A project report on

ENERGY TRADING IN SMART POWER GRIDS

In partial fulfillment of the requirements for the award of the degree of

Master of Technology

In

Control and Instrumentation Systems

Submitted by

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June-2022

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THESIS CERTIFICATE

This is to certify that the project work titled "Intelligent Energy Trading in Smart power Grids" is a bonafide record of work carried out by Mr. **TEJAVATH JAGADISH** (EE20M062) submitted to the faculty of Department of Electrical Engineering in partial fulfillment of the requirements for the award of the degree of Master of Technology at Indian Institute of Technology, Madras during the academic year 2021-2022.

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ACKNOWLEDGEMENT

I wholeheartedly thank my guide **Dr. K. Shanti Swarup**, *Professor, Department of Electrical Engineering, for being a source of motivation, constant supervision and invaluable encouragement, and for guiding me with perfection in doing this work.*

Sincerely

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ABSTRACT

As the population count and Industries were rapidly growing,power consumption is increasing rapidly,The only source that has become dependent is main power grid.It has to supply and balance the load demand.It become a great issue for the present grid system.If it still continuous it has to generate mass value to satisfy the demand,So to do that it requires huge quantity of natural resources which helps in producing electricity and the future generation has to face shortfall of natural resources.To overcome this issue a proper and Intelligent energy trading has to be implemented.So in this paper,I have came up with the multi agent system which integrates all the Distributed energy resources like solar plant,Electric vehicle,wind power,gas engine,batteries etc with the main power grid where these resources will supply or share the load with the main grid and satisfy the load demand.It helps in avoiding stress on main grid.The other method is biding energy where each and every utility participating in biding to buy or sell power with the other utilities to satisfy their existing load and also they can bid sell if excess power is available.By using these techniques we can Overcome the issue of shortfall of natural resources and also satisfy the rapidly growing load demand.

Keywords: DER's-Distributed energy Resources, MAS-multi agent system, SOA-service oriented architecture, Integration, energy trading, Information and communication Technologies (ICT)

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CHAPTER-1

1.1 Introduction

The current times give the big example of having a blast evolution in the technological field in a slow manner with the world and its processes of daily life implementations. Artificial intelligence deals with the system of being done with some actions that are system generated according to the scenario. The amalgamation of artificial intelligence with the smart power grid system has resulted in the eruption of the power distribution system. Power grids hold and deal with a very high amount of voltages to serve electricity to a particular place or area for its people and workstations. So in order to get them provided electricity with having count before distributing and other functional stuff, the computerized system has made it easy.

1.2 Background

A Power Grid is a framework where the electricity is getting hold before having distributed to small to big areas as per the requirement. This time has given the example of how this whole networking system is getting under digitalization. Technical development at each sector leaves a remarkable approach that grows interested in other systems to have it like an updated implementation. The current consumptions of natural resources of people without having a bit of care to the resources compels this situation to get a change in the whole manner of distributing energy and the use capability. ***Distributed Energy Resources (DER)*** has to be integrated at a large scale to get the functionalities of smart power grids as smooth. Automation software needs to be overhauled with an extreme extent of use in ***Information and Communication Technology (ICT)***.

1.3 Aim and Objectives

Aim

The aim of this research is to provide and re-industrialize artificial intelligence into the smart power grid system to lessen the extra use of energy resources for the betterment of the future.

Objectives

- To make an adopted structure of the power grid system by the smooth amalgamation of energy resources
- To Integrate Distributed Energy Resources with the main bus and to trade the energy for proper load balance.
- To start intelligent grid operations with improving technical updating to the whole sector

1.4 Rationale

The people and business industry are decreasing natural resources day by day as per the careless use of them. This extensive use can compel this whole environment to collapse someday. So in order to get a constant towards this limitless use, a stop and a proper distribution are needed to have a change for the betterment for the future. Technical evolution is something that is now the burning topic for rising industries to big ones to get technical updates to ease the workflow of their own. The extensive use of electricity can be controlled by this system as artificial intelligence has the ability to provide the resources as distributed to limited use.

Electricity distribution has to be dealt with limited use and to make it a proper application with this prefixed plan the artificial intelligence (AI) has to be implemented. The problem is severe for the upcoming generations as this system has to be changed and to make it happen, technological development through the sector is needed. A computer is a machine that can calculate and this technology is getting too advanced for any application to make a perfect evaluation of it. In order to know what the problem is, the adoption of technological advancement would make people convinced of its implementation. The current times demand this situation to integrate all the distributed energy resources.

This problem of having afraid of extensive use, which directs the resources to an end, forces them to get all the uses of electricity bound in a limit. This has to be controlled as per the future use of it and electricity is needed to be saved. Electric power grids can be small too big and their size tells the story of how much area generally a power grid covers to facilitate the people. People are unaware of using this, as they do not bother to save it. This can provide a big example of how reckless use drives this whole situation to a critical one. The technical implementation of artificial intelligence helps to get this in a limit as per the machines counting of overall average use. The AI makes the power grid framework smart because it auto sets the division of the electricity.

The power consumption of people without providing a minimum of care would cause people to face issues regarding the scarcity of power. As this whole fact is important with a reason to solve this issue as fast as possible, the technical development by artificial intelligence shows a revival can be possible. Nowadays electricity is much too important to run any sector as in from home to any business institution. So in order to avoid these circumstances as predicted, distribution of electricity should be measured and extra use of it needs to be stopped to have a healthy environment.

In order to know what the issue is right now, there is nothing but to implement a boundary in the use of electricity by using smart technology to the power grid system as Artificial intelligence.Technical development helps to understand the proper execution and distribution of electricity from the power grid. As this is intelligent enough to assume the use of electricity properly, it provides the right amount of electricity in a proper manner by dividing the power to its people or in the city. As per the current situation, the electricity has to be distributed with a prefixed amount to have a balance in everyday use of it.

This system has to be changed, as the integration of the resources is needed before distributing the electricity. The mechanism of smart systems to the power grid provides new methods to implement with optimizations of local interests and limitations of different actors. These actors are aligned with the quality, security, and stability of this power grid system. As per the situation's criteria, the whole power grid has to be smarter and the components of it need to be more intelligent. AI systems can have the proper calculation of the usability of the electricity in a power grid system as this has the mechanism in its programming to have an auto-calculation as an assumption. Proper division in electricity is needed to be implemented for this system to have a change with a preconceived notion to avoid the future being dark.

1.5 Significance

Technical evolution and the power grid system are both a lethal combination that has the ability to get all this extensive use increased within a limitation. Artificial intelligence with implementing smart objects and components to it can give this implementation a proper functional one.Use of the technical involvement has given this system mobility to have the preplanned functions to be executed. The significance is great with this use of it, the overall system can have the proper distribution and people cannot do any extensive use of it. As this whole system is being developed to have the functionalities of artificial intelligence to be executed, this proper division of the electricity from power can save the future as well as the flora and fauna.

The distributed generators are there in the smart power grid system to have this whole management to be in control by the automation software component. Intelligent switches, smart transformers, newly developed sensors are there as smart functions which are far better as compared with the previous one. This whole management of the functionalities offers proper segments of electric power to provide at a particular place or area. As per the approach of the current system, distributed energy resources are linked to the grid to absorb the extent of production of the energy. Active and intelligent management rules have to be implemented to enable the smooth integration process of the distributed energy sources. The smart objects that are connected to the power grid system have done the work of having a proper distribution and control in extensive production.

1.6 Summary

This whole research about this power grid system has to be made implemented to have a control in extensive use of it and to control the overproduction. In this system of the power grid, applying smart objects to it gives its functions to get the proper actions for making the objectives successful. The objective has been met with implementing technical improvements such as artificial intelligence to convert the previous system to a smarter one. In this system, this whole process of having technical evolution to its field has converted the working functions as smart. Each function has its own part to do a specific work as smart objective components are added with the grid to be more efficient.

CHAPTER-2

2.1 Introduction

Energy is the soul of every activity in people's life where without energy nothing is possible to produce. Hence discussion and research studies conducted on energy production and trading have become necessary. This chapter includes the importance of Energy trading in power grids. This research study will be discussed about the primary concepts of energy production and trading.will also be discussed about the application of artificial intelligence in energy production. This study will be discussed about the different benefits of the application of energy production and trading. This study includes both challenges and future possibilities in smart power grids.

2.2 Conceptual framework

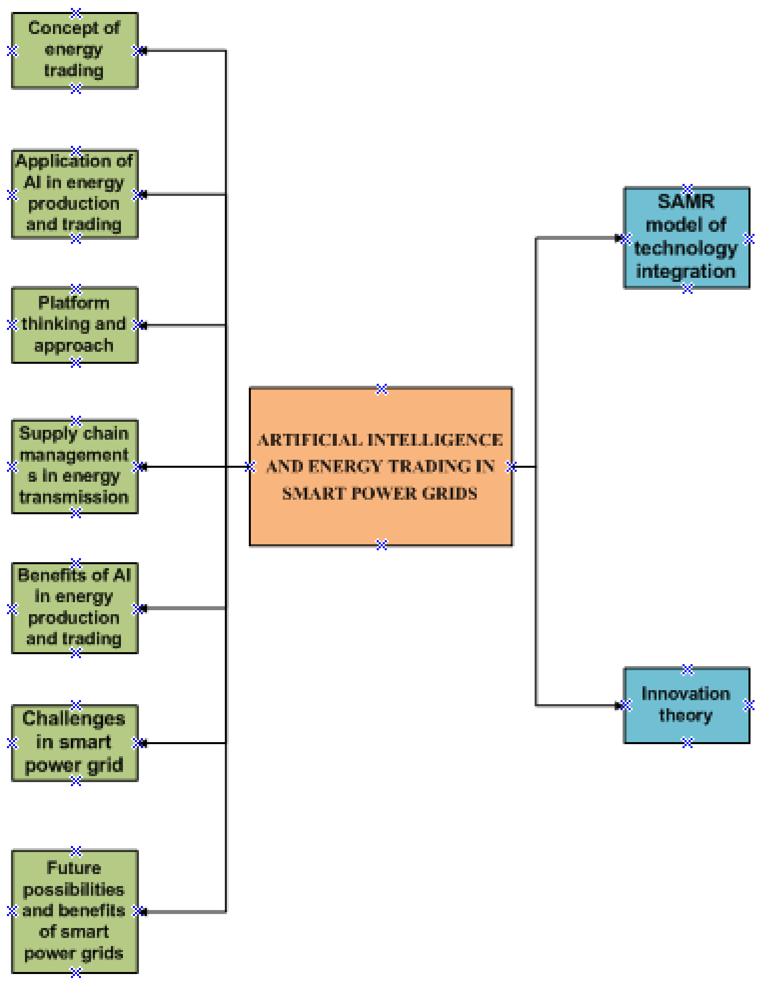

Figure 2.1: Conceptual framework

2.3 Concept of energy trading

The concept of energy trading is evolved when the commercial demands for electricity are drastically grown. Due to this reason governments invite and facilitate many private companies to invest in the energy sector.The concept of energy trading is related to the production, consumption, and per-unit cost of the energy consumption, rules, and regulation provided by the respective authorities of the governments. The energy sector is one of the largest sectors in business that has to fulfil the demand for energy for both commercial and non-commercial purposes. People cannot survive for a single moment without electricity which is one of the important parts of the energy sector. There is a huge demand for energy in the industrial sector, commercial sector, office, school, college, and residential areas. Hence day by day demands of energy is increasing. Due to this reason, energy trading is one of the most important investments and business sectors. Many large companies are interested to invest in the production of energy due to its sustainability and profit. Energy trading refers to the business of the production of electricity and its distribution to the consumer through a smart grid. The smart power grid has a significant role in the sustainability of economic developments. The population of the world is increasing drastically day by day, so to fulfil the excessive energy demands it is necessary to increase the production of electricity. Nowadays in the digital era, many mechanical machinery and equipment are converted into electrical equipment and running's by electricity. Much rapid transportation is running on the electricity in the replacements of the different kinds of petroleum fuel to reduce the carbon emission for the protection of the environment. concepts of green energy evolved which include solar energy, winds energy, and biogas energy. Wind energy is another biggest source of green energy which helps in reducing carbon emission and protects the survival of different species in the environmental ecosystem. Due to this reason production of energy and trading of energy is increasing day by day. One of the biggest sources of the consumption of energy is family households. To fulfil the demands of the growing population of the world, energy trading is increasing day by day. Another important customer of t5he energy is the industrial unit including different production and manufacturing setup. Rapid transportation including high-speed railways, tram, metro, and different kinds of electric vehicles is one of the most important consumers of electricity. due to the increase in the consumption of electricity, the production of electricity on a massive scale with maintaining different societal and environmental values becomes necessary. In a vast city where different kinds of industry, offices, schools, colleges, and hospitals exist in the same area, smart power grids have a significant role in the distribution of the power or energy to the consumer properly concerning their demands. Artificial intelligence helps a company in the elimination of human error in the different processes related to energy trading.

