pool of energy sources. [6]

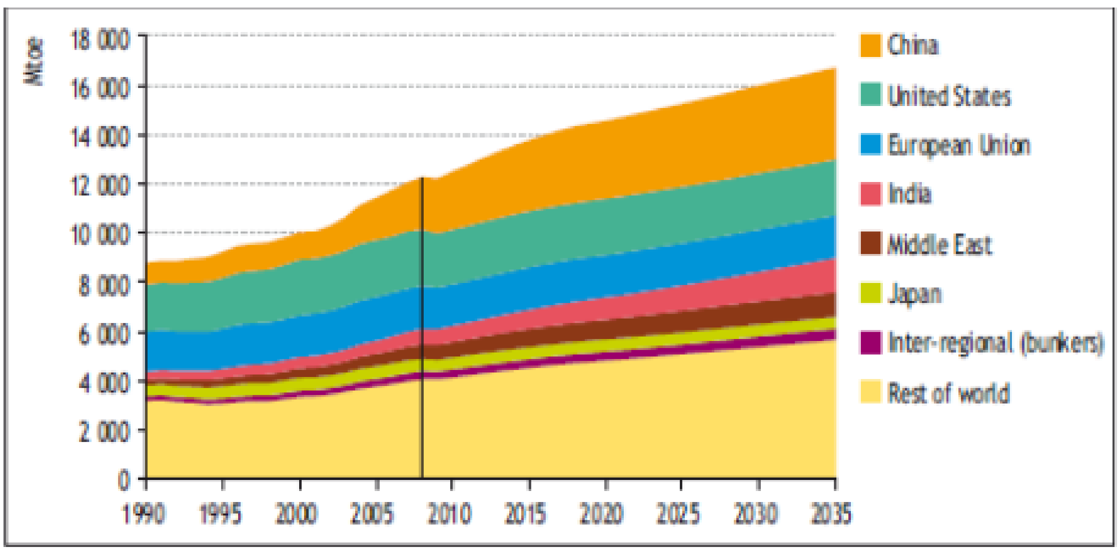

Figure 1: World energy demand scenario in the New Policies Source: Projection of EIA 2009[9]

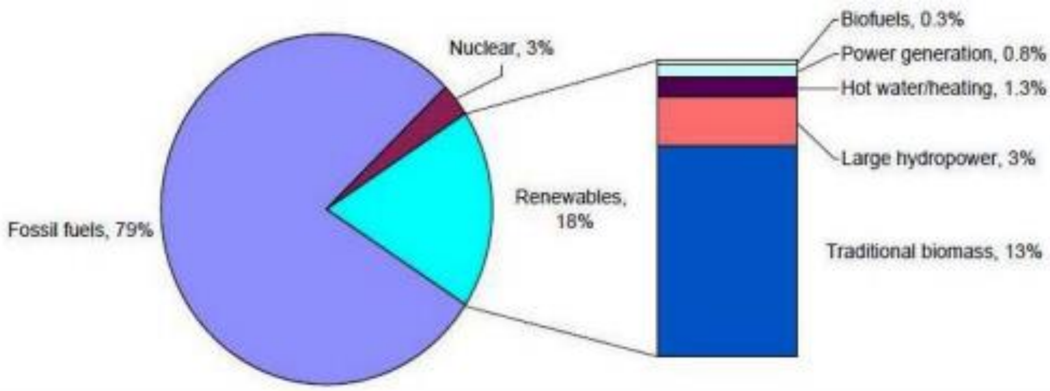

Figure 2: Different Energy Sources of Energy production [9]

Decentralize RES is associated with Multiple steps:

- Development policy in national, global context
- Improving the energy requirements
- Development research and education activities
- Improving the collaboration between public and private sectors

1.2 Energy Supply

Installation and Operation of small power generating technology with storage system and energy management defined as a distributed generation. It improves the delivery of electricity at the end user or near to consumer with connection to electric grid or without connection of electric grid.

Feed In tariff scheme of distributed power source have high efficiencies, low pollution and low maintenance. Modern Embedded System Can provides fast techniques with automation operation and renewable like Wind, Geothermal, Solar. It shows profit by minimizing the size of power plants. [4]

As small technologies can be mass produced and cheap, it may preferable to and most favorable to divide up areas in independent and autonomous decentralized systems. It is called as off-grid system as there is no advantage to have international interregional grid structures. In developing countries without a national grid, the off-grid supply referred to unserved areas.

Distributed energy resource systems are small-scale power generation technologies (typically)in the range of 3 kW to 10,000 kW) which is provide electric power to the system. Due to the decentralized option of the renewable energies, the future rationale option will be implementation of off-grid technologies to all types of services, urban and rural for continuous power supply. [8]

Due to high cost of fossil fuels growth and renewable energy technologies benefits and government support increases, investors, utilities, and governments are following ways to support or investment in distributed renewable energy organization, projects and companies and strategies. [11]

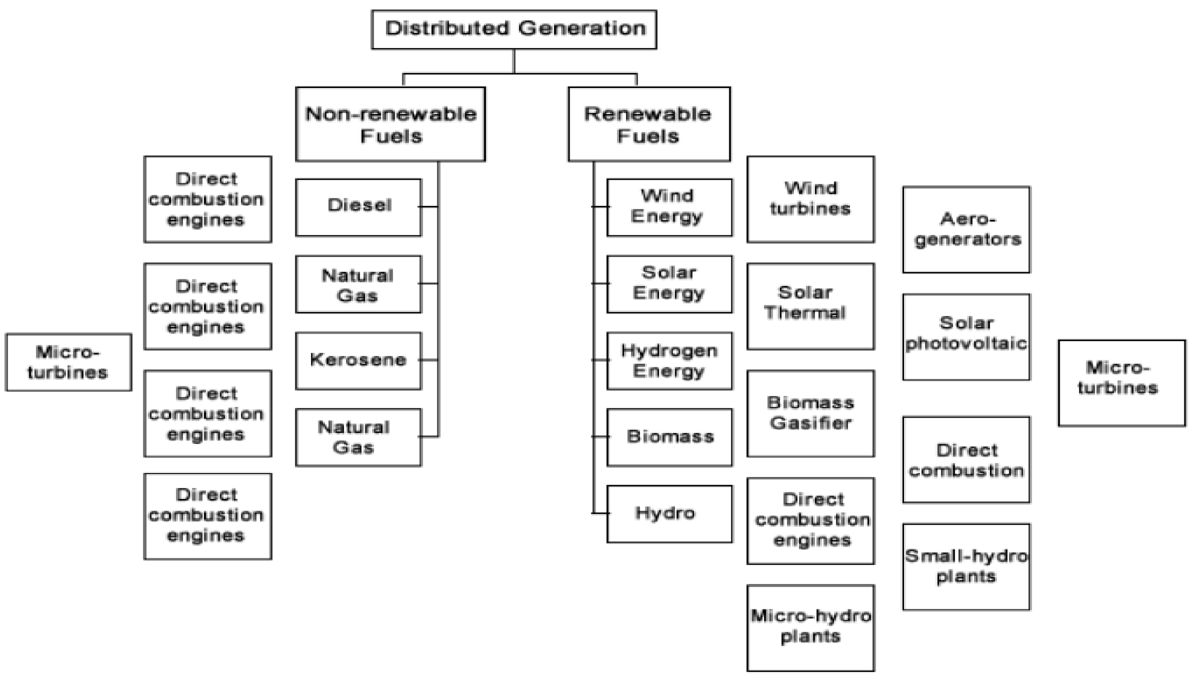

Figure 3: Relevance of Distribution Generation [11]

2. Different types of renewable energy sources

2.1 Solar energy

Solar energy is the energy of sun which radiates (sends out) an anormous amount within the sun itself which is higher than world uses in one year. Sun's energy takes just a little over eight minutes to travel the miles to earth at the speed of light. It is very useful renewable energy source to produce enough power without production of harmful gases foratmosphere.[12]

2.2 Wind energy

This type of Renewable enrgy source use atmospheric air by its motion in the environment. By its moving, each molecule of air has kinetic energy. Combined kinetic energy of all the air molecules become a energy of wind. It is the world's fastest -growing enery sources and also it will never run out and available freely.[13]

2.3 Hydro power

Hydroelectric power comes from the flowing of water from the mountains or reservoir. When water is falling by the force of gravity, can be used to turn turbines and generators that generate power by changing the kinetic moving energy to mechanical (machine) energy. Initial source of energy is water so that we call hydropower plant.[14]

2.4 Biomass Energy

This is the one of the oldest form of energy used by humans:Wood fire. Usually it is the energy from the sun ,via photosynthesis process in plants. Burning biomass to generate electricity having the efficiency same as the fossil fuels. It refers renewable carbon resources, non-fossil, water based, photosynthetic and organic waste organisms like municipal and agricultural waste. Wood, crops, grasses. Waste from the biomass refers to as bioenergy.[15]

2.5 Tidal Energy

Generation of Tides are depends on the interaction of the gravity of the sun, earth, and moon.Significant rise and fall of the tides – more than 12 m in some cases – generates potential energy. Tidal energy technologies are found in Europe around the year 700. However, new technologies have advanced considerably over the past few years and there are many ongoing full-scale demonstration projects. [16]

2.6 Geothermal Energy

Geothermal energy is the energy of heat from within the earth surface. Water is replenished by rainfall and the heat is continuously produced inside the earth so that it is called as renewable enrgy source. Geothermal plants need high temperature (300 to 700 degrees Fahrenheit) hydrothermal resources that may come from either dry steam wells or hot water wells. We can use these resources by drilling wells into the earth and piping the steam or hot water to the surface. [17]

3. Solar Power Generation and Utilization

3.1 Solar Power Generation

Solar power is the energy conversion by direct photovoltaics(PV) or indirectly concentrated solar power from sunlight to electricity. Concentrated solar power System use tracking systems and mirrors to cover the full surface of Sun into a small beam. By photovoltaic effect, PV cells converts sunlight into an electric current. Solar energy is the Powerful Source of energy from the sun which can be used to cool and light our homes and businesses. There are different types of technology convert sunlight to electricity which can be used for utilities like solar photovoltaics and passive solar design for space cooling and heating. In the 1980s, Commercial concentrated solar power plants were first developed. the largest concentrating solar power plant in the world, located in the Mojave Desert of California having 392 MW. current largest photovoltaic power station in the world is the 850 MWLongyangxia Dam Solar Park, in Qinghai, China.

3.2 Photovoltaic system

It is a power system which is supplied usable solar power by use of photovoltaic cell.it consists of several solar panel which is absorb and covert sun energy into electricity, and Solar inverter to convert DC energy from sun into AC energy. Other electrical accessories and mounting, caballing to create a working system. To improve system’s overall performance, it uses solar tacking system. Having silent operation and no moving parts operation, it becomes very useful in recent years.[18] Due to the exponential demand of photovoltaics, prices for PV systems have rapidly declined in recent years.

3.3 Different types of photovoltaic system

3.3.1 Stand-alone system

As the name indicates, this system is operated as standalone operation without connection of electric distribution grid. Application of this system in commercial and house-hold operation in which there in no requirement of grid power. Total number of components in PV system depends on different types of load connected in the system. If only dc loads are connected in system then DC to DC converter use in the system by eliminating inverter operation, there is another possibility to directly connection of PV module to DC Load Example. Water pumping operation. [18]

There are number of PV modules having 12V with power 50 and 100+W each in output. It is automatic solar system which charge the bank of batteries during the day time and when sun energy is not available then use this power at night. To store the electrical power, Rechargeable battery can be used in small-scale PV system. This system is ideal for Rural areas to provide power for lighting and other use. Small scale PV system is more effective compare to local grid system because it can be used for boats, tents and other remote application.

