International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 09 | Sep 2018 www.irjet.net p-ISSN: 2395-0072

FUTURE ENERGY SYSTEMS: MICROGRIDS AND INTEGRATION OF PHOTOVOLTAICS INTO MICROGRIDS

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Abstract- *Photovoltaics are being seen as a reliable alternative to the traditional energy sources such as oil, natural gas, or coal. Power generation systems based on renewable energy sources are bound to experience a large development. It is therefore pertinent to discuss and achieve a lucid understanding of concepts related to microgrid technology and implementation, such as smart grid and virtual power plant, types of distribution network, markets, control strategies and components. Among the components special attention is given to energy storage devices and operation and control of power electronics interfaces. A peek into future trends of PV and its integration into micro grids is also important to get required motivation.*

Keywords*: Smart Grids, Microgrids, Virtual Power Plant, Distribution Network, Power Electronics, Photovoltaics*

Introduction

The consensus among climate scientists is unanimous and utterly lucid that man-made greenhouse gases are dangerous and lead to perilous climatic changes. Hence, it is of utmost importance that ways of using energy more effectively and generating electricity without the production of CO_2 are found. The effective management of loads and reduction of losses and wasted energy needs accurate information while the use of copious amounts of renewable generation requires the integration of load in the operation of the power system in order to help balance supply and demand. Once all the parts are monitored, its states become observable and many possibilities of control emerge. This type of a cost-effective, de-carbonized power system with monitoring and control provided is the basic idea behind the inception of Smart Grids. The main impetus to understand and ameliorate smart grids is to give greater visibility to lower voltage networks and to enable the participation of customers in operation of power systems. Smart grids are deemed to support improved energy efficiency and allow much greater utilization of renewable. The advancements required can be grouped into three main technologies: first, the information and communication systems, second, sensing, measurement, control and automation and finally, power electronics and energy storage. In addition to the evolution of new technologies, some other aspects have motivated India, the increasing environmental concerns, and the depletion of traditional fossil fuel reserves; have motivated a shift towards more sustainable technologies that make use of renewable energy sources, like wind and solar irradiation.[1] Besides, governments are getting more and more aware of the environmental impact of the carbon-intensive traditional energy supply, and this pushes towards a sustainable direction even further.

However, when renewable energy sources and storage systems are integrated in an uncoordinated way, these new components may create technical, economical, and operational problems. Along with that, due to the intermittent and uncontrollable nature of renewable energy sources, their integration in power systems pose a challenge for the successful operation of power systems; especially because keeping the balance between generation and consumption becomes a difficult task with such unreliable sources. Smart grids, in fact, are a way to address this monumental challenge. However, this is possible only with the use of power electronics devices, the selection of appropriate system topologies and the application of suitable control and protection schemes in networks.

Smart grids, not only underline the concepts of intelligent integration, sustainability, low cost and security of the electricity supply but also focuses on the use of ICT, coordination and efficiency of the system, while ensuring reliability and stakeholders' involvement. Also, there is huge focus on the concepts of flexibility and interactivity of the Smart Grid, along with the optimization of system operation and an efficient and economic supply. The European Commission defines Smart Grids as energy networks that can automatically monitor energy flows and adjust to changes in energy supply and demand accordingly. When coupled with smart metering systems, Smart Grids can reach customers and suppliers by providing information on real-time consumption. With smart meters, consumers can adapt - in time and volume - their energy usage to different energy prices throughout the day, saving money on their energy bills by consuming more energy in lower price periods. Smart grids, as already stated, also underscore the pertinence of integrating all low carbon generating technologies but, as sun doesn't glow continuously and wind doesn't blow all the time.[2] So, combining information on energy demand with weather forecasts can allow grid operators to better plan the integration of renewable energy into the grid and keep a power balance. Smart grids also provide the opportunity for consumers who produce their own energy, to respond to prices and sell excess power to the grid.

To pave the way for successful smart grid implementation we must ensure that each small area of the network can be operated in a flexible, reliable and stable manner. Such a single cell of the network can be referred to as microgrid. A microgrid is a small network of consumers connected together with a localized source of energy. A micro grid though generally attached to a national grid is perfectly capable of working independently. Microgirds are seen as the main building blocks of the future sustainable smart grids. In other words, to achieve large-scale grids, we have to properly build them up from the micro level. Thus, micro grids are simply small-scale networks that are able to facilitate the integration of renewable energy sources, like photovoltaic, and controllable loads through flexibility in operation and control.

