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Agents in Smart Grids

Aalto University School of Electrical Engineering

Thesis submitted for the examination for the degree of Master of Science in Technology
Espoo, 22.10.2012

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Abstract of Master's Thesis

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Title of Master's Thesis: **Agents in Smart Grids**

Number of pages: 11+86

Date: 22.10.2012

Language of Thesis: English

Department: Electrical Engineering
Professorship: Power Systems and High Voltage Engineering

Code: S-18

Supervisor: Prof. Matti Lehtonen
Instructor: Prof. Matti Lehtonen

Electricity has played an important role in the development of almost every technology, and has revolutionized human life with comfort and ease in every field. The electric power grid appeared to be the most complex machine on earth. Electricity has provided us with so many facilities to improve our living standard along with the increased demand for highly efficient, and more accurate and intelligent control systems to enhance the grid's reliability and efficiency. Conventionally, the electricity grid has been controlled and monitored using Supervisory Control And Data Acquisition (SCADA) system which is centralized in nature but now, with the introduction of the idea of the smart grid and the availability of more intelligent entities, the grid has to be controlled and monitored by intelligent agents, giving the overall system a distributed nature. The power grid is moving towards a new era of having a decentralized nature, providing greater access to the market place for the consumers and integrating Distributed Energy Resources (DER) in the main grid to improve reliability and reduce energy cost.

Agents are intelligent entities placed in some environment to make wise decisions and act flexibly and autonomously based on their built-in intelligence along with their previous experiences. The smart grid is a vision of a grid with the abilities of integrating renewable energy resources in the grid, energy storage, enabling markets, self-healing, greater reliability, efficiency, improved power quality, etc. This master's thesis has focused on the main features of the smart grid, the anatomy of an agent (what exactly is it?) and the applications of these intelligent entities in a grid to achieve the envisioned goal of a smart grid. A thorough study and literature survey of intelligent agents as well as smart grids, relating the applications of agents in smart grids have been done. Agents appeared to be the intelligent entities best suited for the monitoring, control, electricity market activities and the efficient usage of energy. They provide a market place for electric vehicles and network reconfiguration. They enable self-healing during faults in the network, based on their distributed, self-contained characteristics. A multi-agent based demand side management model has been proposed in this thesis.

Keywords: Agents, Smart Grids, Agent Anatomy, Supervisory Control And Data Acquisition (SCADA), Distributed Energy Resources (DER), Distributed Generation, Microgrid, Energy Balance Management, Demand Side Management (DSM), Electric Vehicles, Network Management, Self-Healing Network, Virtual Power Plant (VPP)

Acknowledgement

First of all, I thanks to almighty GOD, who supported and blessed me in every way of life; patience, humbleness, knowledge and everything to accomplish this task.

I feel immense pleasure to say special thanks to Prof. Matti Lehtonen for believing in my abilities and considering me as a member of his research family. It would be a great honor for me to appreciate and thank to him for his support, guidance and motivation for achieving this goal. He proposed me a topic for this research in which I was crazy to start journey of my research, so once again I would like to present special thanks to Prof. Matti Lehtonen from the core of my heart. Gratitude must be expressed to Mr. Robert John Millar for his support and value able guidance in writing this thesis. Thanks to Dr. Mohamed Abdel Fattah for giving me time and guidance about the technical writing and appreciable discussion.

I would like to say thanks to my senior Mr. Ghulam Amjad Hussain for his support and guidance for completing this degree in such a very short time. This is the time to say thanks to all my friends specially; Mr. Kashif, Mr. Mubbashir, Mr. Shakil, Mr. Atif, Mr. Shahbaz and Miss. Fiza for their moral support in every matter of my life.

Finally, I would like to say thanks to my parents who have been a source of encouragement, inspiration, and motivation for me and continue to pray for my success. I am thankful to all my teachers who tough me not only to get knowledge but also how to live a peaceful life and influenced my life the most, Dr. Abuzar Abid Siddiqui and Dr. Abdul Sattar Malik.

Espoo, Finland.

22.10.2012

Farhan Hameed Malik

Dedication

This thesis is dedicated to my beloved parents

who grown me up to reach this stage of life because of whom I felt the real essence of life

and one of my ideal professor's, I ever met in my life one and only Prof. Matti Lehtonen

who supported me in every way of research and gave me confidence to dive in the deep

sea of research in this innovative field of science.

"Keep your dreams alive. Understand to achieve anything requires faith and belief in yourself, vision, hard work, determination, and dedication. Remember all things are possible for those who believe." Gail Devers

List of Abbreviations

2APL	Double A-P-L (Agent Programming Language)
AC	Alternating Current
ACL	Agent Communication Language
AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
AOP	Agent Oriented Programming
APL	Agent Programming Language
BDI	Belief Desire Intention
CA	Communicative Act
CAS	Complex Adaptive System
CHP	Combined Heat and Power
CL	Content Language
DER	Distributed Energy Resources
DG	Distributed Generation
DOE	Department of Energy
DSM	Demand Side Management
FIPA	Foundation for Intelligent Physical Agents
IED	Intelligent Electronic Devices
IEEE	Institute of Electrical and Electronics Engineers
IEM	Intelligent Energy Management
IP	Interaction Protocol
IT	Information Technology
JADE	Java Agent DEvelopment Framework
MAS	Multi Agent System
MRI	Magnetic Resonance Image
PLC	Power Line Carrier
PMU	Phasor Measurement Units
PRS	Procedural Reasoning System
PSAT	Power System Analysis Tool
PV	Photo Voltaic
RTO	Regional Transmission Organization
SCADA	Supervisory Control And Data Acquisition
VPP	Virtual Power Plant
WAMS	Wide Area Measurement Systems

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Chapter 1

Introduction

1.1 RESEARCH DIRECTION AND MOTIVATION

Electricity along with its grid is the most significant engineering achievements of last the century which influenced human life the most. Electricity is playing an important role in our lives. Electrification has made us so dependent on it that each small appliance in our use, transportation, communication and business activities etc are indebted to it [2]. Power grid is considered as the largest interconnected network on our planet, it is composed of large number of generation units, long transmission lines and much more; making it one of the complex systems. The fact that electricity is to be used the instant it is being generated requires the power grid to match the demand and production in real time with a continuity of supply. It's true our existing power grid is almost 99.97% reliable but still there is a margin for the power outage resulting in the loss of money during those outage times and of course affecting the comforts of its consumers [1].

The demand of electricity has exponentially increased for last few decades, so compelling the existing power grid to be upgraded accordingly. But the more viable solution is to introduce the concept of microgrids and distributed generation in the smart grid to compensate somehow increased demand without increasing the capacity. In this way most of the loads can act like prosumers and would be able to reduce burden on the main grid. Our motivation is to make the existing power grid as intelligent as to accommodate all generation options and consumer friendly to increase consumer's participation in electricity market which is the ultimate goal of the smart grid. Conventionally, the power grid has been monitored and controlled by Supervisory

Control And Data Acquisition (SCADA) system which is centralized in nature and had required a lot of computation power to make intelligent decision for the whole system at once, hence much burden on the main processor. Controlling smart grid using distributed i.e. decentralized entities; like intelligent agents will change the way electricity being consumed and controlled with the addition of many other benefits of increased reliability, more autonomous even at end user level. Control is distributed at local level to get more of it.

Power grid is appeared to be the most complex system, so controlling it by the implementation of distributed processing is the best suitable option to manage it more efficiently and in a short time especially in emergency states. In contrast to centralized processing, distributed process is more flexible, efficient, reliable and economical. Distributed control system has the ability to divide the whole system into many self contained control units, making each unit responsible for real-time monitoring and control of that particular task or unit. In this way effect of any disturbance in one portion of the system would not directly affect the other portions of the system, because the distributed control try to resolve the problem locally, so less information is required to pass to the upper layers. If every problem is supposed to be solved by centralized control system then there might be congestion of the main controller resulting in a delay to some more serious issues to be resolved, hence increasing the chances of big problems. As far as economy is concerned, control system for distributed control is simple and no long communication link is required, hence reducing the capital invests on communication system. But the main focus of distributed control is to increase flexibility and reliability of the grid instead of reducing the money spent on establishing these systems. Efficiency of smart grid monitoring and control is adversely increased; as a single task is divided into multiple subtasks, providing the facility to control the loads even at appliance level, improving the overall efficiency of energy usage.

In this thesis our task is to focus on these distributed intelligent entities which can act effectively and autonomously to achieve the overall goal of the system. Intelligent agents are the most suitable entities implied in this regard in the smart grid to have all the envisioned features of smart grid into reality. This is the real motivation to study and implement these agents into smart grids.

1.2 ORGANIZATION OF THE THESIS

This thesis is organized in nine chapters each presenting the core idea as detailed below:

Chapter 2 provides the details of the concept of smart grid and its vision, Chapter 3 focuses on the inside of an intelligent agent and its anatomy, Chapter 4 relates somehow the concept of agents to smart grid in comparison to other intelligent entities being used, Chapter 5 is dedicated to the development platforms of agents and related software, Chapter 6 introduces distributed energy resources agent and micro grid, Chapter 7 proving the energy balance management model of smart grid based on intelligent agents, Chapter 8 deals with the issue related to network management of smart grid on the basis of agents, Chapter 9 gives the overall clue of the thesis and some light towards future goals based on this work done so far.

1.3 GOAL OF THE WORK

This master's thesis has some major goals to be achieved which could be expressed as:

- The main objective of the thesis is to have good understanding of smart grid and the intelligent agents through an intensive literature review. The core focus is on the anatomy of agents which can be implemented in smart grids to make it more efficient and intelligent.
- To find the applications of these intelligent entities in smart grids in order to achieve the overall goal of the envisioned concept of smart grid based on proper understanding of agents in smart grids.
- To investigate the best agent based models of demand side management to increase the consumer participation in energy market.

Chapter 2

The Smart Grid

The journey begins with the Edison's first generating power station by 1882, in Pearl Street New York City, and that system could transmit the power only up to one square mile. But with the introduction of alternating current (AC) electrical supply system by Nikola Tesla, world come to realize that electricity could be transmitted to longer distances more efficiently [3]. So the researches continued, resulting in a more complex but of course more reliable and efficient power system. Just like the word "Smart" once used for phones having more advanced features and user friendly, the word smart is not new for the grid; it has been used for last few years. The power grid also started to capture the attention of its researchers; why not to make our existing power grid as intelligent as to optimize the usage of energy, more consumer friendly, self healing nature and much more. In order to have all the advanced features in the grid, it has to be modified using more intelligent systems, advanced signal processing, fast communication of data, and automatic meter reading etc. to call it as a ***"Smart Grid".*** The availability and affordability of modern technologies in communication, computation, processing, integration and markets have encouraged the scientists to make the existing power grid more reliable, flexible, competitive, and affordable for the consumers [1].

No doubt, it will take long time to have all the envisioned features of smart grid in practice but now; as the journey has already been started so hopefully it will end up at its targeted destination. It would require a lot of motivation, innovation and devotion for the researchers and acceptance by the consumers to implement it completely in real life. So for having countless outcomes from the smart grid we should be ready to face some challenges as well.

2.1 THE SMART GRID: UNHIDE THE SECRETS

It's a reality that the advancements in power grid are a bit slow as compared to other technologies like telephony which started its journey in the same era as electricity grid does. This is not all about the appearance of a particular system but of course it is the matter of features and flexibility of systems in comparison to the other. The idea of smart grid is to make the existing centralized power grid a decentralized one and consumer friendly that is; aim to change the way of electricity business, energy policy, automation and control methodology and many more while considering all its consumers and stockholders. It is worthwhile to mention here is that some of the ideas behind smart grid already present in the existing grid but all the envisioned features of smart grid could be implemented with the application of internet into the utility having capabilities of two way communications. Distributed computing and communication allows for real time energy balance management even at appliance level. Figure 2.1 gives a clue of smart grid technology [1].

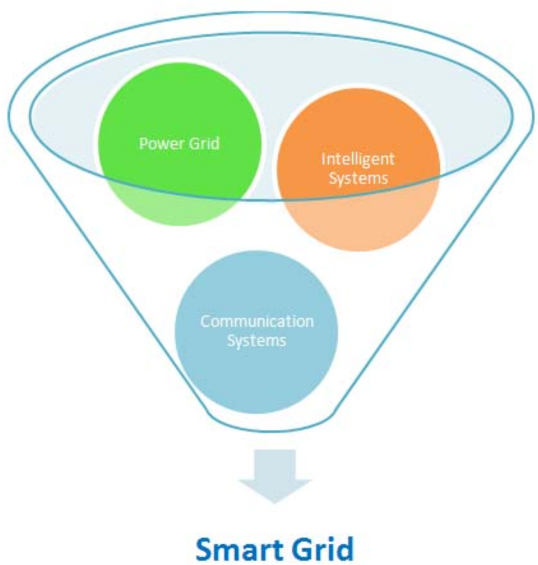

Figure 2.1 Idea Behind Smart Grid [41]

With the advancements in technology world is looking for intelligent power grids, that can optimize the use of energy generated, meet the demand of energy in real-time by the integration of renewable energy resources and can heal itself in case of any fault. While thinking about this intelligent power grid the idea comes to our mind is of

Smart Grid. The implementation of Information Technology (IT) in power system will make power grid more reliable and efficient.

Smart Grid integrates modern sensing technologies, control methodologies and advanced communications into the existing grid in order to make it exhibiting the following characteristics [4]:

- Able to integrate all generation options including renewable energy sources
- Energy storage options
- Must maintain the power quality
- Enhanced enabling of energy markets
- Resist external attacks
- Self-healing in nature
- More consumer friendly
- Provide more reliability, efficiency and optimization of assets

2.2 SOME OF BASIC TERMS RELATED TO SMART GRIDS

The vision of smart power grid introduces some new terminologies to the world of power engineering, for instance; bidirectional power flow, distributed generation, prosumers, self-healing networks etc. These terms are explained below.

2.2.1 BIDIRECTIONAL POWER FLOW

Conventionally, power flows from large generating stations to transmission grid to distribution network and finally to end users. But with the advent of the idea of distributed generation and micro producers of power, now power can be either received from the main grid or it can be sent back to the distribution grid by the prosumers in case of excessive energy generated by prosumers compared to their own demand. In this way power is being transferred in either direction from distribution grid to consumers or from prosumers to distribution network.

2.2.2 DISTRIBUTED GENERATION

When the electricity is generated near the places where it is supposed to be consumed we call it distributed generation. Generally, it is the use of small scale power generation units like small wind turbines or solar panels which enable the reduction of energy cost and carbon emission while increasing the reliability. As the distance between the generation unit and the load become short so it will result in a more efficient and economical use of energy; having many distributed generation units in a particular area will provide its consumers a freedom of choice as well. In some cases bidirectional power flow provides more market place [1].

2.2.3 PROSUMER

The word "Prosumer" is a combination of producer and consumer of electricity. On micro level when a household or small industry produces electrical power and consumes it, while it is able to offer extra power generated for sell to the distribution grid, it is given the name of a prosumer. For instance, if we talk about zero energy buildings, they are introducing prosumers concept into the electricity market.

2.3 SPECIAL FEATURES OFFERED BY SMART GRID

Smart grid not only promised to have all of the above mentioned features but it is a broader vision with no limits. Some of the key benefits from smart grid envisioned today are detailed below.

2.3.1 ABILITY TO INTEGRATE RENEWABLE ENERGY RESOURCES

Increased use of renewable energy resources for the production of electricity is the aim of smart grid but on the other hand intermittent nature of these resources like wind or solar is a big challenge for smart grid as well, which demands most intelligent systems to be implemented in this regard. Smart grid will accommodate all generation options irrespective of their variability. Integration of renewable energy resources in the main grid influence many things in the network; intelligently controlled by smart grid's smart devices.

2.3.2 FLEXIBILITY OF THE NETWORK

Conventional grid is not so much flexible with the reverse power flow to the distribution network, in case of increased generation by a local generation unit compared to the consumption by itself. Smart grid is able to handle multiple generation options with the flexibility of accommodating various types of sources and energy storage options.

2.3.3 RELIABILITY OF THE NETWORK

Any blackout even if it lives for few seconds affects the reliability of the system, and may cost millions of Euros as loss. It affects not only the lives but it also has a very negative impact on the nation's economy [1]. Reliability of the grid and continuity of supply is the major issue to be focused by smart grid. Implementation of the idea of self-healing network along with better demand and supply forecast techniques, reliability can be improved. Distributed generation is also adding to the enhanced reliability of the grid.

2.3.4 NETWORK MONITORING

Idea of implementing distributed intelligent entities in smart grid would improve the monitoring of power grid. Phasor measurement unit system has brought a breakthrough in the field of power grid monitoring and control. Bidirectional communication allows better monitoring.

2.3.5 NETWORK CONTROL

Smart metering infrastructure made it easy not only to control the flow of power but also the detection of fault location as well. Distributed intelligent control entities try to control and resolve issues locally, hence reducing the burden on the main processor and delay caused by communications to avoid big problems. Smart grid provides better control of frequency and voltage, based on more intelligent systems.

2.3.6 NETWORK SECURITY

Security of the network is a big issue these days and it has captured the attention of its researchers too. As life on earth has become almost totally dependent on electricity, from buildings to transportation, communication to bank transactions, social media to business, so this dependence has raised the importance of security of this prime power network. No doubt our interconnected and centralized grid provides us with improved reliability but on the other hand because of its centralized nature the risk of external or internal attacks has been increased. An attack on any part of the centralized grid may lead to the cascading of the problem to a large portion of the network, resulting in the security issue for traffic, communications and other sectors [1].

2.3.7 IMPROVED EFFICIENCY

Even if we are able to improve the efficiency of the grid by few percents more, it would be a breakthrough in power industry, resulting in a reduced carbon emission as well as the reduced generation cost. For instance, only the replacement of incandescent lamps with compact fluorescent lamps would allow the grid to light millions of more houses even with the same generation capacity. Improved efficiency means more affordability and hence reduction in transmission investment [1]. If we are able to have intelligent loads which can switch them according to their need even then overall efficiency of the network would be adversely improved.