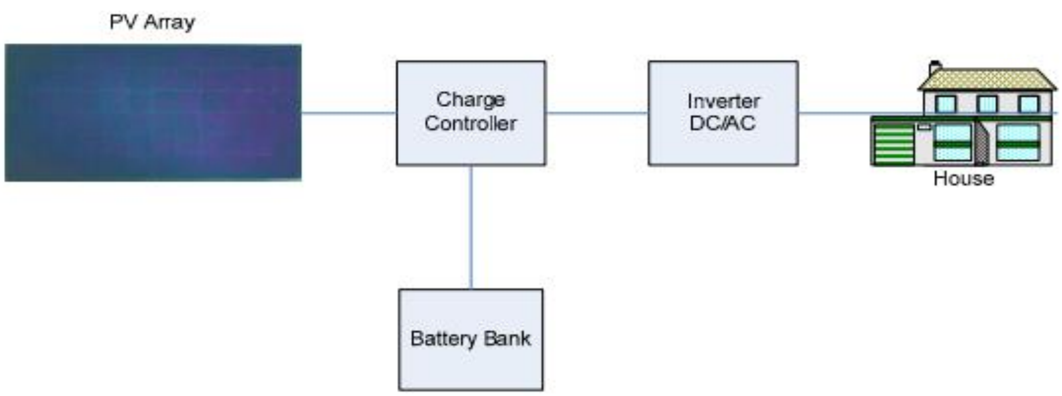

Figure 4: Stand-alone PV system [18]

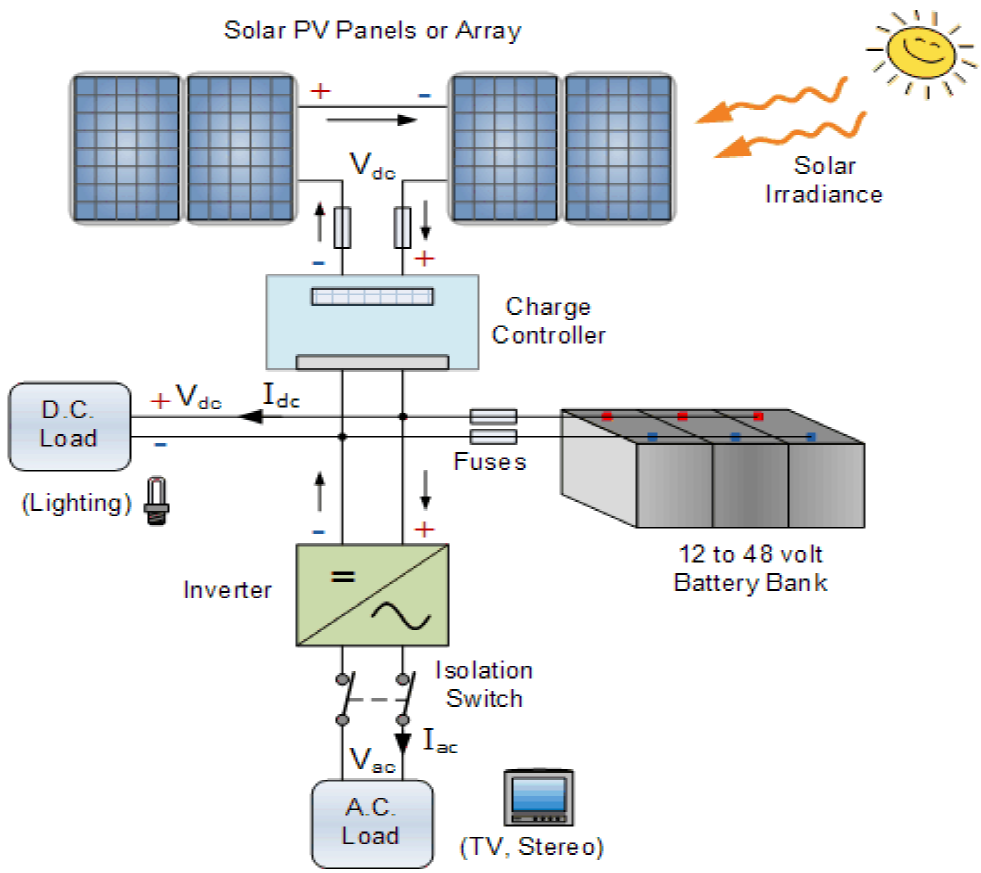

Figure 5: Simplified Stand- alone PV System [19]

3.3.1.1 Major Component of Simplified Stand-alone PV System

Charge Controller

It controls and regulates the output power from PV Modules and to prevent the batteries to be over discharged or overcharged by dissipating the extra power into a load resistance. It can be connected as an optional component but for safety reason, it is good idea to connect in the system. [20]-[21]

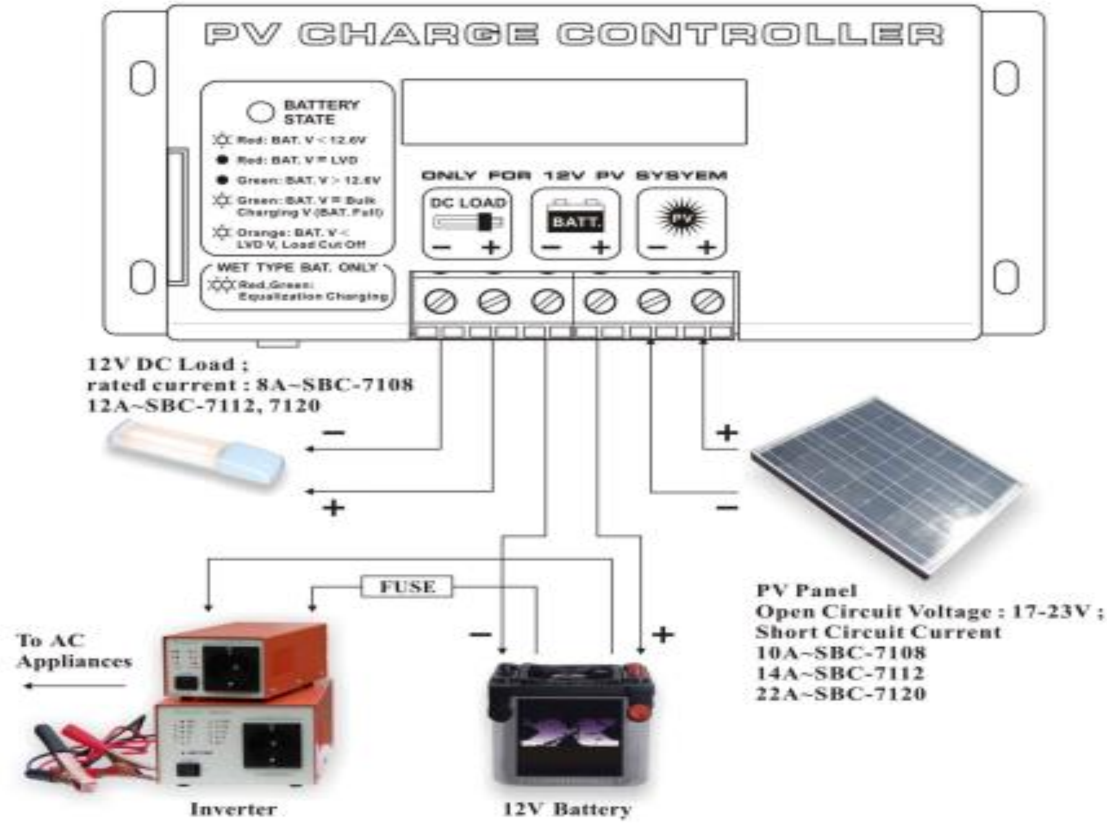

Figure 6: PV charge controller [20]

Battery

Batteries are very important element and heart of any stand alone solar power system to store the excessive amount of power in the system during the day time and use this power during night time. It can be optional depending upon the design. Battery bank can be of 12V,24V or 48V and many hundreds of amperes in total which is depends on solar array configuration.When solar energy is not producing power, then it converts electrical energy into stored chemical energy for use. PV system supplies power to load during the time sunshine. During the cloudy and rainy days,night and low solar irradiance,power supplied to load from battery.[22]

Types of battery used in Stand alone PV system

1. Deep cycle battery
2. Shallow cycle battery

Deep cycle battery is regularly deeply discharged using most of its capacity type lead acid battery having discharge capacity between 45% and 75% of its capacity depending on the construction and manufacture of battery.It is used to store the the power generated by PV module and discharge when the power is needed for use.[23]

Fuses and isolation switches (protecting Device)

These are used for protection purpose of PV System from accidental shorting of Wires. PV string fuses having rating at 1000V and come in 12A,15A, and 20A with the solid wire construction. It is specially design from reverse currents to protect PV module and it is operated under typical low fault condition at PV arrays. DC isolators is the manually isolation of connection between PV arrays and Inverters. It is installed on on-grid and off grid operation. AC isolator is necessary switch of every solar installation projects by performing manual operation. It is connected at the consumer unit.

Figure 7: Battery Fuse and DC isolator [24]

Inverter

The inverter is the important but another optional unit in a stand alone PV system. It is used to produce AC power from the solar array and batteries having the rating of 12V,24V and 48 depends on the requirement. Battery give the power to the inverter which produce 120 VAC or 240VAC for household application. Two types of invertes like Non sine wave and sine wave inverter . Basically Non sine wave inverter can be used in stand alone system for different application like power tools and lighting and pumping water pump due to non sinusiodal output waveform. usally Solar inverter use MPPT(maximum power point tacking) to achieve the large amount of power from the PV module system for any given environmental condition.[22]

There are several factors should be consider during the installaion of PV array/module like system require full amount of sun availability to produce the large amount of power. If the area cover by the PV array is large then it receive a huge amount of sunlight during the day but if the area is small then PV cell does not produce the Sufficient amount of power. So Insallation location of PV module are important factor to be consider. Other factors like average sunlight irradiance, average wind speed ,sufficient land space area availability. Whole system efficiency is depends on individul componet efficiency it means that PV system operate at 60% of its capacity due to loss in the individual system components. Checking and Inspection test should be carried out to make sure that all the components is working properly.

Advantages of Stand alone PV system

- No waste and byproducts
- Low maintenance
- Easy expantion by multiple batteries and solar panels

3.3.2 Grid Connected Solar System

In current trends, several solar power homes connected to the local electric grid has implemented very rapidly. These Type of PV system have solar panels which provide the power to load during day time also being connected to the local power grid during the night time. During the long hot summer months, PV system produces high amount of electricity than is needed or consumed. This extra electricity fed directly into the Power system or stored in batteries.

Mostly homes and Industrial building use all their energy or portion of the solar energy during the daily utilization. According to the sunlight condition and the actual power demand at that time, power flows back and forth to and from the normal power grid. It is also known as on grid or Grid tied solar system having connection with grid which gives power back into the power grid. this system is permanently connected to the power grid so that solar panel sizing calculation and solar energy consumption are not necessary. There are many advantage like relatively low operating and maintenance costs as well as its simplicity and reduced electricity bills. However maximum number of panel should be connected to produce large amount of electric power.[24]

Inverter is the useful component and become a medium of connection between PV system and public electricity grid due to power changing operation from DC to AC. It is very important to choose the high-quality inverter for grid connection operation like efficiency of inverter must be as high as possible to convert the power and it should handle the power fluctuation in grid during high and low power mode.

Electricity meter is called as energy flow meter which continuously record the how much amount of electricity flow from the grid and to the grid. mostly a single bidirectional KWh meter is used to record the how much energy taken from the grid.

AC breaker panel and Fuse is normal type of fuse box which is connected between isolation switch and domestic electricity supply. For maintenance and testing purpose system must be connected with the safety switches and cable. It must be provided for easy excess to disconnect the system and inverter.[24] Usually electrical cable is used for connection of different electrical component having correct size and rating.

If Main supply from the electrical grid be fluctuated then all the system may not be working due to dependent operation with grid system. So, it is not an independent source of power as a Standalone system.[24] Also, Grid Connected PV system with batteries having more component. Charge controller determine direction of power from Solar PV system and deliver this power for dc home application or DC power for battery storage application.

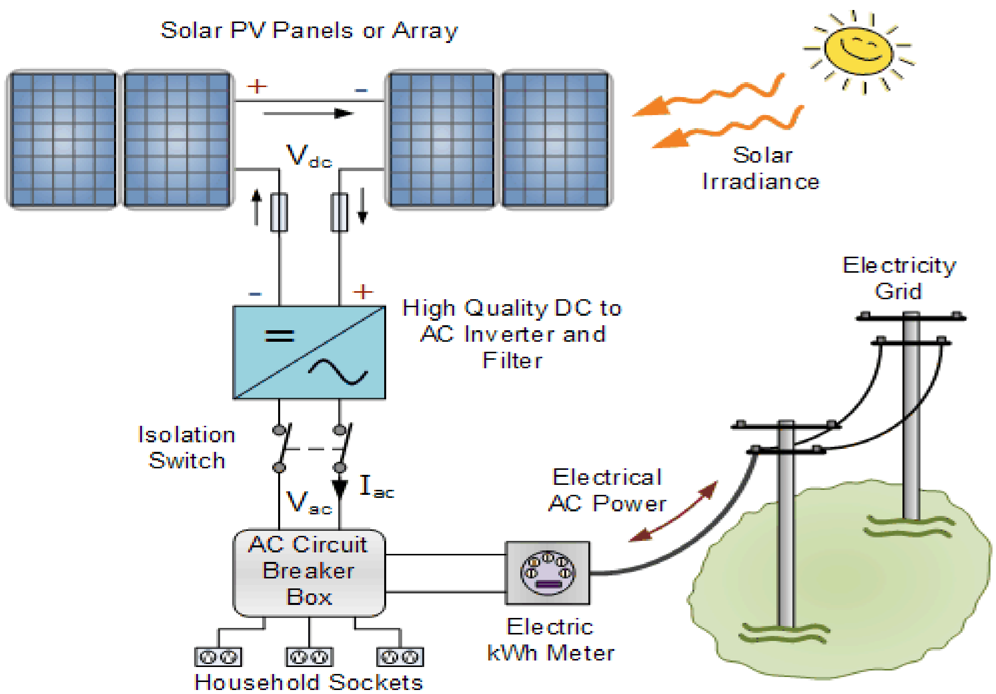

Figure 8: Grid Connected PV system [24]

Grid connected PV system produces only partial solar power and other part of power made up by main power grid company. The excessive energy production does not go to waste during no consumption but it is fed back into the electric grid for neighboring homes by net metering arrangement. It means that solar system produces power when we are not consuming the power.