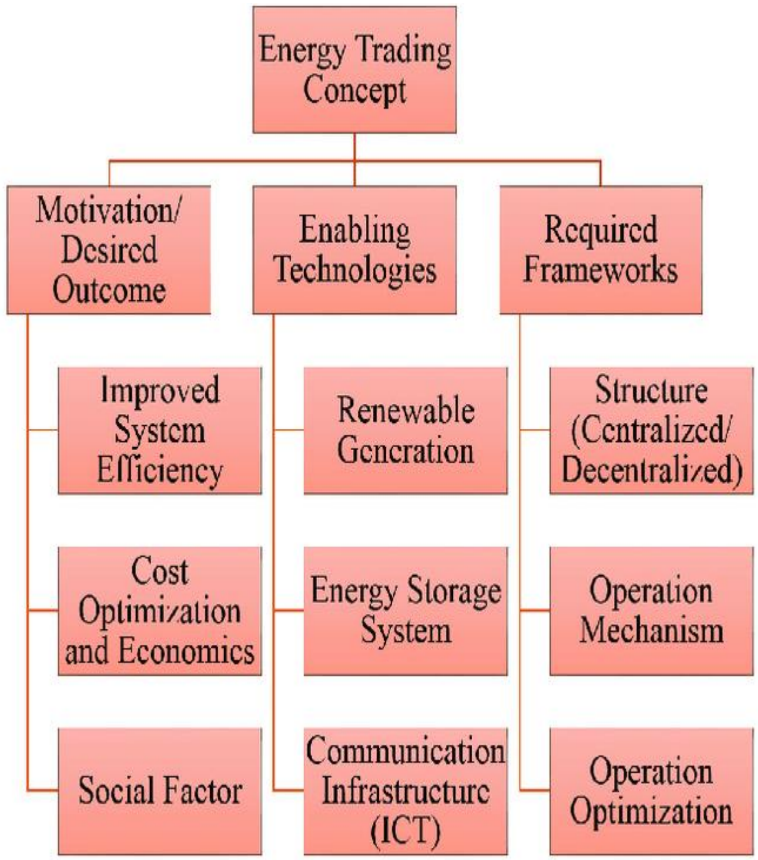

Figure 2.2: Energy trading concepts

2.4 Application of AI in energy production and trading

Due to the excessive demands of electricity, massive production of electricity in a very short time has become the most preferable duty of many energy production companies. To do this properly, energy production companies should adopt the modern technology which boosts them in their massive production of electricity and take competitive advantage from the market where many big players exist in the production of electricity. Production at a low cost becomes the most important goal of any energy production company. For the achievements of the successful low-cost production of the electricity companies should adopt modern and hi-tech technology.

One of the most important modern technologies is Artificial Intelligence (AI) which is very helpful for the company in the production of electricity at low cost and also on a massive scale. Artificial Intelligence and robotics process automation (RPA) plays a significant role in the production of electricity on a large scale which boosts the energy business and trading. Artificial Intelligence is one of the most important tools for the production of green energy which is most effective and less labour-intensive. Production and operation in the solar energy park by using artificial intelligence are comparatively more effective than manpower. Artificial Intelligence has an important role in the different activities in the solar park which includes the setting of solar cells in a disciplined way, regular cleanings of solar cells, and the removal of any solar cell as per the requirements. With the use of artificial intelligence, it is easy to set up any solar station or solar park which is not possible by the manpower rapidly. artificial intelligence has an important role in the production of wind energy and the storage of the energy to utilize for future purposes. Electricity distribution and transmission is not an easy task for the production company due to the illegal connection of electric weir without any permission. This illegal way of stealing electricity is known as transmission loss. A company reduces its transmission loss by using artificial intelligence and distribution through the smart power grid. Smart power grids act as a medium between the electricity sources and consumers which operate with the help of artificial intelligence. The application of artificial intelligence helps to reduce the distribution and transmission loss, which is important for the economy and equally important in the elimination of illegal business related to electricity. In the energy sector both robotic process automation (RPA) and artificial intelligence (AI) are important in the operational models and methods in the company. Both the artificial intelligence and robotic process automation model give value to the energy traders and give the easiest way of transmission to the consumer through smart power grids. In the energy trading, AI and RPA help the traders in the adaptation of the 24X7 typical models which is more important for retention of customer satisfaction. Retaining customer satisfaction is one of the ultimate goals of the company for their future progress where many companies compete with the same services. Successful application of artificial intelligence is necessary for the company if there is a high volume of work associates in a single distribution line.

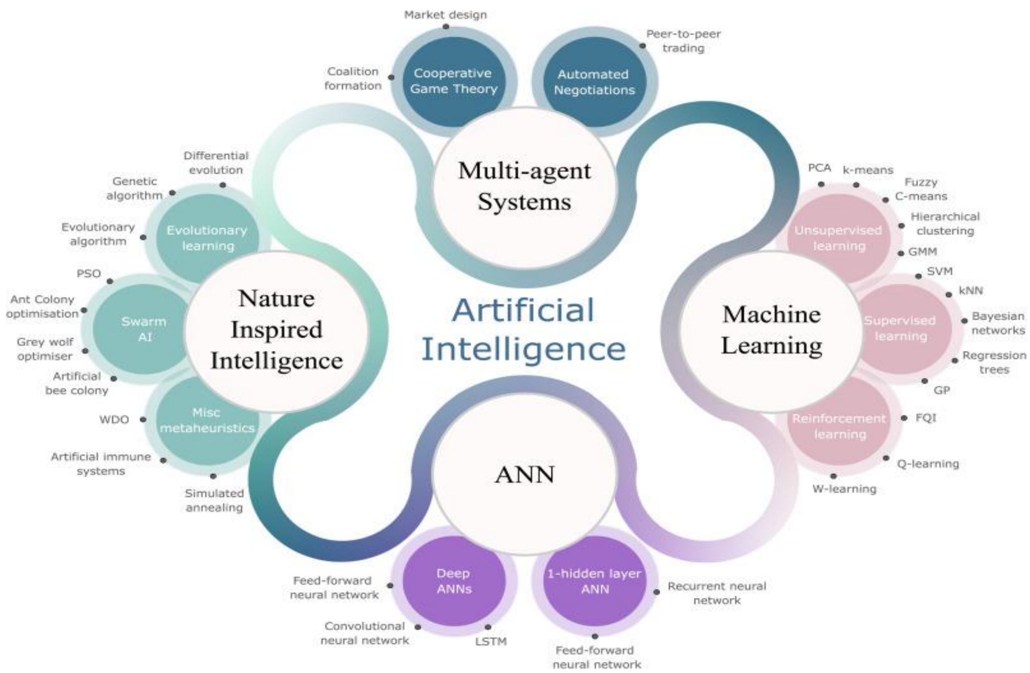

Figure 2.3: Application of AI in the energy sector

2.5 Platform thinking and approach

Different types of modern platforms are used for the study of the application of artificial intelligence in smart power grids. These platforms include Google AI platform, Tensor flow, Microsoft azure, Infosys Nina, Wipro Holmes, Dialog Flow, Premonition, and Watson Studio. Google AI platform helps the research study in the knowledge about machine learning. In the study about the application of artificial intelligence in smart power grids Google AI platform helps in the data collection related to energy production and trading. Information on different activities related to the smart power grids is gathered with the help of the Google AI Platform. With the help of the Tensor flow platform different kinds of numerical data, flow charts, and tables are gathered. With the help of this platform knowledge about the numerical data is gathered which is very useful for the study. Microsoft Azure platform is used for the study which is very helpful in the simple machine learning related with the smart power grids. This platform provides an advanced cloud-based analytical system for the research study. Another most important platform in the smart grid is Infosys Nina which provides deep knowledge in machine learning which is very helpful for the company in driving automation and innovation in smart grid projects. This platform reduces the maintenance cost for both the physical and digital assets related to the smart power grids. Using this platform is becoming more beneficial for the company in the maintenance of smart power grids. Wipro Holmes is one of the effective platforms for the company in the maintenance of the different activities in the smart power grids. Wipro Holmes - artificial intelligence platform has several benefits in the smart power grids including Knowledge virtualization, drones and robotics, application of visual computing, process automation, and predictive system.

Some important platform approaches are machine learning, automation, and cloud infrastructure is used in the smart power grids. Machine learning is one of the necessary approaches to handle the different modern machinery in the power grids. As cited by Bedi (2019), to effectively operate the modern equipment and machinery in the smart power grid system it is necessary to learn the machine and the required skill of the manpower to operate it. Automation has a significant role in the smart power grids by using software and doing the different things automatically without any intervention of the manpower engaged with the smart power grids.with the help of automation different activities in the smart power grids are done without any errors. Automating the manual process helps to save time in the different activities and also protect the resources, information, and data related to the different operational activities in the smart power grids. The use of automation software does everything and no additional skill is required for the employees. Cloud infrastructure is one of the necessary approaches for smart power grids where different kinds of data and information are collected. Cloud 9 fractures saves the data related to the number of consumers, their consumption of energy, demands, and several economical data in particular smart power grids.

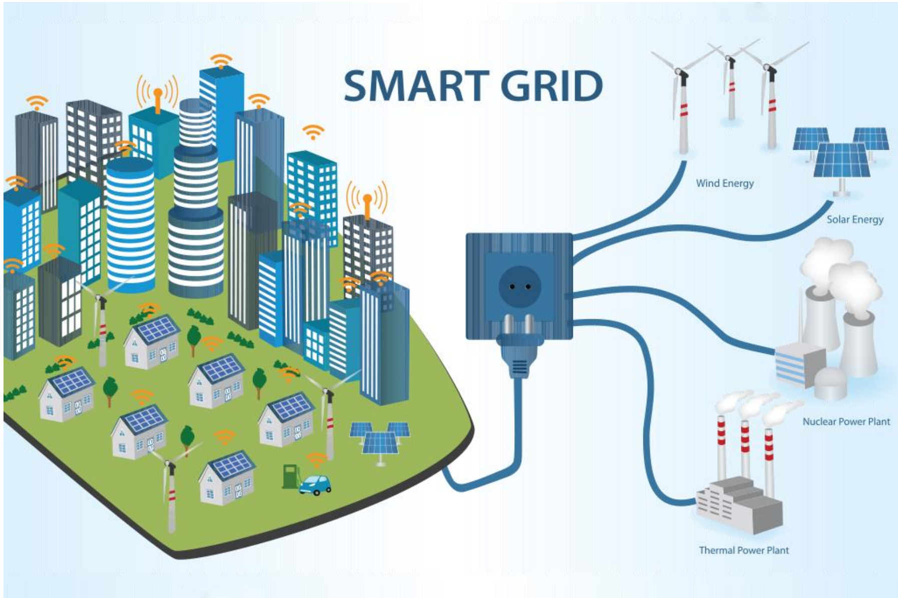

Figure 2.4: Smart grid and renewable energy

2.6 Supply chain managements in energy transmission

Supply chain management in energy transmission is defined as the integration of different key business processes from production to distribution for sales. As per the view of Islam and Huda (2018), in maintaining a balance between demand and supply in energy trading, effective supply chain management is necessary. supply chain management has an important role in the effective distribution and transmission of energy and in reducing the transmission loss of the company.the transmission of electricity is a more difficult job than the production of electricity for the company because a company faces several problems and challenges in the distribution of the electricity in a proper way. one of the major problems in the distribution of electricity is the illegal connection which harms the supply chain management. To eliminate this problem the company must adopt a smart power grid in the distribution of electricity from source to consumers. effective supply chain management professionals are necessary for the company to increase its market share and earn a marginal profit from a respective market. Different processes from source to supply in the energy trading are production-transmission-distribution. leaders in supply chain management have to notice both external and internal activities which are related to the transmission of energy of any company and sustainable supply chain managementtechnology has an important role in a strong and sustainable supply chain. For example, if one city or town required a huge amount of electricity for different consumer exists in the city or town including households, industry, offices, educational institutions, and mall needs a single smart power grid for effective distribution of the electricity. Supply chain management has an important role in the organization's progress and efficiency in different internal activities of the organization. Supply chain management has an important role in the reduction of the loss of any company in the energy sector. Maintaining a strong supply chain is a more difficult job for the company than production in the energy sector.