2.3.7.1 LOAD ADJUSTMENT

We can't oversee the fact that electricity must be consumed at the moment it is generated, but the amount of energy generated at a particular instant of time is rarely equal to the demand of energy at that time. For instance, the connected load to electricity grid is not same all the time due the switching operations of loads. Here comes two scenarios to be discussed, in a case if suddenly a large factory load is connected to the grid causes an increased demand of energy and leave its effect as decrease in frequency of the system, on the other hand if a large load is disconnected suddenly it creates an increase in frequency. Both the cases make our grid dynamic and the system will try to stabilize itself. In order to meet these instantaneous energy demands some of the generators have to be operated as standby. Smart grid eliminates the need of having large number of standby generators to meet this kind of conditions by controlling the loads at the consumer premises, keeping in view of reliability and stability of the network [1].

2.3.7.2 PEAK LEVELING

Demand of electricity depends on many factors and varies for different seasons, time of the day, weather conditions etc. Smart grid provides its consumers with the real time pricing information of electricity, in order to adjust the loads at peak hours. The loads which are not so much critical and can be shifted to off-peak time enables smart grid to level peak hours while benefiting the consumers. The aim is to somehow match the demand and supply every time and providing economic benefits in return of small trade-offs [1].

2.3.8 DEMAND RESPONSE MANAGEMENT

Better forecast about the demand and supply of electricity based on various parameters support eliminate spikes in peak demand hours and remove the necessity of having more reserve generators to meet high demand times in real time. In a broader sense, it improves the life time of equipments and helps guide the consumers to shift use of low priority devices in order to reduce their electricity bills. When the two way communication between consumers and producers is made possible and more space is provided to consumers in energy market then forecasting demand and supply would be adversely improved. Better demand response management in future grid influence the overall efficiency of the grid and reduction in energy pricing as well.

2.3.9 ENVIRONMENTAL IMPACTS

Clean environment means healthy nations. The dependence of electricity generation on coal or gas is the major cause of carbon emission and global warming. Especially the gasses getting out of the plants might be one of the major causes of serious medical problems in living beings. If we wish to see our planet clean of greenhouse gasses then we must have to look for renewable energy resources like solar, wind, bio fuels etc as our source of generation of electricity [1]. Smart grid brings the renewable energy resources into the existing grid with a more decentralized nature to help reduce carbon emission. Environmental impact of smart grid is not only to do with the measure of cleanness of the atmosphere but it takes into account other important issues like, overall social and economical impacts; for instance, demand response, demand side management, improvements to transmission and distribution systems [5].

2.4 TECHNOLOGY BEHIND SMART GRID

Figure 2.2 gives us broad view about the relation between the layers in power grid and communication network to integrate both the systems.

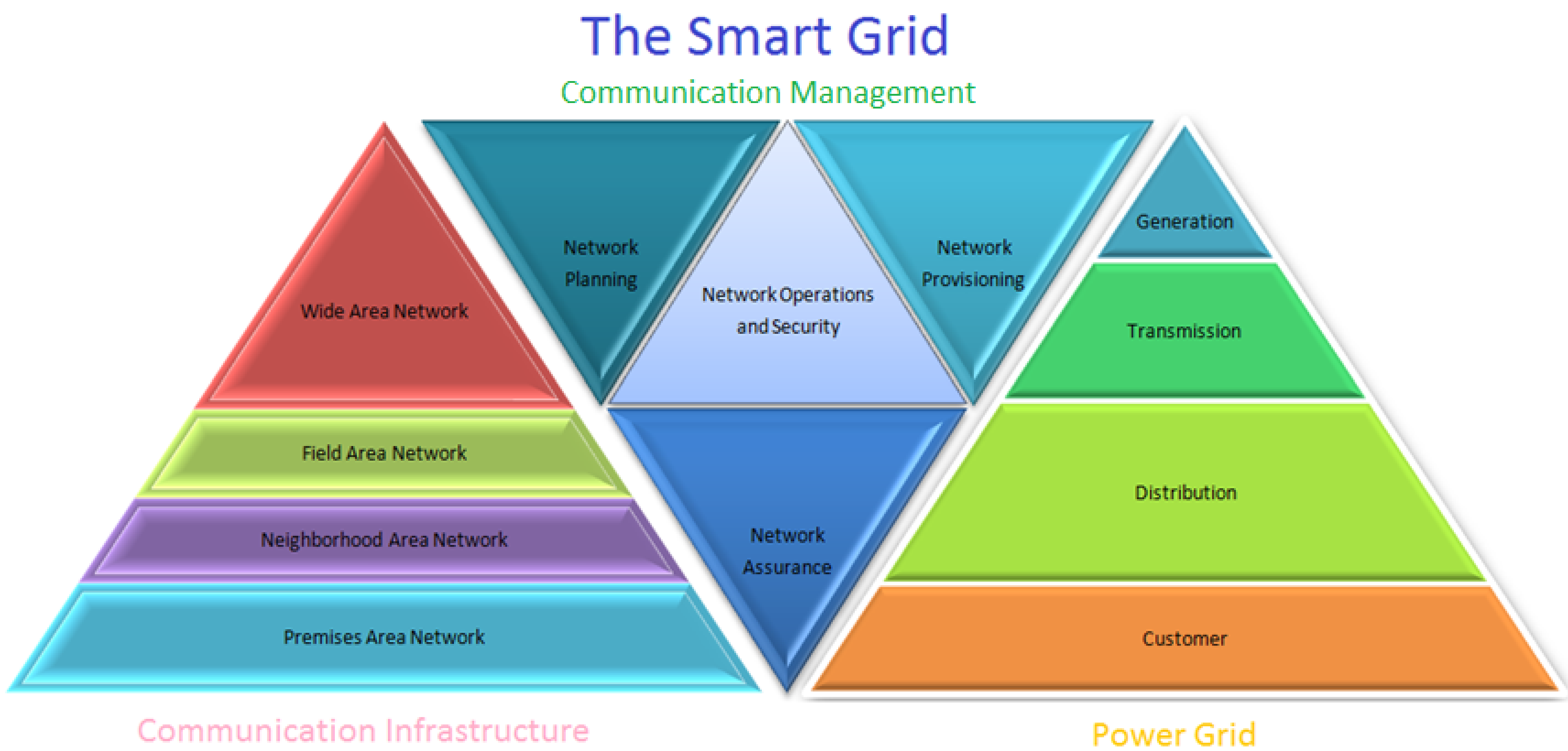

Figure 2.2 Smart Grid Communication Infrastructure (Original source is [6] but some modifications are done by the author of the thesis)

2.4.1 EFFICIENT SENSORS AND SMART DEVICES

Intelligence and two way communications in smart grid require more advanced sensors and intelligent electronic devices to be in function. In this regard, smart grid constitutes smart devices, two way communication links and advanced software. Smart devices capture information about condition of the network, power flow, smart metering and status of equipments in the grid. Intelligent Electronic Devices (IED) are used to control the flow of power and operate equipment while making some particular decisions locally [7].

2.4.2 INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

Smart grid concept integrates advanced information and communication technology with intelligent decision making systems to achieve its overall goal. Introduction of internet in power grid has improved monitoring and control of smart grid. Siemens is currently carrying out research and development in implementing internet as a communication protocol for smart grid communications. But in order to introduce internet to smart grid world, it has to be modified to improve the security of the network and avoid any attacks from the hackers [8].

2.4.3 COMMUNICATION MEDIA

Bidirectional information exchange requires more reliable transmission media in order to monitor and control smart grid in an efficient way. Several types of communication transmission media have been implied which include; Power Line Carrier (PLC), wireless communication and optical fiber. Each transmission media has its particular applications in communication while using it in smart grid depending upon their feasibility and reliability.

2.4.3.1 POWER LINE CARRIER

The word power line carrier or PLC refers to the simultaneous transmission of data signals and alternating current (AC) power on the same conductor. It carries transmission data signals at zero crossing of AC power. PLC finds its application in many areas of electrical grid ranging from control of loads, heating and cooling control in buildings to transmission lines [9]. PLC faces some of the major issues related to interference of data signals with the power signal. Various frequency levels are used for the data signal. For smart grid two way communications infrastructure can be implemented by combining narrowband PLC and wideband PLC, which is proposed by [10].

2.4.3.2 WIRELESS AND RADIO COMMUNICATION

Still the decision is underway to finalize the way and media of communication best suited for smart grid network communication [11]. Each technology has its pros and cons. For instance, cellular 3G networks are trying to prove themselves as the most advanced and cost effective solution for smart grid information exchange. Supported by global standards, high level of reliability, it provides wide coverage for smart grid applications. Cell sites are best suited for smart metering communication and secured way of implementing two way communications from utility to consumer end. 3G wireless technology for smart grid application could be preferred because of having high performance, high scalability, robust security, high reliability, and low cost [12].

2.4.3.3 OPTICAL FIBER COMMUNICATION

Process of sending and receiving information or control signals by transforming them into light signals through fiber optic is called optical fiber communication. In this way light in the form of electromagnetic carrier, carries information from sender to receiver. Its main benefit is that it is not affected by the electromagnetic interference by the power signals. Optical fiber is best because of its high reliability and greater bandwidth capacity for smart grid communications [13].

2.4.4 WIDE AREA MEASUREMENT SYSTEMS (WAMS)

Basically power system is a very large interconnected system, which requires to be monitored every instant of time. Any problem or changes in a specific part of the grid may cause cascade series of problems resulting in a blackout, so health of the dispersed grid has to be checked with a common time stamp. Phasor Measurement Units (PMU) are kind of “Health Meter” for power system. PMU sample voltage and current of a particular portion of power system many times even in a second which in a sense provides the “MRI” (Magnetic Resonance Image) of power system. These PMU are dispersed throughout power system and contain information about the health of particular area and send their data to control center with a common time stamp synchronization provided by the satellite making the system a Wide Area Measurement Systems

(WAMS). Smart grid equipped with WAMS makes it possible to have distributed generation feature [1].

2.4.5 SMART METERING

Measurement method for electricity is changing due to the advancements in technology. Advanced Metering Infrastructure (AMI) has been introduced which has the capability to integrate consumers with the facility, providing to its consumer to optimize the usage of energy as well as helping the utility to detect and locate problems effectively. AMI has the feature of forecasting the price of electricity in the near future depending on the demand and generation scenario for a particular consumer and help them to manage their electricity use habits in a most economical way. For instance, the operation of devices like washing machine or iron etc could be shifted to off-peak load times for cheaper electricity at that time. Two way communications for AMI will help the utility keep an eye on the load even at the consumer level in order to have a better forecast for the near future as well as to have check of the condition of network in real time. This visualization of the whole network at any level has great advantage in many aspects; theft detection, blackouts identification, and the quality of power which is being delivered [1].

2.4.6 ARTIFICIAL INTELLIGENCE (AI)

Artificial intelligence has been playing an important role in robotics, medical science, space science and in many other fields of technology but now smart grid concept has also captured its intentions to be in practice for power grids as well. Intelligent agent has proved to be the promising intelligent entity best suited for distributed control in power networks. More details about this are explained in chapter 3 & 4 of this thesis.

2.5 ECONOMIC PERSPECTIVES

Smart grid focuses on the fair pricing and continuity of energy supply [7]. It is true transformation from the conventional grid to smart grid will require a lot of money to be spent on it but the overall benefits which we are expecting from it are much more than this. A study about the cost and benefits from smart grid has been done by [14]. Smart grid is supposed to recover capita invested on it from its consumer which will make it facing strong opposition from the consumers [15]. Many issues related to economics of smart grid have been raised and well explained in [16]. Smart grid not only intend to deliver cheaper electricity in an intelligent manner but it also aim to create more jobs about 8000 around 2020 and increase exports in UK [17].

2.6 SOCIAL IMPACTS OF SMART GRID

Smart grid will leave some social impacts on the lives of its consumers and stakeholders as well. With the introduction of the idea of smart metering, by knowing the energy usage of a person, one can guess daily routine and habits of people. This thing has received a lot of criticism for the smart grid idea for poking nose into the private lives of the people. Somehow providing more options and freedom to the consumers would adversely affect the social needs of people.

2.7 SOME CHALLENGES

No pain no gain is the best suited proverb here. Every fruitful thing comes in return for sacrificing or paying something. Same is the case with smart grid vision; there are lots of challenges ahead which we have to face before seeing it into our real lives. Some of the key challenges as pointed out in [17] are mentioned below:

- Complexity of technology
- Acceptance by the consumers
- Energy policies have to be reshaped
- Information quality issues and many more

These are not only the hurdles which we are expecting to face in the near future about the smart grid but with the passage of journey towards the ultimate goal there might be some other critical issues to be faced.

Chapter 3

Agent Anatomy

Artificial Intelligence (AI) has been a subject of concern over many years. AI is the intelligence of machines. Now-a-days, AI has surrounded almost every field of technology, ranging from medical [38], transportation, astronomy, security, navigation, entertainment and even in energy usage management. AI puts all its core features to make a system or environment intelligent enough to automate intellectual tasks. AI has its many faces around us depending upon the goal; system is performing, sometimes we call them robots, while in some other occasions it takes the shape of invisible things like software and for some special applications it is known as ***Intelligent Agent***.

3.1 AGENT THEORY: A FLASH BACK

The ultimate goal of Artificial Intelligence is the broad intelligence; however the intelligence we seek from agents is that they can make acceptable decisions to perform actions in their environment [19]. Expert systems had been the emerging AI technology during 1980s [35]. An expert system is capable of solving problems on the basis of built-in knowledge [36]. MYCIN was an expert system which assisted the physicians in the treatment of blood infections in humans. The main difference between agents and expert systems is that expert systems don't interact directly with any environment; i.e. they obtained their required information through the users acting as middle man not via sensors like agents do. Expert systems are not necessarily required to operate in real time. However, some expert systems like ARCHON [37] which performs real-time control tasks was once considered as collection of many expert systems but now it is ended up as Multi Agent System (MAS) [19]. An agent can be seen as any entity that sense any change in its environment with the use of sensors and can act upon its environment through effectors. For instance, a human can be considered as agent with eye, ears, nose etc as sensors and mouth, legs, hands and sometimes facial expressions as effectors. A robotic agent [39, 40] has cameras as sensors and motors as actuators. In the same manner a software agent has encoded bit strings as sensors and effectors [18]. In this way an agent looks like a combination of sensors for sensing the environment and effectors for responding to the environment, but the game is not very simple as it looks like; the main thing is rationality of the agent, that is; a system is rational if it does the "**right things**" at "**right times**". An agent can be a piece of hardware or software whose presence in a system makes the system more intelligent and autonomous [41]. Agents are intelligent and rational systems [30, 31]. Not all agents need to learn from their environment, it depends on the task and scenario in which they are applied, for example capabilities like commonsense reasoning [34] are not necessarily required for many applications. Agents are software entities and AI technique is generally the best way to build them. An intelligent agent can be better explained with the help of a very simple diagram shown below in Figure 3.1:

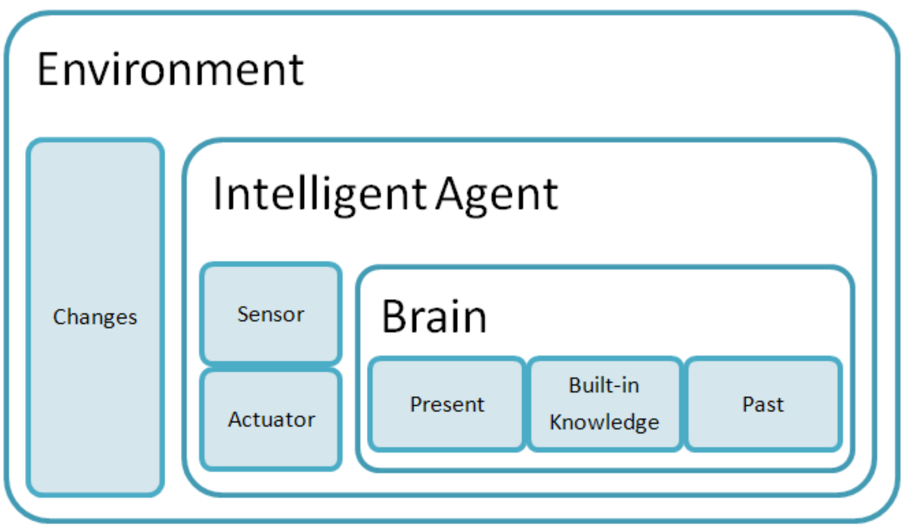

Figure 3.1 The Intelligent Agent

An intelligent agent placed in some environment will always be in interaction with its environment. In case of any change in that environment it will sense that change through its sensors and process the information in its brain by comparing it with the past and built-in knowledge to make the reactions towards that change. It also updates its memory about the current incidence for future references. In this way a real time interaction of colony of agents in that environment is made possible through information exchange.

First we will look at different definitions of Intelligent Agents then finally will purpose a final version of it.

- "Autonomous agents are computational systems that inhabit some complex dynamic environment, sense and act autonomously in this environment and by doing so realize a set of goals or tasks for which they are designed" [23].
- "Let us define an agent as a persistent software entity dedicated to a specific purpose. 'Persistent' distinguishes agents from subroutines; agents have their own ideas about how to accomplish tasks, their own agendas. 'Special purpose' distinguishes them from entire multifunction applications; agents are typically much smaller" [24].
- "Intelligent agents continuously perform three functions: perception of dynamic conditions in the environment; action to affect conditions in the environment; and reasoning to interpret perceptions, solve problems, draw inferences, and determine actions" [25].
- "Autonomous agents are systems capable of autonomous, purposeful action in the real world" [26].