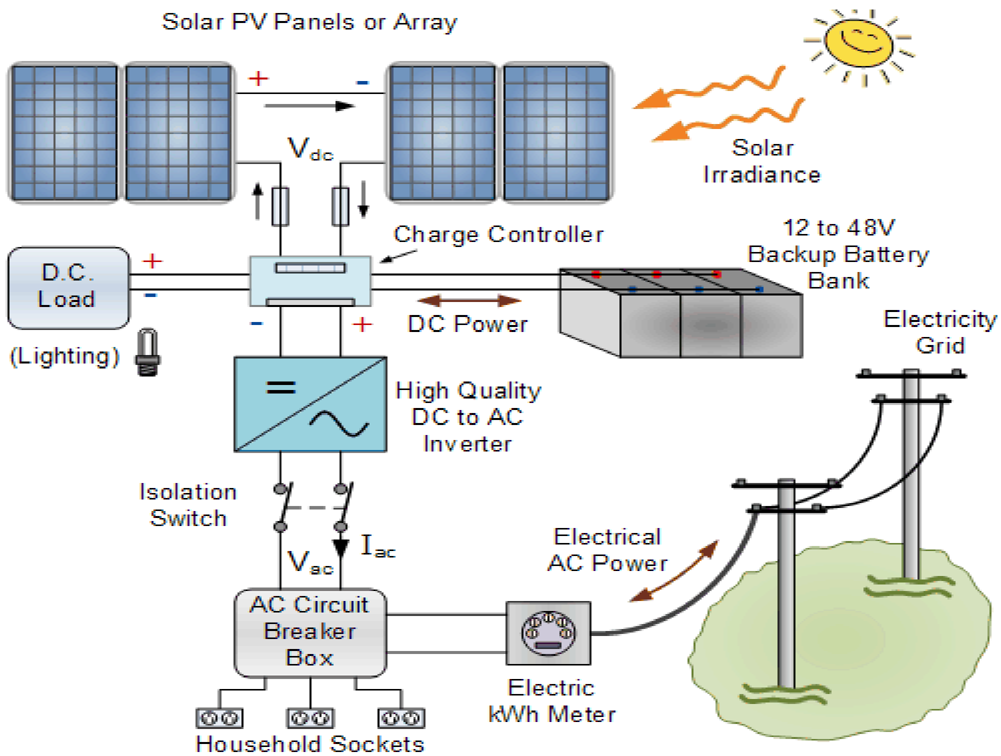

Figure 9: Grid Connected PV system with battery [24]

4. Wind Energy Generation and Utilization

4.1 History of wind energy

Since1000 AD, the wind turbine first came for mechanical power generation as horizontal axis in China and Tibet and Persia. Development in technology lead to transfer of windmill from the Middle East to Europe between 1100 to 1300. Windmill having the rotor of 25 meters diameter was implemented in France during the 19^{th} century.

In early 1890s, 3 phase AC power Production leads to generate electricity from the wind turbine. Electricity Generation using wind power was invented by most widely known Danish engineer and scientist Poul La Cour. He introduced Rotor design having four shuttle sail which approx. generate 10 KW of DC power. To light up the local school ground, he utilized the hydrogen gas for gas lamp by applying the DC current from water electrolysis. Europe gained its achievement to implement number of wind electricity generation plant due to development and commercialization of La Cour's efforts in research. [25]

Capacity ranging from 5-25 kW of several wind mill operation had been introduced by 1908. After that time, high capacity like 500 kW were developed and become wide spread use in inaccessible areas.

Table 1: Wind Turbine Historical Development

Date	Capacity	Blade Length	Technology
Mid 1990s	400-500 kW	15-25 m	Fixed blade pitch angle and Fixed rotational speed
2000	1000 kW	25-35 m	Fixed blade pitch angle and Dual rotational speed
Today	2000-3000 kW	35-45 m	Variable blade pitch angle and Variable rotational speed
Within 5 years	3000-7000 kW	45-60 m	

With Industrial giants like Siemens and GE among the top manufactures, Electricity generation from the wind are selected as most important form of renewable energy technology. The most technologically mature renewables alternatives represent wind energy which has generation source from wind having advantages of cost effective source in small and large power system. [25]

4.2 Wind power generation

The power that can be used from the wind is directly proportional to the cube of the speed of wind. Several factors like design of wind turbine, suitable site to installed the wind projects etc. all this depends on wind characteristics (variation, direction, velocity). Variable characteristics of wind exits over the wide range of scale in both time ans space. Different climate condition on the earth varies the wind characetristics over a year. Prediction of wind energy is more difficult on short time period like few days due to weather system and location. This variation can affect the large scale wind enegy production and integration of grid operation.[26]

Wind power has been used for mechanical application like pumping water, sawing wood and milling grains and also used for transportation like ship propulsion. Growing of global wind power fulfill the the growing the electricity demand at average rate of 28% per year. Investment cost of wind power is relatively low compared to solar photovoltaic plant.[26]

Total power in Wind stream:

$$P_W = 0.5\rho\pi R^3 V_w^3 CP(\lambda,\beta)$$

Where,

P_{w} = extracted power from the wind

ρ = air density, (approximately 1.2 kg/m^3 at 20°C at sea level)

R = blade radius (m), (it varies between 40-60 m)

V_w = wind velocity (m/s) (velocity can be controlled between 3 to 30 m/s)

CP = the power coefficient which is a function of both tip speed ratio (λ), and blade pitch angle, (β) (deg.)

Power coefficient (CP) is defined as the ratio of the output power produced to the power available in the wind.

Especially if wind turbines are placed well, impacts of wind turbines on wildlife and nature are low. Wind power is cost effective power production technology and governmental support mechanisms for renewable energy. It is primary energy. [25]

Capacity factor

It is a term to denote the capacity of utilization of a wind power or different type of generating sources operated at 100% efficiency.

Capacity Factor = Actual amount of power produced over time / Power that would have been produced if turbine operated at maximum output 100% of the time.

Conventional power plant use fossil fuel which has a continuous process of operation so that it has a larger capacity factor. Only capacity factor will drop down during the maintenance of plant. Wind turbine may not always operate at maximum output condition due to variable speed and direction of wind. The capacity factor of turbines is approx. 40% to 45% which is typically low. [25]

Capacity factor of fuel type power plants denotes the reliability of the plant. There are two option exist in wind turbine like lower capacity ratio of higher generator rating and higher capacity ratio of lower generator rating due to different construction of Wind turbine.

4.3 Wind Turbine

Kinetic energy in the wind is converted into mechanical energy by the rotating machine called Wind Turbine. The machine is used to convert this mechanical energy into electricity called as Wind generator. [25]

There are two basically two types of Wind turbine based by its axis construction like:

1. Vertical Axis Wind Turbines
2. Horizontal Axis Wind Turbines

Figure 10: Horizontal Axis Wind Turbine [25]

Wind Turbine several subcomponents:

- Rotors- wind energy convert into mechanical energy of the shaft.
- Enclosure- conversion device like gear shaft, generator etc.
- Tower – for higher speed capturing operation, it increases the height of tower.
- Cables, control equipment and civil works.

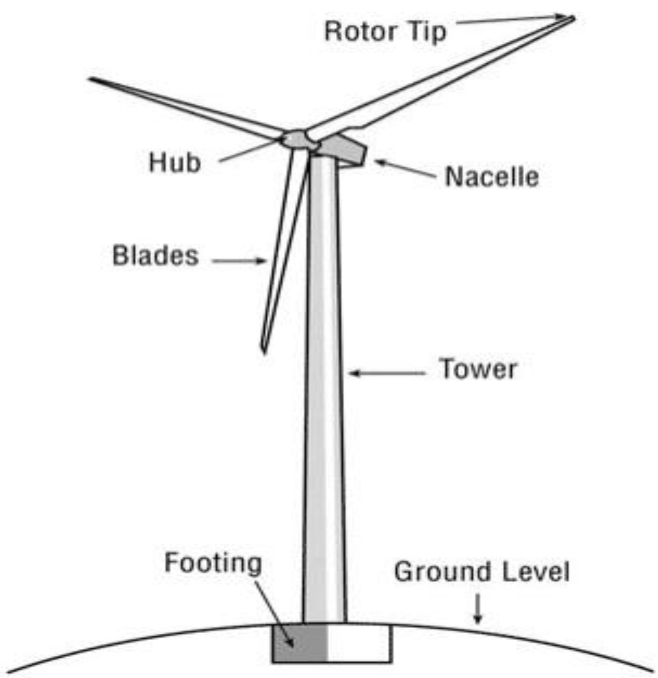

Figure 11: Horizontal Axis Wind Turbine Components [25]

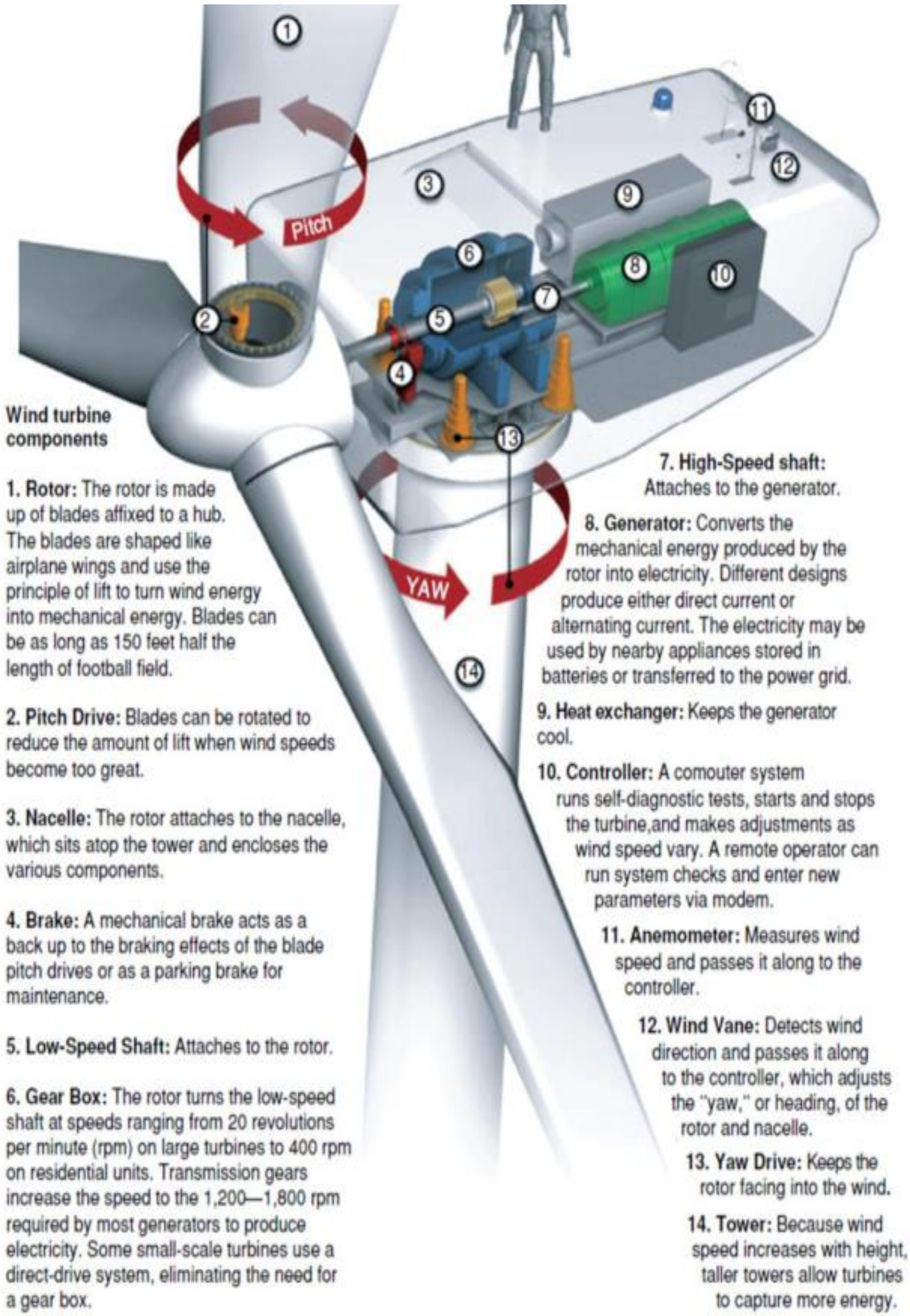

Figure 12: Modern Large Scale HAWT configuration [27]

HAWTs (Horizontal Axis Wind Turbines)

As the name indicates that it has horizontal axis of rotation. At the top of a tower, electrical generator and main rotor shaft are mounted and are pointed into the wind. The requirement of gear system connected to the generator and rotor due to variability of wind distribution and speed. Large turbines use servo motor with a wind sensor. Gear box control the rotation of blades which is more suitable to drive an electrical generator.