Operational Challenges of Power Systems:

To understand how a microgrid works, one must first understand the methodical workings of a traditional power system. A web of numerous electrical components deployed to supply, transfer, store, and use electric power is known as electrical power system. Traditional power systems consist of three main parts: generation that supplies the power, transmission, that carries the power from the generating centers to the load centers, and distribution, that feeds the power to consumers. In traditional power system, most of the electrical energy gets generated from non-renewable sources like coal, oil and natural gases. In fact, yearly gross electricity generation in India by coal is 944,861 GWh (2016-2017) while yearly gross electricity generation by solar is merely 12,086 GWh. From generating centers the electricity produced undergoes a bulk movement to electrical substations located near demand centers. This long distance transmission of electrical power takes place through high voltage transmission lines. Transmission lines when interconnected with one another form a transmission network. The final stage of a power system consists of delivering of electric power from the transmission system to end-use consumers.[3] In this, distribution stage, distribution substations connect users to the transmission system through transformers of different sizes in order to step the voltage levels up or down. Along with the use of transformer between the transmission and distribution areas, transformers are also used between the generators and transmission lines and between the lines of different voltage levels.

Generation, transmission, and distribution are generally vertically integrated in traditional power systems. Power generation is centrally performed at large power plants, which are situated at far off places leading long distances geographically between generation centers and the end-user customers. This makes power systems vulnerable to sudden faults due to various reasons such as adverse weather conditions, accidents, and unexpected component failure, resulting in power interruptions when the system is not robust enough. Moreover, there is little to no role of demand side in power system operation in a traditional set up. This implies that the distribution system, feeding load, despite being humongous and massive is almost entirely passive. With the exception of some very large loads for instance steelworks and aluminum sheltering, there is no real time monitoring of either the voltage or the current drawn by it. There is, thus, very little interaction between the loads and the power system other than the supply of load energy whenever it is demanded. As in traditional power systems, there is no flexibility on the demand side. This leads to the centrally structured power plants becoming solely responsible when it comes to matching generation and consumption. This inevitably increases the price of electricity, especially during peak hours. Along with that, aaccording to the Ministry of Power, averaging 26 per cent of total electricity production, and as high as 62 per cent in some states, India's transmission and distribution losses are amongst the highest in the world. These losses do not include non-technical losses like theft etc. With the ever growing and well suited attention given towards the renewable like wind and solar power, over the past decade, such energy sources have been installed, at some places, particularly at the distribution side. It should be mentioned here that the existing power systems were not designed to integrate highly intermittent renewable energy sources, and therefore existing power systems are facing unprecedented challenges. For example, the introduction of distributed generation at the distribution side has the potential to raise a number of power quality problems such as voltage variations and harmonic problems. Thus, there is an understanding that power system can be de-carbonized at a realistic cost if and only if it is incessantly monitored and controlled effectively. Another factor to be considered while trying to integrate such energy sources is that the generation of active power at the downstream network has the potential to dramatically affect the flow of power in the upper network. This active power generation near distribution centers can lead to power flows to become bidirectional in future power systems.[4] This upstream power flow can cause protection and stability problems in the existing network, as the installed equipments of traditional power systems, were designed to operate in a system where there is a unidirectional flow of power from generation to distribution.

Another complex challenge in power systems is generation expansion. With the needs of electricity growing at an exponential rate, it is must for the power systems all around the globe to increase generating capacity to keep up with the increasing demands. However, the construction of power plants requires large investments and the optimal size and location of these plants is not easily obtained. On top of this, expensive transmission and sub-transmission lines need to be built. Additionally, the distribution networks shall be required to be reinforced or expanded as well, in order to meet the requirements of large loads, such as electric vehicles which readily becoming common and gaining popularity.[5] As generation, transmission and distribution are all dovetailed it is only rational to address the challenges encumbering each part of the power system together.

Some operational aspects of the power grid that must be seriously considered over the long term in short and large scales are:

- Power quality
- Voltage management
- Grid stability
- Congestion management
- Fast and slow reserves
- Adequacy and resiliency
- Security of supply

Additionally, in future power systems, energy storage systems may play a vital role to stabilize the system as such systems store a large amount of electrical energy, which can be provided later during several hours or days, depending on the system design. Power electronics devices too are gaining more and more important roles in our power system in keeping the system stable as PED are used to control and convert electric power. They serve as an interface to connect distributed sources to the power system as they allow fast control of active and reactive power leading to many fast phenomena, such as frequency and voltage deviations to be effectively addressed. These new actors will play crucial role in achieving high control and to match generation and consumption in future power systems.