Let us agree on more specific definition of Intelligent Agent. Most precisely we can define an agent as:

"An intelligent decision making system that is situated in some environment and can act flexibly and autonomously in response to any change in that environment to meet its design objectives" **[19].**

3.2 KEY FEATURES: INTELLIGENT AGENT

Agents are capable of the following main characteristics [20]:

a. AUTONOMY

They are able to make some particular decisions without any direct intervention by other agents and humans;

b. REACTIVITY

Agents are able to sense changes in the environment in which they are placed and can react to these changes accordingly;

c. PRO-ACTIVENESS

They can also take initiatives in some cases in order to exhibit goal oriented behaviors;

d. SOCIALITY

Agents are social like humans. Communication between different agents is also possible via some agent communication language (ACL) [21]. Due to this property agents can interact with each other in order to solve complex problem.

3.2.2 SIMPLE EXAMPLE TO UNDERSTAND INTELLIGENT AGENT

In order to have a general understanding of all these four characteristics that an intelligent agent must have; consider a very simple but well explained example scenario given in [19]: For instance autopilot controlling an aircraft with the goal of safely landing at some of the airports. We expect the system to plan how to achieve this goal by considering the pre-defined scheme for this task rather than reasoning from the very basic level, and it has the freedom to make some subsidiary tasks if it requires (e:g ascend to some particular height and proceed towards a particular direction). This is what we call pro-activeness. We also want the system not to execute the predefined plans blindly; i.e. in the event of any changes in weather conditions or any kind of faults or may be some special requests from the air-traffic control the system must respond to the new situations accordingly in the real time. This is what we meant by reactiveness. We also aim our autopilot to be involved in communication with air-traffic controller and with other aircrafts. This is the social ability of our system. It has the freedom to make many decisions towards achieving its goals. This is known as its autonomy.

Generally, an intelligent agent consists of four components: Input Interface, Output Interface, Decision Making System and Communication System. They constitute sensors to monitor the system, some memory to store the information, microprocessor to make decisions on the basis of some predefined algorithms and two way communication interfaces [41]. Now this is the time to draw a model of an intelligent agent as shown in Figure 3.2:

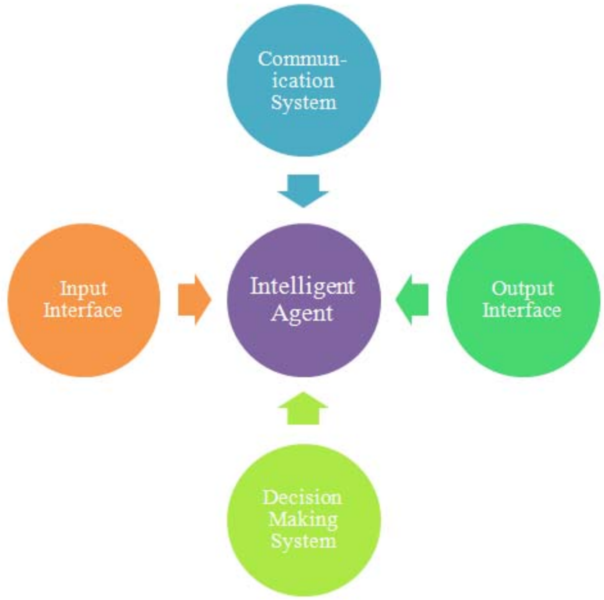

Figure 3.2 Agent Model [41]

3.3 CLASSIFICATION OF INTELLIGENT AGENTS

There are many ways to classify agents. Agents are generally classified according to the subset of properties they have. Every agent has the four characteristics which we mentioned above but on the basis of what additional properties do they have, they are categorized. On the other hand we can classify software agents on the basis of tasks they perform, for example, information gathering agent or email filtering agent. Classification on the basis of control architecture might also be possible, for example, fuzzy subsumption agent while Etzioni and Weld's Softbot would be a planning agent [27]. Agents may also be classified by the range and degree of sensitivity of their senses, or by the range and effectiveness of their actions. Brustoloni [28] classified software agents as regulation agents, planning agents and adaptive agents. Regulation agent always knows what to do with the input from its sensors but it neither plans nor learns from its experience. Planning agents plan in different ways, either using operation & research based methods or by using randomizing algorithms. On the other hand, adaptive agents not only plan but they also learn from their experience in a particular environment. Another way to look at the classification of agents is by the type of environment in which they are residing, for instance, software agent as opposed to artificial life agents. Here comes another direction to classify our agents as either biological, robotic, or computational agents as these seem to be natural kinds [29]. At the class level we might further classify software agents into task-specific agents, entertainment agents and computer viruses. All these classifications of intelligent agents are summarized in the tree diagram in Figure 3.3:

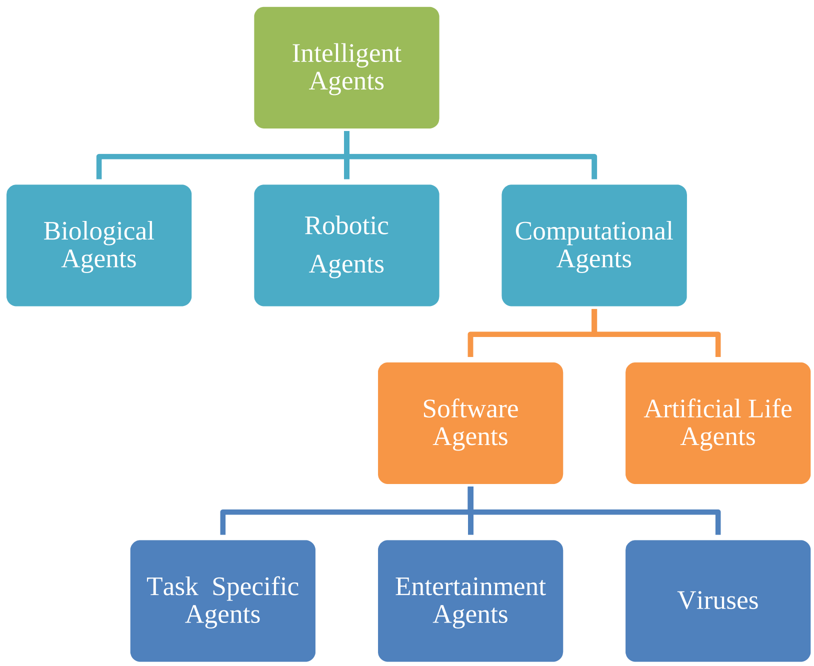

Figure 3.3 Classification of Intelligent Agents [22]

3.4 AGENT BEHAVIOR

Intelligent agent posses certain human intelligence and can think and functions like a human. In other words, agents are simply active objects that can be used to model parts of real-world system. There are many inter-relational behaviors of agents and these behaviors are based on different kind of parameters. These parameters may include attributes, capabilities or strategies; behaviors like cooperation, competition, conflicts or it might be sources of strength and weakness, which may be physical, social, technological or intellectual. There is always a fitness function corresponding to each agent. One of most important thing about intelligent agents is their adaptability. It is the capacity for modification of goal-oriented individual or collective behavior in response to any change in the environment. For agents there are two types of adaptations:

- **Passive Adaptation**
- **Active Adaptation**

A passive adaptive agent responds to any changes in its environment without leaving any modification in its environment. But an active adaptive agent tries to put some control or influence on its environment for the purpose of improving its adaptive power. In fact, active adaptive agent initiates things in its environment and learns from the experience. Agents must have flexibility to adapt themselves with the new changes in their environment in order to be focused towards their goal. Agent has to gather enough information about its environment including other agents in that environment to efficiently forecast and deal with changes that might occur at any time. On the basis of past experiences they can make short term or long term evaluation. In the longer run agents modify the older strategies with the new ones in order to handle the situations in real-time. There might be temporary conflicts in the real-time control, in case of short term evaluation but they must be resolved in that same time frame. In order to reduce the doubts in short term, a “look ahead” for the real-time solution is required but the schemes for where and how to “look” are evolved over the long term [41].

3.5 MULTI AGENT SYSTEM (MAS): *MIND OF BRAINS*

Generally, agent based system is composed of more than one agents and is called Multi Agent System (MAS). In this way, the control is distributed among different agents in the same system. In MAS, each agent has its unique ID for communication between the agents. MAS is implemented to break a complex problem (which is supposed to be done by a single entity), into many simple tasks to be handled by many entities in order to achieve distributed processing [41]. An agent based system is one in which the core entity used is an agent. Agent based system may contain a single agent as in case of user interface agents or software secretaries [32] but they approach towards their goal in a much better manner if they are coordinating as a colony of agents to accomplish a goal which we call MAS [33]. Social ability of agents made it possible that every agent wants to know what is happening around it as well as which agents are present in the system in which it is residing in order to seek the proper information at the time when it needs that information. All this information exchange between agents is carried out through a communication language called Agent Communication Language (ACL) [21]. MAS is a team of agents working and cooperating for the purpose of winning a common goal. Coordination of agents is necessary in order to avoid any conflicts between agents for a particular decision. In MAS it is not necessarily that agents on the same level can communicate and coordinate with each other, but they can communicate with the agents at upper level agents if needed. Figure 3.4 shows a very simple scenario for MAS communication between agents towards a goal. Further, MAS in power system will be presented in detail in chapter 4.

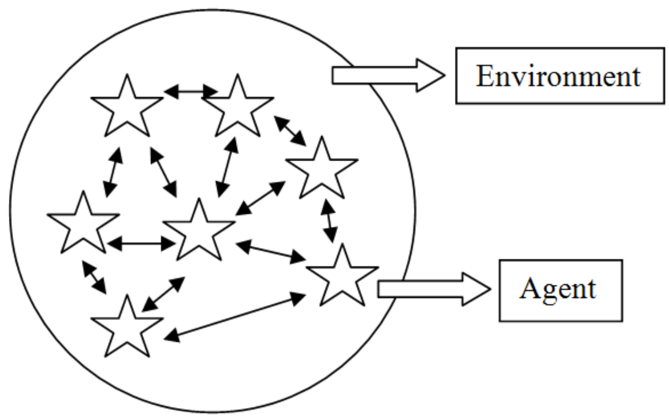

Figure 3.4 Interaction of Agents in MAS

Chapter 4

Smart Grid Agents

The word "Agent" has been used in many fields of technology because of its smart applications as an intelligent entity in a system; for example in medical, robotics and computer software etc. Because of versatility of agent's functionality, researchers started to think about introducing them as the distributed control decision making building block in smart grid. Agents system in smart grid would assist in reliable and protected operation with a dynamic scenario while acting as a distributed control system [43].

4.1 ROLE OF AGENTS IN SMART GRID

Conventionally, Supervisory Control and Data Acquisition (SCADA) system have been used for the control and communication in power system [44]. SCADA system employed some signaling protocols to maintain and control the operation of power system hardware. Multi Agent Systems (MAS) have many advantages over the SCADA system for the implementation of micro-grid because of its distributed control nature. MAS can be employed in power system in order to make the power grid more stable and reliable. The disturbance diagnosis [45, 46], power network restoration [47], secondary voltage control [48] and visualization [49] of power system can be made possible by using MAS. Power system is considered as a Complex Adaptive System (CAS) for which to achieve real-time optimization and control, agent based distributed control is the most suitable option. Design of agent based intelligent power system can improve the efficiency and security in a geographically distributed system. Agents work in collaboration to detect the outages and react accordingly to allow the micro-grid to operate autonomously in islanding. In such situations agents based micro-grids load management control to check the prioritized list of loads and secure the critical loads by putting its internal generator into operation. Integration of distributed power generation by the renewable energy sources is made possible by the implementation of intelligent agents. Location of the faults in the grid can be located by agents. A multi agent based smart grid will be able to perform risk based contingency analysis. Intelligent agents can be implemented in smart grid at each hierarchical level of power flow from generation to the consumer end including the distributed generation to a device level.

With combination of intelligent and fast sensors and intelligent electronic devices, such as distributed control intelligent agent based system provides the real-time operation and management of a fully automated power system which would be able to exhibit the following characteristics [41]:

- Monitored by local intelligent sensors
- Modeled as a hierarchical system for competing and cooperating adaptive agents
- Computations are done in a parallel and distributed manner
- Controlling local operations automatically in understanding with the global optimization criteria
- Communication of essential information is made possible over the power transmission lines
- Robust enough to operate either independently or in a group when separated by disturbances

4.2 SCADA and MAS: A SHORT COMPARISON

SCADA is a computer based industrial control system. It can be implemented to control and monitor large networks like power system to a long distances. Multiple components and software merge to form SCADA. It is a centralized control system meaning that it is supervised by a main computer and almost all decisions are done by it thus having a lot of processing burden on it. As all the things are decided by a supervisory system so there might be some processing delays, hence increasing the risk of big problems caused by this delay. SCADA systems are most likely become a victim of cyber attack showing a lack of security of the network, hence raising issue related reliability of power grid. National Communications System [50] has presented a detailed report about SCADA, presenting the architecture, technology, protocols, communications, security issues and standards about SCADA.

On the other hand, Multi Agent System (MAS) has proved to be the most intelligent control entity having distributed control nature, meaning that any problem or issue if it occurs is resolved locally. This decentralized nature of MAS makes it easy to solve complex problem efficiently and intelligently by breaking the whole problem into sub-problems and performing parallel processing to achieve the ultimate goal, hence reducing the computation burden on single machine. They have less possibility to be hacked, attacked or jammed by outsiders. As almost all the issues are supposed to be resolved locally so there is less chance of cascaded problem in the network. Agents learn from their environment and update their knowledge based on their past experiences so they can handle problems more accurately based on their experience from the past and some base knowledge [4].

4.3 AGENT BASED MODELING OF SMART GRID

Without reshaping the power system infrastructure the most feasible way to modify it as smart grid is to model it in control theory perspective. Not overseeing the fact that, most complex system on earth i.e. power system can only be monitored and controlled by intelligent agent based system [51]. For smart grid, Complex Adaptive System (CAS) simulation can be employed to model computational intelligence of a geographically dispersed but globally connected power grid. Hierarchical approach would better to transform the whole control architecture into MAS in which agents and subagents are considered as autonomous objects. Communication among these intelligent entities can be carried out via various communication media like microwaves, optical fiber, or power line carrier. Every team of agents in a particular local area tries to solve the problem locally and minimizing the impact this on the system as a whole. Agents are supposed to be in interaction with each other to have complete knowledge about each other for better collaboration. Agent based model of smart grid can practically evaluate the impact of hypothetical dynamics on the power grid. Smart grid based on intelligent agent will represent two classes of agents one representing the energy market issue, energy balance management, energy pricing and energy scheduling while the other one focus on the issues related network security, reliability, fault handling, efficiency etc [41].

4.4 TYPES OF AGENTS IN SMART GRID APPLICATIONS

There are different types of agents depending upon their functionality in power systems applications which are described below [42]:

a. DEVICE AGENT

Individual devices in the power grid, such as generators, circuit breakers, transformers, voltage regulators and relays etc are controlled by Device Agents.

b. DISTRIBUTED ENERGY RESOURCE (DER) AGENT

A Distributed Energy Resource (DER) agent finds its application in micro-grids. In a case when the power from the main distribution circuit is not enough to supply the critical load, then the consumer agent communicates with the DER agents to purchase power from the renewable energy resources. Furthermore, in case of islanding mode of the circuit DER agent takes initiative to supply power to the local critical load.

c. CONSUMER AGENT

These agents play a very important role by providing interfaces with power consumers at the end-use site. On the basis of interfaces provided by consumer agents flow of power is monitored which results in proper modeling of demand and response of power. If the power required by the load is not enough then this agent starts a negotiation process with the DER agent to purchase the power in order to meet the demand and supply requirements.

d. INTELLIGENT PREVENTION CONTROL AGENT

The task of these agents is to assess the states that could cause the failure of the power due to natural disasters. They prepare a report on the basis of their analysis about the future condition of the network due to any changes in the environment and report them to their supervisor agents who are responsible for making decision about how to make reconfiguration of the network to avoid the failure. These agents forecast the states of the system on the basis of future environmental condition predictions.

e. INTELLIGENT RESPONSE CONTROL AGENT

These agents monitor the network for the occurrence of any malfunctions in real-time and demand a response to maintain high-performance system operation. These agents report their conclusions to their supervisor agents to take further decisions. Some of the important system status info to be reported is operating frequency and voltage, generator synchronization status, and quality of power level, and devices not operating properly. They act as supervisor agents for device agents.

f. GRAPHICAL USER INTERFACE (GUI) AGENT

These agents monitor all operational activities on the basis of real time network status data received by them from the other agents and provide graphical visualizations and reports of system performance.

These are not only the intelligent agents, whom we can find in power systems but it is their application in many different ways which gives birth to a new name of agent. Agents are the most intelligent entities in AI so by harvesting these benefits of intelligence of these smart entities we can find the solution of every problem in our smart power grid; from operation, management, security, optimization, protection, self-healing to integration of new energy sources to our existing power grid.

4.5 MULTI AGENT SYSTEM (MAS) IN SMART GRID

Power generated at the power plant after passing through transmission and distribution networks reaches the end user; makes the power system a complex and highly interactive system. In order to achieve the high reliability of the power grid at each level power system should be modeled as a collection of intelligent entities that can adapt to their surroundings and act both competitively and cooperatively in representing the power system. These agents can range from a simple threshold detector to very intelligent systems. By mapping each component to an adaptive agent, a realistic representation of power system can be achieved. For example, disturbances like lightning may last for a few microseconds, but the network's ability to communicate data globally may take longer than this. Thus each agent must have real-time decision making power on the basis of local information. The adaptive agent based system could manage the power system using multi level distributed control. If an agent senses any unusual change in its surroundings, several agents start to communicate with each other in order to solve the problem locally. In this way agents prevent the cascading of power system disturbances. Agents are distributed throughout the network, each is assigned a particular task to accomplish, and a single agent sometimes might not be able to solve a complex problem so it has to coordinate with neighboring agents either on the same level or the other. This requirement of coordination of multiple agents in smart grid makes it a multi agent system. Multi Agent System (MAS) in the smart grid consists of heterogeneous, adaptive and cooperative agents [41].