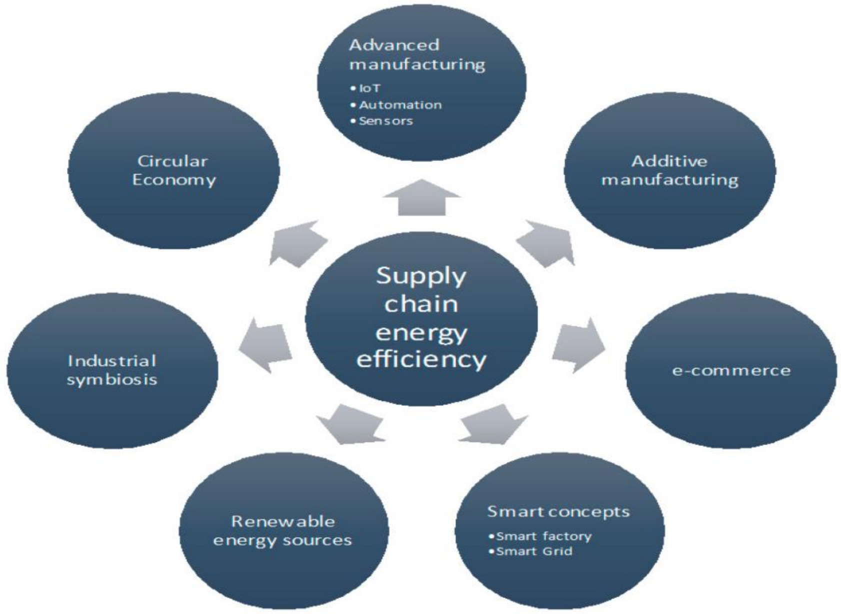

Figure 2.5: Supply chain management in energy sector

2.7 Benefits of AI in energy production and trading

There is a huge benefit of using artificial intelligence in energy production and energy trading. One of the most important benefits of using artificial intelligence in the energy sector is that AI saves many losses from power cuts in energy trading, another important benefit of using artificial intelligence in energy production and energy trading is the lower production cost of energy. The lower production cost of electricity helps to reduce the per-unit cost of electricity which is more important for customer retention and increase in market share. In the present times of high application of the technology, artificial intelligence is something that can be called as the milestone for all the sectors associated with production and supply. Doing something exceptional such as huge calculations, large data processing, and management of the machines without error is possible due to the advent of artificial intelligence. The systems which can do the human works with ultra human caliber enhance the possibilities of human evolution along with the technology. Voice commands, security management, auto-driving of machines and other applications of this technology made the lives of the human race easier that can even drive human capabilities to the Godly level.

Commercial application of these technologies in the production houses, power stations, automobile industries and other places pave the way for the increment of human efficiency in a way that can change the world while keeping in consideration the natural order of the environment. In most of the cases for energy production companies, AI application in the data analysis gives an optimized outcome for the utilization of the resources in a manner that can increase the efficiency of usage of the limited supplies. Time is one of the most essential factors for a production house like power grids and the generation of power requires a continuous supply of resources. In other words, trading of supplies or resources or raw materials and along with the distribution of the supplies like energy within and around a region requires high consideration of time management.

Using AI in the extraction of fuel, controlling delivery to the stations, quantity measurement and presumption of the production of energy and finding flaws in the mechanism all are vital organs of a power grid. All the smart power grids are active in the present time in different nations mostly in the USA, the UK, China, India, Australia, Russia, Germany, France, the UAE and other renowned advanced countries along with other developing nations working on the efficiency on their power generation are highly concerned with the application of advanced mechanism that can provide a cost-effective and clean source of production (Sadeeq and Zeebaree, 2021). Companies that are highly in demand for supplying these mechanisms such as Google, Microsoft, Intel and others are developing such mechanisms that are increasing the efficiency of production and trading of generated power from the power grids many folds with the application of automation in the relevant sectors.

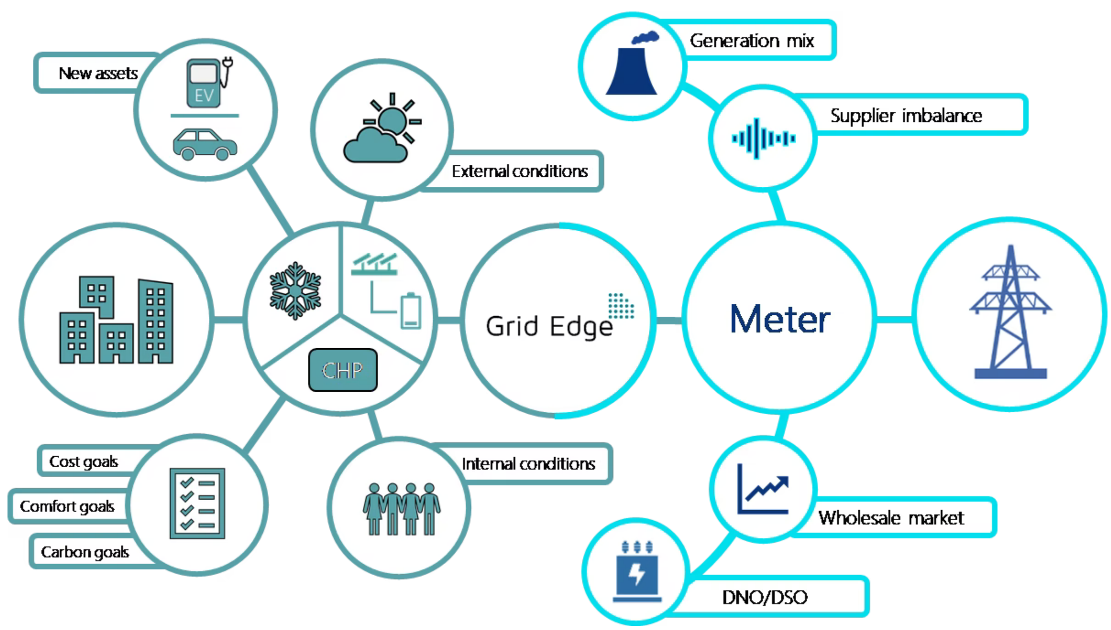

Figure 2.6: Smart grid system

2.8 Challenges

It is expected from the smart power grids to increase efficiency, economy, reliability and sustainability while generation and distribution of power. Though the application of AI is considered to be highly effective, certain drawbacks are required to be highlighted. Management in the supply and delivery of power and equal distribution, control and security in the transmission along with resource accumulation mechanisms are considered to have high priorities. But occasional malfunctioning of any mechanism and sourcing alternatives with the available technology often seems to become a high concern for those authorities responsible for the entire process.

In most of the cases of smart power distribution systems, human involvement is quite less compared to the older systems of generation of power. In AI, a certain number of synchronized commands are always in action, for example, power requirement and capacity of a source, requirement of raw materials, efficient supply during production and maximizing supply mechanism can be computed. But, complex sociological aspects, consumer's change of requirements, a glitch in the mechanism and protection of the source and resources are often challenging only with the utilization of AI. There are different sources for the generation of power such as thermal with fossil fuels, hydel with the current of water, solar with solar panels, wind with the flow of wind, volcanic heat, and most importantly nuclear power generation.

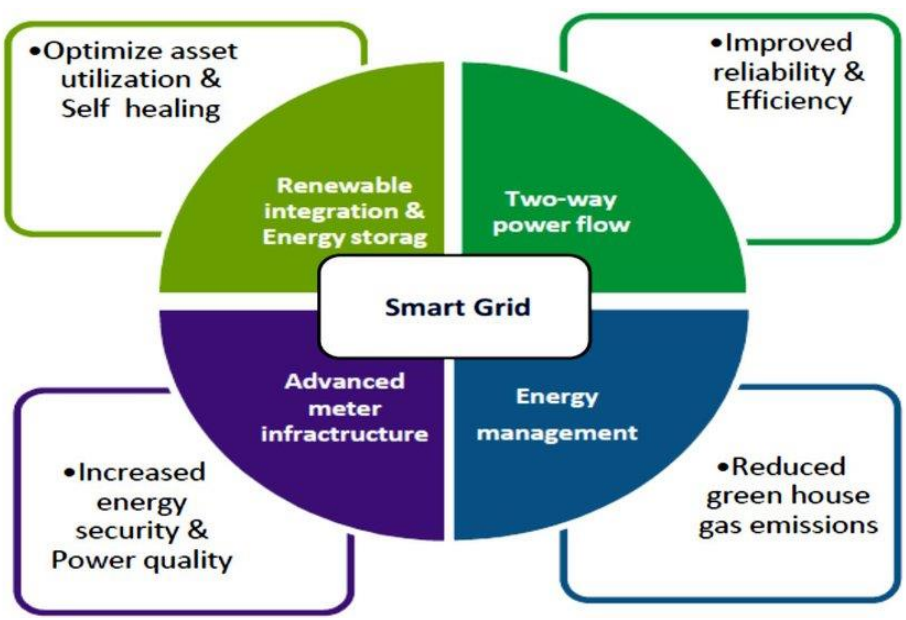

Figure 2.7: Challenges of the smart grid system

Fossil fuel is limited on earth thus many complexities in acquiring them can come and using AI for solving these complexities to date is not possible. Hyled power requires river or tide currents which are natural phenomena. In a particular region or searching the proper place where this can be applicable is not possible without the involvement of humans. Other resources such as solar, nuclear, and geothermal and others can be used in the generation but its supply cannot be operated with AI. Again, during energy trading, there may be political or sociological complexities that cannot be resolved only with system commands.

Ecological turmoil's often come into action that cannot be overdone with simple but reliable technology. The recent global requirement for reliable and sustainable energy sources requires a higher technological application to meet the requirement of the up surging energy crisis. To implement these technologies in the practical field requires a lot of funding which is not always within the hands of the commanding authorities. Again, some of these technologies are under research and in the trial stages. Without finding out the negative impacts or flaws, these can be harmful to the entire smart energy grid whose mechanisms are interconnected. Security controls are one of the important facts in the management of the funds, database, operation and resources. Absolute control under one shade with the AI platforms in the smart power grids is a crucial part of the management of these controllers. It can be said that the advanced systems can be more difficult and provide absolute security to these power grids. But, it can be hardly said that it is impossible to breach the security of these organizations that make them vulnerable.

2.9 Future possibilities and benefits of smart power grids

Since the advent of smart power grids, there are changes at a certain level in the social, economical and environmental background that have been observed. But, the noted fact is smart technologies have increased the possibilities while keeping the application restricted at a certain level. Of which a little change only has been encountered in this sector compared to the traditional system of power grids and trading methodologies. The subject of concern is the future possibilities and benefits of smart grid technology and energy trading mechanisms. The possibilities are huge and in the optimistic view of a researcher, some of the important potentials of this technology are -

Efficient transmission of electricity - It is referred to as the high economical approach where the loss of energy can be minimized and efforts can be shortened with the application of smart AI-based systems. These systems require advanced machinery that can increase the amount of supply to the consumers by keeping them in the loop of the supply chain. This increases the reliability and activity of the consumers towards the suppliers and business can run smoother with the increasing involvement over time. Systematic management of information helps in maintaining a good reputation along with the quality of supply without any disturbance during transmission.

Quicker restoration procedures - It is occasional in many regions around the world where disruption of power supply can be encountered. This can happen due to a lack of fuel, increased consumption in some areas, overloading of circuits that result in burning off the power grids along with components like transformers. It may also happen due to natural calamities like storms, floods, earthquakes, outer space radiation, explosions and others. It often takes a long time for the authorities responsible for restoration by getting informed to repair the machines and resuming the supply. Time is crucial, there could be emergencies in certain places mostly in the hospitals, fire stations, airports, railways and others. The utilization of AI keeps the entire supply chain connected and provides an easier and faster approach to the restoration of the supply.

Reduced operation and management cost - Using smart grid supply, the cost of maintenance becomes less than the traditional methods. labor costs, travelling costs, fuel costs and other important factors that can increase the expenses in the supply mechanism drops significantly as most of the work is done by the AI itself.

Increase awareness and develop communication mechanisms - Smart technologies help keep the connection between the authorities and consumers. Delivering services to the different regions will increase the social and communal bandings along with satisfying the power requirements.

Ecological impacts - Ecological impacts play a crucial role in the development of any community and smart technology can be utilized in awareness campaigns to save electricity and protect the environment. Along with this, introducing less pollution producing resources and managing them with advanced technology in a systematic manner can provide sustainability to the environment.

Improvement of security - Advanced technology provides advanced security and better control of the system management. Computing the possible glitches AI provides an option for a better and advanced security mechanism of which the propaganda of the development of humanity can be protected.

Figure 2.8: Future possibilities of smart grid

2.10 Theory

2.10.1 SAMR model of technology integration

The ***SAMR*** model deals with the online practice of learning and understanding the concepts of a particular theory or replacing the traditional methods with advanced and developed methodologies. It is the abbreviation of ***substitution***, ***augmentation***, ***modification*** and ***redefinition***. The research is based on the secondary data collection method where this model of approach is quite useful. In this discussion the detailed analysis on the above-mentioned topic in the context of the ***SAMR*** model.