Vertical Axis Wind Turbines (VAWTs)

Arrangement of main rotor shaft of VAWTs is vertically so that the plane of rotation is vertical. There is no requirement of yaw control mechanism to be pointed into the wind in VAWTs. It can be placed nearby the ground which enables access to electrical components. This type of turbine is useful where wind direction is random or possibility of large obstacles like houses, trees etc. These are placed near to the ground and hence to maintain easily and a lower noise signature. [25]-[26]

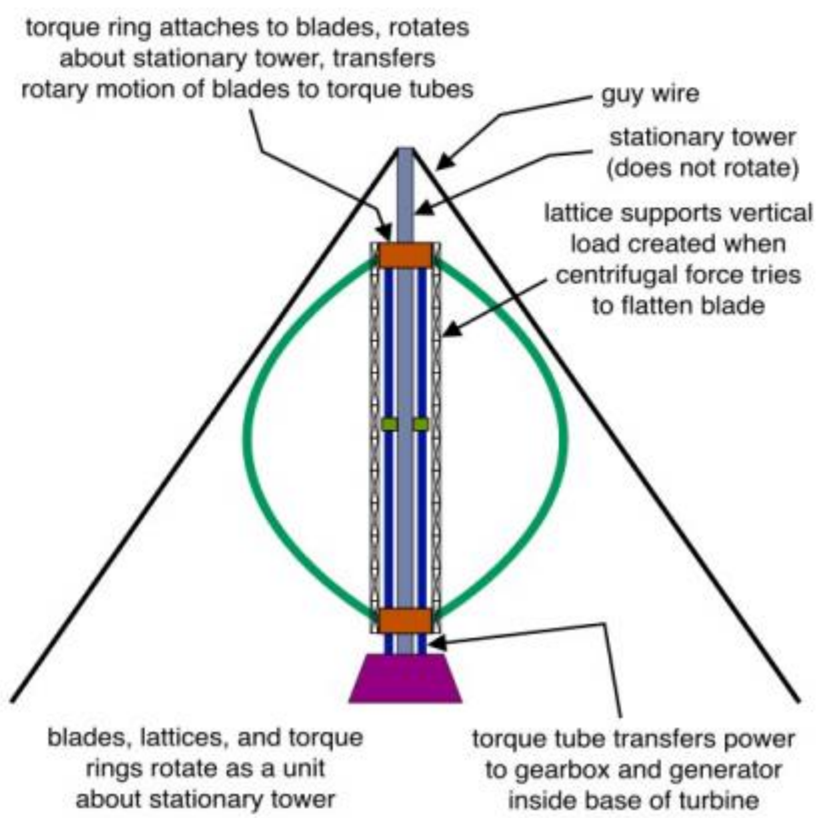

Figure 13: Darrieus Turbine (High Mechanical Efficiency Centrifugally stable) [26]

4.4 Wind Power Plant Grid Connection

Types of Wind Energy System

Wind Energy systems are characterized into following types:

- Mechanical wind energy system (without energy storage)
- Electric Standalone system (with energy storage)
- Grid connected wind electric system (without storage requirement)
- Hybrid energy system (battery hybrid, solar electric, wind diesel etc.)

Wind energy to Electrical Energy conversion:

Utilization point of view

- Energy storage requirements during hazard periods
- Grid connection or Standalone system

Rotor Speed of Wind Turbine

- Variable speed with fixed Pitch blades
- Average constant speed
- Constant speed with gear and speed pitch control

Types of Output

- AC with Constant frequency
- AC with Variable frequency
- DC

Constant frequency variable speed system

This type of system uses thyristor converters to rectify the output at appropriate level. Variable input to the generator system which produce variable frequency output. Due to the additional cost of rectifier inverter, this system become an expensive. System has optimal efficiency of wind generation and doesn't require any pitch control.

Nearly constant speed and grid constant frequency

Induction generators are used in this type of system having level of tolerance +/- 10%. Reactive power draws from the grid by induction generator thus to fulfil the requirement of reactive power Synchronous Condensers, Static VAR compensators are used. Generally medium and small units rated 100 kW to 300 kW use in this system.

Constant Frequency Constant speed system

This type of system is used in most modern grid connected wind farm which implies that constant frequency is a necessity. Variable pitch control is necessary to maintain constant torque output thus system use Synchronous Generators. Ex. Smith Putman, 1.25 MW Ruthland, USA (1945).

Monitoring and Control Systems in Wind Farm

There are 3 levels of control system:

- Unit WTG controller
- Master wind farm controller
- Control system for Distribution network

All-important variables like power factor, rotor speed, wind speed, power, current, voltage, bearing temperature, wind direction etc. are monitored and measured by centrally located control system in Wind Farm and transmitted digital signal by control cables to the master controller. All the signals are transmitted and received for specific power output.

Energy storage system in wind power plant

During the grid connection of the wind system, energy is stored in batteries on low load condition and energy is fed into the grid in case of high load condition. Energy storage system is used in Standalone systems to store the energy for later utilization purpose. [26]

Deficit power generation during the load power P_L is more than delivered power P_D. There are several solutions during the deficit power generation describe below:

- Storage energy is let out
- Utilization of diesel power generator to feed the plant
- Utilization of grid power to the load

4.5 Offshore Wind power plant

4.5.1 Development of Offshore Wind Turbine

Several developments of Offshore wind turbine have been carried out which is describe below.

Small scale 500kw -class prototype:

In the northern European countries like Denmark, Netherland and Germany, the first research of offshore wind turbines was started in 1970's. The first small scale 500 kW prototypes wind turbines were designed and tested.

Megawatt-class Prototype Wind Turbine (The First Generation):

Megawatt-class type offshore wind turbines were installed and tested in early 2000's which was the first new development in the offshore wind turbine. Development in ship maintenance with modified anti corrosion features was carried out and implemented.

Megawatt-class Prototype Wind Turbine (Second Generation)

It consisted of turbines with rating of 3-5 MW and 90-115 m long turbine rotor. It provides the higher energy efficiency and high dependability due to its robust design. It has special features for anti-corrosion in the off-shore wind turbine.

Megawatt-class Prototype Wind Turbine (Third Generation)

It has turbines having ratings greater than 5 MW and diameter typically in the range of 120m. Due to larger turbines, higher energy yields have been obtained. It is more cost effective. Several manufactures of offshore wind power generation like Nordex (Germany), Repower (Germany), GE Wind Energy (USA), Bonus (Denmark), Vestas(Denmark), Enercon (Germany) etc.

Offshore Installation and Operation steps:

- At the selected spots, Piles are driven into the seabed after proper selection of site. Erosion protection schemes are placed at the base of piles to protect against corrosion.
- To make visible to ships, the top of the foundation is generally painted brightly. For the ease of access, the maintenance chamber is setup at this spot.

- By utilization of powerful sea cranes and barges, turbines are assembled at the proper places. Sensors are mounted on the turbine to detect the wind direction and turn the nacelle into the direction of wind flow.
- At the rated wind speed, it enables the proper functioning of the rotor. The rotor is connected to a shaft inside the nacelle, this shaft is further connected to a gearbox, which steps up the speed to around 1200-1500 rpm.
- The generator fixed with the turbine system runs at this speed, and produces power.
- Subsea cables are used to transmit the power to an offshore transformer set, which then converts it to 33 kV high voltages. This is then transmitted to the grid substation on land by use of cables.

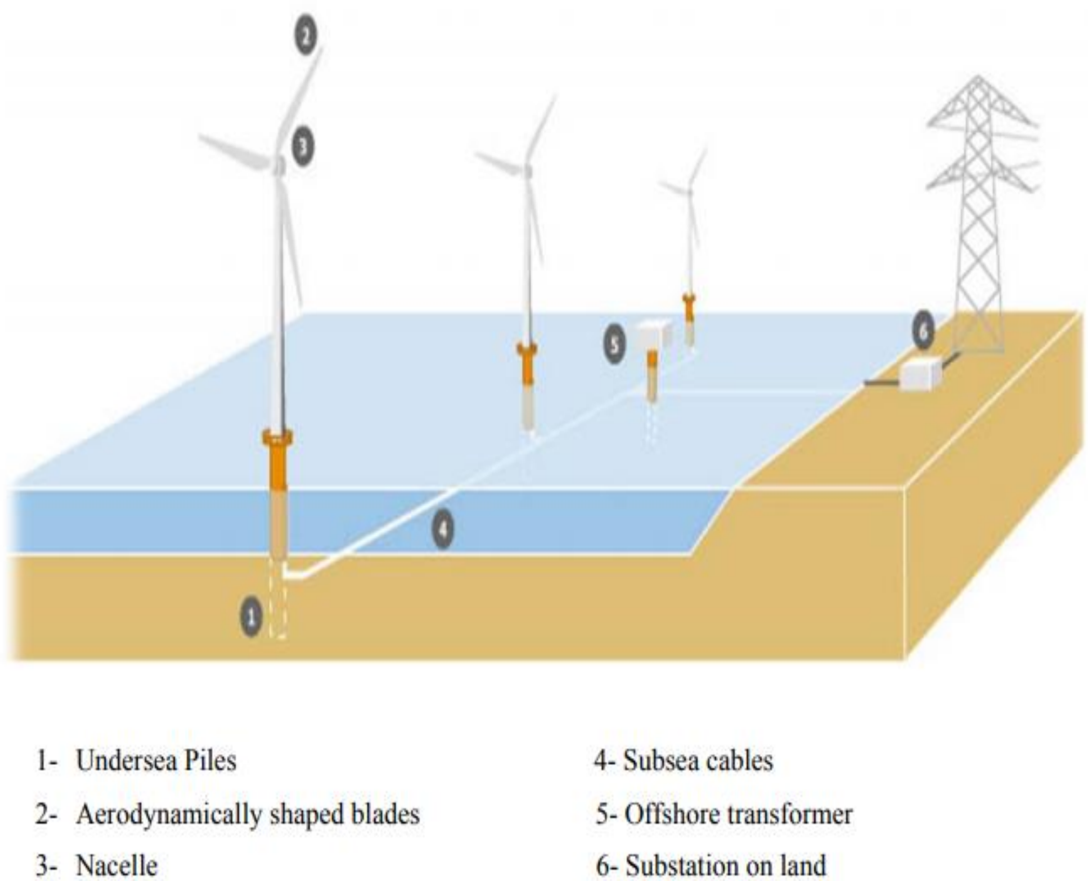

Figure 14: Simplified Off-shore Wind Farm [25]

4.6 OffShore Wind Power Plant Development

Germany:

By 2011, Wind Energy installed capacity will be increased up to 3000 MW. Offshore wind power plant construction has been increased more due to lack of suitable venues and land for on shore wind power plants examples Butendiek and Bor-kum wind farms.

Denmark:

Denmark has a global market share more than 1/3 which becomes the world’s wind power industry’s leaders and pioneers. Large offshore wind power plant was completed at Horns Rev with the capacity of 209 MW at the end of September 2009. Bt 2030, it is estimated that wind power generation capacity will account for 50% of all total generating capacity of the country.

United Kingdom:

There are two large scale offshore wind power plant at NorthHoyle and ScrobySands with total capacity of 6o MW have been implemented to use. Further development of new projects is in under process with the much more capacity to produce the enough power on current demand of electricity.

5. Microgrid

5.1 Microgrid Concept structure

Microgrid is the local small energy network of distributed energy resources with local loads,which is connected in parallel with the grid to provide a high realibility.it is independent of local electrical power grid and act as single controllable utility with respect to power grid. It is used to deliver the electricity to colleges,hospitals,factories,military bases or entire communities. There are two operation like Grid connected and island mode during the emergency operation. In control strategy, protection and control are big problem in the microgrid. Usaully microgrid connect with Low voltage distribtuion network with different type of energy sources like (PV ,fuel cell,etc.), energy storage system, storage battery, and variable loads. There area several distinct advantages to customers and utilities i.e. lesser overall energy consumption, reduction of environmental impact, increse reliability and resilience,most cost efficient power infrastructre.[28]

By supporting voltage and reducing voltage dips and lower cost of supply energy, it reduce emission and improve power quality. From customer point of view, it provide power and thermal needs. Demand for distribution and transmission facility has been reduced by use of MG from the utility point of view.It connect usally with MV distribution network.[28]

Research project FP5 Project MI-CROGRIDS (ENK5-CT-2002-00610) mainly deal with the single microgrid operation through laboratory experiments. This projects's main objectives are describe as:

- Inventing new techniques for different control of maximum number of distributed sources.
- Development of storage and load controller and smart micro-energy sources.
- Testing of new technologies and concepts in real pilot sites.

