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Emerging Trend in Power Generation and Utilization

Ambarnath Banerji
Department of Electrical Engineering, Narula Institute of Technology, Kolkata India

*Corresponding author's e-mail: ambarnathbanerji@gmail.com

Abstract. Power generation technology has been evolving ever since Edison put up his first generating station. It started with generation near the load center. To capitalize on the economics of scale large power plants were set up near the energy centers like the coal mine heads. This led to development of long distance transmission lines and the grids. Then came the restructuring of the rules and regulations governing the power system. With the issues of pollution and Global warming coming to the fore a paradigm shift is noticed in the generation of electrical power. Large number of renewable energy sources (RES) based small generators started getting connected to the distribution system. The concept of microgrid evolved to control and regulate the RES based generations. In order to effectively use these RES based generation and to capitalize from the electrical energy trading the concept of Virtual Power Plant and Community microgrid have started taking shape.

Keywords. Centralized Generation; Distributed Generation; Microgrid; Virtual Power Plant

1. Introduction

Economic development of a country depends on the energy consumed by the people. More energy available means shorter working days, higher agriculture and industrial production, better transportation and healthier and balanced diet. Thus, there is a close relation between the per capita energy consumption and the standard of living. Larger the average amount of electricity consumed by the people of a country better is their living standard and higher is the per capita income of the country.

Early Power Generation was near the source of power like hydro power generation at the Niagara Falls in north America and utilization was also done close to generation centers like in case of Edison's steam power station.

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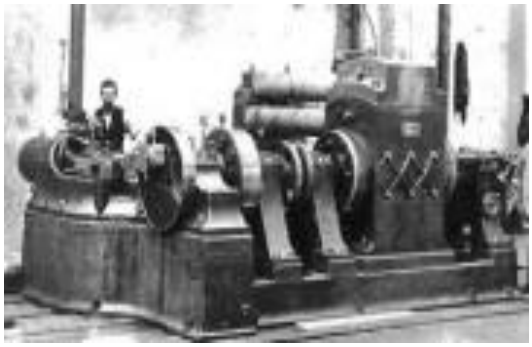

Figure 1. Edison's Jumbo dynamo (Source: https://artsandculture.google.com/asset/pearl-street-station-jumbo-dynamo-edison-electric-light-company/2wFauEbLa90a-Q?avm=3)

Momentous year 1882 saw on September 4th the inauguration of Thomas Edison's power station on Pearl Street in New York City. All the land close to the falls was occupied by industries needing ready access to the falling water for their source of energy. Landowners and industries began looking into ways of moving some of the immense amounts of energy that could be developed at the falls to locations farther afield. Moving the energy would, in one stroke, make better use of the crowded and expensive land near the falls and increase the value of energy by using it in land more remote from the falls.

2. Centralized Power Generation

Winning combination was to generate electricity on the scarce land close to the source of energy and distribute that electricity to where it could be put to better use. With the development of transformer by Westinghouse in 1886 people started thinking of generation at the energy center and evacuating the electrical energy through long distance transmission lines at higher voltage.

To capitalize the economics of scale people started developing larger and larger generating machine. Considering the Indian Electricity generation scenario, it was in 1970s BHEL that was manufacturing 210 MW Generators. By 1975 NTPC was set up and India started contemplating of setting up Super Thermal Power Stations (STPS) with more than 1000MW capacity using generators of 500MW capacities. By 2000 people in India started thinking of setting up Ultra Mega Power Projects(UMPP) which had capacity of 4000 MW or more.

3. Distributed Generation

Thus as planners of the economy were thinking of larger power stations away from utilization centers of electricity, long distance transmission lines at higher and higher voltages (latest being 765kV) started coming up to reduce the transmission losses.

As the above was going on in one hand another group of people were busy harnessing the vast renewable resource available in the country. Prof. Bhim Singh et al. started experimenting with Induction Generator, Self Excited Induction Generator (SEIG) [1-5] and Doubly Fed Induction generators (DFIG) for micro/ mini hydro and Wind renewable energy resources (RES) [6].

Another group of researchers was working on generation of electricity from solar energy. Two areas emerged: solar thermal[7] and solar Photo Voltaic [8]. Still another group was working on smart buildings using solar energy [9].

The development of RES based electrical power generation got a fillip from the development on the Power Electronics front. This produced the Custom Power Devices [10,11] and the FACTS [12,13] which resulted in controlled generation/ absorption of reactive power and elimination Harmonic, flicker and other power Quality issues that cropped up with the generation of electricity with RES and use of heavy duty loads and nonlinear loads.