4.6 LAYERS OF COMMUNICATION IN SMART GRID MAS

The MAS of power grid is classified into cognitive and reactive agents. A cognitive agent is an intelligent agent with a complete base knowledge that comprises all the data and knows how to carry out its tasks and to handle interactions with other agents. On the other hand reactive agent is not necessarily intelligent but can respond to stimuli with fast speed. From the Figure 4.1 given below it is clear that multi agent system in power grid usually has three layers: Deliberative Layer, Coordination Layer and Reactive Layer.

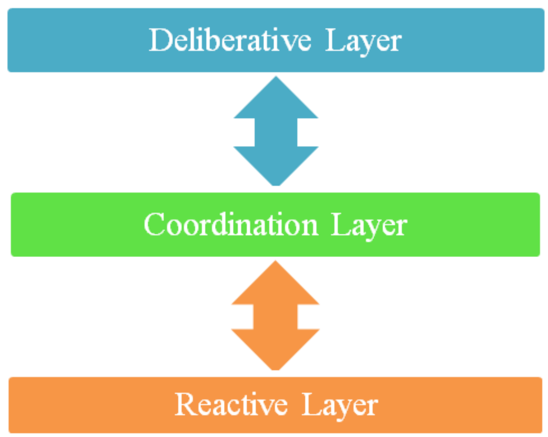

Figure 4.1 Layers of MAS in Smart Grid [41]

Reactive Layer performs immediate self healing actions on the basis of preprogrammed knowledge. This layer is distributed at every local subsystem and interfaces with the middle layer. Coordination Layer checks that which triggering event from the reactive layer is more urgent on the basis of pre defined priorities. A triggering event is allowed to reach the top layer only if it exceeds the preset threshold. This layer also analyzes the commands to the top layer and decomposes them into actual control signals in order to make them compatible for the agents of the bottom layer. Deliberative Layer prepares higher level commands, such consistency assessment with the help of the information provided by the coordination layer. Middle layer in MAS makes the communication between the bottom and the top layer compatible for both layers. Reactive Layer contains many agents that locally control the system behavior and make short term planning, while in deliberative layer system is analyzed from a wide area point of view and can plan for a longer period of time. For instance, a generation agent may decide, based on its local view, to trip the generator. However, if reconfiguration agents in the deliberative layer based on the global view decide to block the tripping actions, then the action of generation agent at the reactive layer will be inhibited. Coordination Layer continuously updates and stores the current state of the power system. Agents on different layers and on same layer can communicate with each other. All communications among the agents can be implemented through a dedicated link with potential access through the internet using IP protocol [41].

Chapter 5

Agent Platform and Development Tools

In order to develop any intelligent entity a platform is needed, which is a set of tools providing the base to get started along with a run-time environment for their creation and execution. As far as intelligent agents are concerned, interoperability of different systems is one of the most important things to be considered.

5.1 FOUNDATION FOR INTELLIGENT PHYSICAL AGENTS

The Institute of Electrical and Electronics Engineers (IEEE) computer society has a standard organization named Foundation for Intelligent Physical Agents (FIPA) which has the goal of standardization of intelligent agent based systems and their interoperability with other systems. FIPA is a part of IEEE computer society since June 2005 [52]. FIPA has been playing a major role in the development of agent technologies for heterogeneous agent based systems. It sets standards for agent implementation systems, for the execution of agents like agent platforms and also defines standards for the communication of agents among themselves as well as interaction with the environment in which they are present.

5.1.1 SPECIFICATION LIFE CYCLE

Life Cycle of agent specifications keeps track of levels as specification goes through being the part of FIPA standards process. FIPA specification goes through some stages before it becomes a FIPA standard. Specification life cycle has several steps starting from preliminary stage to experimental before acknowledge as a standard or obsolete. The purpose of specification life cycle is to identify the level of progress of a particular specification [52].

5.1.2 SPECIFICATION IDENTIFIER

A Specification Identifier is assigned to a specification at the preliminary stage of its specification life cycle. FIPA specifications could be accessed and followed at any stage of their specification life cycle and may be identified by their formal or informal specification identifier. Hence any FIPA specification is approached by its document number and specification identifier. Informal specification identifier is used to address a specification internally within FIPA. Basically informal specification identifier is a combination of status of specification in specification life cycle and its document number. For instance, XC00025 could be read as “Experimental Component specification number 25.” On the other hand, formal specification identifier is used to address FIPA specifications either from other FIPA specifications or any other document. For instance, format for formal specification identifier contains word “FIPA” and then the document number like, “FIPA00025”. One thing here for formal specification identifier to mention is that it doesn’t identified the stage of specification in the specification life cycle, in fact it identifies the latest available version of the specification in the specification life cycle. As far as referencing of specifications in other FIPA specifications or any other documents are concerned, formal specification identifier is always used. “SC00026H” represents, FIPA Request Interaction Protocol Standard Component Specification number 26 version H [52].

5.1.3 CLASSIFICATION OF SPECIFICATIONS

Classification of FIPA specifications is based on the stage in which they reside in the specification life cycle. In FIPA, five categories or stages of specifications have been defined [52].

Preliminary: This is the initial stage of specification life cycle. Specifications at this stage are generated by the technical committees of FIPA. Preliminary staged specifications are considered as draft version of specifications subject to further changes. At this stage specifications are not considered to be implemented practically. Preliminary specifications can be identified by an informal specification identifier starting with “P” as they are just used internally in FIPA.

Experimental: After preliminary check of specifications, they are submitted to FIPA architecture board for up gradation of their status to Experimental stage. When FIPA architecture board is done with all tests then it is approved by the committee as experimental status, identified with a new informal document identifier “X” instead of “P”. Each specification has to reside in experimental status for two years before they are promoted to next stage. Only minor changes are allowed in experimental stage with the approval of committee. Experimental version could be implemented in agent platforms in compliance with FIPA. Implementations of these specifications for many times along with their performance decide the time of their up gradation to upper level.

Standard: The most stable status of any specification in its life cycle is standard status. Any specification could be upgraded to standard level after a lot of implementations of this specification at experimental level and approval by FIPA architecture board. Standard specifications must be able to be implemented in more than one FIPA compliant agent platform. When a specification gets the status as standard specification, then it has an informal specification identifier starting with letter “S” instead of “X” used for experimental version. Standard version is suitable for general purpose implementation for agent platforms which are FIPA compliant. Changes in this version are only allowed with the approval from the FIPA architecture board. Standard state of specifications is considered as the most advanced state of any specification.

Deprecated: A standard specification is considered as unnecessary because of changes in technology or some other reasons; it is referred as deprecated specification. A deprecated specification is identified by an informal specification identifier starting with “D”. It is not necessary that a specification can be deprecated at standard state; in fact it can be deprecated from any state in the specification life cycle. Approval by FIPA architecture board is compulsory to move any specification to deprecated state. A deprecated specification can also be placed back to the stage from where it was moved to deprecated state before the end of grace period, if latter it is found that it shouldn’t be obsolete.

Obsolete: If a specification in deprecated state pass the grace period then it is really considered as unnecessary for FIPA standards and regarded as obsolete. Now the obsolete specification is identified with informal specification identifier starting with "O" instead of "D". Specification in obsolete state can be retrieved back but with FIPA architecture board approval.

5.2 AGENT SPECIFICATIONS

Set of standards defined to represent the services of agents and to make the interoperability of heterogeneous agent systems possible. This set of standards is given the name FIPA specifications. Each specification defines a particular set of services of agents. They are grouped into Component, Informative and Profile specifications, based on type of specification and are also grouped according to category like, applications, Abstract Architecture, Agent Communication, Agent Management and Agent Message Transport. Applications specifications define application areas in which FIPA agents can be created and provide service description specifications. Abstract Architecture specifications are committed to provide abstracts for the creation of agent environments. Detailed description of each FIPA specifications of agents, whether it is Preliminary, Experimental, Standard, Deprecated or Obsolete specification could be found online on FIPA website [52].

5.2.1 AGENT COMMUNICATION

Agent communication protocols, messages, protocols for message exchange, communicative acts, agent communication language are provided by FIPA agent communication specifications. Agent communication specifications are further categorized as: Interaction Protocols Specification, Communicative Acts Specifications and Content Languages Specifications [52].

5.2.1.1 INTERACTION PROTOCOLS

There are some predefined set of rules for message exchange between agents for Agent Communication Language (ACL) which are categorized under Interaction Protocols (IPs) specifications [52].

5.2.1.2 COMMUNICATIVE ACTS

Agent Communication Language (ACL) messages are expressed by different expressions and fall under Communicative Act (CA) specifications of FIPA [52].

5.2.1.3 CONTENT LANGUAGES

Contents of messages in Agent Communication Language (ACL) can be represented by various representations and are the part of Content Language (CL) specifications of FIPA [52].

5.2.2 AGENT MANAGEMENT

Agents are controlled and managed in agent platforms by Agent Management Specifications. SC00023K is a standard Agent Management specification while DC000087C is deprecated component Agent Management Support for Mobility Specification of FIPA [52].

5.2.3 AGENT MESSAGE TRANSPORT

Agent messages are transported through heterogeneous media including wired and wireless etc. In order to maintain interoperability of agent message transport among different environments, FIPA defined some specifications focusing on this issue which provide a set of rules for message transportation on different networks [52].

5.2.3.1 ACL REPRESENTATIONS

Agent Communication Language (ACL) messages can be represented in different forms and format for messages. They are set by ACL Representation of FIPA specifications [52].

5.2.3.2 ENVELOPE REPRESENTATIONS

Envelope for agent messages can also be represented in different formats and are dealt by Envelope Representations specifications of FIPA [52].

5.2.3.3 TRANSPORT PROTOCOLS

Interoperability of different network transport protocols for transporting agent messages across different networks is set by Transport Protocols specifications [52].

5.2.4 LIST OF SPECIFICATIONS

Currently there are three Preliminary, fifteen Experimental, twenty six Standard, twenty nine Deprecated and twenty five Obsolete specifications are available online on FIPA website [52]. Here we will only tabulate FIPA standard specifications.

Identifier	**Title of FIPA Standard Specification**
SC00001	FIPA Abstract Architecture Specification
SC00008	FIPA SL Content Language Specification
SI00014	FIPA Nomadic Application Support Specification
SC00023	FIPA Agent Management Specification
SC00026	FIPA Request Interaction Protocol Specification
SC00027	FIPA Query Interaction Protocol Specification
SC00028	FIPA Request When Interaction Protocol Specification
SC00029	FIPA Contract Net Interaction Protocol Specification
SC00030	FIPA Iterated Contract Net Interaction Protocol Specification
SC00033	FIPA Brokering Interaction Protocol Specification
SC00034	FIPA Recruiting Interaction Protocol Specification
SC00035	FIPA Subscribe Interaction Protocol Specification
SC00036	FIPA Propose Interaction Protocol Specification
SC00037	FIPA Communicative Act Library Specification
SC00061	FIPA ACL Message Structure Specification
SC00067	FIPA Agent Message Transport Service Specification
SC00069	FIPA ACL Message Representation in Bit-Efficient Specification
SC00070	FIPA ACL Message Representation in String Specification
SC00071	FIPA ACL Message Representation in XML Specification
SC00075	FIPA Agent Message Transport Protocol for IIOP Specification
SC00084	FIPA Agent Message Transport Protocol for HTTP Specification
SC00085	FIPA Agent Message Transport Envelope Representation in XML Specification
SC00088	FIPA Agent Message Transport Envelope Representation in Bit Efficient Specification
SI00091	FIPA Device Ontology Specification
SC00094	FIPA Quality of Service Specification
SC00097	FIPA Design Process Documentation Template

Table 5.1 FIPA Standard Specifications [52]

5.3 SYSTEMS USING FIPA STANDARDS

Many agent development tools are compliance with FIPA standards. Some of them are listed below:

- JADE [53]

- ZEUS
- Java Intelligent Agent Compontentware (JIAC) [54]
- JACK Intelligent Agents [55]
- Jadex Agents [56]
- AgentService [57]

These are not only the FIPA standard compliance development tools for intelligent agents some other are also available in market but above mentioned platforms are used most frequently.

5.4 AGENT PROGRAMMING LANGUAGES

Agents could be programmed in any of general purpose programming languages like; C, C++, Java, Prolog etc. But it is always better and easier to program intelligent agents using Agent Programming Languages (APL) which focus on the implementation of Belief Desire Intention (BDI) model of intelligent agents. According to [58], agent programs can be executed either online to directly control the behavior of agents or offline to get strategic goal by changing plans. There are quite many agent programming languages which are based on BDI model and some are listed below:

2APL: This is pronounced as double a-p-l and considered as a practical agent programming language, allowing the creation of multi agent systems. It supports BDI architecture. For multi agent systems in 2APL, constructs of programming are divided into two individual sets, one specifying individual agents and the other one for environments in which these agents are supposed to make their actions. This agent programming language is provided with its execution platform for the execution of agents programmed in 2APL. More details could be found in [59].

AgentSpeak: Based on BDI architecture AgentSpeak is a logical language intended to program rational agents. Jason platform provides a development environment for AgentSpeak language to develop multi agent systems. More details could be found in [60].

GOAL: For programming agents in GOAL whole program is divided into many sections each focusing on a particular characteristic of agent like, belief, desire and information about the environment etc. GOAL implements the declarative beliefs and goals with rule based action selection [61].

These are not only the agent programming languages used for building multi agent systems. Many other powerful languages are available for the development of agent based systems but their applications vary according to the requirements of the desired system, for example; NetLogo, Procedural Reasoning System (PRS) and StarLogo etc.

5.5 AGENT PLATFORMS

A tool or set of Java Virtual Machines (JVM) intended to execute services and functions related to agents is considered as agent platform. Identification and definition of agent platform is done by preferences file which contains information about the location of each JVM, services expected to be executed on or across the platform and also the agents which can run on that particular platform. Every agent platform has a particular set of services that it can support to agent on the same platform or agents on different platform looking for some specific information. Services provided by agents platform include; security, life cycle and behavior of individual agents. Agent platform is dedicated to provide agents with the unique naming, logging on and off, and presence of other agents in the directory and message exchange services. Naming service is entitled to assign globally unique names to agents among distributed platform. Directory service keeps record of agents based on information provided by agent description. Lifecycle service of agent platform is responsible for the creation, suspension and destruction of agents. Transport service is intended to make inter-agent communication possible [62]. There are many agent platforms available some of them are listed below:

- Aglets software development kit [63]
- JADE [53]
- Tracy [64]
- SPRINGS [65]
- INGENIAS Development Kit [66]

5.5.1 JAVA AGENT DEVELOPMENT FRAMEWORK (JADE)

Java Agent Development Framework (JADE) works as a middleware, best suited for the development of distributed autonomous intelligent entities like agents and multi agent systems. JADE is implemented in Java language. It is a framework providing a simple and developer friendly environment by hiding all the complexity of middleware. JADE is a FIPA compliant platform and allows FIPA Agent Communication Language (ACL) for the coordination of agents. It provides an environment for the execution of agents and communication between agents either on the same or different platforms [53]. Combination of multiple containers forms a platform. Containers may be distributed on different computing devices for the achievement of a distributed platform. Agents are contained in the containers identified with their proper names. There exists a container in each platform called the main container. It is a special type of container and acts like an administrator for all other containers present in the same platform. Main container has two special types of agents present in it; Agent Management System (AMS) agent and Directory Facilitator (DF) agent. All containers other than main container must register to main container in the same platform at the bootstrap time. Every main container created is responsible for giving birth to a new platform [67].

AMS Agent: This agent is kind of an authority of a platform and must perform management tasks of a platform. It has the right to manage agents in the main container and the agents in the containers registered to this particular main container and can start or kill not only agents but can shutdown even the whole platform if necessary.

DF Agent: This agent provides Yellow Pages space for the agents to put information about their services which they can provide and also provide access to agents for getting information about the other agent's services whenever they need it.

Figure 5.1 shows the JADE architecture for the creation, communication and interaction of agents, containers and platforms in a network.