Microgrid offers Maximum flexibility in terms of ownership constiution compared to central generation concepts. Microgrid can be built by grid operator or by consumer or by free market player platform. There are benefits to use of microgrid as power supply having emission reduction power supply and lower tarrif to end consumers. For future evaluation of energy service provision ,Microgrids play a significant role to overcome the demand growth of electricity. Distribution generation and distributed storage are located near the consumer location which provide improved reliability Integration of various DG technologies with the utility power grid is an important pathway to a clean, reliable, secure, and efficient energy system for developed economies with established levels of quality and reliability of electrical service. Various studies have found that a large number of utilities as well as consumers that have installed DGs at their facilities realize benefits like local waste heat capture, improved reliability and reduced cost . A microgrid is created by connecting a local group of small power generators using advanced sensoring, communications, and control technologies.[29]

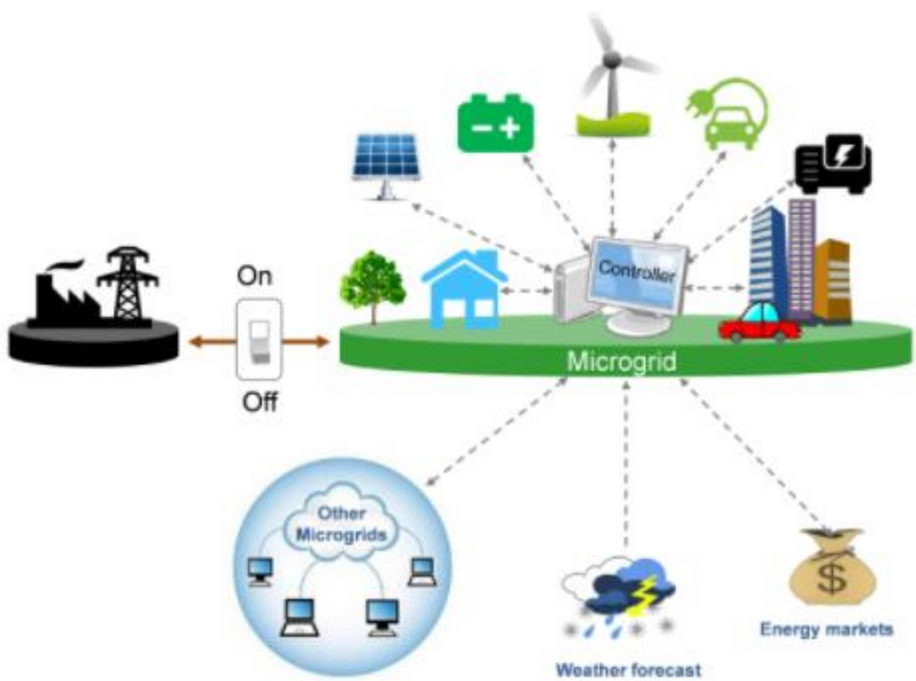

Figure 15: Simple concept of Microgrid [30]

Microgrids can be operated as two modes like off grid mode (standalone mode) or main grid connection mode.Usaully generation and loads are connected at low or medium volage level.microgrids has several generation reneable sources like solar cell, fuel cell ,winfd energy and power storage system(battery). Maximum number of power system are connected to microgrid due to this operator should be very alert.[31]

The followings are parameter of Microgrid:

- Small microgrid have 1-5 km radius.
- It can produce power upto to 1-5 MW to deliver the customres.
- There in no requirements of long distance transmission lines and free from transmission power loss.

Dc microgrid concept could be implemented in recent year for power generation and utilization system. DC microgrid can be placed at minimum distance between electricity generation and loads., DC storage devices such as batteries, capacitors, and fuel cells also fulfill the re-quirements of local DC power. In essence, the self- network of power generation and energy storage devices, known as the Microgrid is basically a small network of the larger power grid. This self-sufficient PV-based" Nanogrid" can generate, store and distribute its own power, which is ideally suited for rural electrification.[32]

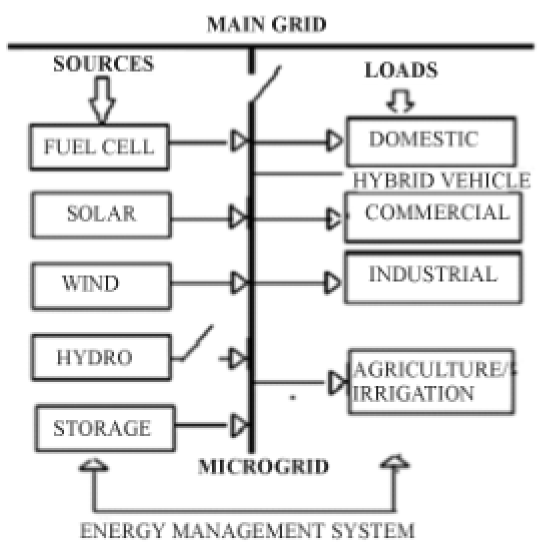

Figure 16: Architecture of Microgrid [32]

Selection of Renewable energy sourcey is very important cosideration due to location and environment condition of that land. Integartion of this sources require proper energy storage and monitoring system. Electronics technology are being used for monitoring sytem of Microgrid opration. Energy storage and management system have several reason like smart gris, distributesd energy sources, bad impact on environmnet due to fossil fuel use, after use of storage energy, development of electric vehicle which is focussed on implementation of renewable energy sources in microgrid. This system will provide smooth, unintruppted energy to home appliances by using resynchronization algorithm and advanced islanding detection.

Table 2: System component of Microgrid [32]

Main Sources	Macro Grid Generators
Renewable Energy Resources	• Small hydro system • Wind energy • Bio fuel energy • PV solar cell • Ocean energy and geothermal energy
Energy Storage Systems	• Fuel cells (PEM, SOFC and alkaline) • Batteries (lithium) • Super capacitor • Pump storage • Fly wheel
Types of Loads	• Small (domestic) • Medium (commercial) • Large (agriculture/irrigation three phase) and industrial-three phase
Technical Parameters	• Preferably linear • Balanced line not unbalanced • System should be dynamic

Decentralizing system is called as microgrid system by stanalone opration which increase the system overall efficiency upto 85%- 95% by use of CHP system and reduce the loss of energy in transmission system.

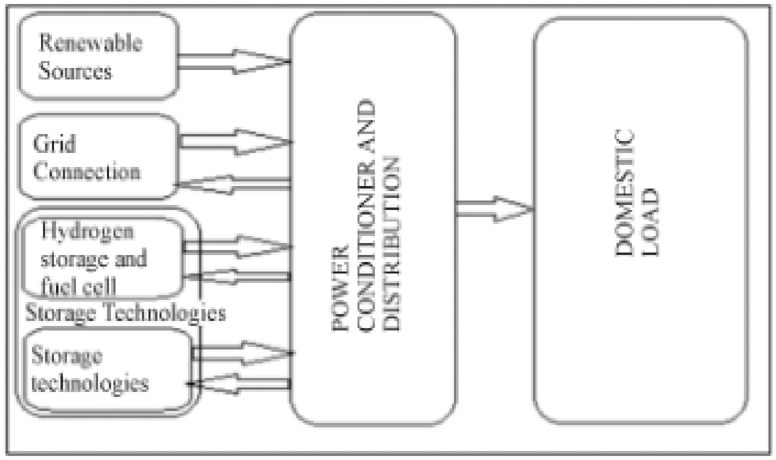

Figure 17: Proposed Microgrid Distribution system [32]

To manage the flow of sytem active and reactive power balance, distributed generation can be used with banks of capacitor in power system.[32] Control system takes care of whole system while all the resources is integrated in the main grid and reduce environmnetal impacts such as:

- Reduce the green house gase emission
- Increase the energy security by use of distributed generation and all energy sources sharing

Microgrids carry out dynamic control over energy sources, enabling autonomous and automatic self-healing operations. During normal or high demand, or during the time of power grid failure, a microgrid can operate standalone of the power grid and disconnect generation nodes and power loads from disturbance without affecting the power grid connection. Microgrids interoperate with existing power systems, network infrastructure, and information systems and are capable of feeding power back to the larger grid during times of grid failure or power outages. [33]

Microgrid Features

Microgrid components such as renewable or fossil-fueled generators, several circuit breakers and its control, loads, energy storage systems, must fulfill several requirements to produce reliable operation. Lawrence Berkeley National Laboratory has observed some important top-level microgrid features that should be considered in all standardization projects and research and development projects: [32]

Compatibility: Microgrids are compatible with the current power grid. They may be considered as main units that support the development of the current system in an economically and environmentally friendly way.

Stability: Independent local control of generators, batteries, and loads of microgrids are based on frequency and voltage rating at the point of each component. Microgrid can perform stable operation during nominal operating conditions and during transient condition, without dependency of larger power grid. To achieve a high level of stability, additional research is required.

Efficiency: The utilization of generators, manage charging and discharging energy storage units, and can manage centralized as well as distributed microgrid supervisory controller structures consumption optimize. In this way energy management goals can be optimized on environmental related condition.

Economics: According to market research studies, by evaluation of microgrids economics of heat recovery it can be identified current market of energy. In addition, use of renewable energy resources will help to reduce greenhouse gas emission and cost of fuel.

5.2 Different Types of Microgrid

Depending on size,location and market condition, microgrids can be divided into different types. Some microgrids are described below.[31]

Institutional Microgrids/campus environment microgrid

Major concern about onsite generation with several load which are connected in industrial park. In microgrid segments, single owner of both generation and large loads can manage very easily and avoid several problems. Generation power range from 4 MW to 40MW or more.

True Microgridor Customer Microgrid

It is connected at single point of common coupling(PCC) and self operated. Usually it fit nearly to the current technology and control structrure. Deployment of this type would be preferable from Customer point of view.

Remote off grid Microgrids

Opeartion of this microgrid is in island mode without connect to the main grid. remeote village power system in Village and genreration of wind power are the best example of this type of microgrid which are interconnected and supply power to the local distribution. By implemaenting distributrd wind and run of the river hydropower and solar photovolatics, reducing fossil fuel goal has been achieved. Village power sytem have the lowest average capacity of power generationand distribution.

Military base microgrids

This type of Microgrids are implemened with the focus on both cyber and physical security for military purpose to provide unintruppted power without relying on the power grid. for forward operating bases , it includes mobile military microgrids i.e. Afghanistan. This approach is actively working by U.S department of Defense(DOD).

Utility/Community Microgrids

There is no islanding operation in this type of Microgrid. European Countries lead this segment. By use of one or more distribution substations, community microgrid is corealted with local grid network and supported by local enewable energy sources and several distributed energy sources(DES).It provides Cost effective energy, secure and more sustainable energy. It use load flattering and efficient load design to reduce transmission cost and costly peaks. More efficient grid operation and power quality operation has achieved by use of community microgrid.

Industrial and commercial Microgrids

This type of microgrids have good realiability and good power supply security, Usaually big manufacturing industries is implementing this type microgrid due to its constant power supply capacity. For balancing and storing the energy , utility can be provided additional resources which is satisfied industrial energy needs. For Conventional energy production,PV technology is becoming an alternative energy source due to environmnetal concerns during the grid connected operation. Batteries are most impratant to match power generation and consumption demand.

Figure 18: Utility/Community Microgrid [34]

5.3 Main Microgrid Component operation

Microgrids consist of Several components like energy management system, communication system,controllers and power conversion elements,distributed energy resources and main key component is customer.[35]

- It is main functions in power prediction from renewable energy sources,power planning and load forecasting. For power system realibility evaluation, data collecting and estimation has been done by energy management system.
- By Proper monitoring and control information sharing, communication system become medium in microgrid system. It is inteconnect with different component and ensures control and management task in the system.
- Electrical Parameter of system like voltage,frequency and power quality which is controlled by use of proper controller. It is very important for the microgrid operation to change the parameter of sytem according to the requirement.

- Power conversion equipment like current and voltage transformer, are used to detect current and voltage limit for power system. Power electric converter interface is necessary to change the AC and DC voltage and current from the Distributed energy sources.
- DER produces the sufficient amount of energy to fulfill the demand of energy in Microgrid system and supply energy to meet require energy demand.
- Microgrid can be implemented according to the customer energy demand and customer participation is the important consideration for smart grid.

5.4 Impact of microgrids on the distribution system

There are several important parameters of microgrid operation should be consider as key feature during the production and transmission of electricity throughout the whole microgrid which is describe below: [35]

Fault level Increase

Most MG use both synchronous and induction generator for energy generation so that it will increase the fault level of the distribution system and contribute to the system fault levels. Introducing impedance by reactor or transformer between the system and generator, system fault can be reduced. Development of distributed Generation can be a serious problem in urban areas where the existing fault level increase the rating of switch gear.[35]

Power Quality

Usually two aspects are considered to be imporatant in power quality like:

- Variation in transient voltage
- Harmonic distortion of network voltage

Load as well as source fluctuation can cause voltage variation. It is very important to control the voltage variation due to relatively very large current changes during the disconnection and connection of the generator. Standalone operation of MG system observe more voltage changes due to load disturbance which cause current change to the DG inverter. Ac output volage from the inverter will fluctuate by significant change in in voltage drop due to high output impedence of inverter.

Injection of harmonic current into sytem by incorrectly design MG with power electronics interface which cause voltage distortion of the network. These harmonics depends on mode of operation, power converter technology, the interface configuration. Fortunately, most new inverters are based on Insulated Gate Bipolar Transistor (IGBT), which uses Pulse Width Modulation (PWM) to generate quasi-sine wave. Higher frequency of carrier wave has quite pure wave form without distortion by use of recent advances semiconductor technology.

Stability

Objective of the Distributed generation scheme to generate the power from the RES and control the generator transient stability. During the fault condition in the distribution network, network voltage changes occurs and generator trips so that is the loss of generation for short period of time. MGs will trip the internal protection scheme and control system takes a command to restart automatically. DG is observed as power system support then transient stability becomes more considerable importance.