These RES are being used to generate power in small quantities or in bulk. Large RES power parks

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were created in remote location and were connected to the grid through transmission lines. On the other hand, large number of small RES, called the Distributed Energy Resources DER, were either directly connected to the distribution system or were used to feed local loads in autonomous mode. Fig.2 Shows the schematic connection of the DERs to the Distribution System.

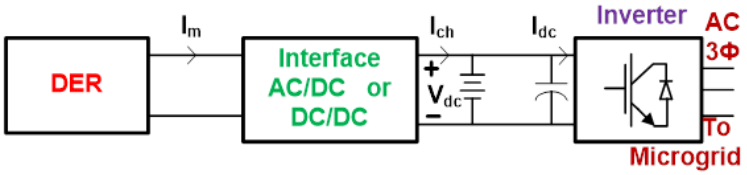

Figure 2. Connection of DERs to the Distribution system.

At times it was felt that these small RES being connected to the distribution system created more problem than they solved. The exiting protection system of the distribution system went haywire because of more power being directly fed into the distribution system.

Then the issue of global warming harming the earth's ecology came to the fore front. United Nations Framework Convention on Climate Change (UNFCCC) declared a moratorium on fossil fuel plants that are polluting the atmosphere and leading to global warming.

4. Present Scenario

Thus the present scenario of power generation is Centralization Power Generation with fossil fuel and some bulk RES Generation connected to the Grid with ever increasing small RES based generation being connected directly on to the Distribution system.

The power System and its rules and regulations were restructured to allow this scenario to sustain. In India, Electricity Act 2003 started this restructuring. Any person can now generate electricity for his own consumption and even sell it to the grid.

On the load front a lot of power system polluting loads like the arc furnace, smps, very large motors etc. started to evolve. Need for providing quality power along with the benefits of the grid to the sensitive loads started getting felt. The series compensator DVR and the shunt compensator DSTATCOM were introduced to mitigate these pollutions in the power system. This also led to the evolution of the microgrid. A schematic diagram of the microgrid is shown in the Fig. 3.

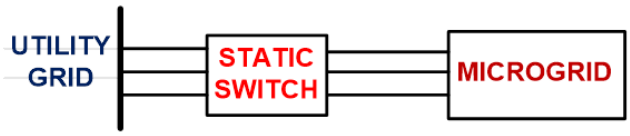

Figure 3. schematic diagram of the microgrid

5. Microgrid

The Microgrid has RES based generation, local electrical power storages and local loads and is connected to the distribution system by a static switch. It presented itself as a single entity to the distribution system. The microgrid had its local grid control & operation mechanism and provided quality power to its sensitive loads. It islanded itself from the utility grid, through the operation of static switch, whenever there was disturbance on the utility grid and maintained the supply to its load in an autonomous manner. Fig. 4 shows the schematic diagram of microgrid providing Quality power to its local sensitive loads[14-17].

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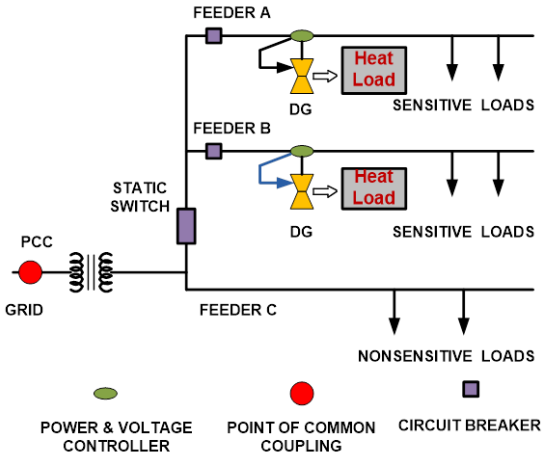

Figure 4. Schematic diagram of microgrid providing Quality power to its local sensitive loads.

At some places the human habitats are quite far apart, like in Australia, microgrids are formed in those habitats and connected to the main grid through long tie lines.

Some of the RES like solar PV generated DC power and some generated AC power. Similarly some of the loads operated with dc voltage while many operated on ac voltage. To avoid converting and reconverting the concept of dc and ac microgrid evolved. Further the ac and dc microgrids are sometimes interlinked through power electronic converters to transport power from one side to the other, giving to the formation of a Hybrid Microgrid [18].

With large centralized power station generating power at a fixed rate the loads were made to match the generation: 'concept of load following the generation.' With small RES based generation which can be switched on or off very fast or can be made to store the generated electrical energy in a storage system the concept has now shifted to 'Generation following the Load'. Generate as much as the load demands.