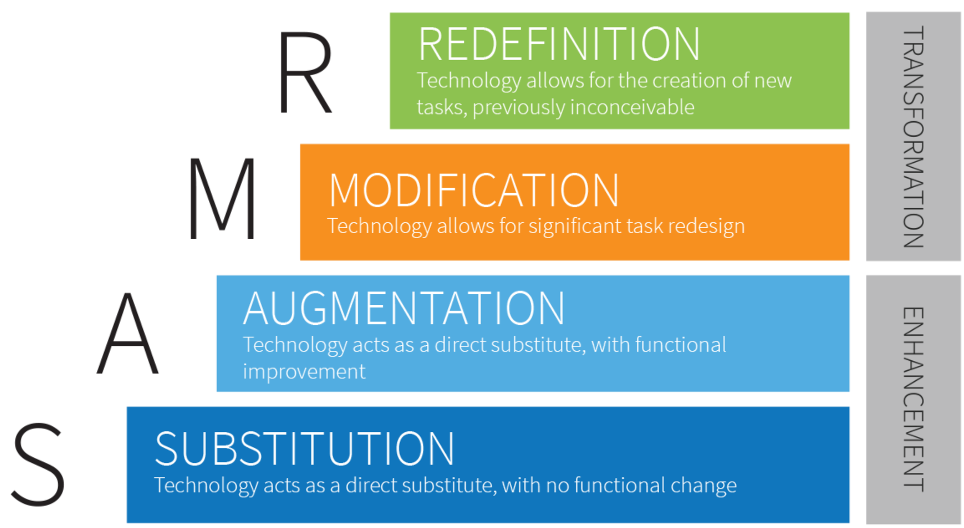

Figure 2.9: SAMR model

Substitution includes the replacement of the usual or traditional mechanism for developmental purposes. The possibilities associated with the advanced machines in the grid system are numerous. But, implementation often seems hazardous as this requires the application of machinery and application of computer skills (Yang *et al.* 2018). AI systems are something that is developed by coders and digital designers who innovate ideas that can replace the traditional system. Automation of calculations, analysis, system management and project development can save both time and labor along with money.

Augmentation means the incorporation of digital platforms keeping the original purpose intact. Well, presentation of modules and designs, increased involvement of participants through virtual media and keeping the system chain updated is the basic concept of this part. In the case of smart power grids and energy trading mechanisms, the application of advanced technology such as AI systems can increase the pace of growth of any nation manifold.

Modification refers to the skill set required for controlling and developing advanced mechanisms and becoming accustomed to that. Tracking information, energy requirements, production capacities and updating machinery on time is included in this case of smart power grids.

Redefinition is associated with learning outcomes that can either be derived from theoretical study or from the practical application of theories. Mistakes are justified and the things that require development are especially focused in this case. Every day AI is accomplishing a new height and with time there will be a time when it will control all the requirements of the people who designed them.

2.10.2 Innovation theory

Smart grids are developed with the prudent application of the advancement of science and technology. AI with the help of the internet is controlling almost everything and increasing the efficiency of the human race. But, there are steps and theories which are associated with smart grid technology and these are required to be mentioned to elaborate the topic of innovation theory. Smart grids encompass ***grid robustness***, ***grid design***, ***and grid control*** and ***grid regulation***.

Grid robustness is something that deals with the discontinuation of the supply and the methods to tackle them. Developed framework with the application of artificial intelligence gives better performance of the entire system.

Grid design incorporates the base and control room for the entire process that can operate anything either faults or betterment of the machinery or digital design. It encompasses the main station of supply that generates and supplies the electricity.

Grid control deals with the supreme control or the commanding authorities who work as a connection between the smart power grids and their users.

Grid regulation is associated with the ethics and laws that effectively controls and commands the supply chain mechanism.

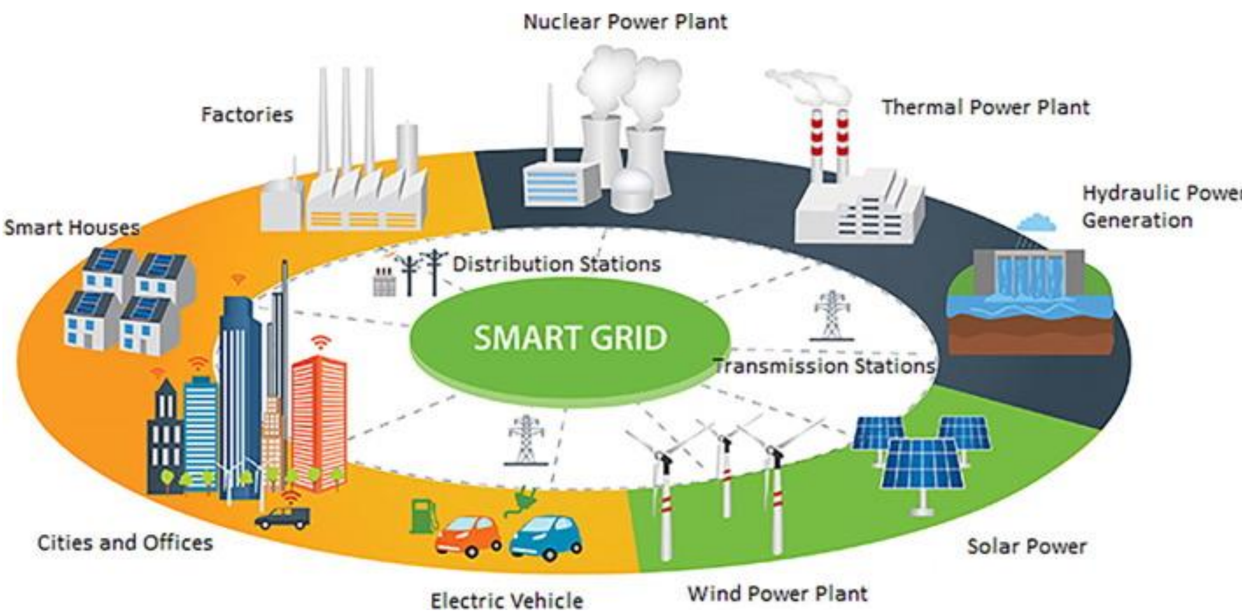

Figure 2.10: Distribution of Power in Smart Grid system

2.12 Summary

The report is based on the introduction of the usage of AI in smart grid systems along with its utility in energy trading mechanisms. Some concern may arise over the application of AI systems in the modern-day energy supply depending upon the errors that the systems occasionally encounter but the fact is it reduces the workload of any individual. It can provide absolute control over the mechanism of the supply chain while some glitches may arise due to security beaches. Advanced infrastructure, strong funds, expert operation and innovative concepts are making the lives of millions easier by supplying the required amount of energy on a daily basis.

CHAPTER-3

3.1 Introduction

Evolution of Electric Grid–Need for smart grid– Difference between conventional & smart grid – Overview of enabling technologies–International experience in smart grid deployment efforts– Smart grid road map for INDIA– smart grid architecture Evolution of the Electricity Grid The first alternating current power grid system was installed in Great Barrington, Massachusetts. At that time, the grid was a centralized unidirectional system of electric power transmission, electricity distribution, and demand-driven control. In the 20th century local grids grew over time, and were eventually interconnected for economic and reliability reasons. By the 1960s, the electric grids of developed countries had become very large, mature and highly interconnected, with thousands of 'central' generation power stations delivering power to major load centres via high capacity power lines which were then branched and divided to provide power to smaller industrial and domestic users over the entire supply area. The topology of the 1960s grid was a result of the strong economies of scale: large coal-, gas- and oil-fired power stations in the 1 GW (1000 MW) to 3 GW scale are still found to be cost-effective, due to efficiency-boosting features that can be cost effective only when the stations become very large. Power stations were located strategically to be close to fossil fuel reserves (either the mines or wells themselves, or else close to rail, road or port supply lines). Siting of hydro- electric dams in mountain areas also strongly influenced the structure of the emerging grid. Nuclear power plants were sited for availability of cooling water. Finally, fossil fuel-fired power stations were initially very polluting and were sited as far as economically possible from population centres once electricity distribution networks permitted it. By the late 1960s, the electricity grid reached the overwhelming majority of the population of developed countries, with only outlying regional areas remaining 'off-grid'.

3.2 FUTURE SMART GRID

Metering of electricity consumption was necessary on a per-user basis in order to allow appropriate billing according to the (highly variable) level of consumption of different users. Because of limited data collection and processing capability during the period of growth of the grid, fixed-tariff arrangements were commonly put in place, as well as dual-tariff arrangements where night-time power was charged at a lower rate than daytime power.

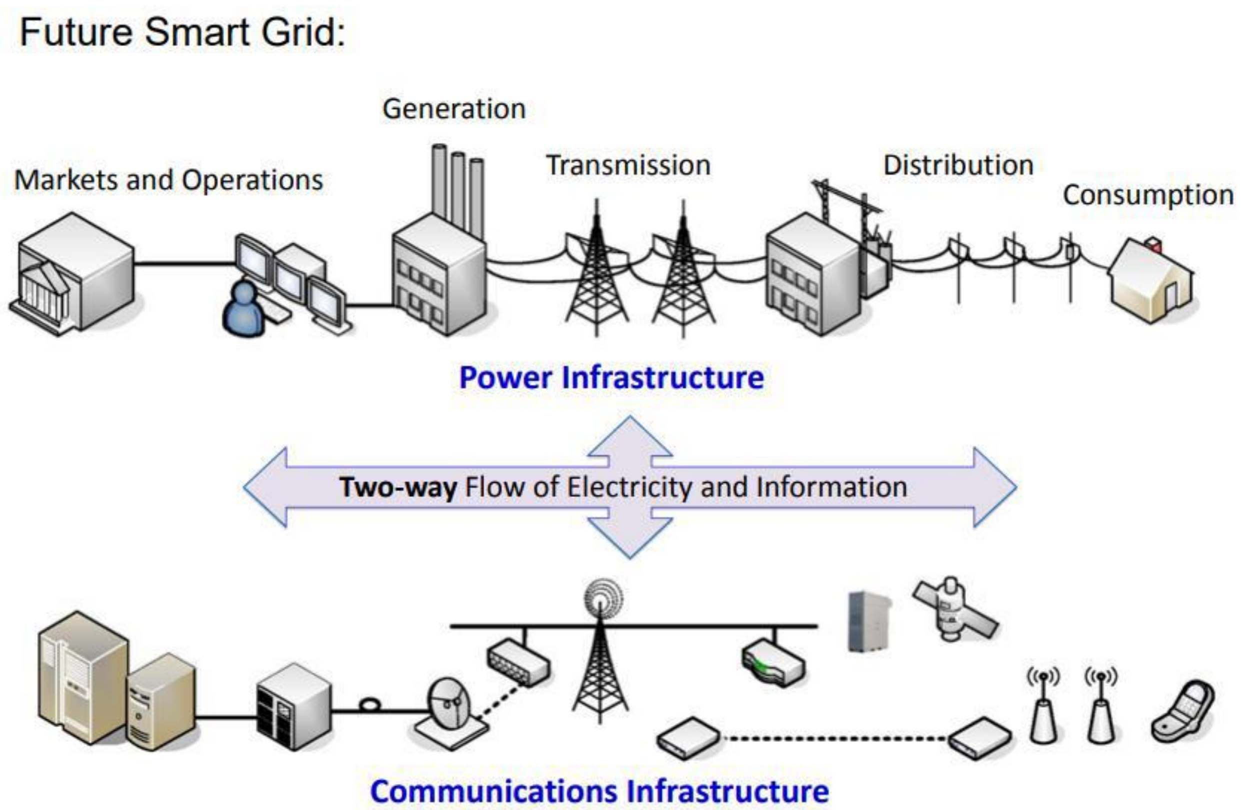

Fig.3.1 Future smart grid

The motivation for dual-tariff arrangements was the lower night-time demand. Dual tariffs made possible the use of low-cost night-time electrical power in applications such as the maintaining of 'heat banks' which served to 'smooth out' the daily demand, and reduce the number of turbines that needed to be turned off overnight, thereby improving the utilisation and profitability of the generation and transmission facilities. The metering capabilities of the 1960s grid meant technological limitations on the degree to which price signals could be propagated through the system. Through the 1970s to the 1990s, growing demand led to increasing numbers of power stations. In some areas, supply of electricity, especially at peak times, could not keep up with this demand, resulting in poor power quality including blackouts, power cuts, and brownouts. Increasingly, electricity was depended on for industry, heating, communication, lighting, and entertainment, and consumers demanded ever higher levels of reliability. Towards the end of the 20th century, electricity demand patterns were established: domestic heating and air-conditioning led to daily peaks in demand that were met by an array of 'peaking power generators' that would only be turned on for short periods each day.