Distribution Networks

For large scale renewable energy integration, the distribution grids need a transition from the present so-called passive distribution networks to active distribution networks. As a result of which it is pertinent to understand the differences between passive and active networks and the challenges in operation and control of an active network.

Most of the distribution networks in existence at present are passive. In passive distribution network the flow of power takes place unidirectional from the upstream to the downstream network. In passive networks voltage and frequency control are performed exclusively at the generation and transmissions sides.

With ADN seeming to be a potent and effective approach to solve the problems such as the high-penetration of intermittent renewable energy, interaction between grid and charge-discharge facilities, and also the analysis and operation of smart grid a little focus on the same poses extreme necessity. After all, active distribution network (ADN),based on the application of information and communication technology (ICT) and advanced metering infrastructure(AMI),is one of the alternative solutions to the problem of arduous planning and difficult operation of traditional passive distribution in accommodating the high penetration of distributed energy resources(DER). ADN can balance the power at distribution levels and between transmission and distribution levels that is, ADN will be an infrastructure as a regional exchange of all kinds of energy. According to the definition given by CIGRE, an active distribution network is an efficient platform to control a combination of distributed energy resources, including distributed generators, loads and storage.[6] ADN thus have the possibility to manage the electricity flows using a flexible network topology, make the flow of power bidirectional and cause a decentralization of decision-making and control.

Another starking contrast between passive and active networks lies in the way network management operation and exchange of information take place. In passive networks control and monitoring of distributed generation renewable sources is low, and is often performed by the transmission system operator.

There is a lack of regulations, as well, when it comes to distributed generators contribution. Active networks, however, have the potential to feature tools to manage distributed energy sources and thus, flexibility support will be required between distribution system operators and transmission system operators. New system services for distribution system operators are needed to be arranged for ADN via commercial ancillary services and grid codes. In passive distribution networks, a topic that requires tones of attention is information exchange as in such networks there is little or no communication between Transmission System Operators and distributed generators owners or distribution system operators.

Another probable benefit of active network over that of passive is that through the advent and implementation of information and communication technologies (ICT)power generation and consumer demand can be efficiently matched.

Moreover, unlike passive networks, active distribution networks have the potential to support stand-alone operation since generation is decentralized and it is often coupled with storage units. Additionally, due to the proximity of distributed generators to the demand centers it becomes feasible to reduce the transport-related losses. Finally, Active networks have the potential to provide the network with support by relieving congestion and offering restoration after faults, among other ancillary services.[7]

It would be remiss if there isn't a mention of technical challenges encumbering ADN that include but are not limited to the following:

- The control of a large number of distributed energy resources
- Requirement of substantial investments for making the current distribution networks active and smart as well as offering both offline and real-time information exchange.

- Arduous and complicated automation, implementation and power electronics- based frequency and voltage control.

Electrical power grid layers

The operation of power systems can be represented in three layers. The highest layer is the "power grid" layer, where generation, transmission, and distribution are carried out. The second layer, or intermediate layer within the distribution network, is defined as "utility service area", which may include various residential, industrial, or commercial regions. At the lowest level, one will find a microgrid, which may consist of a few feeders or electrical components. A supervisory control system can be present; demand side management scheme might or might not be implemented and distributed generation units may be connected.

Fundamental characteristics of microgrids

It has been more than a decade since the inception of the concept of microgrids. According to Community Research and Development Information Service (CORDIS) Europe, a microgrid is defined as a series of electrical loads, elements of generated power supply and storage elements that, connected to the electric grid by means of a single point of connection, are all linked through a strategy that manages both the flow of energy within the grid as well as the interchange of power with the main supply grid.

Although in the existing literature, there are various of definitions for a microgrid, there are 4 fundamental characteristics that are common to each one of them.