The loads can be categorized into two parts. In colder regions of the world a significant part of the generated energy is used for heating and in tropical part it is used for cooling/ bringing down the ambient temperature. The other part is used to operate the electrical appliances. Thus the generation can follow the heat load or the electrical load or a mixture of the two i.e. follow a hybrid load [19]. Fig.5 shows the schematic diagram of a generation system following different types of loads.

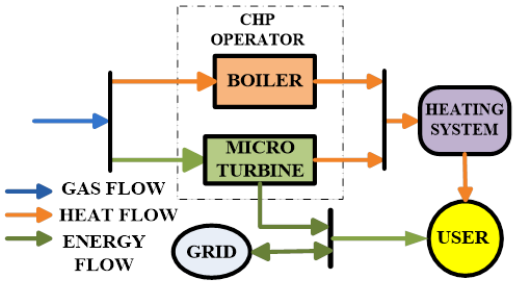

Figure 5. A schematic diagram of generation system following different types of loads.

The owners of small RES based generation (like roof top Solar) who are now being called Prosumer (Producer + Consumer) started thinking about generating profit from the sale of a part of the electricity their small plant generated. The need for measurement of the power sold and bought from the grid caused the concept of smart net metering to get introduced into the power system [20]. Fig. 6 shows the schematic diagram of electrical energy trading between the prosumer and the utility Grid

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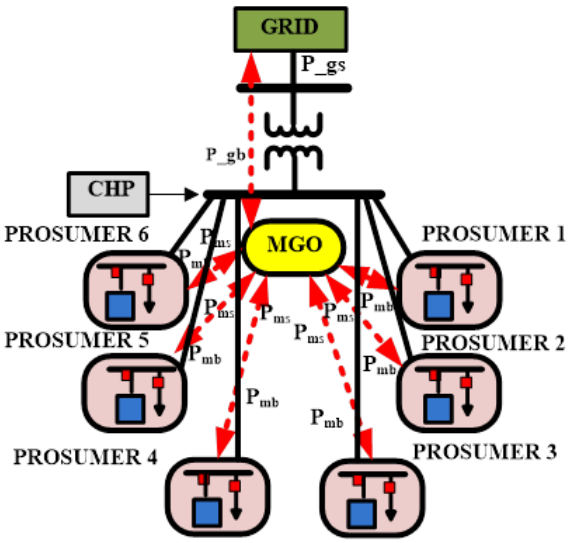

Figure 6. Schematic diagram of electrical energy trading between the prosumer and the utility Grid

With the coming up of the Electrical Power Exchanges the prosumers of the microgrid felt the need for trading the power generated by them on the exchange to increase their profits. However the amount of power a microgrid could offer for trading was too small for viability of the trading on the power exchange. They felt the need of an aggregator to bundle the requirement / surplus of several microgrids to make the magnitude of power requirement /surplus significant to make it viable for trading on the power exchange. Therein came the concept of Virtual Power Plant and the community microgrid.

6. Virtual Power Station

Distributed energy resources (DERs) in the distribution network, such as wind turbines (WTs), photovoltaics, (PVs), combined heat and power generators (CHPs), energy storage systems (ESSs), heating, ventilation, and air conditioning systems (HVACs) have much potential of flexibility in electrical power generation. However, the characteristics of DERs like small size, heterogeneous and distributed, makes them very difficult to manage and utilize their power generation flexibility. The concept of virtual power plant (VPP) is introduced to efficiently manage these DERs in a group [21]. The VPP operator aggregates the flexibility of power generation of DERs and provides energy and auxiliary service to the grid. Thus scientific decision making can be done for dispatching power in the power system operation and for participating in the power market. Using optimization methods the DERs can be aggregated into a virtual generator and virtual storage and the operation management platform of the virtual power plant is designed for dispatching power and for power market actions [22]. Fig.7 shows schematic diagram of Virtual Power plant and electrical energy trading between it & utility Grid