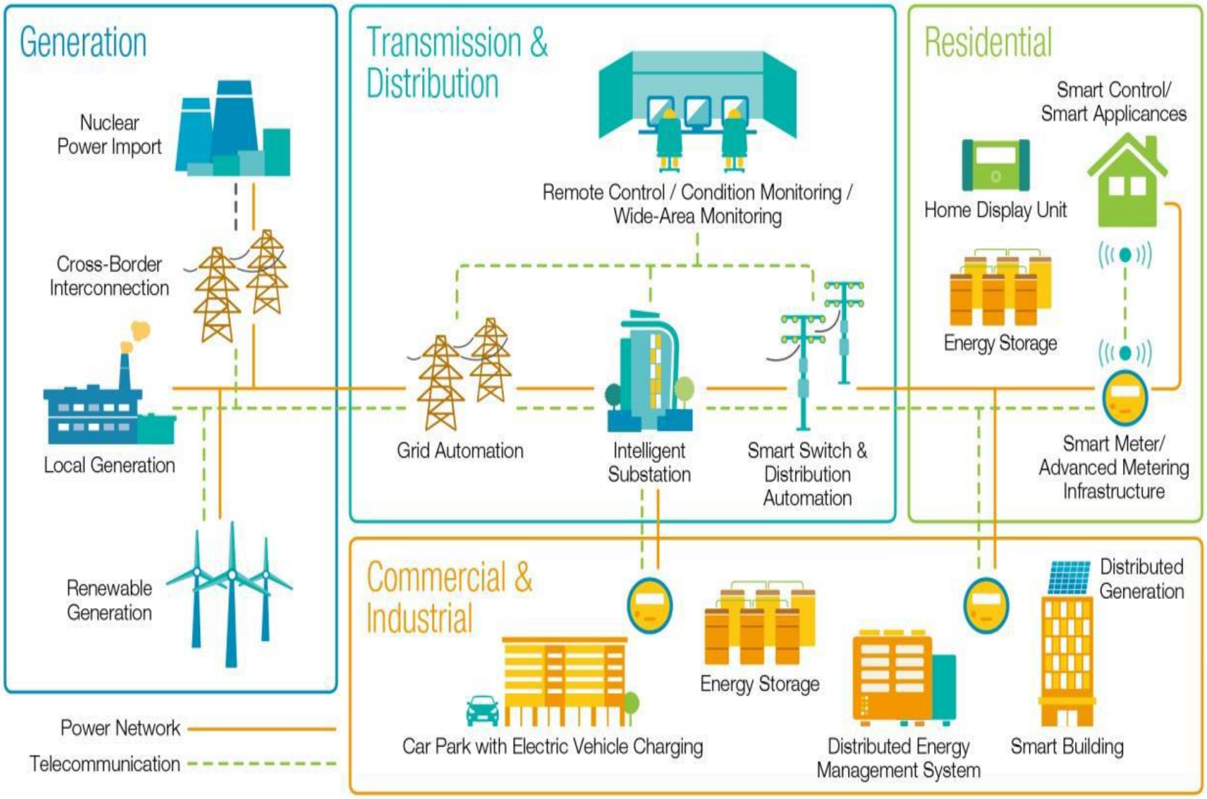

Fig.3.2. Structure of smart grid

Dominant forms such as wind power and solar power are highly variable, and so the need for more sophisticated control systems became apparent, to facilitate the connection of sources to the otherwise highly controllable grid. Power from photovoltaic cells (and to a lesser extent wind turbines) has also, significantly, called into question the imperative for large, centralised power stations. The rapidly falling costs point to a major change from the centralised grid topology to one that is highly distributed, with power being both generated and consumed right at the limits of the grid. Finally, growing concern over terrorist attack in some countries has led to calls for a more robust energy grid that is less dependent on centralised power stations that were perceived to be potential attack targets.To achieve each of the following, which together characterize a Smart Grid: (1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid. (2) Dynamic optimization of grid operations and resources, with full cyber-security. (3) Deployment and integration of distributed resources and generation, including renewable resources. (4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources. (5) Deployment of `smart' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation. (6) Integration of `smart' appliances and consumer devices. (7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning. (8) Provision to consumers of timely information and control options. (9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid. (10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services." A common element to most definitions is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. Various capabilities result from the deeply integrated use of digital technology with power grids. Integration of the new grid information is one of the key issues in the design of smart grids.

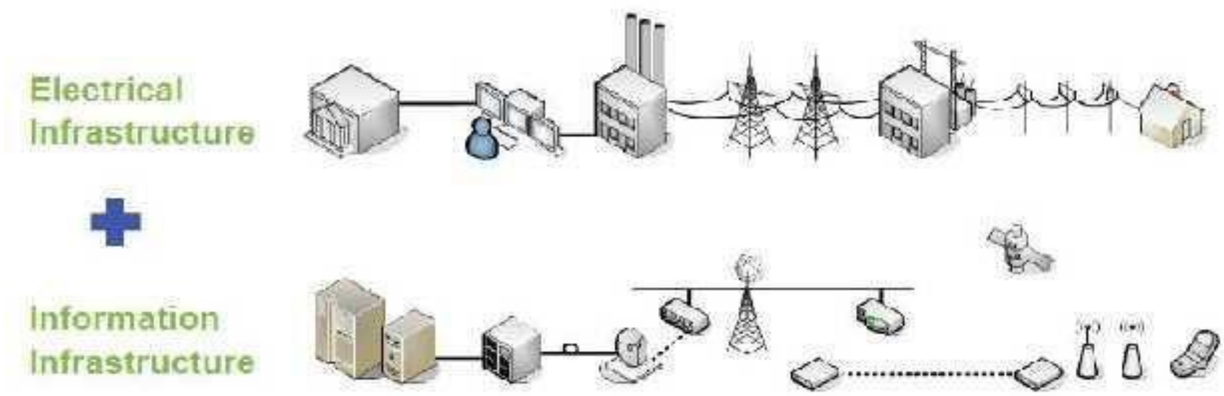

Fig.3.3.Electrical and Information Infrastructure

. Electric utilities now find themselves making three classes of transformations: improvement of infrastructure, called the strong grid in China; addition of the digital layer, which is the essence of the smart grid; and business process transformation, necessary to capitalize on the investments in smart technology. Much of the work that has been going on in electric grid modernization, especially substation and distribution automation, is now included in the general concept of the smart grid

Early technological innovations Smart grid technologies emerged from earlier attempts at using electronic control, metering, and monitoring.Automatic meter reading was used for monitoring loads from large customers, and evolved into the Advanced Metering Infrastructure whose meters could store how electricity was used at different times of the day. Smart meters add continuous communications so that monitoring can be done in real time, and can be used as a gateway to demand response-aware devices and "smart sockets" in the home. Early forms of such demand side management technologies were dynamic demand aware devices that passively sensed the load on the grid by monitoring changes in the power supply frequency. Devices such as industrial and domestic air conditioners, refrigerators and heaters adjusted their duty cycle to avoid activation during times the grid was suffering a peak condition.

3.3 FEATURES OF THE SMART GRID

The smart grid represents the full suite of current and proposed responses to the challenges of electricity supply. Because of the diverse range of factors there are numerous competing taxonomies and no agreement on a universal definition. Nevertheless, one possible categorization is given here.

- Reliability

The smart grid will make use of technologies, such as state estimation, that improve fault detection and allow self-healing of the network without the intervention of technicians. This will ensure more reliable supply of electricity, and reduced vulnerability to natural disasters or attack. The economic impact of improved grid reliability and resilience is the subject of a number of studies and can be calculated using a US DOE funded methodology for US locations using at least one calculation tool.

- Flexibility in network topology

Next-generation transmission and distribution infrastructure will be better able to handle possible bidirectional energy flows, allowing for distributed generation such as from photovoltaic panels on building roofs, but also the use of fuel cells, charging to/from the batteries of electric cars, wind turbines, pumped hydroelectric power, and other sources.

- Efficiency

Numerous contributions to overall improvement of the efficiency of energy infrastructure are anticipated from the deployment of smart grid technology, in particular including demand- side management. The overall effect is less redundancy in transmission and distribution lines, and greater utilization of generators, leading to lower power prices.

- Load adjustment/Load balancing

The total load connected to the power grid can vary significantly over time. Although the total load is the sum of many individual choices of the clients, the overall load is not a stable, slow varying, increment of the load if a popular television program starts and millions of televisions will draw current instantly. Traditionally, to respond to a rapid increase in power consumption, faster than the start-up time of a large generator, some spare generators are put on a dissipative standby mode..

- Peak curtailment/leveling and time of use pricing

To reduce demand during the high cost peak usage periods, communications and metering technologies inform smart devices in the home and business when energy demand is high and track how much electricity is used and when it is used. It also gives utility companies the ability to reduce consumption by communicating to devices directly in order to prevent system overloads. Examples would be a utility reducing the usage of a group of electric vehicle charging stations or shifting temperature set points of air conditioners in a city.

- Sustainability

The improved flexibility of the smart grid permits greater penetration of highly variable renewable energy sources such as solar power and wind power, even without the addition of energy storage. Current network infrastructure is not built to allow for many distributed feed-in points, and typically even if some feed-in is allowed at the local (distribution) level, the transmission-level infrastructure cannot accommodate it.

- Market-enabling

The smart grid allows for systematic communication between suppliers (their energy price) and consumers (their willingness-to-pay), and permits both the suppliers and the consumers to be more flexible and sophisticated in their operational strategies. Only the critical loads will need to pay the peak energy prices, and consumers will be able to be more strategic in when they use energy.

- Demand response support

Demand response support allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes. Eliminating the fraction of demand that occurs in these spikes eliminates the cost of adding reserve generators, cuts wear and tear and extends the life of equipment, and allows users to cut their energy bills by telling low priority devices to use energy only when it is cheapest. Demand response can be provided by commercial, residential loads, and industrial loads.

- Platform for advanced services

As with other industries, use of robust two-way communications, advanced sensors, and distributed computing technology will improve the efficiency, reliability and safety of power delivery and use. It also opens up the potential for entirely new services or improvements on existing ones, such as fire monitoring and alarms that can shut off power, make phone calls to emergency services, etc.

3.4 NEED FOR SMART GRID

With a population of over a billion people and a current GDP growth rate of about 8 percent, India is certainly one of the fastest growing countries in the world. Despite its robust economic growth, the country is still plagued by basic problems such as shortage of electricity, with nearly 40 percent of its rural households having no access to electricity. Although India has almost doubled its energy generation in the past decade by adding over 85 GW of capacity, its grid systems lose more than 30 GW of this generated power. This is highly disturbing to people working in the power sector in India, who are concerned with the efficiency of the distribution of electricity.

3.5 Advantages of Smart Grid Technology

- Help businesses reduce their carbon footprint

- New opportunities for tech companies

- Reduce cost of power cuts
- Meet increasing demand for power supply in India

3.6 Implementation of the Smart Grid

1. Aging assets and lack of circuit capacity

In many parts of the world (for example, the USA and most countries in Europe), the power system expanded rapidly from the 1950s and the transmission and distribution equipment that was installed then is now beyond its design life and in need of replacement. The capital costs of like-for-like replacement will be very high and it is even questionable if the required power equipment manufacturing capacity and the skilled staff are now available. The need to refurbish the transmission and distribution circuits is an obvious opportunity to innovate with new designs and operating practices.

2. Thermal constraints

Thermal constraints in existing transmission and distribution lines and equipment are the ultimate limit of their power transfer capability. When power equipment carries current in excess of its thermal rating, it becomes over-heated and its insulation deteriorates rapidly. This leads to a reduction in the life of the equipment and an increasing incidence of faults. If an overhead line passes too much current, the conductor lengthens, the sag of the catenary increases, and the clearance to the ground is reduced. Any reduction in the clearance of an overhead line to the ground has important consequences both for an increase in the number of faults but also as a danger to public safety.

3. Operational constraints

Any power system operates within prescribed voltage and frequency limits. If the voltage exceeds its upper limit, the insulation of components of the power system and consumer equipment may be damaged, leading to short-circuit faults. Too low a voltage may cause malfunctions of customer equipment and lead to excess current and tripping of some lines and generators.

4. Security of supply

Modern society requires an increasingly reliable electricity supply as more and more critical loads are connected. The traditional approach to improving reliability was to install additional redundant circuits, at considerable capital cost and environmental impact. Other than disconnecting the faulty circuit, no action was required to maintain supply after a fault. A Smart Grid approach is to use intelligent post-fault reconfiguration so that after the (inevitable) faults in the power system, the supplies to customers are maintained but to avoid the expense of multiple circuits that may be only partly loaded for much of their lives.

5. National initiatives

Many national governments are encouraging Smart Grid initiatives as a cost-effective way to modernise their power system infrastructure while enabling the integration of low-carbon energy resources. Development of the Smart Grid is also seen in many countries as an important Economic/commercial opportunity to develop new products and services. A lot has been done to mitigate the potential for blackouts—particularly in the effort to provide new technologies that can help make electricity more reliable, in order to sustain an increasingly high-tech economy which is based, in part, on the use of power-sensitive equipment.

3.7 CONVENTIONAL GRID (TODAY "S GRID) VERSUS THE SMART GRID

As mentioned, several factors contribute to the inability of today ' s grid to efficiently meet the demand for reliable power supply. Table compares the characteristics of today ' s grid with the preferred characteristics of the smart grid.

OVERVIEW OF ENABLING TECHNOLOGIES

Overview of the technologies required for the Smart Grid To fulfill the different requirements of the Smart Grid, the following enabling technologies must be developed and implemented: 1. Information and communications technologies: These include: (a) Two-way communication technologies to provide connectivity between different components in the power system and loads; (b) Open architectures for plug-and-play of home appliances; electric vehicles and micro generation; (c) Communications, and the necessary software and hardware to provide customers with greater information, enable customers to trade in energy markets and enable customers to provide demand-side response; (d) Software to ensure and maintain the security of information and standards to provide scalability and interoperability of information and communication systems. 2. Sensing, measurement, control and automation technologies:

These include:

(a) Intelligent Electronic Devices (IED) to provide advanced protective relaying, measurements, fault records and event records for the power system;

(b) Phasor Measurement Units (PMU) and Wide Area Monitoring, Protection and Control (WAMPAC) to ensure the security of the power system;

(c) Integrated sensors, measurements, control and automation systems and information and communication technologies to provide rapid diagnosis and timely response to any event in different parts of the power system.