- A microgrid is a localized integration platform where generation, storage and demand are all together placed within a local distribution grid.
- A microgrid tends to be able to work in two operation modes: grid-connected mode and emergency mode (or islanded mode)
- A microgrid enables an active operation of the distribution network.
- A microgrid has the capacities to operate at multiple scales. For instance, a low scale microgrid could simply be limited to one house with PV panels, power converters and loads. A microgrid catering to a factory could be a medium scale microgrid and a bigger scale microgrid could be a university campus, or a society.

The most striking features of Microgrids are higher resiliency, efficiency and modularity.

Classification of microgrids in terms of Power Capacity:

One of the many ways through which microgrids can be categorized[8] is in accordance with power capacity:

- High-power microgrids: Such microgrids can consist of several distribution feeders, to which different types of loads, renewable sources and storage units can be connected and have power capacity that typically ranges from a hundreds of kilowatts to a few Megawatts.
- Medium power microgrids: Medium power microgrids comprise of a single feeder that connects generators and loads at distribution level. A bidirectional flow exists at the single feeder as well as information exchange between the microgrid controller and the micro-generation owners at the distribution level.
- Low power microgrids: Low power microgrids are made up of of a single feeder and can be connected to several loads and generators. A low power microgrid can even be at a small scale, simply a single household that works both as load and generator.

Misconceptions apropos microgrids:

Being a relatively new concept there are various misconceptions surrounding microgrids. First of all, many tend to assume that microgrids are isolated and purely independent networks that solely have the capability to function in islanded mode. However, a microgrid can operate in grid-connected mode as well. A microgrid can not only exchange power with central grid but even provide necessary support to its services. It is also sometimes thought that microgrids are invariably expensive to build, in each and every case. Although, to be candid the price of electricity is high for some microgrids that contain a piqued participation of RES, but they, in fact, can still constitute as a cheaper alternative in countries where the infrastructure is not at all available at present.

Along with that a very common belief is that a microgrid can simply comprise of any group of customers who own micro-sources. However, as management and coordination is a vital part of microgrids and active distribution networks, if there is no interaction with a central microgrid controller or coordination between the actors, a group of customers owning micro-sources cannot possibly be considered as a microgrid. Another prevalent misconception is that microgrids are composed of only spasmodic renewable energy sources (RES), and because of the sporadic and unreliable nature of RES, microgrids too are unreliable and easily subject to failures and black-outs. Quite contrary to this belief, microgrids are integration platforms, which allow the connection of various renewable sources as well as traditional units. A good energy management system can therefore, certainly prevent the microgrid from experiencing the dreaded failures and black-outs. Finally, one of the biggest misapprehensions is that it poses a threat to consumers privacy[9]. However, from the perspective of cyber-security, physical consequences of malicious commands can be modeled as contingencies to assess risk and develop mitigations well in advance and although working towards a cyber secure for the smart grid is bringing together two communities that until recently have spoken different languages, research in the areas are providing fruitful results. Moreover, demand side management is performed in order to increase consumers' comfort and their role in the decision-making process instead.

Virtual power plant

Micro-generation, distributed generation, electric vehicles, energy storage devices and other Distributed Energy Resources (DER) are gaining vogue due to various initiatives to de-carbonize the power system. A virtual power plant (VPP) is an alternative to cope with the challenges introduced by distributed generation. However, a virtual power plant is significantly different from a microgrid.

The concept of VPP is is to aggregate many small generators into blocks that can be controlled by the system operator and then their energy output is traded. Through aggregating DERs into a portfolio, they become visible system operator and can be controlled. Thus, this clustered distributed energy resources(DER) that is collectively operated by a central controller can take the place of a conventional power plant, while providing more flexibility as the aggregate output of VPP is arranged to have similar technical and commercial characteristic as a central generating unit.

The clustered capacities of several distributed generators are hugely impacted by the materialization of the Internet of Things (IoT) and Information and communication technologies (ICT). The VPP concept allows individual DERs to gain access to and visibility in the energy markets. The VPP provides mediation between the wholesale electricity market and DERs. In this way, owners of PV panels can participate in the electricity trading market through the VPP. A virtual power plant can also provide necessary support to both the distribution and the transmission system operators. Furthermore, system operators can benefit from the optimal use of all the available capacity connected to the network.[10]

Difference between microgrids and virtual power plant:

- Locality: In a microgrid, energy resources are located within the same local distribution network and they aim to satisfy primarily the local demand. In a VPP, distributed generators are not necessarily placed in the same local network and they are coordinated over a wider geographical area.
- Size: The installed power capacity of a microgrid ranges from few kilowatts to several megawatts. A VPP, on the other hand, can have much higher power rating.
- Customer involvement: Major focus, in the case of microgrids, is on producing power so as to satisfy a localized consumption. A VPP, instead, considers consumption as a flexible resource that can be traded in the energy market.