Protection

Different protection steps can be identified:

- Loss Of mains protection or anti-islanding
- Impacts of Existing protection of distribution system of MG
- Generation Component protection
- MGs faulted distribution network protection

5.5 Current Project of Microgrid

There are several major research efforts which has been supported by The European Union to devote exclusively to Microgrids. This Projects focused on Demonstration activity of Microgrid operation through laboratory experiment, appropriate control techniques investigation, and individual operation of single Microgrid. Maximum number of DER connected to create a Microgrid with laboratory facility was implemented in National Technical University of Athens (NTUA)Kythnos Island, Greece. Main objectives to control the microgrid operation and test small scale equipment. The system has two poles each connected with local Wind and PV generation and battery storage system, also connected each other by low voltage line as well as to the main power grid. By its own connection to the grid, each pole may operate as a Microgrid or by two bus microgrid connection, both pole may be connected via the low voltage line. [36]

In Netherland, another Microgrids Project is located at Bronsbergen Holiday Park near Zutphen. It covers 210 cottages and 108 of them are connected to grid-connected PV systems. Three phase 400v network is connected to 10-KV medium-voltage network via distribution transformer.

Consortium for Electric Reliability Technology Solutions(CERTS) microgrid is located in Columbus, Ohio in USA. It has thyristor based static switch and three 60-kw converter based sources and internal combustion engine use natural gas which achieve maximum efficiencies over a wide range of loads. To insure a constant AC frequency at microgrid, output has been rectified and inverted.

In Japan, there are three projects are implemented at three different location like Kyoto Eco-Energy project (Kyotango Project), Expo 2005 Aichi, and Regional Power Grid with Renewable Energy Resources in Hachinohe City (Hachinohe Project). Capable of matching energy demand and supply for microgrid operation has been established in these three projects. In Expo 2005 Aichi project, PV and a battery storage system and fuel cell has been used in power supply system. In September 2007, it declared a second grid-independent operation mode. In Hachinohe Project, Microgrid has private distribution line more than 5km to supply electricity primarily generated by the gas engine system. It has several small wind turbines and PV systems. [36]

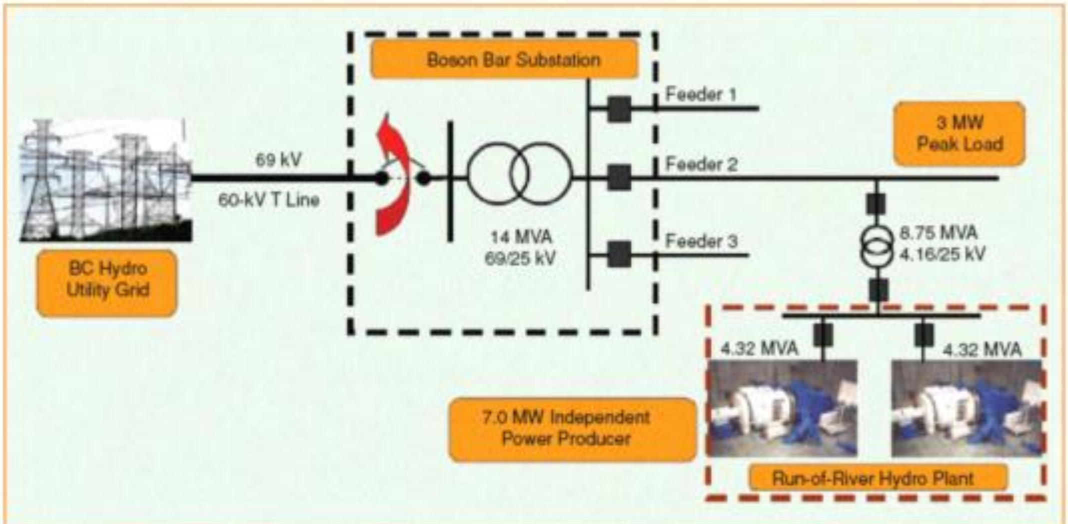

Figure 19: System configuration for the Boston bar IPP and BC Hydro planned islanding site [36]

In Canada, several power outages in Boston Bar town had been experienced two or three times per year. One option to operate in an island mode and supply load on more or one feeder of substation and utilize the local independent power producer (IPP). It has two 3.45 MW hydro power generator It is connected to one of three feeders with the peak load of 3 MW. [36]

5.6 Advantage and Challenge of Microgrid

Power quality and Reliability of current power sytem has been improved by systematic application Microgrid technologies at the local distribution level. There are mainly threee major benefits includes: ensure local supply control (30%), fulfil local demand (approx.49%), and enhance grid reliability (36%). Reducing energy cost and good electricity supply reliability and grid security depends on lower frequency response of microgrid technologies. Integration of Distributed energy sources (DER) and battery storage option becomes a foundational building block in the ultimate smart grid. During the brownout and blakouts, ability of microgrid is to island itself from the distribution system which enables Microgrid enablinf technologies both islanded and online like:

- Advanced Energy storage
- Smart transfer Switch
- Smart Meters
- Distribution Automation (DA)

Several research noted that most important technologies for Microgrid deployment were:

- Communication sensors and technologies,
- Distribution management system,
- Energy management system.

Microgrid can operate as a single collective load within the power system which is the primary advantage of a microgrid from the electric grid's perspective. Small scale renewable enrgy sources and small-scale combined heat and power (CHP) generate distributed power which can increase energy efficiency and environmental advantages over central generation. Microgrid technologies leads to way od thinking about building and designing smart power grids. By energy generation and distribution like heat, Microgrids economically and efficiently integrate buildings and customers needs and enhance power reliability.[37]

Power disturbances and blakouts are either substantially minimized or eliminated due to local power generation, ability to island ,redundant distribution, smart switches operation of microgrid technologies. By selling the power back to the utility/grid when not islandes, Microgrids can generate revenue for businesses and constituent consumers. Microgrids can set the stage for added consumer revenues from carbon credits and plug-in electric vehicles.

CHP operation of Microgrid makes more flexible and efficient power network. It is more convenient to traspoer electricity than transporting heat. In electrical service, several methods are used for measuring power reliability and power quality. While deterioration in power quality has mixed and low effects like voltage swells,imbalances and harmonics etc., unscheduled outages are becomes more threatening nand disruptive to property and people. Universal level of PQR to every load should be provided in the network.[37]

Microgrid Concept observe the number of challenges in dispatch, control and protection point of view. Several new technical challenges are describes below.

- Two modes of operation: Standalone/islanded and Grid connected mode.
- By connection/disconnection of loads, storage system and generators, gradually changes in LV network.
- In islanding operation, Low level of Short-Circuit current due to Power electronics Interfaced distibuted generation(DG).
- Bidirectional power flow in both low voltage and medium voltage generation system.
- High rotating machine penetration which lead to increase fault current and rating of equipment.
- During the fault in LV and MV system, slower tripping time of system.
- Difficult protection tripping due to fault on feeders.

Usually Many microsources are connected to the microgrids by use of power electronics inverter which has uncompatible output with the grid voltage. There are several problems have to be considered due to small fault current contribution of inverter output which is considered below:[37]

- Difficulties in Inverter operation for Short circuit studies hence control strategy dependent operation.
- During the change of operation from Grid connected to islanded mode, fault current level is reduced significantly.
- For Different characteristics, The whole microgrids may have different inverter throughout the whole system.

  Inverter design and application depends on inverter characteristics in cas of individual inverter.

6. Case study: Overview and Description

In this case study, photovoltaics power plant (PVPP) has been connected in two types of distribution system ex. Medium voltage network (22 kV) and Low voltage network (400 V). For analysing the voltage profile and current at each branchs and nodes on the medium and low voltage network, eVlivy software has been used. This software gives the best possible data for the connection of PVPP to distribution network having not more than voltage diffrenece 2% of nominal voltage between PVPP and main power grid network.

6.1 PVPP connection to 22 kV Medium voltage network in Central Bohemian region

The PVPPs are connected to distribution line 22 kV medium voltage. The line is fed from transformer 110/22 kV with the capacity 40 MVA. Impact of the two new PVPP to voltage profile in the medium voltage line has been observed in eVlivy software.

Scheme of the Medium voltage distribution line

In this scheme, Two PVPPs are connected to 22 kV medium voltage distribution line having a consumer loads like Z1 to Z8. Voltage at each nodes and braches before and after connetion of PVPPs has been carried out by use of eVlivy software. By getting the voltage difference at each nodes and braches not more than 2% of nominal voltage of network, PVPPs can be connected to medium voltage network.

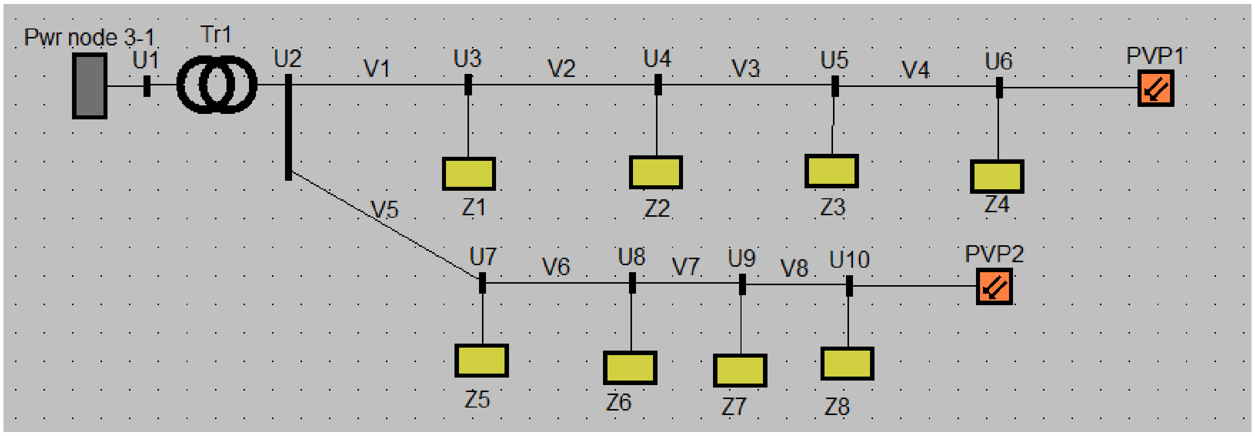

Figure 20: Schematic diagram of Two PVPPs connected to 22 kV medium voltage distribution Network

Distribution Network Parameters

Input parameter of schematic system like Transformer, Overhead lines, consumption system (loads) etc. have been described in this part.

Table 3: Input parameter of transformer of distribution network

Transformer	U_1[kV]	U_2[kV]	S[MVA]	P[kW]	U_k[%]	I_0[%]	P_0[kW]
Tr1	110	23	40	208.2	10.8	0.5	41.30

Table 4: Parameters of two PVPP connected to overhead line 22 kV

Name	Voltage [kV]	Power factor	Active Power [kW]	Reactive Power [kVAr]	Apparent Power [kVA]	Current [A]
PVP1	22	1	3000	0	3000	79
PVP2	22	1	3000	0	3000	79

Table 5: Overhead lines 22 kV parameters

Power line title	Type	Wire Type	Resistance [Ω/km]	Inductive Reactance [Ω/km]	B [μS/km]	Line Length [km]	I_{max} [A]
V1	OH	120AlFe6	0.225	0.363	1.469	4	357
V2	OH	120AlFe6	0.225	0.363	1.469	5	357
V3	OH	120AlFe6	0.225	0.363	1.469	2	357
V4	OH	120AlFe6	0.225	1.256637	1.469	4	357
V5	OH	120AlFe6	0.225	0.363	1.469	6	357
V6	OH	120AlFe6	0.225	0.363	1.469	5	357
V7	OH	120AlFe6	0.225	0.363	1.469	6	357
V8	OH	120AlFe6	0.225	0.363	1.469	5	357

Table 6: Loads consumption parameters on overhead line 22kV

Network Node	Voltage [kV]	Power Factor	Active Power [kW]	Reactive Power [kVAr]	Apparent Power [kVA]	Current I [A]
Z1	22	0.92	579.6	246.909	630	15.886
Z2	22	0.93	465	183.78	500	12.662
Z3	22	0.91	364	165.843	400	10.14
Z4	22	0.95	380	124.9	400	10.159
Z5	22	0.95	380	124.9	400	10.102
Z6	22	0.92	368	156.767	400	10.145
Z7	22	0.93	585.9	231.563	630	16.034
Z8	22	0.92	230	97.98	250	6.368

Impact on short circuit

At operation of new PVPP will be short circuit power occured very little. It is supposed that short circuit current of the PVPP will be ot more than 1.5% of nominal current.

Table 7: Short circuits power and current parameters

Network Node	R22kV	R22kV	PVPP	PVPP
	Short Circuit Power [MVA]	**Short Circuit Current [kA]**	**Short Circuit Power [MVA]**	**Short Circuit Current [kA]**
P = 0 MWp	337	7.613	88	1.130
P = 3,0 MWps	337	7.763	92.1	1.206

Harmonics

Inverters are used in PVPP to change the value of voltage from the DC to AC for the grid connection. There are several powe electronics components that produce current harmonics like 5,7,11,13,17,19,23, and 25th harmonics depends on the type of inverters used. By the Czech standards, the harmonic value nort be allowed parameters. It is necessary to insure the measuring the harmonics value from the investor point of view before come to operation. If harmonics values are higher than its permitted in the standards, the harmonics filtration has to be installed to get the smooth output. In the following tabel are given allowable values of the harmonics.