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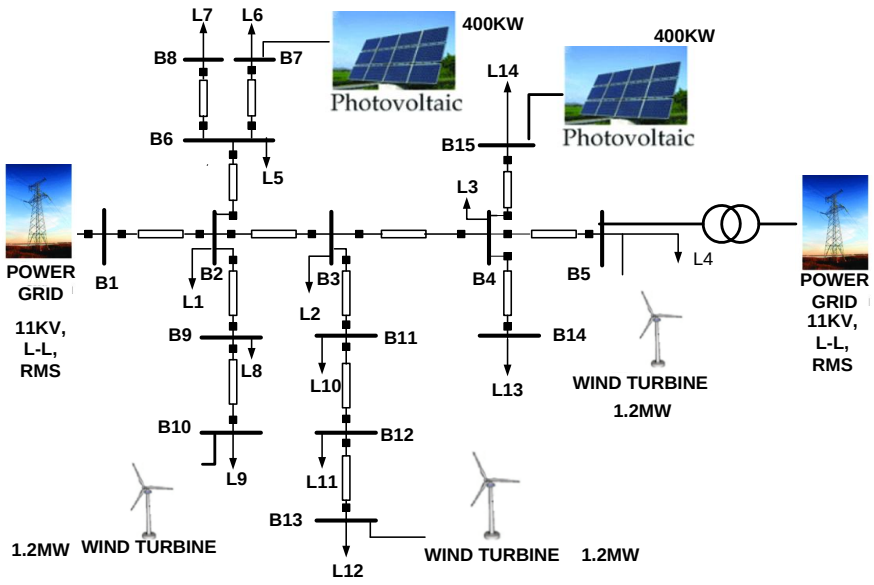

Figure 7. Schematic diagram of Virtual Power plant and electrical energy trading between it & utility Grid

7. Community Microgrid.

Multiple microgrids in the neighbourhood are linked via interlinking converters to form a community microgrid. Each microgrid will maintain their connection to the main utility grid while have an interconnection with the microgrids in the neighbourhood [23]. Each microgrid maintains its autonomous nature and can have their own specific frequency and voltage requirements. Each microgrid is able to cooperate with microgrids in the community by providing backup power to enable them to overcome the emergencies and also for economic aim. Further a community microgrid cause the advantages of both ac and dc microgrid to merge and also enhance the reliability and economic performance of each microgrid. Thus bringing about all the benefits of the main grid within the community microgrid.

An hybrid microgrid is basically a blend of ac and dc configurations in a single microgrid with the ac side having a link with the main grid. In contrast a community microgrid is a cluster formed by interlinking various ac and dc microgrids in the neighbourhood without affecting the autonomous nature of each microgrid. A community microgrid maintains the power exchange within the participating microgrids while maintaining the community as island. Power exchange allows the participating microgrids to optimally reduce their installed capacity which is highly beneficial in a congested area like a metropolitan neighbourhood. A possible configuration of the community microgrid [24] is shown in the Fig.8

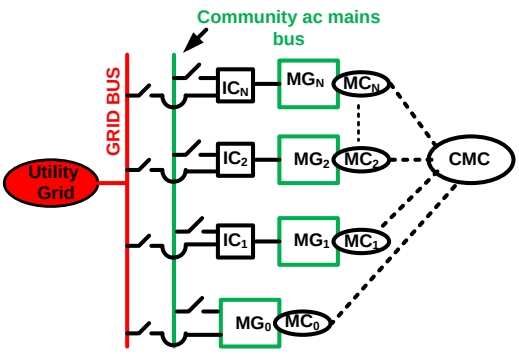

Figure 8. Schematic diagram of the Community microgrid.

MG_0 is the slack microgrid and is directly connected to the community bus or grid bus. MG_1 to MG_N are the other microgrids in the community. They are coupled to the community bus or the grid bus by their respective interlinking converters (IC_1 to IC_N). Each microgrids have their own connection to utility grid and are also linked with each other through community ac mains bus they can exchange power and provide emergency backup through community ac mains bus. Each microgrid is controlled by its own microgrid controller MC (MC_0 To MC_N). These Microgrid Controller is centrally supervised by Community microgrig Controller (CMC), which controls the overall operation of the community. The ICs are basically a buffer between the microgrids to allow them to operate in autonomous manner. The IC is an dc-ac converter in case of dc microgrid and an ac-ac or ac-dc-ac converter in case of ac microgrid. The presence of MG0 and community ac mains bus improves reliability by providing each microgrid with backup access to the utility grid in case of unintentional islanding.

8. Conclusion

Concluding we may say that there is a paradigm shift in the way the power is generated and transmitted to the load- from large centralized generating stations to small renewable based generation connected to the distribution system. With the development of power electronics and enhanced computing power harnessing the renewable energy resources and generation of power from them have got further impetus. Accordingly the grid and the protection system are becoming smarter. The transmission and distribution losses are getting reduced. The restructured environment of the power system has benefited both the customer and producer of the electrical power. It has brought healthy competition in the power generation transmission and distribution. The cost per unit is likely to get reduced. This is going to help in the development of mankind and in the improvement of the economy.

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