(d) Smart appliances, communication, controls and monitors to maximise safety, comfort, convenience, and energy savings of homes;

(e) Smart meters, communication, displays and associated software to allow customers to have greater choice and control over electricity and gas use.

3. Power electronics and energy storage:

These include:

(a) High Voltage DC (HVDC) transmission and back-to-back schemes and Flexible AC Transmission Systems (FACTS) to enable long distance transport and integration of renewable energy sources;

(b) different power electronic interfaces and power electronic supporting devices to provide efficient connection of renewable energy sources and energy storage devices;

(c) series capacitors, Unified Power Flow Controllers (UPFC) and other FACTS devices to provide greater control over power flows in the AC grid;

(d) HVDC, FACTS and active filters together with integrated communication and control to ensure greater system flexibility, supply reliability and power quality;

(e) Power electronic interfaces and integrated communication and control to support system operations by controlling renewable energy sources, energy storage and consumer loads;

(f) Energy storage to facilitate greater flexibility and reliability of the power system.

(i) Wide Area Monitoring Systems (WAMS) WAMS are designed by the utilities for optimal capacity of the transmission grid and to prevent the spread of disturbances. By providing real - time information on stability and operating safety margins, WAMS give early warnings of system disturbances for the prevention and mitigation of system - wide blackouts.

(ii) Phasor Measurement Units (PMU)

Phasor Measurement Units or Synchrophasors give operators a time - stamped snapshot of the power system. The PMUs consist of bus voltage phasors and branch current phasors, in addition to information such as locations and other network parameters. Phasor measurements are taken with high precision from different points of the power system at the same instant, allowing an operator to visualize the exact angular difference between different locations.

(iii) Smart Meters

Smart meters have two functions: providing data on energy usage to customers (end - users) to help control cost and consumption; sending data to the utility for load factor control, peak - load requirements, and the development of pricing strategies based on consumption information and so on Automated data reading is an additional component of both smart meters and two - way communication between customers and utilities. The development of smart meters is planned for electricity, water, and gas consumption. Smart meters equip utility customers with knowledge about how much they pay per kilowatt hour and how and when they use energy. This will result in better pricing information and more accurate bills in addition to ensuring faster outage detection and restoration by the utility.

(iv) Smart Appliances: Smart appliances cycle up and down in response to signals sent by the utility. The appliances enable customers to participate in voluntary demand response programs which award credits for limiting power use in peak demand periods or when the grid is under stress. An override function allows customers to control their appliances using the Internet. Air conditioners, space heaters, water heaters, refrigerators, washers, and dryers represent about 20% of total electric demand during most of the day and throughout the year.

(v) Advanced Metering Infrastructure (AMI) AMI is the convergence of the grid, the communication infrastructure, and the supporting information infrastructure. The network - centric AMI coupled with the lack of a composite set of cross industry AMI security requirements and implementation guidance, is the primary motivation for its development. The problem domains to be addressed within AMI implementations are relatively new to the utility industry; however, precedence exists for implementing large - scale, network - centric solutions with high information assurance requirements. The defense, cable, and telecom industries offer many examples of requirements, standards, and best practices that are directly applicable to AMI implementations.

3.8 SUMMARY:

Smart grid is a technological paradigm being developed to satisfy the needs for considerable efficiency improvements in power generation and distribution processes. In this idea, the objects and devices, used in people's everyday lives, are equipped with embedded intelligence and communication capabilities allowing them to be interconnected via the Internet. In the IoE vision, the grid will be based upon the intelligent communicating nodes acting on behalf of renewable resources, electric vehicles, home appliances, and smart meters, constituting the decentralized and service-oriented ecosystem.

CHAPTER-4

4.1 INTRODUCTION:

MAS is a paradigm that allows to design large-scale distributed control systems in an alternative way . It is derived from the field of distributed, artificial intelligence, and uses autonomous and cooperative agents, exhibiting modularity, flexibility, and robustness . This concept exhibits the capability to distribute the control over a network of software entities, the agents. Each one has its own knowledge, skills, and autonomous proactive behavior. They cooperate together achieving global objectives and offering a decentralized control structure, opposite to traditionally used rigid and centralized solution. MAS technology provides a fast response to condition changes and supports reconfigurability

4.2. MULTI AGENT SYSTEM MODEL

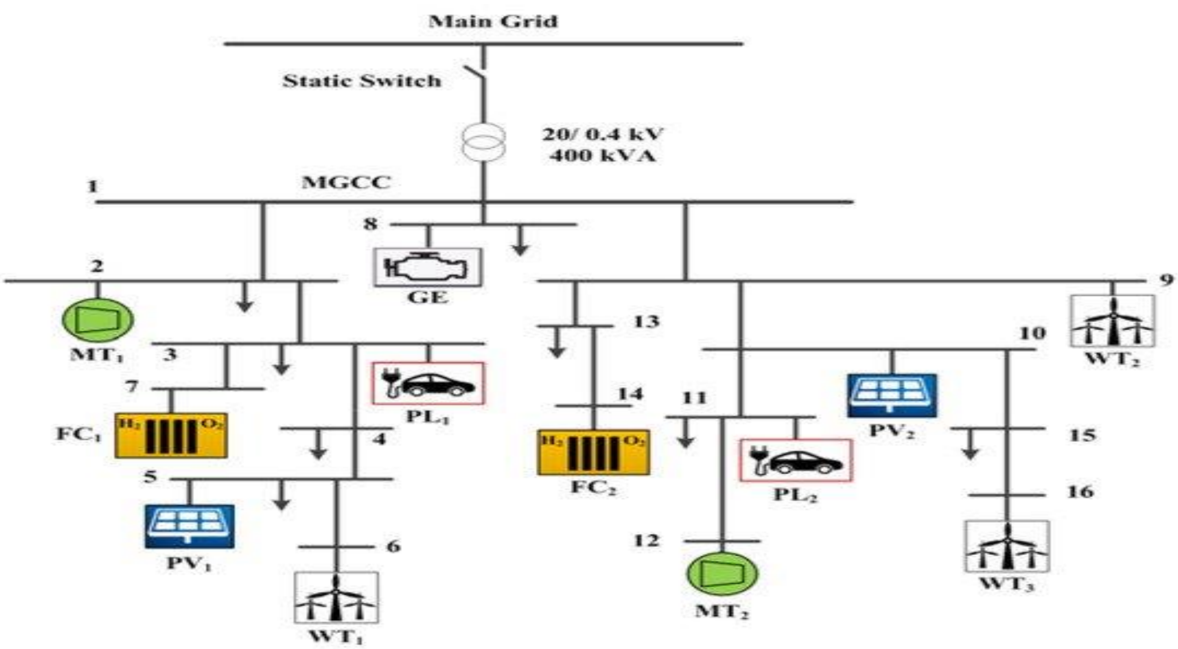

Fig.4.1 multi agent system model

Table-1

4.2.1.Generation and Load Data

Bus No	Generation Source	Gen (kW)	Load Location	Load (kW)	Shiftable Load	Non-shiftable Load
1	-		-			
2	MT1	5.0	L2	5.0		NSL2 [5.0]
3	EV1	2.0	L3	5.0	SL3 [5.0]	NSL3 [2.5]
4	-		L4	2.5	SL4 [2.5]	
5	PV1	5.0	L5	5.0	SL5 [2.5]	NSL5 [2.5]
6	WT1	5.0	-			
7	FC1	1.0	-			
8	GE	5.0	L8	5.9	SL8 [2.5]	NSL8 [2.5]
9	WT2	5.0	-			
10	PV2	5.0	-			
11	EV2	2.0	L11	5.0	SL11 [2.5]	NSL11 [2.5]
12	MT2	5.0	-			
13	-		L13	2.5	SL13 [2.5]	
14	FC2	1.0	-			
15	-		L15	2.5	SL15 [2.5]	
16	WT3	5.0	-		SL16 [5.0]	
Total		44	-	30	25.0 kW	15.0 kW

4.3 .CASE-1:

(Day time 1200hrs):- Generation exceeding Load. No Demand response

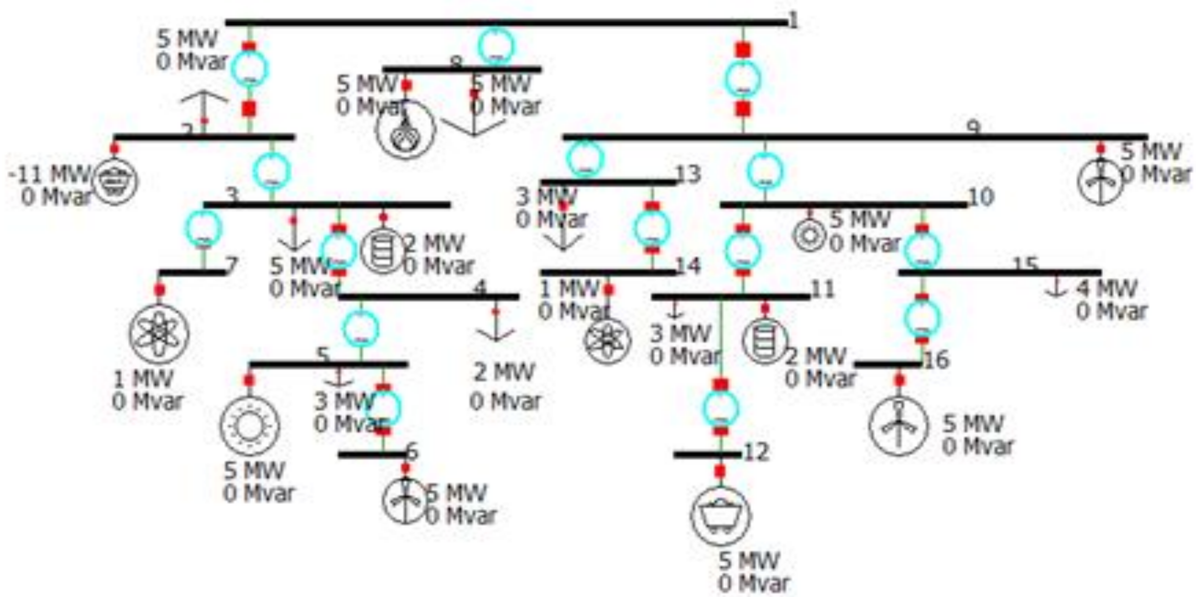

Fig.4.2 case-1 no demand response

Table-2

4.3.1.(Day time 1200hrs):- Generation exceeding Load. No Demand response

Bus No	Generation Source	Gen (kW)	Load Location	Load (kW)	Shiftable Load	Non-shiftable Load
1	-		-			
2	MT1	5.0	L2	5.0		NSL2 [5.0]
3	EV1	2.0	L3	5.0	SL3 [2.5]	NSL3 [2.5]
4	-		L4	2	SL4 [2]	
5	PV1	5.0	L5	3	SL5 [0.5]	NSL5 [2.5]
6	WT1	5.0	-			
7	FC1	1.0	-			
8	GE	5.0	L8	5	SL8 [2.5]	NSL8 [2.5]
9	WT2	5.0	-			
10	PV2	5.0	-			
11	EV2	2.0	L11	3	SL11 [0.5]	NSL11 [2.5]
12	MT2	5.0	-			
13	-		L13	3	SL13 [3]	
14	FC2	1.0	-			
15	-		L15	4	SL15 [4]	
16	WT3	5.0	-			
Total		46	-	30	15.0 kW	15.0 kW

4.4.CASE-2

<u>(Day time 1200hrs):- Generation exceeding Load. Compensation done by using EVs as consumer. (6 kW consumption each). With demand response.</u>

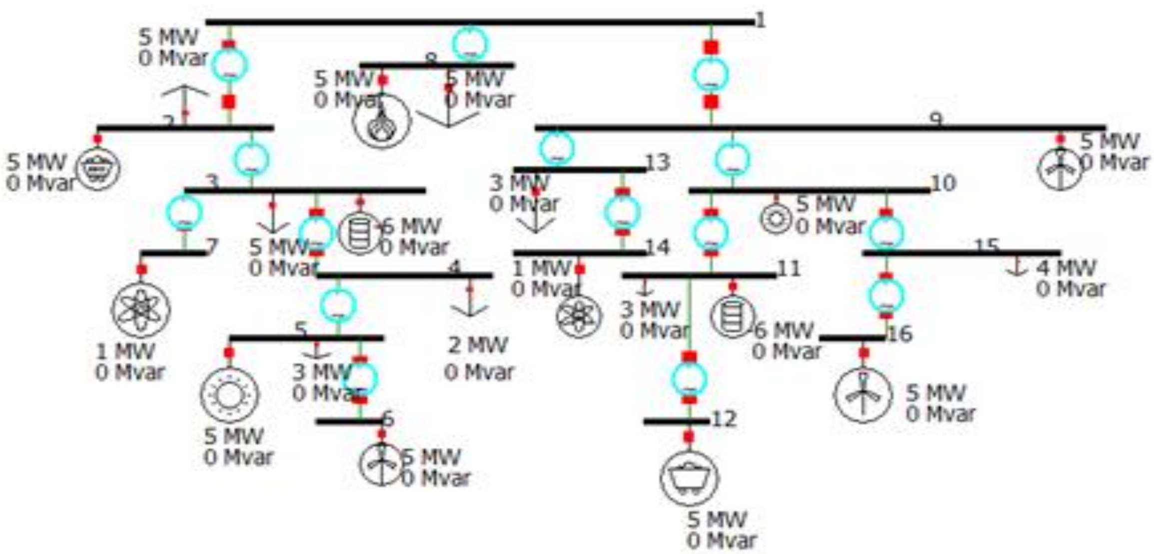

Fig.4.3 case-2 Generation exceeding load

Table-3

4.4.1. (Day time 1200hrs):- Generation exceeding Load. Compensation done by using EVs as consumer. (6 kW consumption each). With demand response.