Table 8: Allowable values of current harmonics at PVPP connection

Current Harmonics U	Allowable Reference current [A/MVA] For 22 kV network	Allowable Current Harmonics i_{vpr} [A]	Inventor Fronius 350 I_v [A/MVA]	Inventor Fronius 500 I_v [A/MVA]
5	0,058	13,22	7,60	1,80
7	0,041	9,35	1,50	2,65
11	0,026	5,92	0,26	0,38
13	0,019	4,33	1,11	0,43
17	0,011	2,50	0,75	0,94
19	0,009	2,05	0,11	0,24
23	0,006	1,37	0,23	0,56
25	0,005	1,14	0,21	0,30

For PVPP connected to medium voltage network are allowed harmonic currents lower than standard values. Induced harmonic voltage have to be higher than 0,2% Un (Voltage for 5 harmonic). Change of voltage for remaining harmonics can not be higher than 0,1 Un.

Allowable values of harmonic current in the medium voltage ditribution system has been carried out according to the CSN EN 50 160 in the given table below.

Table 9: Rated values of the current harmonics in medium voltage system

Number of Current Harmonics U	**Rated current i_{vpr} [A/MVA] For 22 kV network**
5	0,058
7	0,041
11	0,026
13	0,019
17	0,011
19	0,009
23	0,006
25	0,005

Results and Discussion:

Medium voltage and low voltage distribution system parameters like voltage profile and power losses at each nodes and branches have been calculated before and after connection of PVPPs into the distribution system with help of eVlivy software analysis. The main focus is on the overall response performance on distribution system.

Condition before PVPP connnection (Medium voltage 22 kV)

Range of Voltage in MV networks is 22 kV ± 10%.

Table 10: Voltage in network nodes before connection of PVPP

Node	Name	Voltage U [kV]	Voltage Difference U_n [%]
0	U1	114.924	-0.082
1	U2	23.013	-0.552
2	U3	22.896	-0.766
3	U4	22.799	-0.95
4	U5	22.775	-0.996
5	U6	22.732	-1.195
6	U7	22.862	-0.837
7	U8	22.765	-1.016
8	U9	22.685	-1.165
9	U10	22.666	-1.2

Table 10 shows values of voltage at each nodes before connection of PVPPs operation. Value of voltage at generating point is higher than the end point of distribution. Here we got the value 23.013 at node U2 which is higher than the value of voltage at distribution point U10 and U6. There

Table 11: Currents and Power in Network Branches and Nodes Before PVPPs connection

Branch	Node	Active Power P [kW]	Reactive Power Q [kVAr]	Apparent Power S [kVA]	Current I [A]
Pwr node 3-1	U1	-3422.93	-1586.15	3772.573	18.952
Tr1	U1	3422.931	1586.296	3772.637	18.953
	U2	-3376.41	-1344.16	3634.134	91.175
V1	U2	1799.493	728.669	1941.425	48.707
	U3	-1793.08	-721.386	1932.756	48.736
V2	U3	1213.472	474.46	1302.93	32.855
	U4	-1209.83	-472.39	1298.78	32.89
V3	U4	744.82	288.602	798.779	20.228
	U5	-744.267	-289.233	798.492	20.242
V5	U2	1576.922	615.498	1692.785	42.469
	U7	-1569.61	-608.297	1683.36	42.512
Z5	U7	380	124.9	400	10.102
V6	U7	1189.606	483.391	1284.067	32.428
	U8	-1186.05	-481.462	1280.05	32.464
V7	U8	818.062	324.707	880.148	22.322
	U9	-816.04	-325.988	878.743	22.365
V8	U9	230.133	94.415	248.747	6.331
	U10	-229.996	-97.974	249.995	6.368
Z1	U3	579.6	246.909	630	15.886
Z2	U4	465	183.78	500	12.662
Z3	U5	364	165.843	400	10.14
Z6	U8	368	156.767	400	10.145
Z7	U9	585.9	231.563	630	16.034
Z8	U10	230	97.98	250	6.368
V4	U5	380.278	123.408	399.801	10.135
	U6	-380	-124.9	400	10.159
Z4	U6	380	124.9	400	10.159

Condition after PVPP connection (Medium Voltage 22kV) with capacity 3000 kW, power factor = 1.

Table 12: Voltage in network nodes after connection of PVPP

Node	Name	Voltage U [kV]	Voltage Difference U_n [%]
0	U1	114.925	0.014
1	U2	23.024	0.109
2	U3	22.985	0.213
3	U4	22.984	0.429
4	U5	22.998	0.543
5	U6	23.032	1.436
6	U7	22.99	0.299
7	U8	22.99	0.519
8	U9	23.027	0.846
9	U10	23.105	1.205

Table 13: Currents and Power in Network Nodes after PVPPs

Nodes	Name	Active Power P [kW]	Reactive Power Q [kVAr]	Apparent Power S [kVA]	Current I [A]
Z1	U3	579.6	246.909	630	15.825
Z2	U4	465	183.78	500	12.56
Z3	U5	364	165.843	400	10.042
Z4	U6	380	124.9	400	10.027
Z5	U7	380	124.9	400	10.045
Z6	U8	368	156.767	400	10.045
Z7	U9	585.9	231.563	630	15.796
Z8	U10	230	97.98	250	6.247

Table 14: Values of Current and Power in Network Branches after PVPPs

Branch	Node	Active Power P [kW]	Reactive Power Q [kVAr]	Apparent Power S [kVA]	Current I [A]
Pwr node 3-1	U1	579.792	-1572.51	1675.993	8.42
Tr1	U1	-579.791	1572.646	1676.119	8.42
	U2	625	-1358.05	1494.963	37.488
V1	U2	-202.656	741.687	768.876	19.281
	U3	203.664	-743.168	770.569	19.356
V2	U3	-783.277	496.238	927.24	23.291
	U4	785.112	-497.149	929.278	23.343
V3	U4	-1250.11	313.379	1288.787	32.374
	U5	1251.522	-312.641	1289.981	32.384
V5	U2	-422.332	616.374	747.182	18.737
	U7	423.761	-618.728	749.932	18.833
V6	U7	-803.773	493.809	943.344	23.69
	U8	805.671	-494.62	945.386	23.741
V7	U8	-1173.66	337.874	1221.324	30.671
	U9	1177.472	-336.367	1224.574	30.703
V8	U9	-1763.39	104.771	1766.501	44.291
	U10	1770.013	-97.958	1772.721	44.297
V4	U5	-1615.52	146.797	1622.178	40.723
	U6	1620	-124.9	1624.808	40.73
PVP1	U6	-2000	0	2000	50.135
PVP2	U10	-2000	0	2000	49.976

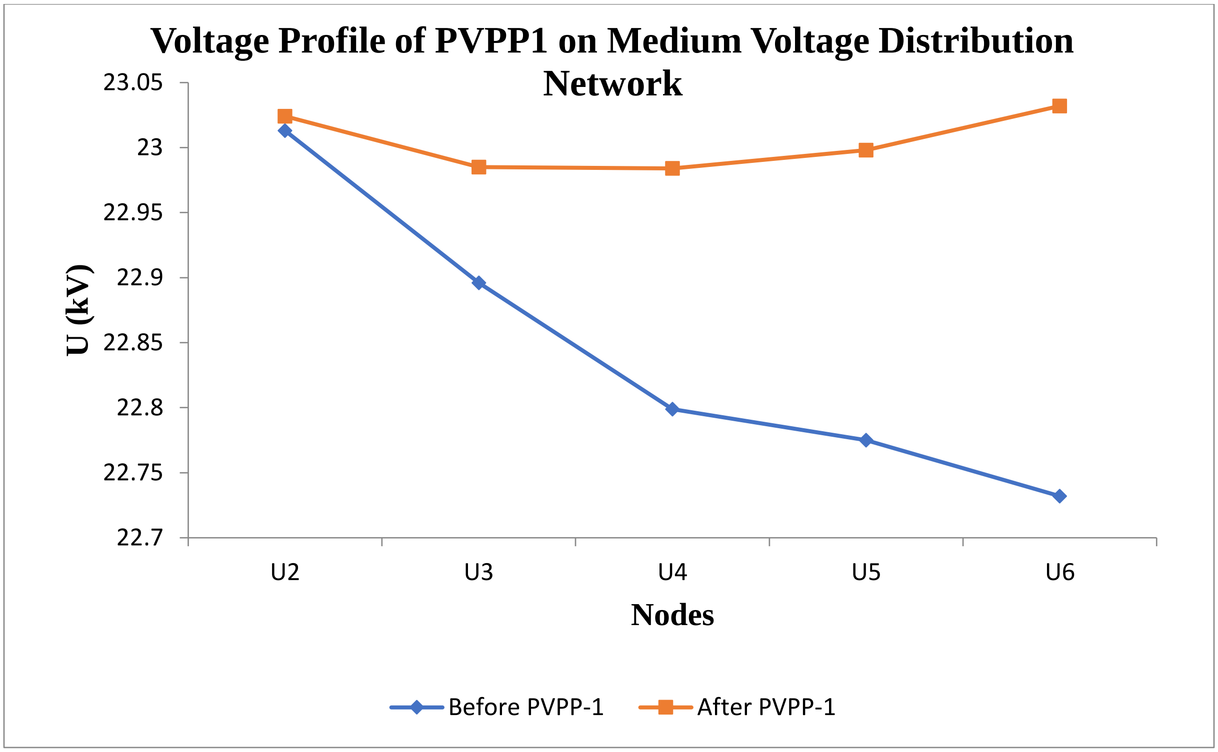

Figure 21: Voltage Profile of PVPP1 on Medium Voltage Distribution Network

The measured voltage profile at each nodes has been described in the figure. Before connection of PVPP1 into the distribution network, Voltage profile decrease from node U2 to U6 gradually. But after connection of PVPP1 at node U6, value of voltage profile increase from U2 to U6.

Before connection of PVPP2 into the distribution network, Voltage profile decrease from node U2, U7 to U10 gradually. But after connection of PVPP1 at node U10, value of voltage profile increase from U2,U7 to U10.

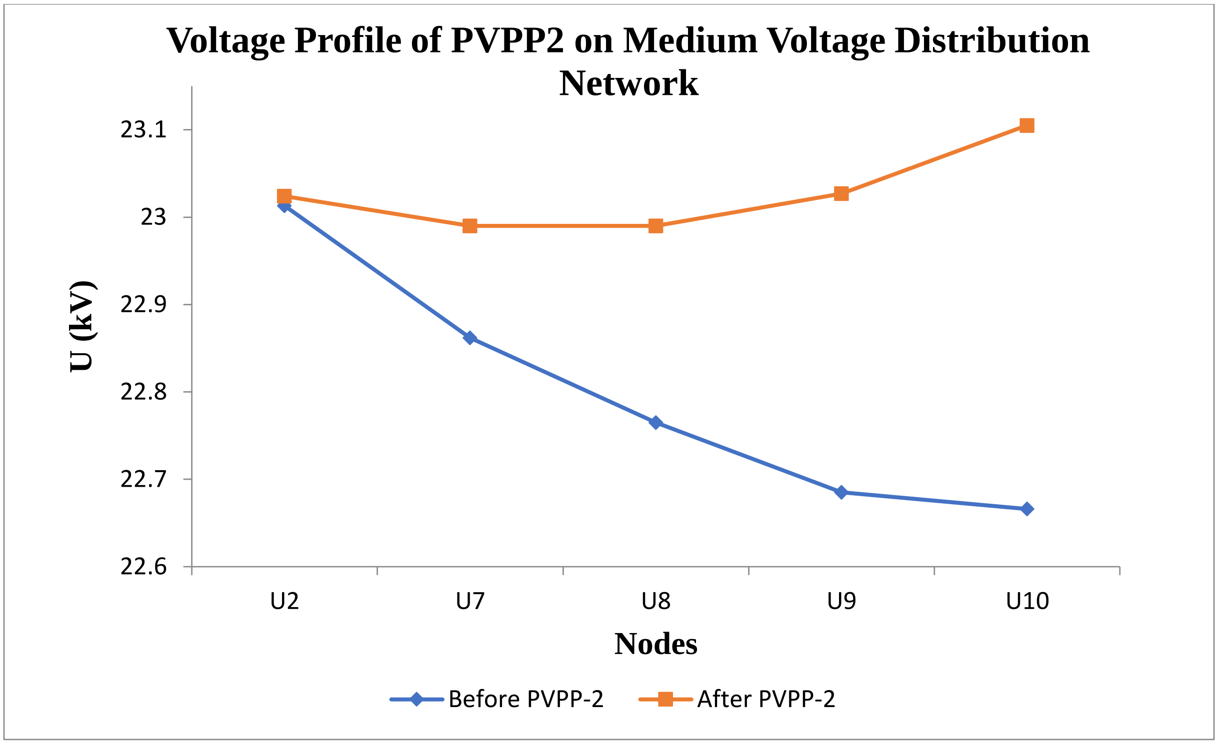

Figure 22: Voltage Profile of PVPP2 on Medium Voltage Distribution Network

Difference of voltage before and after connection of PVPP to distribution network must be lower than 2% of nominal voltage.

Voltage difference of each node can be described by given formula:

$$\Delta u = \frac{U_A - U_B}{U_{NOM}} .100\ [\%]$$

Where:

U_A is voltage after connection of PVPP

U_B is voltage before connection of PVPP

U_{NOM} is nominal voltage 22 kV

We use the equation for evaluation of impact of PVPP1 at node U6 and for PVPP2 at node U10.