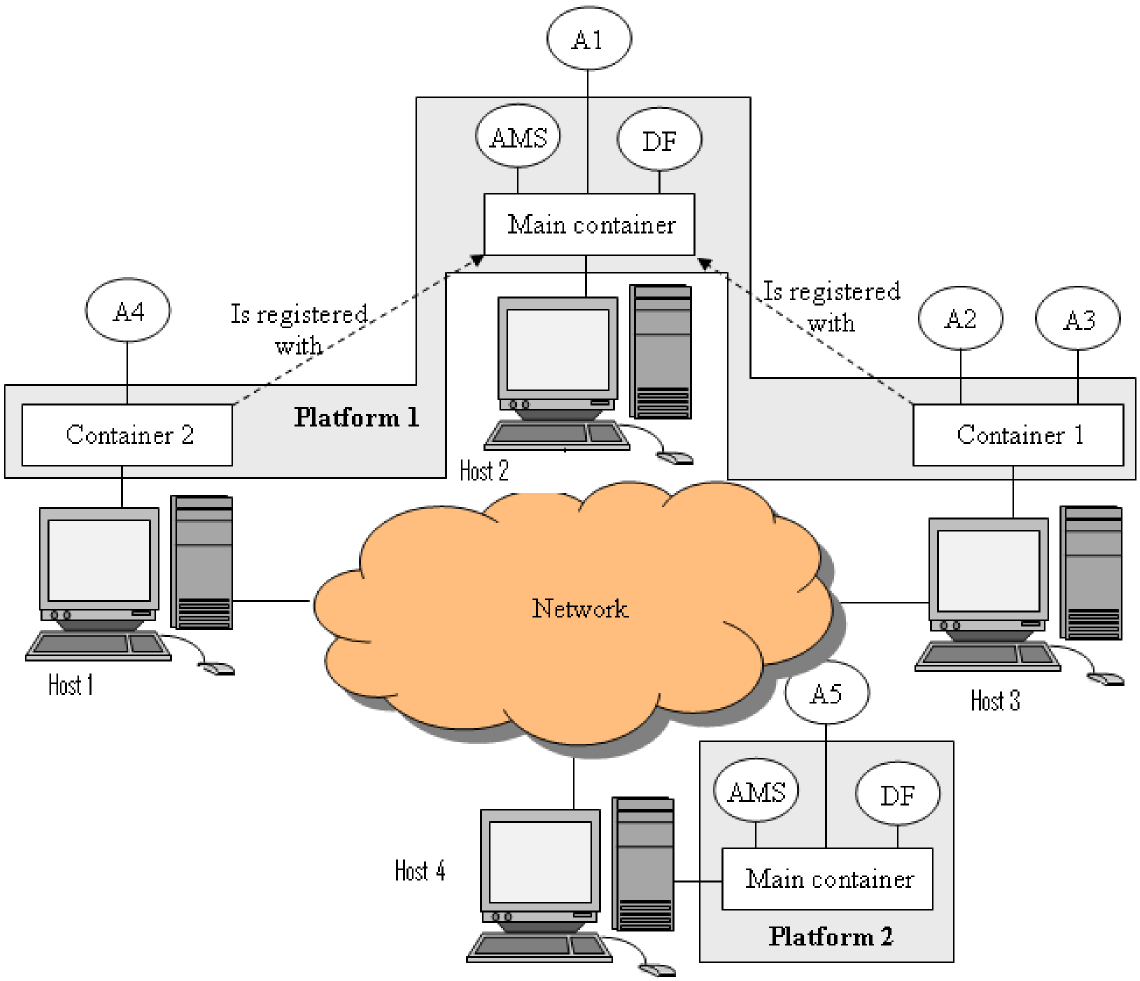

Figure 5.1 The JADE Architecture [67]

There are quite lot of simulations tools for power system analysis and control available in the market, some of them are open sources while others are available commercially. Some of the power system simulators are dedicated for the study of some particular aspects of power system, like UWPFLOW [68] is implied for continuation power flow. Many Matlab based power system tools like, Power System Toolbox (PST) [69], MatPower [70], MatEMTP [71], and Power System Analysis Tool (PSAT) etc have been used. PSAT [72] is a Matlab Toolbox used for the simulations of electric power networks for the analysis and control of electric power flow. PSAT provides graphical user interface for assessing power flow, stability, load optimization, time domain simulations and Phasor Measurement Unit (PMU) placement etc. It supports different static and dynamic component models to get accurate power system analysis. Its utilities include Simulink which provides library for drawing different power networks for simulation and Graphical User Interface (GUI) which includes the facility for setting system parameters. Filters are used to convert data from one form into another. PSAT can form a link with other programs in order to get some inputs from other platforms. There are lots of built-in functions to simulate different topologies of power networks [73].

5.6 SOME IMPORTANT DISCUSSION

In order to develop an agent based smart grid we need to learn many development tools and languages. Agent programming language for programming agents, agent communication language to facilitate coordination of agents, a platform like JADE for providing environment to agents for performing their actions, a power system simulator and a middle which has the ability to integrate all these heterogeneous systems. Need of learning FIPA specifications, other standards and protocols must not be overlooked.

Chapter 6

Distributed Energy Resource (DER) Agent

No doubt it's a bitter reality that our planet is dying out of the natural resources like oil, coal, gas, fossil fuel etc. and certainly use of these resources for the generation of electricity is the main cause of carbon emission to pollute the environment. Currently our planet is hosting about six billion people and this number will be raised to almost nine billion by the mid of this century, hence increasing the demand of energy required as well. Because of the deficiency of these conventional energy resources, world has to look for renewable energy resources like solar, wind and hydro etc, which also help to reduce the carbon emission in addition to the abundance of these resources providing cheaper electricity.

6.1 DISTRIBUTED ENERGY RESOURCES (DER)

Use of renewable energy resources for the generation of electricity has revolutionized the world of electrical power industry in many ways, technologically, economically and environmentally [74]. Distributed Energy Resources (DER) are small power generation or storage units installed on site usually with a capacity less than 10 MW [77] connected either to the main grid or isolated from the grid to feed a particular load. DER technologies can help reduce the need of additional power from the main grid in addition to improve power quality and enhanced reliability. In order to gain full potential benefits from DER technology the systems shouldn't be installed blindly, there are many things to be considered beforehand. DER technology appeared to solve almost every problem which we can face with the current system, [77] has provided a list of several steps to be considered for choosing the best suitable DER system for a facility. First step is to analyze the energy needs of facility, what type of load is going to be connected with DER system either critical or non-critical i.e. can this load afford the interruptions in supply etc, cost of energy from the main grid as compared to energy from DER, other energy requirements like heating or cooling. How would suggested DER system for a particular facility help in matching the peak demands of electricity? Quality of power from the main grid as compared to power from DER system is also worthwhile to mention. How would DER system be able to improve the reduction of emissions to keep the environment clean?

Second step is the selection of best suitable DER technology for solving the entire major problems considered in first step. Suitability of DER depends on the facility's location i.e. where the DER system needs to be installed, for instance; places near the sea shores have abundance of wind and tidal energy but on the other hand desserts; which are quite hot areas are more suitable for solar thermal and PV technology. For example, hot areas having implemented solar thermal technology where the demand of energy for cooling is more, so the production of energy is also raised proportionally due to more irradiance of solar energy during that time. DER is not bound to be implemented one technology at a time; some locations have potential for more than one DER technologies. Sometimes in most congested areas even small scale conventional power plant could be installed just by having trade-off for some aspects of DER systems. Thus the most optimized DER generation system could be implemented while keeping in mind all aspects mentioned in first step.

Thirdly, here comes the feasibility consideration of the chosen DER technology for the facility. For instance, eliminating the DER options which appeared to be non practical for a given location. This thing ensures the right decisions for the project being taken and helps us in analyzing the economics of selected DER source. We always need to keep an eye on all the trade-offs in consideration. Next thing to be focused is the availability of resources like; process experts, technical experts and financial support. Development of the project plan comes at number five. Sixth step is the consideration of hurdles which may create problems for the implementation of the project i.e. obtaining permits as well as the technical challenges. Seventh and the last step is the practical implementation of designed DER system and starting its operation.

6.1.1 TYPE OF DER AND TECHNOLOGY

DER typically installed with renewable sources of energy, such as; wind, solar, geothermal, biofuels, fuel cells and hydro etc. Low cost fuel means cheaper energy and almost all renewable energy resources are in abundance and freely available. DER systems could be implemented as a standalone system or as hybrid systems containing multiple DER in a system [77].

6.1.1.1 PHOTOVOLTAIC SYSTEMS

Sun is the most abundant source of energy shinning on our planet. If we could be able to harvest energy present in few acres of sun, we can meet the energy demands of our whole globe for many years. Solar energy falling on the surface of earth has to major components of energy; light energy and heat energy. For utilizing light energy of the sun Photo Voltaic (PV) panels could be installed to get clean electrical energy. Of course amount of power obtained from these panels is totally dependent on the incident light energy on the surface of these panels which varies from place to place. So by improving the efficiency of PV panels and connecting the battery storage system we can get more of it [77].

6.1.1.2 SOLAR THERMAL SYSTEMS

The other potential exist in solar energy is in the form of heat energy from the sun. This heat energy could be utilized for heating and to generate electrical energy as well. Theme is that heat energy coming from the sun is concentrated in a particular area to get high temperatures in order to have super hot steam to run the steam turbine or engine which is further coupled to a generator to generate electricity.

a. PARABOLIC TROUGH TECHNOLOGY

Long parabolic shaped mirrors are placed such that facing the parallel rays coming from the sun fall on their surface and then after reflecting from the parabolic surface they are focused on a focal point to raise the temperature of the fluid placed at the focal line of the collector. Through heat exchanger heat of this heated fluid is transferred to water to convert it into steam which then runs steam turbine coupled with a generator to generate electricity. Intelligent electronic systems track the sun throughout the day so that the surface of the parabolic trough mirror always remains perpendicular to the parallel rays coming from the sun. This type of technology could be used for getting heat energy which can be stored in molten salt and electrical energy. Currently a 354 MW commercial power plant is in operation in U.S. Sargent & Lundy U.S has estimated; by 2020 electricity price using trough technology could be dramatically reduced to 6.2 cents/kWh [82].

b. CENTRAL TOWER TECHNOLOGY

In this solar thermal technology flat moveable mirrors called heliostats are used to focus the received sunlight on a central tower containing molten salt to store heat energy received. Beauty of this technology is that we can get electrical energy from it even during night times when there is no sun shining, it's because of the fact that heat energy is stored in large tanks containing molten salt which then release the stored heat energy when needed. All further process of getting electrical energy is same as in any conventional thermal power plant. Cost reduction in electricity estimated by Sargent & Lundy U.S for power tower technology by 2020 is to 5.5 cents/kWh [82]. Aim of getting cheaper electricity could be made possible using solar thermal technologies because this fuel is free and abundant in amount, which is the main constituent of electricity price, secondly improvement in efficiency of these systems could lead to even cheaper electricity.

c. PARABOLIC DISH STIRLING ENGINE TECHNOLOGY

Parabolic dish can also serve as a collector for receiving parallel rays of sun and providing the intense focused beam of heat to a stirling engine placed at its focal point to generate power from the generator coupled with the stirling engine. These systems are useful for producing power in the amount ranging in few kilo Watts and are so compact and portable.

6.1.1.3 WIND TURBINE SYSTEMS

Potential existing in wind power could not be overseen. But the dependence of wind power on location is also a big issue and energy production from wind is so much intermittent due to variation in speed of wind and seasonal variations. On the other hand appending storage options with this DER technology surely increase reliability of this type of systems [77].

6.1.1.4 SMALL BIOPOWER SYSTEMS

Waste of plants, crops and other biological materials can replace the fossil fuel used for power generation. Mostly biomass obtained from food, forest, and trees is utilized for this purpose but sometimes sewage treatment plants can also provide this kind of biofuels. Natural oils along with fats and some amount of alcohol called biodiesel can act as fuel for diesel engines wherever it is feasible. Biodiesel also help reduce CO_2 and SO_2 emissions [77].

6.1.1.5 FUEL CELLS

Fuel cell converts chemical energy into electrical energy through a chemical reaction. Compared to batteries, fuel cells need constant supply of fuel usually hydrogen to produce electricity. Fuel cells find their applications in automobiles, airplanes, submarines either as a backup or primary source to power remote industrial and residential areas. Fuel cells are highly efficient and produce fewer emissions. Fuel cells can provide clean electricity with a reasonable price when implemented as primary source of power. Fuel cell produces heat and water along with electricity which can be used for heating purpose in order to implement it as a combined heat and power (CHP) plant. Detailed applications and markets of fuel cells as a primary and back-up source of supply can be found in [83].

6.1.2 ENVIRONMENTAL IMPACTS

Consideration of environmental issues related to DER systems is an important aspect. Most of the DER systems help reduce emissions because of the use of renewable energy resources. Like wind, solar and fuel cell systems virtually have no air emissions. DER systems if implemented as CHP systems have low emissions and improved overall efficiency, as the heat emitted is utilized. As DER systems are installed near the facility so while choosing suitable DER technology noise consideration is a big issue. Visual appearance of the system somehow has impact on the community [77].

6.2 DISTRIBUTED GENERATION

Opposed to centralized generation of electricity by distant large power plants using conventional energy resources, distributed generation brings the concept of power generation on small scale mostly using renewable energy resources closer to the location where it is supposed to be consumed. Distributed Generation (DG) [76] provides us with a lot of benefits including enhanced reliability, improved security as well as cheaper electricity. As the load ends are just near to generation so the dependence on transmission system is somehow reduced and hence reducing the transmission losses and cost. Power quality is also improved in DG along with a reduced risk of faults because of somehow elimination of long transmission lines. As the end consumer of electricity has to pay extra money for transmission of electricity in his utility bills so DG will reduce this cost. DG can be implemented on two scales; first small generation plants feeding a particular area, secondly, end users produce their own electricity by installing small wind turbines or Photo Voltaic (PV) panels on their homes and act like a prosumer [75].

6.2.1 ECONOMICS OF DG AND COST FACTORS

Cheaper electricity with a high level of quality is the main goal of DG. Prosumers have the potential to sell surplus amount of generated power to the main grid resulting in a significant amount of revenue during peak demand hours. Cogeneration (combined heat and power) technology has shown a great potential to industrialists, reuse the thermal energy generated during industrial processes for the generation of electricity made possible by DG [75].

6.2.2 EFFECT ON RELIABILITY OF THE SYSTEM

Reliability assurance is another big pillar of DG. Because of generation of electricity locally, it provides with a reduced demand of electricity during peak hours and hence minimizing the congestion of power on main grid, hence avoiding the risk of blackouts.

6.2.3 OTHER KEY BENEFITS FROM DISTRIBUTED GENERATION

Now-a-days because of law and order situation in the world it is good to have small generation units like DG near the end user premises to avoid any large blackouts in case of any terrorist attacks, thus eliminating the security threats. In case of large power plants at distant locations if any undesirable thing happens in the network it may result in a big disaster but DG has overcome this risk. Requirement to upgrade and expand transmission network with the exponentially growing demand of power on newly installed loads is almost eliminated. As far as environmental issues are concerned, in large centralized power plants a lot of toxic gasses are emitted and become the cause of environmental pollution. Its true some DG options use conventional energy resources for generation but it has substantially reduced emission with the implementation of renewable resources on small scale for the generation which helps keep clean atmosphere. DG can also act as back up source for the most critical loads like hospitals, airports, fire safety department, military, and communication systems. According to CIGRE report, [85,86] has mentioned several encouraging reasons for the implementation of DG:

- Frequent availability of compact generators
- Can be accommodated in small places thus eliminating the need for large areas for plant
- Less time required to install the system and short capital cost
- Diversity of energy resources

Apart from all these potential benefits there exist serious issues that make it somehow difficult to implement this idea of DG using renewable energy resources. Some technical and social issues try to stop this transition from centralized to decentralized nature of the power grid. The main thing here is the capital cost of this kind of small generation units that makes it uneconomical for domestic consumers for the time being. In this way implementing DG with the current available technologies which are more expensive is not a good idea because it actually lags behind its main motive of providing its consumer cheaper energy. Power from the renewable energy resources is not always constant hence making it dependent on the main grid every time in order to meet demand of energy.

6.3 INTEGRATION OF DISTRIBUTED ENERGY SOURCES

Integration of DER in the main grid to make its market place is a big challenge for the researchers. But this is the task which has to be done with more advanced control and communication technologies like the introduction of intelligent agents. Smart grid enables the micro sources of energy and DER to be integrated in the main grid. Intelligent agents provide support to react instantaneously to any imbalances caused by variable sources of energy. Owners of different DER systems might be different, making central management system decisions difficult to manage, in order to avoid this kind of contradiction between different DER systems intelligent DER agents must have given freedom to make major decision based on their own intelligence through coordination among themselves. Integration of different DERs not only involves the connection of different DER systems, but there are lots of things to be considered like, voltage control, frequency control, market price of energy and expected amount of generated energy in the immediate future and demand. So most of the decisions are expected to be made locally thus giving birth to agent based distributed management and autonomous systems [84]. Increase in penetration of DER might cause reverse power flow making distribution network an active system with power flow and voltage level dependent on sources and loads. For instance, in case of CHP, it may absorb or export reactive power in case of decrement in load depending upon excitation of the generator. As the induction generator of wind turbine requires a source of reactive power to operate so it may also absorb reactive power. Voltage source convertor of photovoltaic system may induce harmonic currents in the network. Hence the change in real and reactive power in the distribution network due to distributed generation has shown an important consideration for technical and economical issues in the smart grid [87]. Particularly Denmark has put a lot of efforts to estimate the energy production from wind turbines by forecasting wind speed. And for distributed CHP generation, Denmark has found a solution of operating the system at three different power factors based on the time of the day [88, 89]. There are so many other issues need to be consider in consideration to DER like, power quality [90, 91], voltage variations, protection issues and stability of the smart grid.

6.4 A DEEPER LOOK INTO DER AGENT

Distributed Energy Resource (DER) Agent keeps the information related to DER, and performs the operations of monitoring and controlling of DER power levels and its status. Main information contained by DER agent is about the identification number, type, power rating of DER, price function and availability of fuel in near future forecasted by forecast agent (for wind and solar) associated with metrological department. DER agent also conducts market analysis for sell of electricity while keeping in consideration with the availability of DER. It is DER agent’s responsibility to keep all the relevant information up to date and provide that information to other agents for further actions to be taken while having interaction with other agents of MAS. For instance, [4] has proposed a multi agent system for the control and coordination of DER in microgrids including DER agent along with control agent, user agent and database agent. DER agent takes its required data from agents at lower level like device agents for DER generator, circuit breaker, and measurement data in order to have real time information to make right decisions about how to proceed next according to information received from other agents. DER agent is autonomous and makes decisions based on its built-in knowledge without any intervention by other agents, it is reactive as it can sense any changes in its environment and can react to those changes accordingly. Proactiveness is another aspect of DER agent which allows it to take initiatives to exhibit its task, while it is social like other agents and gets involved with other agents through agent communication language.