Energy storage technologies

With increasing renewable energy penetration, energy storage components become crucial. For microgrids and balancing solar energy the battery energy storage is generally considered suitable. With a lot of technical advancements undergoing around the world, the capital costs of battery technologies are in general swiftly lowering. Particularly, the capital costs of li-ion batteries are expected to become below 200 EUR per kilowatt hour by 2020. The life time of batteries, be it lead acid, nickel cadmium, sodium sulphur, lithium ion or flow batteries, of course, depend on the type of services they provide which ranges from 5 to 15 years, depending on number of cycles, depth of discharge and many other parameters such as c rate (charge and discharge rate) and temperature. Currently, the most mature technology is that of Lead acid battery. Albiet, the li-ion battery is developing pretty fast as well, the flow battery, however is still under development. The most widely used rechargeable battery technology in use is the Lithium-ion battery. Sony first developed the lithium ion technology in Japan in 1991.

The discharge time, the time required to transfer from fully charged to fully discharged status, is highly fitting when choosing any energy storage device. Super capacitors have very low discharge time, typically, approximately about seconds. Most of the battery technologies (except sodium sulphur and flow batteries) along with flywheels have the discharge time from one minute to tens of minutes. Sodium sulphur batteries and flow batteries, which are suitable options for stationary applications, might have the discharge time up to several hours.

It should be noted that both power and energy are also relevant factors when the question of energy storage comes. It is commonly noted that capacitors and super capacitors have large power density with low energy content. Storage units of this kind are very suitable for relatively fast power-based services like transient voltage stability. Storage units like flywheels and batteries have reasonable amount of both power and energy densities. The connection of batteries determines the amount of power. If battery cells are connected in parallel then the equivalent resistance draws up high current, and thus, provides high power. If the cells are put them in series, then due to high voltage the power becomes low.[10] Therefore, ideally, a combination of batteries and capacitors would be the best-such a combination of different storage technologies is called hybrid energy storage.

In order to find the suitable size of storage technologies in microgrids it is important to know to what extent they are charged or discharged. As it is known that the difference between generated power and consumed power goes to get stored in energy storage devices. During this period, the minimum energy charged to energy storage systems is

$$E_{Ch}^{\min} = \int (P_{Load} - P_{Gen,\max}) \cdot dt$$

If the generation is lesser than energy required for consumption then some amount of energy moves from energy storage unit to load. During this period, the minimum energy discharged from energy storage systems is:

$$E_{Dch}^{\min} = \int (P_{Gen,\min} - P_{Load}) \cdot dt$$

However there is also a DC / AC power conversion which has power losses. If we consider both E^{min} (discharging) divided by discharging efficiency and E^{min} (Charging) multiplied by charging efficiency, then the suitable size of the energy storage system is selected as the maximum value of these values taking into account the charging and discharging efficiencies.

Optimal photovoltaic sizing

Many areas such as Asia, Africa, South America and southern Europe have high solar irradiation over the period of one year and some parts of North America and northern Europe too have fairly well solar irradiation, especially in summer time. It is important to note, however, that due to spasmodic and unreliable nature of solar energy storage devices are a must. Adding PV and wind together and throwing in storage device with a slight oversize can actually prove to be a sensible energy management system for maintaining reliability.

Power electronic interface

Power electronic interface is required for connecting components such as generators (solar or any other and storage with the loads) within a microgrid. Different conversion steps such as DC-AC, but also AC-DC or DC DC are needed to match the input and output voltage of the single component to a microgrid voltage. In order to convert AC to DC, and also invert DC to AC, there are a large number of possible topologies. One of the most popular among these are four switch two-leg inverter which inverts the DC to a single phase AC. Another very prevalent topology is a six switch three-leg inverter which inverts the DC to a three-phase AC.[11]

It is interesting to see that if these switches are replaced with diodes then a diode bridge-based topology is created that unlike switch-based inverter does not have control over the voltage and not able to conduct bidirectional flows. In order to connect a PV unit to a AC microgrid, first it is required to invert the input DC voltage to three-phase AC, which can be a common three phase inverter. Then, the three phase voltage can be stepped up using a transformer, which is usually expensive and bulky. To eliminate the bulky transformer, it is possible to use a smaller-size high frequency transformer, which also provides isolation. The high frequency transformer is placed between these two converters. Finally the DC voltage output of the diode bridge is inverted to AC. To connect a PV unit to a DC microgrid, typically a boost DC DC converter is used where the DC link voltage of the grid has high value. To increase the performance and efficiency, a DAB converter topology is used.