Bus No	Generation Source	Gen (kW)	Load Location	Load (kW)	Shiftable Load	Non-shiftable Load
1	-		-			
2	MT1	5.0	L2	5.0		NSL2 [5.0]
3	EV1	-6	L3	5.0	SL3 [2.5]	NSL3 [2.5]
4	-		L4	2	SL4 [2]	
5	PV1	5.0	L5	3	SL5 [0.5]	NSL5 [2.5]
6	WT1	5.0	-			
7	FC1	1.0	-			
8	GE	5.0	L8	5	SL8 [2.5]	NSL8 [2.5]
9	WT2	5.0	-			
10	PV2	5.0	-			
11	EV2	-6	L11	3	SL11 [0.5]	NSL11 [2.5]
12	MT2	5.0	-			
13	-		L13	3	SL13 [3]	
14	FC2	1.0	-			
15	-		L15	4	SL15 [4]	
16	WT3	5.0	-			
Total		30	-	30	15.0 kW	15.0 kW

4.5.CASE-3

<u>(Night Time 2000 hrs):- PV generation not available. One Wind turbine not available due to breakdown. Both EVs charging with 1 kW each. Shiftable loads SL4 and SL13 switched off by means of demand response</u>

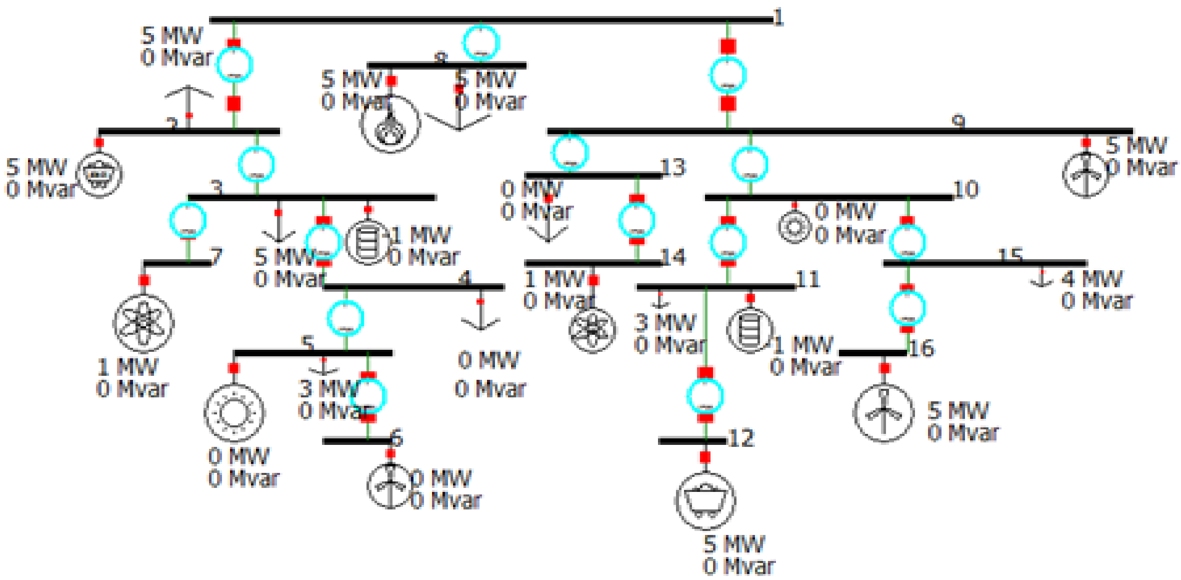

Fig.4.5 PV generations not available. One Wind turbine not available due to breakdown

Table-4.

4.5.1 (Night Time 2000 hrs):- PV generation not available. One Wind turbine not available due to breakdown. Both EVs charging with 1 kW each. Shiftable loads SL4 and SL13 switched off by means of demand response

Bus No	Generation Source	Gen (kW)	Load Location	Load (kW)	Shiftable Load	Non-shiftable Load
1	-		-			
2	MT1	5.0	L2	5.0		NSL2 [5.0]
3	EV1	-1	L3	5.0	SL3 [2.5]	NSL3 [2.5]
4	-		L4	0	SL4 [0]	
5	PV1	0	L5	3	SL5 [0.5]	NSL5 [2.5]
6	WT1	0	-			
7	FC1	1.0	-			
8	GE	5.0	L8	5	SL8 [2.5]	NSL8 [2.5]
9	WT2	5.0	-			
10	PV2	0	-			
11	EV2	-1	L11	3	SL11 [0.5]	NSL11 [2.5]
12	MT2	5.0	-			
13	-		L13	0	SL13 [0]	
14	FC2	1.0	-			
15	-		L15	4	SL15 [4]	
16	WT3	5.0	-			
Total		25	-	25	10.0 kW	15.0 kW

CONCLUSION

- MAS based approaches receive a significant attention as a proper automation technology in the field of smart grids.
- Every components acts as Agents and the interaction between agents leads to proper co-ordination in smart grid.
- Using Multi Agent System(MASs) integrated all the DERs with the power system and the behaviour of every Agent(component) which allowed every Agent for participation in Energy trading without overloading the main grid
- Proper Load balance occurs with the help of integration of Distributed Energy Resources with the grid.

CHAPTER-5

5.1 INTRODUCTION

Instead of a central dispatcher scheduling the generation of all the utilities, we assume that there is a central broker who receives bids for sell and purchase of energy from the four utilities. The broker schedules the interchanges by matching the highest buy bid with the lowest sell bid.

The utilities simulate their ELD individually and obtain their respective marginal cost characteristic, which is the first derivative of the cost characteristic, and can be found to be as follows, for the given system

$dC_A / dP_A = 3.6Pg + 10.5$ $dC_B / dP_B = 5.6Pg + 24.5$

$dC_C / dP_C = 6.0Pg + I\,5.6$ $dC_D / dP_D = 3.0Pg + 20.1$

Considering the above data for energy trading by the four utilities,I simulated these equations which satisfy the load and participates in energy bidding at discrete time intervals for each bid block size for buying bid and selling bid.Succesfully simulated using the matlab coding got the satisfying results for the whole bidding process.

Each and Every utility will have Pmin ,Pmax and load demand.Pmin is the minimum power that a utility can bale to generate the power to satisfy its load demand.Pmax is the maximum power which utility can able to generate.

Load demand is the power which each utility has to satisfy the consumer or load.If the utility has power more than it's load demand then it particiapte in sell bid process at marginal cost which is higher than it's marginal cost of the buying bid.

Meanwhile a utility can participate in buy bid to satisfy it's load demand at discrete intervals of 50MW each at a marginal cost lesser than it's sell bid.

After getting the buy bid data and sell bid data,the broker will plan a strategy for power sharing of highest buy bid block utility with lowest sell bid block.In such a way that every utility can satisfy their load demand effectively.

Buy bids are arranged in Descending order and Sell bids are arranged in Ascennding order in the table so that according to the above procedure bidding is easy for the broker to execute the energy trading process effectively.In the simulated graphs we can get the marginal cost of power at and every value.

5.2. Simulations results and discussions

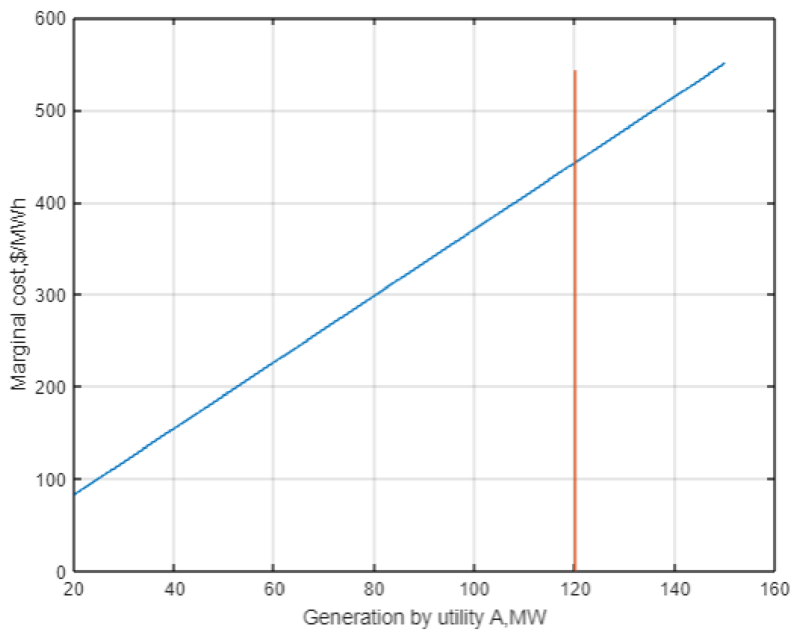

Figure 5.1. Marginal cost characteristics of utility A. The vertical line shows the power demand in utility area.

Utility A will generate minimum power of 20MW and will particiapte in bidding for 100MW in two states of 50MW each bid at separate marginal cost.While it can sell power of 30MW because it has maximum generation capability of 150 MW.So for Utility A energy will be traded in three states as two buy bid blocks of 50MW are to satisfy it's own load demand and the third bid is sell bid to sell it's extra power after satisfying it's own demand.The load demand of utility A is 120 MW and that point the marginal cost is 442.5 $/MWh.It can sell power above 120MW which is 30MW at marginal cost more than 442.5 $/MWh.

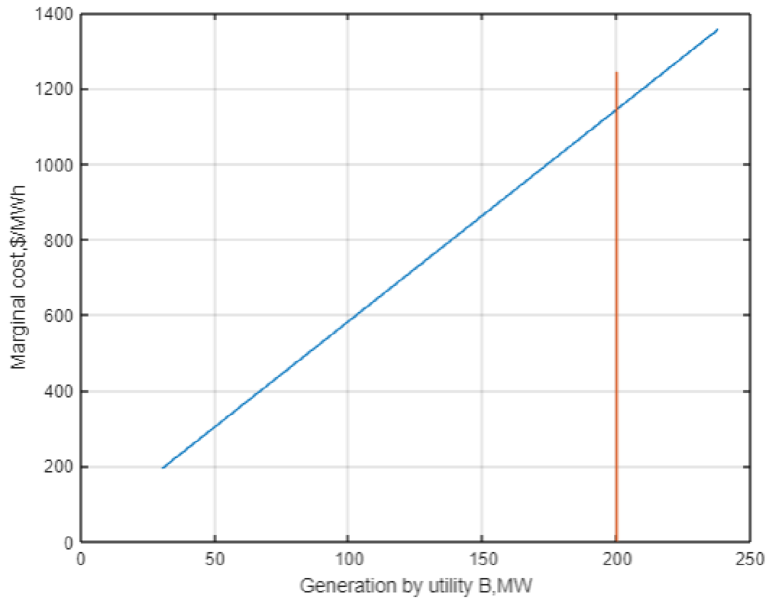

Figure 5.2. Marginal cost characteristics of utility B. The vertical line shows the power demand in utility area.

Utility B will generate minimum power of 30MW and it has to satisfy load demand of 200MW.So,it has the capacity of generation till 250MW.So it can participate in buying bid for 170MW.It occurs in 4 discrete price intervals. Three buy bids each of 50MW and 20MW.It can sell the remaining power of 50 MW in two intervals of 25MW each. As sell bid block is for 25MW. The load demand of utility B is 200 MW and that point the marginal cost is 1144.5 $/MWh.It can sell power above 200MW which is 50MW at marginal cost more than 1144.5 $/MWh.