6.2 PVPP connection to 400 V Low voltage network in Central Bohemian region

The PVPPs are connected to distribution line 400 V low voltage. The line is fed from transformer 22 kV/400 V with the capacity 0.4 MVA. Impact of the PVPPs to voltage profile in low voltage line has been observed in eVlivy software.

Scheme of the Low voltage Distribution line

In this scheme, Three PVPPs are connected to 400V low voltage distribution line having a consumer loads like Z1 to Z4. Voltage at each nodes and braches before and after connetion of PVPPs has been carried out by use of eVlivy software. By getting the voltage difference at each nodes and braches not more than 2% of nominal voltage of network, PVPPs can be connected to low voltage network.

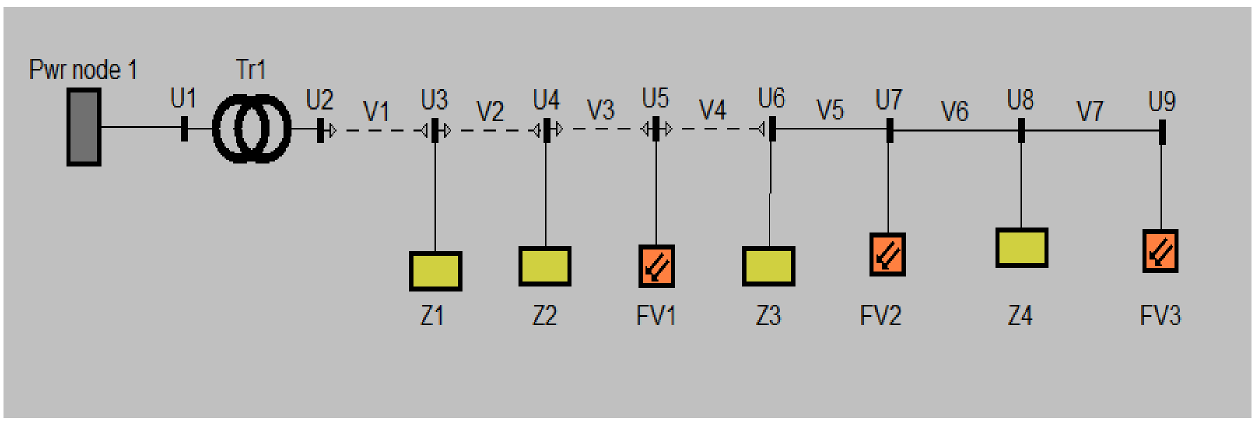

Figure 23: Schematic diagram of Two PVPPs connected to 22 kV medium voltage distribution Network

Distribution Network Parameters

Table 15: Network 22 kV parameters

Name	U_n [kV]	U_{oper} [kV]	I_{zkr} [kA]	S_{zkr} [MVA]
NET_22	22	23	1.57	60

Table 16: Input parameters of Transformer

Name	U_{n1} [kV]	U_{n2} [kV]	S_t [MVA]	P_k [kW]	u_k [%]	Primary connection	Secondary connection	I_{n1} [A]	I_{n2} [A]
TR_3	22	0.4	0.4	4.6	4	D	YN	0	0

Table 17: Low voltage lines parameters

Name	Type	Cros-section [mm²]	Un [kV]	R [Ω/km]	X [Ω/km]	B [μS/km]	Length [km]	Imax [A]
V1	120AYKY70	120	0.4	0.258	0.069	1	0.06	245
V2	120AYKY70	120	0.4	0.258	0.069	1	0.06	245
V3	120AYKY70	120	0.4	0.258	0.069	1	0.06	245
V4	120AYKY70	120	0.4	0.258	0.069	1	0.1	245
V5	70AES70	70	0.4	0.443	0.084	1	0.08	178
V6	70AES70	70	0.4	0.443	0.084	1	0.08	178
V7	70AES70	70	0.4	0.443	0.084	1	0.1	178

Table 18: Load consumption parameters

Name	U_n [kV]	I [A]	cos φ [-]	P [kW]	Q [kVAr]	S [kVA]
Z1	0.4	8.7	0.92	9.5	3.9	10
Z2	0.4	20.8	0.92	13.8	5.9	15
Z3	0.4	20.8	0.95	13.8	5.9	15
Z4	0.4	8.7	0.95	9.5	3.9	10

Table 19: PVPPs Parameters

Name	**U_n [kV]**	**I [A]**	**cos φ [-]**	**P [kW]**	**Q [kVAr]**	**S [kVA]**
FV1	0.4	6.95	1	5	0	5
FV2	0.4	4.2	1	3	0	3
FV3	0.4	20.7	1	15	0	15

Results and Discussion (Low Voltage 400 V)

Network operation - PVPPs are out of operation P = 0

Condition before PVPP connnection (Low voltage 400 V)

Table 20: Voltage values at each Node

Name	U [kV]
U1	22,994
U4	0,417
U5	0,415
U6	0,413
U7	0,412
U8	0,411
U9	0,410
U10	0,409
U11	0,409

Table 21: Values of Current and power at each Node and PVPPs

Name	Node	I [A]	P [kW]	Q [kVAr]	S [kVA]
Z1	U5	13,913	9,200	3,919	10,000
Z2	U6	20,948	13,800	5,879	15,000
FV1	U7	0,000	-0,000	-0,000	0,000
Z3	U8	21,081	14,250	4,684	15,000
FV2	U9	0,000	-0,000	0,000	0,000
Z4	U10	14,114	9,500	3,123	10,000
FV3	U11	0,000	-0,000	-0,000	0,000

Table 22: Load flow in LV Network branches

	Uzel	**I [A]**	**P [kW]**	**Q [kVAr]**	**S [kVA]**
NET_22	U1	1,272	-47,356	-17,979	50,654
TR_3	U1	1,272	47,356	17,978	50,654
	U4	69,954	-47,289	-17,754	50,512
V1	U4	69,953	47,288	17,753	50,511
	U5	69,953	-47,061	-17,693	50,277
V2	U5	56,056	37,862	13,773	40,289
	U6	56,056	-37,716	-13,734	40,138
V3	U6	35,155	23,915	7,856	25,172
	U7	35,155	-23,858	-7,840	25,113
V4	U7	35,168	23,868	7,840	25,122
	U8	35,168	-23,772	-7,814	25,023
V5	U8	14,087	9,522	3,130	10,024
	U9	14,087	-9,501	-3,126	10,003
V6	U9	14,101	9,511	3,127	10,012
	U10	14,101	-9,490	-3,123	9,990
V7	U10	0,014	-0,010	-0,000	0,010
	U11	0,014	0,010	0,000	0,010

Condition after PVPP connection (Medium Voltage 22kV) with capacity 5 kW, 3 kW and 15 kWand power factor = 1.

Network operation with PVPPs

Table 23: Values of Voltage in nodes

Name	U [kV]
U1	22,994
U4	0,417
U5	0,416
U6	0,415
U7	0,415
U8	0,415
U9	0,415
U10	0,416
U11	0,417

Table 24: Load flow in LV network branches

Line	Node	I [A]	P [kW]	Q [kVAr]	S [kVA]
NET_22	U1	0,749	-23,990	-17,734	29,833
TR_3	U1	0,749	23,990	17,734	29,833
	U4	41,201	-23,967	-17,657	29,769
V1	U4	41,199	23,967	17,656	29,768
	U5	41,199	-23,888	-17,635	29,692
V2	U5	27,884	14,688	13,716	20,096
	U6	27,884	-14,651	-13,706	20,063
V3	U6	10,943	0,852	7,827	7,873
	U7	10,943	-0,846	-7,826	7,871
V4	U7	13,580	5,846	7,826	9,768
	U8	13,580	-5,832	-7,822	9,757
V5	U8	12,505	-8,418	3,138	8,984
	U9	12,505	8,435	-3,135	8,999
V6	U9	8,718	-5,435	3,135	6,274
	U10	8,718	5,443	-3,133	6,280
V7	U10	20,744	-14,943	0,011	14,943
	U11	20,744	15,000	-0,000	15,000

Table 25: Values of Current and Power at each ode and PVPPs

Name	Node	I [A]	P [kW]	Q [kVAr]	S [kVA]
Z1	U5	13,876	9,200	3,919	10,000
Z2	U6	20,848	13,800	5,879	15,000
FV1	U7	6,951	-5,000	0,000	5,000
Z3	U8	20,878	14,250	4,684	15,000
FV2	U9	4,169	-3,000	0,000	3,000
Z4	U10	13,882	9,500	3,123	10,000
FV3	U11	20,744	-15,000	0,000	15,000

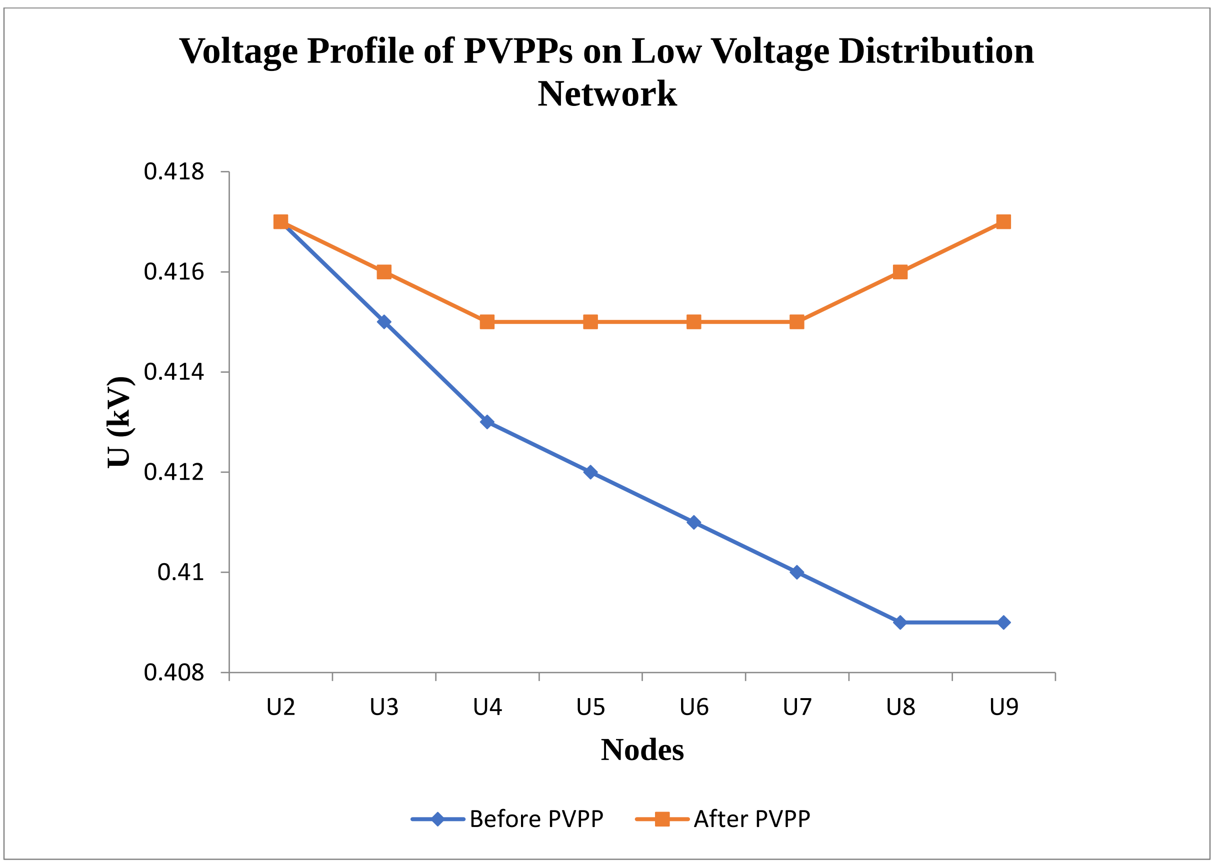

Figure 24: Voltage Profile of PVPPs on Low Voltage Distribution Network

7. Conclusion

Review of different types of renewable energy sources and supply has been described theoretically. Both most useful renewable energy sources like Solar energy and Wind Energy has been mentioned in detail with different types of utilization aspects. Solar power generation and Wind power generation from past to recent years with maximum power generating capacity is going to become a future for power production from renewable energy sources. Distributed Generation is become a good option for rural and village areas to produce power at generation station as there is no requirement of long length trasmission line. Current challenges and impact of microgrid in distribution network have been summerized based on condition of connection of renewable energy sources into the microgrid.

By integration of PVPP into the distribution network affect the overall power system performance like Voltage Profile , Network Power losses, etc. This Thesis study assessed the value of voltage profiles at each node in the distribution line before and after connection of PVPP into the Medium and Low voltage distribution line. From the analysis and calculation of network parameters using eVlivy software, it is very important to balance the voltage profile during the integration of RES into the distribution network. Voltage difference in Network must be lower than 2% of nominal voltage before and after connection of PVPP into Medium and Low Voltage distribution line. It has been observed that, Voltage Profile at each node increase slightly after integration of PVPP comapre to before integartion of PVPP into both distribution network.

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