6.4.1 DER AGENT COORDINATION

DER agent can't solve any problem alone so in order to resolve any issue it has to interact and coordinate with other agents in MAS present in the same environment. How the agent utilizes its resources and skills in a particular environment defines its behavior and this behavior is set by the goal it is going to perform. Agents are typically goal oriented, for instance, due to their distributed nature they just have the knowledge in their immediate surroundings (agents on the same level) however they can estimate or call the information from upper or lower level agents if required, but they don't have knowledge about the status of whole system. This is the main beauty of MAS, to perform tasks locally with minimum exchange of messages. Each distributed energy source (generation unit) in microgrid acts like a DER agent. Agent based systems provide self organization for agents to be involved in coordination using the same platform and information exchange protocols. One method is that agents in the same environment register themselves in a common directory service and then set their specifications. If in case one of the agents is out of service then the system must be able to self organize itself to achieve the overall goal. Each DER agent can have somehow different specifications even in the same micro grid because of the nature of fuel, different for different DERs. DER agent will forecast the amount of energy generated in coordination with other agents. Energy storage agent helps DER agent to maintain its supply to load as source in case of more demand of energy and as sink for the surplus amount energy to store that extra energy during off peak times. So now energy storage agent and DER agent together control the flow of power along with load and control agent. In a broader sense, all agents in a particular environment not necessarily know each other but it is their query which force them to inquire in directory, whether their desired partner agent is present or not in order to get their required information.

6.5 MICRO-GRID

Micro Grid, as the name suggests it a complete electrical grid which generates, distributes and regulates energy to end users but locally. It is an electrical grid consisting of several loads, micro power sources including renewable energy resources which operates as an independently controlled system and provide both electric and heat energy to local consumers efficiently [79]. Microgrid is the best way to integrate and improve the penetration of renewable energy resources at the consumer level. Microgrids are like the building blocks of smart grid, integration of these microgrids give birth to smart grid. More precisely we can define microgrid as:

"A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode" [78].

Microgrids are best when operated as autonomous agent based power system components [81]. Grid modernization and combining different smart grid technologies are the focused goals of microgrids. Reduction of transmission losses and peak loads by utilizing the concept of distributed generation is another unique aspect of smart micro grid. Giving consumer a freedom of choice and providing them chance to participate in the grid's demand-side management is its beauty. Support to sensitive loads while keeping in consideration the variable production from renewable energy resources is the main intelligent aspect of microgrid [78]. There are several R&D projects are going on under U.S Department of Energy (DOE) and many related projects are in progress in many European countries as well, to find the solutions to implement microgrids practically in consideration with all the issues related to their integration with the main grid. DOE is focusing on the applications of advanced sensing, control and communication technologies to find an optimized and dynamic way for the implementation of microgrid [80].

6.5.1 MICRO-GRID CONTROL WITH AGENTS COORDINATION

Because of its distributed nature and requirement of advanced control capabilities for network operations it is quite difficult to control microgrid using traditional control systems which are intended to monitor and control large generation units based on centralized control scheme. It would be nice and make our job easy to control microgrid if we can transform the control mechanisms of micro grid from centralized type to distributed one, then this issue can be resolved efficiently. For instance, each generation unit in microgrid would be able to operate independently due to distributed control. Hence, a multi agent system can be developed to have distributed control for microgrids [79]. Decentralized control for intermittent renewable energy resources is best suited. Distributed control provide us achieving full benefits of renewable energy resources while same time reducing the control and coordination burden on the utility grid [81]. MAS having several agents is a very useful tool for the control of smart grid. It has three main features [92, 93, 94]:

- The core entity of this system is agent which is autonomous in nature. It shows that every agent has the capability to control its unit operation independently through its actions.
- Information exchange with other agents makes it possible solve even complicated problems.
- Agent is known for its behavior and adoptability which tends to satisfy certain objectives by the use of pre-defined services.

Seven layers MAS can be implemented for the control of micro grid which is shown in Figure 6.1 given below.

Figure 6.1 Seven Layers Control Architecture of Micro Grid

- Component level and load agents are responsible for the monitoring of measurement and control equipment as well as switching of load.
- Prosumer agents coordinate with the upper and lower level agents and forecast the amount of energy expected to be generated in the near future and expected demand based on information provided by load agent. On the basis of this forecast and analysis prosumer agent makes decision either to purchase or sell energy from the distribution network.
- DER agents interact with other DER agents in the same distribution network in order to set the energy pricing for the near future and update its status about the expected generation in the immediate future.
- Microgrid agents are taking care of all loads and micro generation units connected that particular microgrid.
- Distribution level agents make a bridge between the micro grid and the main grid through transmission system organization (TSO) agent.
- TSO agent makes major market decisions based on the information about the energy demand received from the low level agents and convey its requirements to generation units.

- Main grid agents are keeping the overall look on the whole system status and in case of issues which were not resolved by the low level agents locally, they perform major decision to achieve the overall goal.

6.5.2 ISSUES WITH MICRO-GRID INTEGRATION

Most critical issue faced by microgrid is to have better control over supply and demand balance. If the microgrid is operated in “islanding mode”, change in frequency of system gives the information to make decisions about the control of outputs of generators because change in frequency is proportional to the change in demand of energy. But in case when the microgrid is connected to the main grid, then just information about the change in frequency is not enough or available to control supply and demand balance because the frequency change mainly depends on the supply and demand balance in whole bulk power system. Furthermore, as now the generation is becoming more distributed, owned by different owners, so it is difficult to directly control individual DG by control order from the system operator, hence it needs reregulation of energy management infrastructure [95]. In [96] a new model for supply and demand balance control has been developed based on mobile agent technology it is able to promote the bilateral trading among customers.

6.5.3 ENERGY TRADING USING MOBILE AGENT

Now consider a basic example of how the energy will be traded in Micro-Grid [95]:

i) Every consumer through a ‘token’ or ‘mobile agent’ in the information and communication network for the need of purchasing 1 kWh of energy along with the price information of energy consumed with that token. Price is decided by consumer at random.

ii) This mobile agent is passed throughout the micro grid while increasing the price of the token with the passage of time.

iii) Whenever this token reach any DG owner, it checks the price information attached with the mobile agent and if the proposed price is sufficiently higher than the cost of fuel consumed for the generation of energy then this token is accepted by that DG.

iv) When the price agreement between the consumer and the DG owner is done then DG increase its generation to provide the demanded power to the respective consumer.

Chapter 7

Agent Based Model for Smart Grid Energy Balance Management

It is absolutely true that our existing power grid is doing well for monitoring and control of the power system, things related to reliability, power quality, fault handling and somehow trying to match the demand and supply. But the thing is that if our existing power grid was so efficient in its task handling then why today everybody started to talk about smart grid. Is it just a new smart name given to the power grid or it really has some meaning? This appears to be a tricky question but we have to define a clear boundary between a conventional power grid which we have today and the new concept of innovative smart grid for the future. In order to solve this mystery we have to look on both conventional and smart grid deeply so that we can realize clearly that which are the innovative features provided by smart grid we don't have today in our existing power grid. Let's have a look on the most important features of smart grid, which are the Intelligent Energy Management (IEM) [97], bidirectional power flow from prosumers end, availability of energy storage options at distribution level, end user participation in the electricity market, penetration of electric vehicles and self healing nature of smart grid and many more innovative feature which we don't see in conventional power grid.

7.1 THE REAL ESSENCE OF SMART GRID

It would be unjust to the idea of smart grid considering it a "thing" rather than a "vision". Before we start to aim this vision into reality, we need to look it from different perspectives; its demand, acceptance, envisioned features and the required building blocks and technology to implement it. Smart grid provides its consumers with the facility to participate in electricity markets while keep them informed with energy pricing and options. This is the way how consumers would know to adjust their energy demands and participate in balancing the overall demand response and help reduce capital as well as operating cost of the system. Like telecommunication companies facilitating its customers by offering them different plans and packages, smart grid also aim to make it available to offer different plans and options to its consumers in order to give them more space to have their hand the electricity market. One of the most attractive features of smart grid its ability to engage all “plug and play” energy generation and storage options even at distribution level which was just a dream in the conventional grid. This feature will also include penetration of hybrid vehicles in the market with an addition of cleaner environment. Electricity market going to be more mature linking the Regional Transmission Organization (RTO) to end consumer, even home energy management system at consumer level. Our conventional power grid has put efforts on avoiding outages rather than focusing more on power quality issues, but smart grid is going to provide power options along with pricing based on needs of consumers. More intelligent controlled smart grid will have the ability to optimize its assets and efficient usage of energy to get even more of it. Smart grid introduces the idea of self healing network, either by predetermining and settling the abnormal situations before they occur or by acting so fast and intelligently to minimize the effects of those disruptions and restoring the system immediately. Smart grid will focus on the security of the grid to make it resistant to any external or internal attacks and make it more reliable and secure [98].

7.2 ENERGY BALANCE MANAGEMENT

The fact that electricity has to be used at the moment it is generated makes it a big challenge to balance the energy production and consumption every time. This is because electrical loads are always switching and making the overall load on the grid variable. Smart grid’s main focus is on the energy balance management of the power grid, well described by the figure 7.1 below.

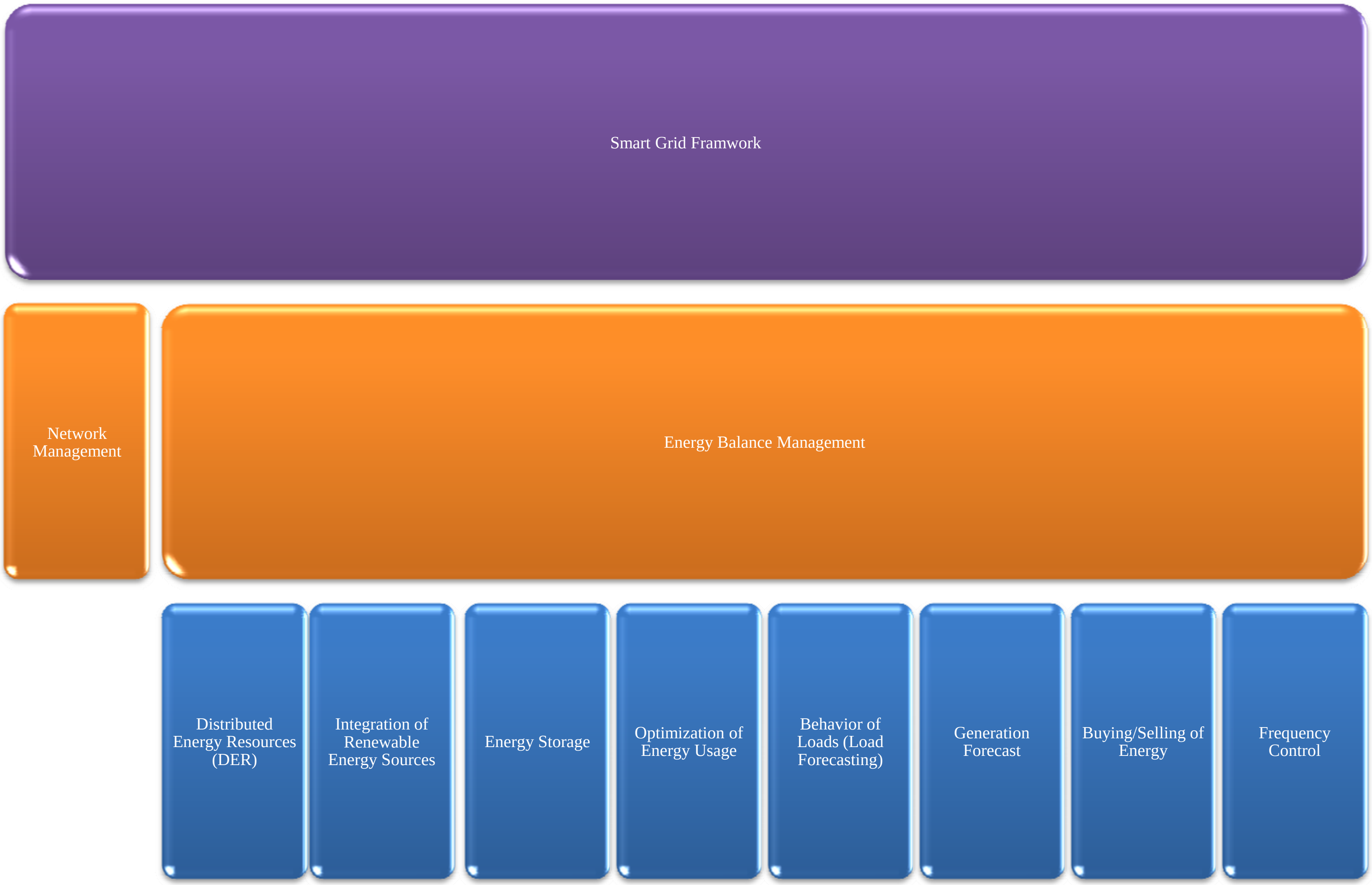

Figure 7.1 Smart Grid: A Big Picture

7.2.1 DEMAND RESPONSE

Demand Response is: "*Changes in electric usage by end use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*" [101,102]. We can also elaborate it like this, adjusting the usage of energy in consideration with the supply conditions in order to reduce the consumption of electricity for non critical loads in peak demand hours or prompting consumers to use energy for non critical loads in off peak hours by providing somehow cheaper electricity to meet the demand and response in real time. The reason why demand response is necessary to be implemented in our electricity network energy balance management is somehow justified as: a large difference in demand and supply of electricity may cause interruptions hence, affecting the reliability of the system, having more power sources in the network as standby in order to meet the spikes in the demand is neither environmental friendly nor cost effective, this makes it important to think about adjusting the loads without expanding the existing system. Demand response is the way of utilizing the resources in hand optimally and efficiently. U.S department of energy and Berkeley National Laboratory have carried out a lot of research on demand response, benefits from it and its feasibility. Some of the empirical evidences have been discussed in detail in [103].

7.2.2 ELECTRICAL LOADS CLASSIFICATION

Electrical load could be seen as any entity, device, appliance or machine which consumes electrical energy. Electrical load acts as a sink for electrical energy in power system. Electrical loads can be classified into many classes depending on their nature, operation, functionality, and importance. It is important to keep in consideration types of electrical loads connected to the system while planning an energy balance management system. It not only helps in energy balancing but rather in other issues related to power quality and reliability. Figure 7.2 shows classification of electrical load based on different parameters.

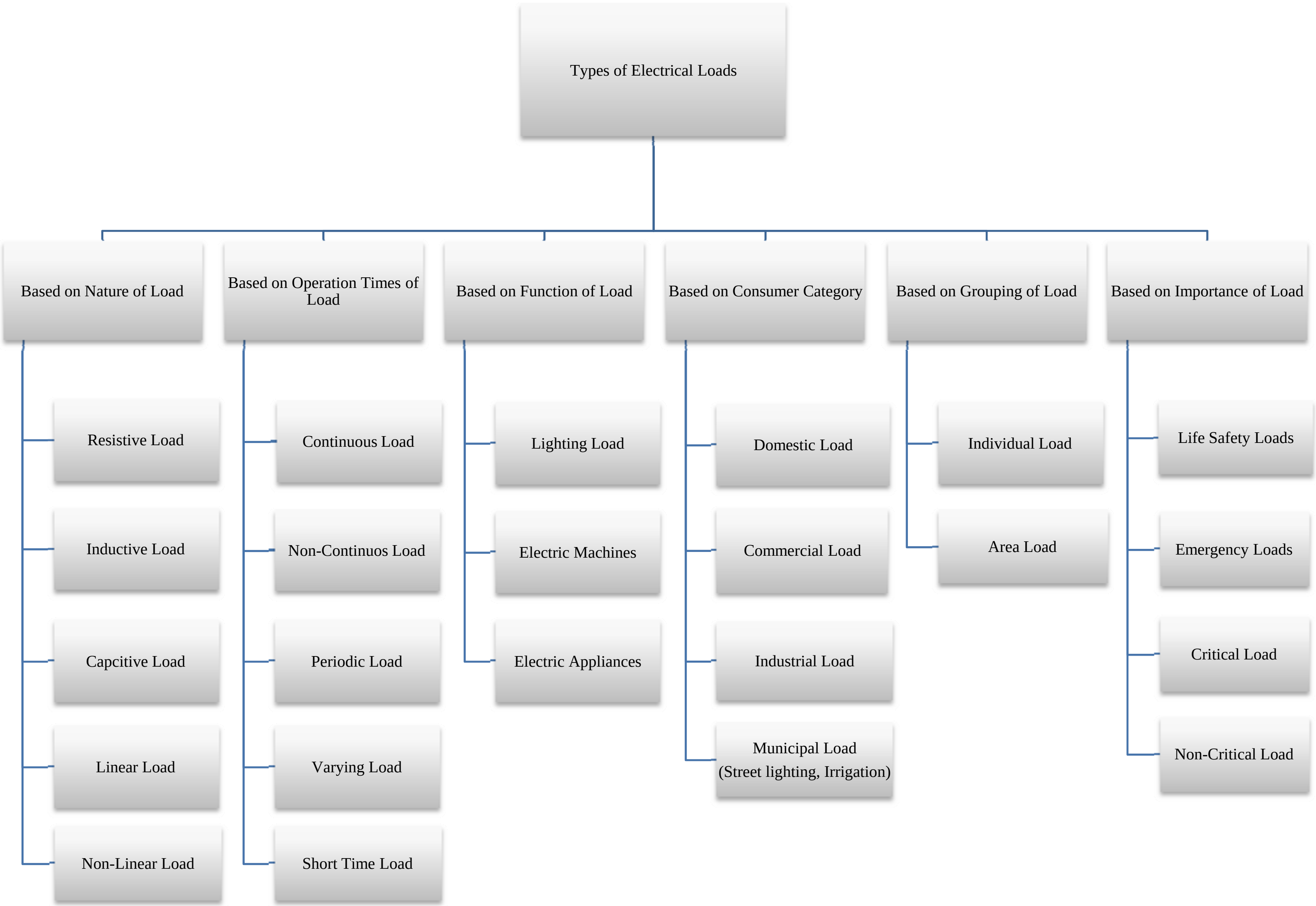

Figure 7.2 Electrical Loads Classification

7.2.3 AGENT BASED ARCHITECTURE FOR DEMAND SIDE MANAGEMENT (DSM)

This is the time to model agent based architecture for energy market of smart grid. We proposed four agent based model having five layers of communication and market. First we will start by introducing every agent at each layer after that we will talk about the coordination between these different layers. Let's consider an example scenario of a colony of prosumers meaning that each of the consumers has his own generation unit like; solar panels or micro wind turbines installed on the roof of each home. Each consumer has intelligent agent based energy management system installed in his premises containing, **Load Agent**, **Source Agent** and **Battery/Hybrid Vehicle Agent**. Each agent has its responsibilities to do while coordinating with the other agents of its team as well in order to achieve overall goal. All these three agents are considered to be first layer agents. Now we will proceed by explaining the functionality of these three agents:

- **Source Agent:** It keeps all information regarding generation capacity of the source, expected generation in the near future, coordination with the *forecast agent* to know about the weather condition and other related metrological data. It also communicates with the load and battery agent on the same layer and with the prosumer agent on the upper layer.
- **Battery/Hybrid Vehicle Agent:** This is kind of a component level agent. Its goal is coordinate with source and load agent in order to store power from the source in low demand times or deliver power to the load in case of low generation times when the source is not able to provide the demanded power to the load. It also has to have information and control for charging or discharging of the battery depending on its capacity and provide its status to the prosumer agent for further actions.
- **Load Agent:** Optimized usage of energy for domestic load is the ultimate goal of load agent. It controls the loads connected to domestic source and demand energy from the source depending on the forecasted demand in the near future and coordinate with the battery agent to fulfill its energy needs if source is not able to supply the required amount of energy. Load agent communicates with the prosumer agent to inform it about the expected energy demands. More details

about the Load Agent will be presented later in this chapter. Coordination among these agents is illustrated in Figure 7.3:

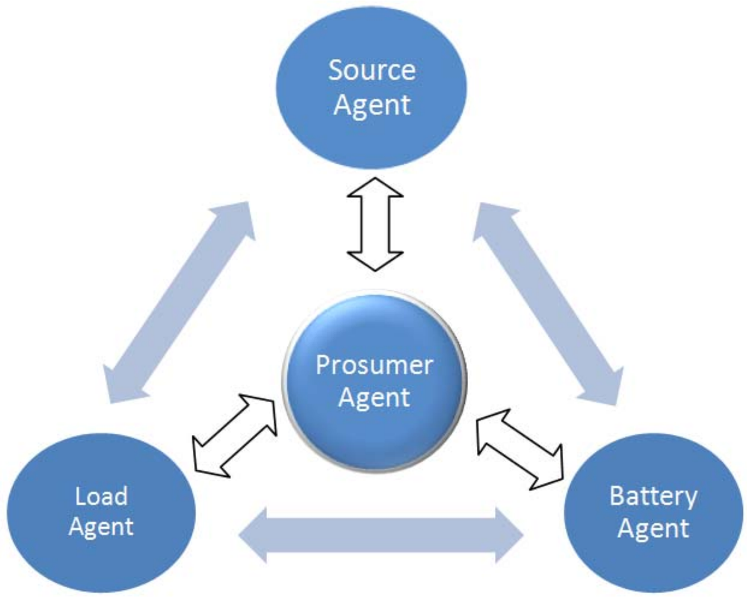

Figure 7.3 Coordination of Agents to make a Domestic Energy Management (DEM) System

- **Prosumer Agent:** It is a second layer agent in Domestic Energy Management (DEM) system; the entire three first layer agents communicate with prosumer agent in order to inform it of their status, demands and needs. Prosumer agent performs the status check of three agents and collects information about their supply and demand for the near future. For instance, Source agent provide with the expected generation for the upcoming period (let's say next hour), battery agent tells prosumer agent about its capacity and stored energy which would be available, and load agent based on its forecast information about the energy usage sends demand request. Now having all this required information from the sub-agents game of making final decision comes to prosumer agent, it will decide whether the domestic load is deficit of energy or excess of energy. If the overall prosumer unit has more energy than it needs then prosumer will act like seller agent but if overall available energy is less than the demanded or required energy then prosumer agent will perform as a buyer agent.

Figure 7.4 Coordination of Prosumer Agents with Local Market Agent

- **Local Market Agent:** This is like that prosumer agent is responsible for the sell/purchase of energy for a domestic consumer and sends request/offer to the local market agent accompanying a colony of prosumer agents. Of course, different consumers of electricity have different energy demands even if they are residing in the same environment. There might be many situations when some of the prosumers have more energy than they need so they offer it to Local Market Agent for sell while others prosumer might be deficit of energy at the same time so depending on the settling of price of energy it is local market agent's goal to make agreements between different prosumer for the sell/purchase of electricity. Figure 7.4 shows the interaction of prosumer agents with the local market agent. Local Market Agent can be regarded as a colony agent.
- **Distribution Market Agent:** In a case when the local agreements couldn't be made due to some abnormal weather conditions, the generation of each prosumer goes down or stopped then local market agent has to purchase energy from the Distribution Market Agent or in a reverse case when production form prosumers

end is more than their overall need then excess energy could be sell to distribution market. Distribution Market Agent keeps the record of demand and response of energy from prosumer agents and uses that data to forecast future sell/purchase of energy contacts from the upper level agents. This coordination is expressed in Figure 7.5 below:

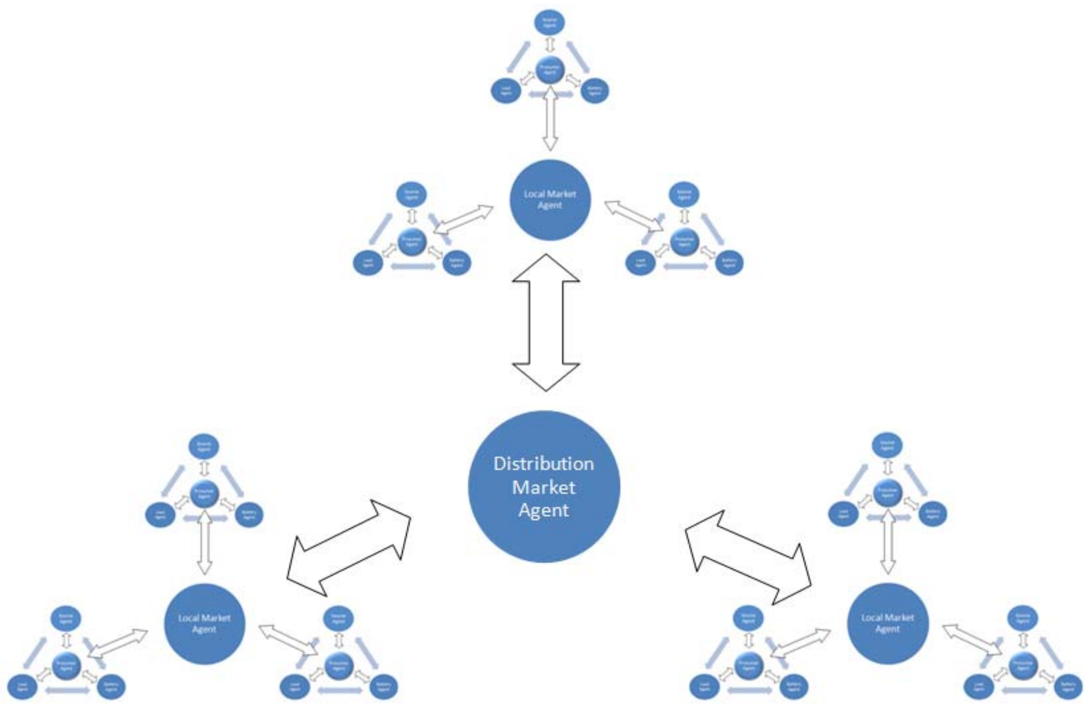

Figure 7.5 Coordination of Local Market Agents with Distribution Market Agent

- **Regional Transmission Organization (RTO) Agent:** Distribution Market Agent is in coordination with the local Distributed Energy Resources (DER) Agent and also with the Regional Transmission Organization (RTO) Agent for the long or short term contract of energy selling or purchasing. RTO Agent is communication with the distribution market agents and with the large centralized power plants to estimate sell and purchase of energy. In this case we just considered communications among three agents but in reality a large number of prosumer or local market agents are communicating to achieve the end goal of efficient generation and consumption of energy. Communication between RTO agent and distribution market agent is shown in Figure 7.6 below:

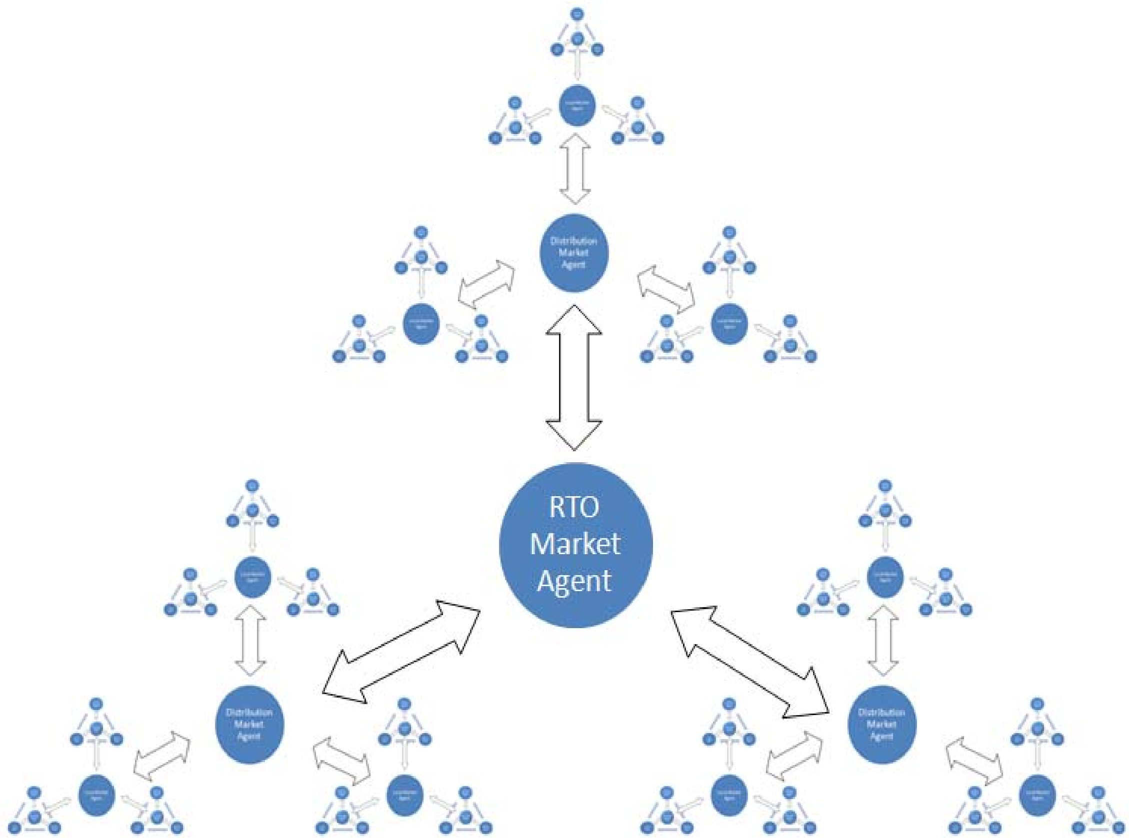

Figure 7.6 Coordination of Distribution Market Agents with RTO Market Agent

7.2.4 DOMESTIC LOAD AGENT TO OPTIMIZE ENERGY USAGE

Increasing generation, purchasing more energy from the main grid were the old concepts of matching demands with supplies. But now with the advent of more intelligent systems and advanced communication technologies encouraged researcher why not control the loads itself even at domestic and appliances level to optimize the usage of energy. In this regards we suggested to introduce a Domestic Load Agent at prosumer level. Domestic load agent monitors and controls the loads at appliances level. For instance, domestic load agent observes the habits of the consumer related to energy usage and updates its knowledge in case of any unusual event. It gathers information about the energy pricing from the prosumer agent and makes best suggestion for the usage of appliances to get optimized result. In this way shifting of load at domestic level could also be controlled by domestic agent to reduce the burden on the main grid during peak demand hours. By the continuous observation it can estimate the demand for the near future for the consumer based on its past experiences. On the bases of this estimate for the load it can better inform prosumer agent to sell/purchase energy for upcoming hour. Consumer behavior and activities are the most important parameters for the domestic load agent. But still there will always be some uncertainty and margin of freedom is imposed on the system. Every agent has some *degree of freedom* allowed by the environment and system which helps it to make decisions. Degree of freedom is a power to determine actions without restraints given to agents make decisions on consumer's behalf. It is obvious that we don't expect the agent to make stupid decisions to sacrifice consumer's comfort but on the safer side in more advanced MAS degree of freedom could be adjusted in order to fix the risk factor. Risk factor increases with the increase in degree of freedom.

7.2.5 LOAD ADDRESSING OR TAGGING SYSTEM

Loads even at appliances level or industrial level large loads could be controlled and shifted better by assigning them proper addressing or naming or tagging. Nomenclature for loads is suggested to be standardized in order get more control on them. Loads at appliances level when tagged can help agent based energy management system to adjust energy balance in the entire system.

7.2.6 PRIORITIZING THE LOADS IN AGENT'S MIND

Prioritizing the loads as important, critical or noncritical help load agent to shift and switch loads accordingly. This thing not only has to do with the energy management system but also in case of abnormal conditions in the systems, like faults or very low generation. After having a prioritized list of loads in mind agent can better consider consumers comfort as well as economics of the electricity and can participate efficiently in the electricity market.

7.2.7 SUPPLY FORECASTING ON THE BASIS OF ENVIRONMENT AGENT

Source agent is assisted by Environment Agent in order to estimate its generation in the near future. Environment agent forecast the weather conditions based on the metrological data, for example in case of solar panels it informs source agent about the expected solar isolation and for wind turbine it estimates the speed of wind and other necessary parameters which help source agent to have an estimate of its production. It also provide source agent with information about any unusual conditions happening in the atmosphere.

7.3 SMART BUILDINGS FROM AGENTS POINT OF VIEW

When prosumer model become reality for the smart grid then the idea of making our buildings smart enough to optimize the energy usage would be easier to implement. Smart building sometimes referred as zero energy buildings are considered as self sufficient for themselves with regard to energy requirement but sometime they require more energy from the main grid and on some other occasions they can also sell energy to grid. Intelligent agent based system can be implemented to automate our buildings to have optimized asset management in our homes. Agent based home energy management system is also a rational idea to be considered in the near future.

7.4 SMART CONSUMERS

Without smart consumers the idea of smart grid seems like a dream because consumers are the main stakeholders. Acceptance by the community and having implemented in their real life is the main ultimate thing to be considered before going further. Smart consumers are aimed at adopting all the potential benefits offered by smart grid. All this game is to reduce carbon emissions in the atmosphere if the consumers are not willing to do so then how it is possible to gain this benefit. Contribution from individuals will be required to reach our final destination. Using energy efficiently in our homes, offices and everywhere would be possible by educating our consumers and making them realize all of its social, global, environmental and economic benefits. Open investment opportunities in front of them so that they can also participate in energy market and put their share in making our planet free of greenhouse gasses [100].

7.5 ENERGY STORAGE

Principally, electrical energy is generated and consumed in real time. Controlled flow of electrical energy is possible by the introduction of energy storage systems into the electrical grid. There are many storage media available for storing energy in any forms of energy for instance, flywheel (for rotational mechanical energy), dam to store water at a height (gravitational potential energy), molten salt (for storing heat energy), batteries (electrochemical), and sometimes in the form of compressed air. Energy storage is useful to meet supply and demand of electrical energy. Energy storage systems help smart grids to cope its goal of efficient use of electricity. Changes in demand can only be accommodated either by cutting supplies from the main grid in case of low demand times or by injecting more energy in the system by turning ON extra standby generators in case of peak demand times. This method of meeting supply and demand is not a feasible solution, so the best idea is to store extra energy generated in low demand hours in any form of energy then taking back the stored energy during peak demand hours. Energy storage is best option when the system not only has variable loads but the variable producers of energy like solar and wind power plants (weather and location dependent) as well.

Load leveling, frequency regulation, improvement in reliability (backup source) and providing support to intermittent sources of electrical energy like solar and wind are the main motives of energy storage systems in smart grids. Traditionally distribution system didn't provide the space for active power generation and energy storage at distribution level [99].

7.6 ELECTRIC VEHICLES

Vehicles powered by electricity are electric vehicles. Electric Vehicles (EV) are going to write a new era of electricity markets, power system stability and reliability. Electric vehicles provide a good storage option for the electrical energy and help reduce emissions. Increase in penetration of electric vehicle in the smart grid demands more intelligent systems like agents to be in practice to control the flow of power and electricity markets. According to [104] United States is contributed almost 25% of whole carbon emission in the world, most of the part of this emission is because of use of oil in transportation. This thing and some other critical benefits prompted to encourage the use of electric vehicles. Increased penetration of EV will leave some issues and challenges about the grid reliability, power quality, energy pricing and demand response on electric network as well. Intelligent agent based charging infrastructure for the charging of EV could be implemented in order to resolve all the critical issues related to it. [105] has presented some of the potential benefits which we can have from EV.

Chapter 8

Smart Grid Network Management Using Agents

Smart Grid architecture is managing all the needs of the grid in two ways one is Energy Balance Management (EBM) of the network and the other one is Network Management of power grid. Energy Balance Management is already discussed in previous sections, now we will focus on more technical issues related to the operation of the grid.