Design of photovoltaic converters families and photovoltaic topologies

Advances in technology have led to a transformation in the inverter topologies from large thyristor-equipped grid connected inverters to smaller insulated-gate-bipolar-transistor (IGBT) equipped ones. An IGBT is a three-terminal power semiconductor switching device which provides both high efficiency and fast switching. These transistors permit to increase the power switching frequency in order to extract more energy and fulfill the connecting standards. In general, PV cells are used in both kinds of applications, they can be connected to the grid (grid connection application) or they can be used as isolated power supplies.[12]

There are three distinct designs of converters families defined as:

- Central converters- The central converters connect in parallel and/or in series on DC side, One converter is used for the entire PV plant (often divided into several units organized in master-slave mode)
- Module-oriented or module-integrated converters: The module oriented converters with several modules usually connect in series on DC side and in parallel on AC side. In the module-integrated converter topology one converter per PV module and a parallel connection on AC side are used. Although this topology optimizes the energy yield, it has lower efficiency than the string inverter.
- String converters: As an extension of a module-level power converter is the string convertor, which is suitable for a string or parallel strings of modules connected in series.

In general, PV topologies can be classified into two major categories:

- PV inverters with DC/DC converter (with or without isolation)
- PV inverters without DC/DC converter (with or without isolation).

A transformer placed on either the grid or low frequency (LF) side or on the high-frequency (HF) side was used in both the categories to attain isolation. Due to the size, weight, and price of the line-frequency transformer is an important component in the system. Although, the HF transformer is more compact however reduction of losses is huge concern. The use of a transformer leads to the necessary isolation and modern inverters tend to use a high-frequency transformer. However, PV inverters with DC/DC converter without isolation are usually implemented in some countries where grid-isolation is not mandatory.

Future Trends

The demand for Solar Electric Energy has grown consistently by 20-25% per annum over the past 20 years, mainly due to the decreasing costs and prices. This unprecedented reduction in the cost and prices is due to increasing efficiency of solar cells, manufacturing technology improvements, and economies of scale. There are various industry-led efforts to develop new PV inverters, controllers, and energy management systems that will greatly enhance the utility of distributed PV systems. This fact predicts a great future for PV systems in the coming years. The future PV technology will have to fulfill standards, regarding the connection of PV systems to the grid, minimizing simultaneously the cost of the system as much as possible.[13] In addition, the incorporation of new technologies, packaging techniques, control schemes and an extensive testing regimen must be developed. Testing is not only the part of each phase of development but also the part of validation of the final product.

Conclusion

With the inception of concepts such as that of smart grids one can expect the Smart Grid to spur the kind of transformation that the internet has already brought to the way we live, work, play and learn. A smart grid applies technologies, tools and techniques available now to bring knowledge to power – knowledge capable of making the grid work far more efficiently. Smart Grid is a nebulous term spanning various functionalities geared towards modernizing the electricity grid. At its core, a smart grid utilizes digital communications and control systems to monitor and control power flows, with the aim to make the power grid more resilient, efficient and cost effectiveSmart grids are potpourri of intelligent integration, sustainability, low cost and security of the electricity supply while immense focus on the use of ICT, coordination and efficiency of the system, while ensuring reliability and stakeholders' involvement. Microgrids can be considered as the building blocks of smart grids. The increased attention given to RES it is only obvious that steps to amalgamate photovoltaic and microgrids are taken. To achieve this with it is necessary to imbibe the concepts of Virtual power plant, energy storage which are of utmost importance as RES are highly intermittent and unreliable. Moreover, we discussed power electronic devices interface, as the new power electronics technology plays a very important role in the integration of renewable energy sources into the grid. PV sizing and design of photovoltaic converters families and photovoltaic topologies were gone through to understand ameliorate the same. After gaining an absolute understanding of these issues we also looked at future trends regarding the integration of photovoltaic in microgrids.

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