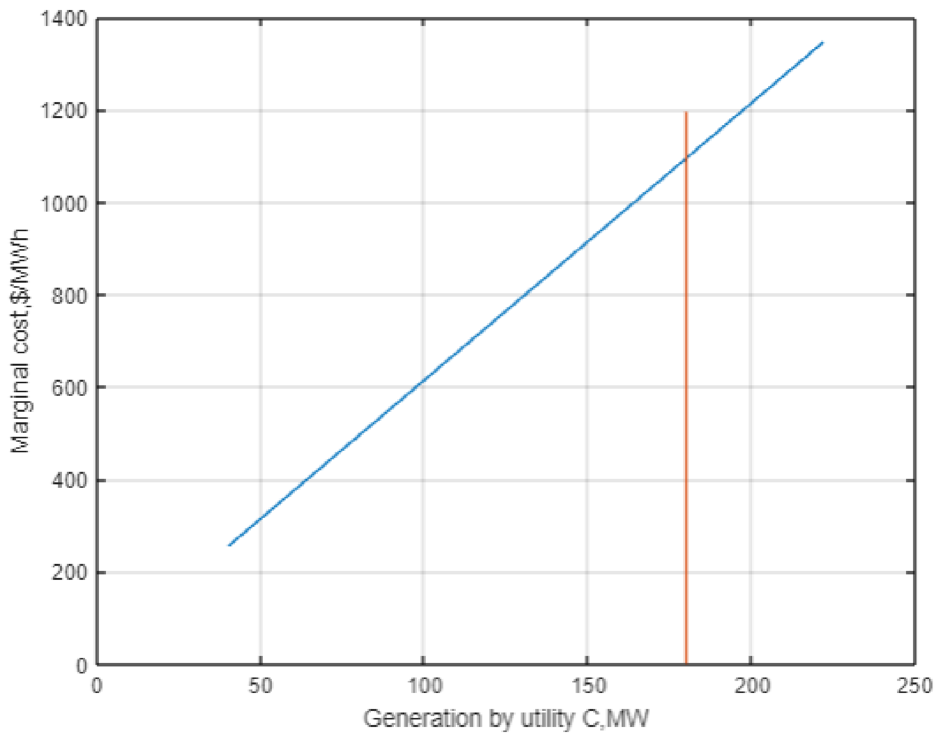

Figure 5.3. Marginal cost characteristics of utility C. The vertical line shows the power demand in utility area.

Utility C will generate minimum power of 40MW and it has to satisfy load demand of 180MW.So,it has the capacity of generation till 230MW.So it can participate in buying bid for 140MW.It occurs in 3 discrete price intervals. Two buy bids each of 50MW and one of 40MW.It can sell the remaining power of 50 MW in two intervals of 25MW each. As sell bid block is for 25MW. The load demand of utility C is 180 MW and that point the marginal cost is 1095.6 $/MWh.It can sell power above 180MW which is 50MW at marginal cost more than 1095.6 $/MWh.

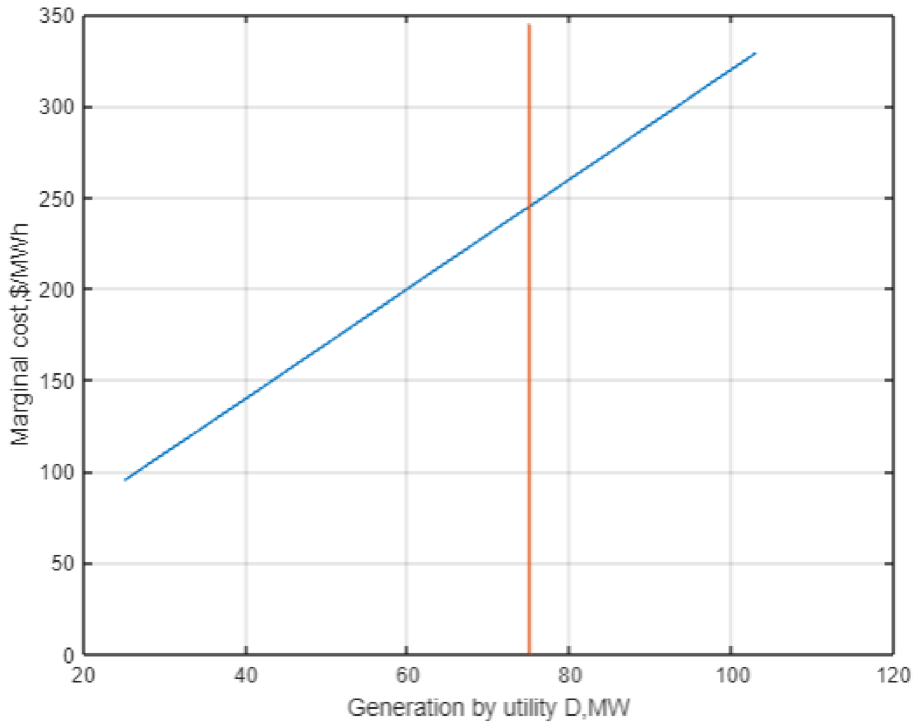

Figure 5.4. Marginal cost characteristics of utility D. The vertical line shows the power demand in utility area.

Utility D will generate minimum power of 40 MW and it has to satisfy load demand of 180 MW. So, it has the capacity of generation till 230 MW. So it can participate in buying bid for 140 MW. It occurs in 3 discrete price intervals. Two buy bids each of 50 MW and one of 40 MW. It can sell the remaining power of 50 MW in two intervals of 25 MW each. As sell bid block is for 25 MW. The load demand of utility D is 75 MW and that point th marginal cost is 245.1 $/MWh.It can sell power above 75 MW which is 50 MW at marginal cost more than 245.1 $/MWh.

We assume that the utilities place their bids without considering unit commitment decisions. Therefore, for example, if a utility so desires, it can purchase as much energy as to meet all of its demand and shut down its generators. Based on the marginal cost characteristic, step-wise bid blocks for buy and sell can be formulated for each utility. Figure 5.5 shows the formulation of such bid blocks for utility-A. Since the marginal cost characteristic is a monotonically increasing linear function, a band size of 50 MW has been used to construct the bid blocks. It is to be noted that such a bid formulation is not a unique one.

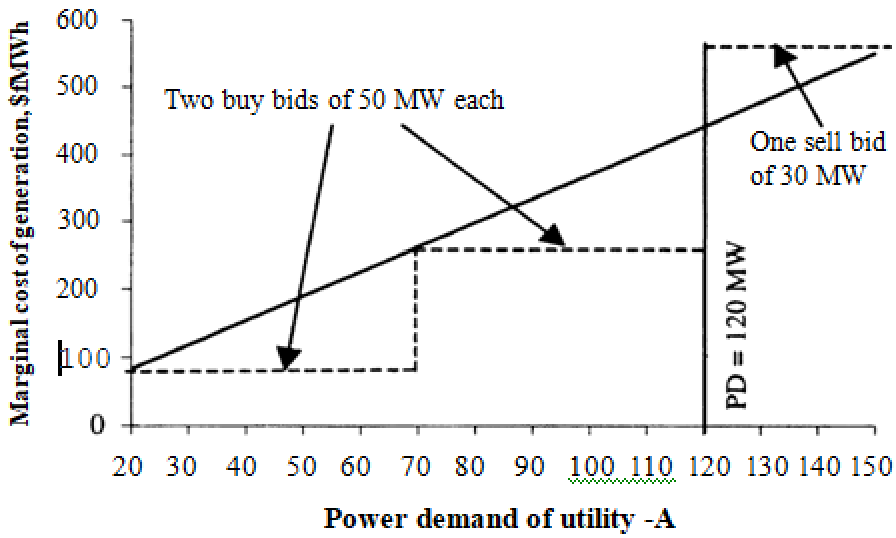

Figure 5.5. Marginal cost characteristic of Utility-A and formulation of its bidding blocks

In this particular instance, utility A has a demand of 120 MW, which is shown by the vertical line. The marginal cost corresponding to this load is $442.5/MWh. Understandably, utility A will be willing to buy power at prices less than $442.5/MWh and sell power at prices more than $442.5/MWh. It can sell a maximum of 30 MW, after meeting its load of 120 MW, since it has a maximum generation capacity limit of 150 MW. Similarly, if we assume that it will not shut down all its own generating units, it can buy power up to 100 MW while generating the minimum 20 MW, to meet its load. Accordingly, the buy and sell bid blocks are prepared by considering the purchase of 100 MW in two bid blocks of 50 MW each, and the sell of 30 MW, in one bid block only and placing them at discrete price intervals.

Table 1 lists all the bid blocks thus formulated for each utility in the same manner as discussed for utility-A. Utility B can sell a maximum of 50 MW due to its capacity limit and thus its sell bid is in two blocks of 25 MW each, while it can buy 170 MW, which is constructed in four blocks. Utility C has two selling bid blocks and three buying bid blocks while, utility D has two blocks each for buying and selling bids.

Table-1 Bid Blocks								
Utility	Pmax	Pmin	Demand	Marginal cost of the utility to meet the demand with own generation K $/MWh	Buy Bid		Sell Bid	
					Quantity MW	Price $/MW	Quantity MW	Price $/MWh
A	150	20	120	442.5	50	262.5	30	550.5
					50	82.5		
B	250	30	200	1144.5	50	864.5	25	1284.5
					50	584.5	25	1424.5
					50	304.5		
					20	192.5		
C	230	40	180	1095.6	50	795.6	25	1245.6
					50	495.6	25	1395.6
					40	255.6		
D	125	25	75	245.1	25	170.1	25	320.1
					25	95.1	25	395.1

The bids so formulated are submitted to the central broker for settlement of the transactions, who then arranges the bids in order, i.e. buy bids are arranged in descending order of prices and sell bids in the ascending order (Table 2).

Table-2 Buy bids and Sell bids are arranged in decreasing and increasing order respectively					
Buy Bids			Sell Bids		
Utility	Price $/MWh	Quantity MW	Utility	Price $/MWh	Quantity MW
B	864.5	50	D	320.1	25
C	795.6	50	D	395.1	25
B	584.5	50	A	550.5	30
C	495.6	50	C	1245.6	25
B	304.5	50	B	1284.5	25
A	262.5	50	C	1395.6	25
C	255.6	40	B	1424.5	25
B	192.5	20			
D	170.1	25			
D	95.1	25			
A	82.5	50			

Buy bids are arranged in Descending order and Sell bids are arranged in Ascennding order in the table so that according to the above procedure bidding is easy for the broker to execute the energy trading process effectively.In the simulated graphs we can get the marginal cost of power at and every value.

5.3 Summary:

Settlement of transactions without considering transmission limits:
The bids are matched in the order in which they have been arranged in *Table2*. The broker clears three transactions in all, two of which are between the same utilities (B and D). Hence, in physical terms there are two transactions, a 50 MW transfer from D to B and a 30 MW transfer from A to C. The system savings achieved from the brokerage is $32698. This is somewhat less compared to the system savings obtained with multi-area joint dispatch case without transmission limits ($49605.5).

5.4 CODE:

```
utility = ["A";"B";"C";"D"];

a = [3.6;5.6;6;3];

b = [10.5;24.5;15.6;20.1];

Pmax = [150;250;230;125];

Pmin = [20;30;40;25];

Demand = [120;200;180;75];

tab = table(a,b,Pmax,Pmin,Demand,'Rownames',utility);

chara_plotter('A',tab)

chara_plotter('B',tab)

chara_plotter('C',tab)

chara_plotter('D',tab)

marginal_cost('A',tab,50)

marginal_cost('A',tab,50)

marginal_cost('B',tab,50)

marginal_cost('B',tab,20)
```

```
marginal_cost('C',tab,50)

marginal_cost('C',tab,40)

marginal_cost('D',tab,25)

buy_bids('A',tab,50)

buy_bids('B',tab,50)

buy_bids('C',tab,50)

buy_bids('D',tab,25)

sell_bids('A',tab,30)

sell_bids('B',tab,25)

sell_bids('C',tab,25)

sell_bids('D',tab,25)

function [] = chara_plotter(utility,tab)

m=tab{utility,'a'};

c=tab{utility,'b'};

a=tab{utility,'Pmin'}:26:tab{utility,'Pmax'};

b=m.*a+c;

idx_ = 1:size(cell2mat(tab.Row));

figure()

plot(a,b)

hold on

grid on

plot([tab{utility,'Demand'} tab{utility,'Demand'}],[0
tab{utility,'a'}*tab{utility,'Demand'} + tab{utility,'b'} + 100])

end

function [mc] = marginal_cost(utility,tab,p)

mc = tab{utility,"a"} * p + tab{utility,"b"};

end
```

```
function [bids] = buy_bids(utility,tab,bid_size)

i_ = 1;

n_bids = floor((tab{utility,"Demand"}-tab{utility,"Pmin"})/(bid_size));

res_bid = tab{utility,"Demand"} - tab{utility,"Pmin"} - n_bids*bid_size;

res_bid

if res_bid > 0

    bids(1,:) = [res_bid,  marginal_cost(utility,tab,tab{utility,"Pmin"})];

    i_ = i_ + 1;

end

if res_bid == 0

while bid_size*(i_) + res_bid < tab{utility,"Demand"}

        bids(i_,:) = [bid_size,  marginal_cost(utility,tab,bid_size*(i_ -
1)+tab{utility,"Pmin"}+res_bid)];

  i_ = i_ + 1;

    end

else

     while bid_size*(i_ -1) + res_bid < tab{utility,"Demand"}

        bids(i_,:) = [bid_size,  marginal_cost(utility,tab,bid_size*(i_ -
2)+res_bid+tab{utility,"Pmin"})];

        i_ = i_ + 1;

     end

end
```

CONCLUSION

- Thus by simulating the data of four utilities using the transmission limits, Energy Trading occurs effectively.
- Energy trading occurs in a way that highest buy bid shares power with lowest sell bid
- Accordingly while trading energy, marginal cost is Effective with respect to every utility power capacity that to be traded in each bid block.
- Each bid block of every utility will have separate marginal cost for effective energy trading.

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