8.1 NETWORK MANAGEMENT

The smart grid is considered as a network of many networks making it a very complex network. Electrical transmission grids, distribution grids which are geographically spread and interconnected and integrated with telecommunication grid from generation to consumption need very intelligent systems to be implemented to achieve the real time management of the network. In order to integrate these heterogeneous networks some standards and protocols need to be defined before we start to implement them practically. Network management demands a distributed architecture for both power network as well as communication network. Devices present in the network belong to different vendors causing some challenges to be appeared in front of us before moving ahead. Network management could be best handled if we do it using intelligent software agents. Network management is composed of two management layers [106]:

- Network Mediation Layer
- Management Application Layer

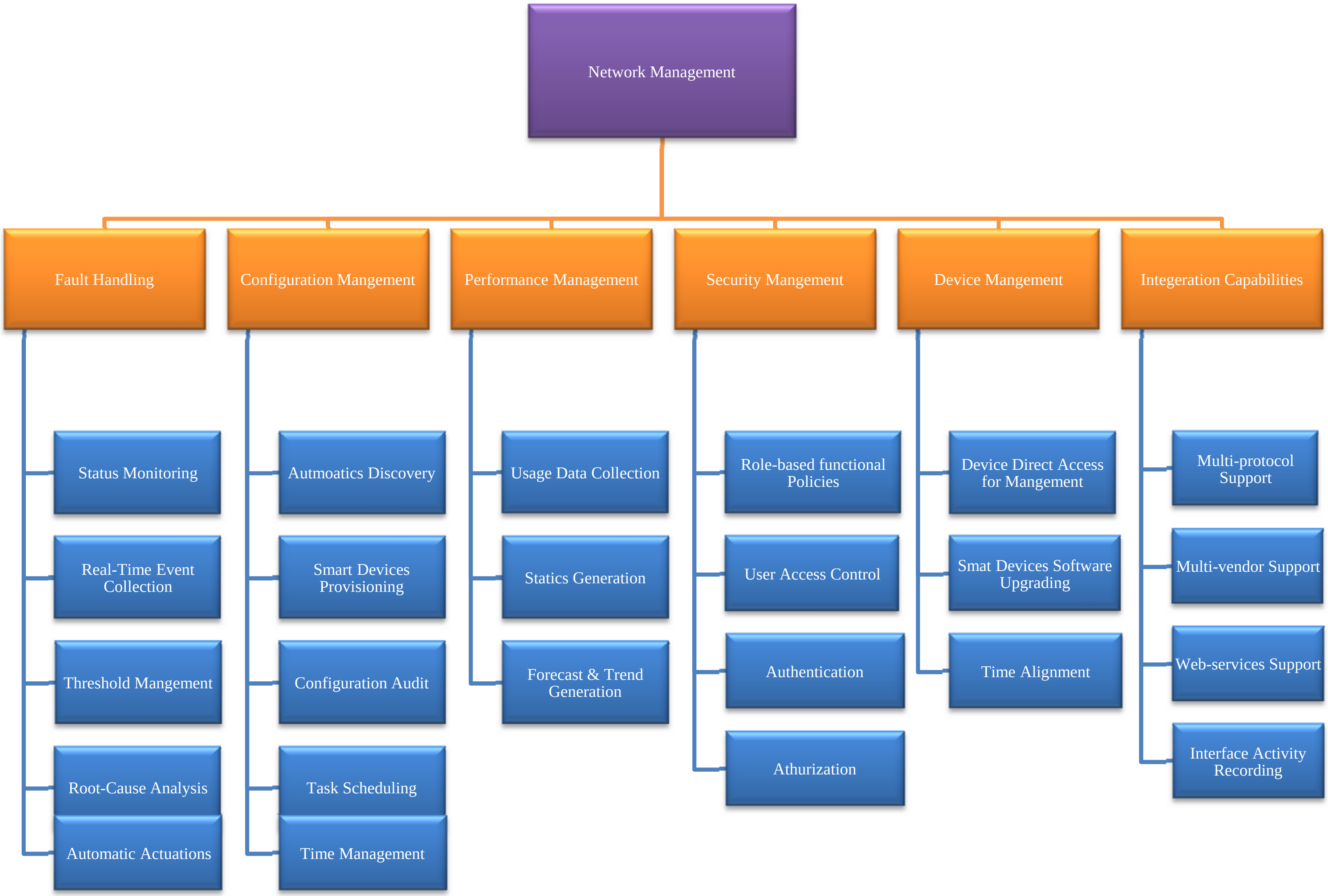

Figure 8.1 Smart Grid: Network Management [106]

Each layer is a combination of different agents which coordinate with each other through an intra system communication link. Communication between agents at different layers is also possible in order to resolve any issue. Figure 8.1 shows the network management architecture of smart grid.

8.1.1 VOLTAGE CONTROL

In power grid different issues are interlinked; change in any parameter anywhere in the network affects the overall system. Increased penetration of heterogeneous distributed generation units and electric vehicle will increase the variations of voltage in the low voltage (LV) networks [107]. Instead of using conventional method for voltage control which are being used, agent based systems along with smart devices need to be implemented to restrict the voltage levels in the network to a specified value while considering the other related issues at the same time.

8.1.2 FREQUENCY CONTROL

Changes in demand or supply of electricity directly influence the frequency of the network either increased in case of low demand or decreased if the demand of energy is increased. Frequency of supply must be maintained at the standard level all the time. Better forecast about the demand and supply would lead to better frequency control of the grid. When agent based demand response idea start to become reality this reduces the more frequent fluctuations in the frequency.

8.1.3 FAULT HANDLING

As the smart grid is going to be monitored and controlled by intelligent agents more efficiently, hence reducing the chances of faults to occur. Perhaps we cannot oversee the fact that some of the faults are unpredictable they might due to natural disasters or some other reason but the thing is that they must be resolved in a short time in order to maintain the supply of power. Now due to advent of more advanced systems for smart grid word of self healing network has been introduced.

8.2 SOME OF THE BASIC TERMS

Here we will present some of the basic terms related to smart grid.

8.2.1 CRITICAL AND NON CRITICAL LOAD

When electrical loads are classified according to their importance they are categorized as critical and non critical load. Those loads for which supply of electricity is obligatory to be continued in any circumstances are the critical loads. When a load can be switched off or can be shifted in case of peak demands or due to any other reason then this load can be regarded as non critical load. Critical loads have high priority and non critical loads have low priority in the power grid.

8.2.2 GRID CONNECTED MODE

The condition when the micro grid is connected to the main grid then it is said to be in grid connected mode.

8.2.3 ISLANDIC MODE

The condition when the micro grid is isolated from the main grid and is operating independently as an isolated grid then it is said to be in Islandic mode.

8.3 SELF-HEALING NETWORKS

Self healing nature of network can be defined as: “The capability for a system to automatically detect and recover functionality when faced with a single or many casualty events” [81]. For smart grid it is the immediate identification of problems; their location and causes, necessary actions for the minimization of the adverse impacts and prompting the recovery of the system to stable state [108,109]. A self healing power grid is network which can respond to disturbances, threats, material failure by preventing the cascading of the problem. It must be able to recognize the occurrence of any problem, isolation of the faulty parts, fast response, minimize loss of resources and service. This type of network highly demands the presence of intelligent system and high performance communication infrastructure to respond immediately to disturbances in the geographically dispersed system. Self healing is accomplished in two stages: firstly, emergency reaction stage and the second one is restorative stage. In first step location of the casualty event is identified and system tries to minimize the affected area usually by isolation. Many of the emergency reactions are predefined for agent based self healing networks. After the first stage when the system has already made its transition based on predefined algorithms now the restoration of the system starts to begin. Together with other installed hardware for the protection of the network, a series of reconfiguration schemes for the network take place which may involve operation of intelligent switches, manipulation of circuit breakers, and adjustment of load or generation units or some other actions which can lead to improve the overall system condition. Restorative stage might be long as compared to first stage because it needs to make several intelligent decisions thus making the overall calculations somehow complex. Performance of self healing can be measured considering different parameters involved; speed of achieving stable reconfiguration, quantity of network component still energized, minimized equipment recycling during this phase. A multi agent system can be implied for self-healing of smart grid, this requires some particular algorithms for the reconfiguration of network in case of occurrence of a fault [81]. ABB has proposed a vision for the self healing power system [109]. In order to have a true self healing grid, it is important to consider operating conditions of the network, resources, and installed equipment and system operating limits, primary and backup protection of system etc. All the offline data analysis must be transformed to online one.

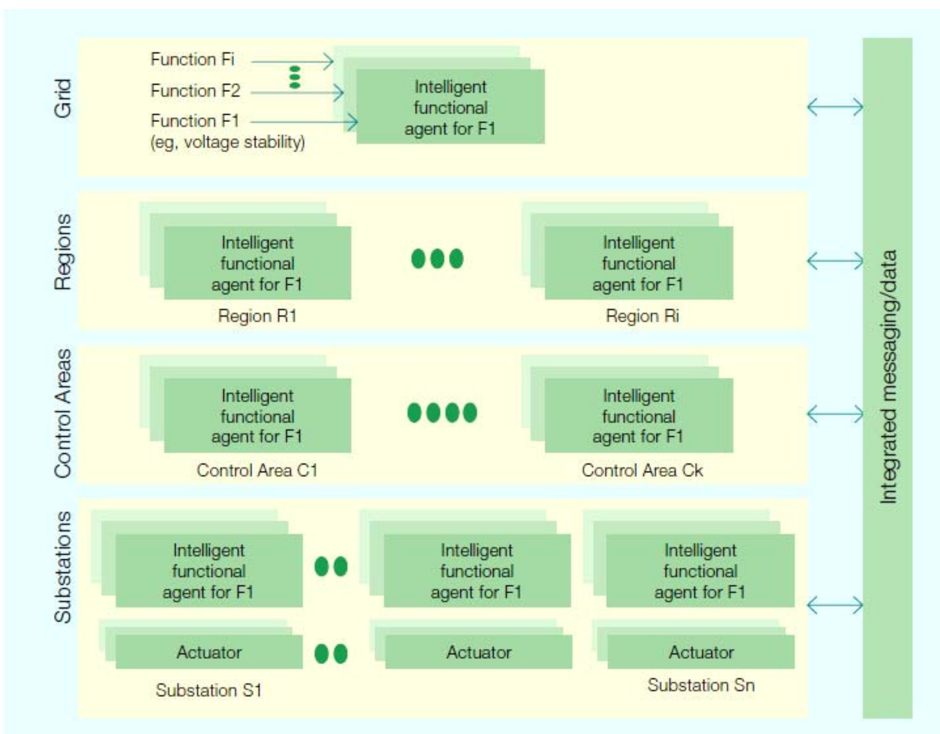

Figure 8.2 Intelligent Agent Based Infrastructure for Self-Healing Smart Grid [109]

Figure 8.2 shows the hierarchy of agents at different levels to achieve the self healing power grid. The tasks of various agents at different levels can be distributed based on the time scales for different phenomenon in power grid. This coordination of agents is accomplished in several execution cycles, where each execution cycle is a set of related tasks for a temporal coordination. This is demonstrated in figure 8.3.

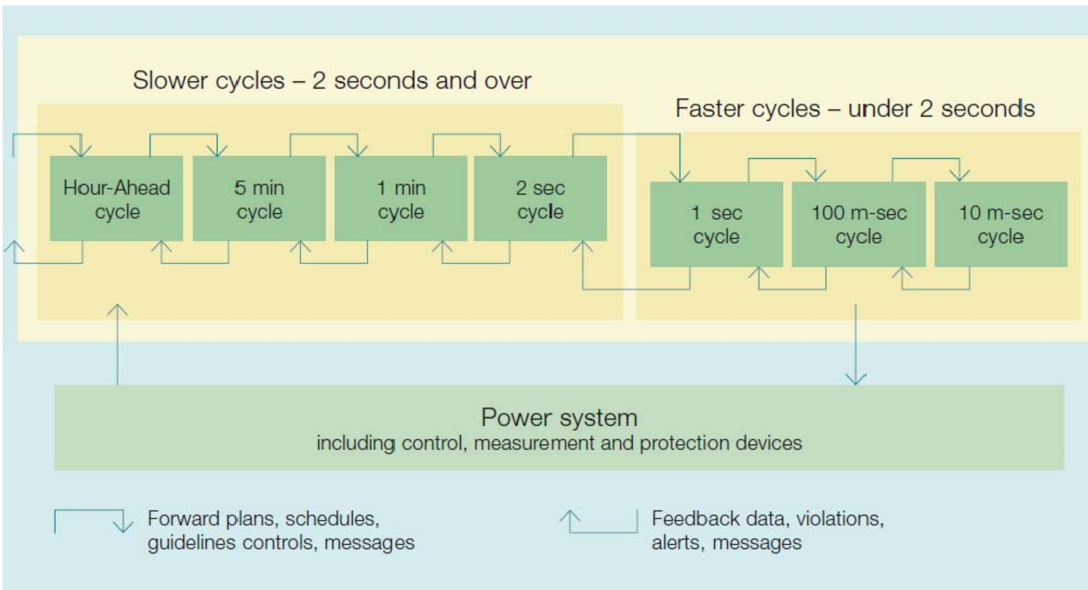

Figure 8.3 Organization and Interactions of Execution Cycles [109]

Each cycle has its own conditions to be executed at each interval. For instance, 1-hour-ahead cycle assures adequacy of resources and identification of system bottlenecks, while 5-minute cycle assures reliability and efficiency with the update of control parameters and limits. 1-minute cycle adapt the more recent models and maintain the efficiency and reliability like 5-minute cycle. 2-second cycle collects and validates data for use by control area or interconnection including data acquire in 10-millisecond cycle. It also performs close loop controls and adapts limits for control parameters and limits for faster cycles. 1-second cycle control extended transients. 100-millisecond cycle provides control for imminent system instabilities. 10-millisecond cycle perform intelligent fast protection actions [109].

8.3.1 NETWORK RECONFIGURATION

Continuity of electricity for critical loads is the most important thing to be considered in case of occurrence of any fault in the distribution network, especially when it is loaded with distributed generation and prosumers. Intelligent agent based system could be implemented to reconfigure the distribution network to minimize the number of affected consumers. Network reconfiguration is another aspect of the idea of self healing networks. Network reconfiguration not only provide the surety of continuity of supply to critical loads but it also help to stop the cascading of any unusual phenomenon in the network which could lead to a big disaster. Multi agent based network reconfiguration model could be suggested which could be able to consider all the different network topologies to make the best suitable reconfiguration based on fuzzy logic and some other advance estimation techniques.

8.3.2 ADDRESSED BASED INTELLIGENT SWITCHES

Addressed based intelligent switches can be implemented at each node in the network in order to isolate any part or load of the network to minimize the number of affected consumers in case of any fault. Each switch will have its own unique address by which it can be identified. For instance, if a fault occurs at node "A" then only the switches connected to this node will be operated as instructed by multi agent system. This idea will increase the reliability of the overall system and also the continuity of power to critical loads. These intelligent switches also help reconfigure the network in case of emergency conditions in order to isolate faulty parts of the network from the healthy ones. With the presence of intelligent addressed based switches it would be easy to locate and isolate the faulty nodes in the network.

8.4 AGENTS CONCERN FOR NETWORK SECURITY

In conventional power grid, communication links utilized by utility companies for the control and communication of network were dedicated to electric grid and less susceptible to cyber attacks. The growing application of common protocols for telecommunications and communications in smart grid can enhance the chances of attacks against power grid from hackers or terrorist organizations. The smart grid will be implying extensive communication and computing infrastructure, hence increasing the probability of external attacks based on cybercrime. We can make our grid attack resistant but there is no 100% solution available against cybercrime. There is no system which we can say is completely safe from cyber attacks but we can make our power grid survivable in case of any usual happening like this. It needs public-private partnership to achieve best of the security level for smart grid, [110] has suggested some other solutions for the smart grid security. [111] has raised all the security issues which can lead to a high level of risk from cyber attacks. However, due to their distributed nature in the system, agents can better serve to enhance the security of the smart grid.

8.5 VIRTUAL POWER PLANT (VPP)

Clustering of several distributed heterogeneous generation units give birth to a Virtual Power Plant (VPP) while eliminating the need of conventional power plant [112]. In principle, each dispersed generation unit in the network can be a part of VPP. But VPP prefers to have those generation units which can be adjusted any time depending upon demand and supply scenario. VPP provides a lot of benefits to its consumers like: it makes a bridge between energy and enterprise, monitor electricity consumptions and billing, provide useful data for energy usage, energy audits and easy to conduct. It maximizes the revenues for demand response and contributes to optimized use of energy. It has the ability to promote environmental benefits globally. It provides more flexibility in the network by delivering peak load electricity even at a short notice having the feature of load-aware power generation. VPP is intended to react efficiently to demand fluctuations. According to [113] VPP is regarded as an “Internet of Energy”. Based on intelligent entities and smart decisions virtual power plant optimizes assets and maximize benefits for both the utility companies and end users intelligently. [114] has presented agent based control of VPP.

Chapter 9

Conclusions and Future Work

9.1 CONCLUSIONS

A comprehensive understanding of smart grids and intelligent agents has been achieved through an extensive literature survey. Agents have proved to be the most intelligent entities to be considered for smart grid applications. It is concluded that any envisioned feature of smart grid can be brought into reality by implementing intelligent agents as the distributed control building blocks in smart grids. A better knowledge about the preference of introducing intelligent agents in smart grids instead of SCADA is grasped. Software tools, languages and development platforms for the creation of agents have been reviewed somehow. A complete structure and organization of agent specifications in Foundation for Intelligent Physical Agent (FIPA) is understood. Importance of integration of distributed energy resources and issues related to this integration has been revealed. Micro grid is the new concept of giving more space to consumers in electricity market and providing them with more clean, reliable and continuous supply of power. Role of energy storage systems, smart buildings and electric vehicles to support the idea of smart grid and their impact on the overall performance of the system has been analyzed. It is understood that without having smart consumers of electricity, smart grid will remain a dream not the reality, because smart consumers are the most important part of this vision of the smart grid. Agent based model for demand side management is proposed in this thesis. The smart grid network management having intelligent agents as key entity, would be the most efficient way of resolving network issues related to fault handling, frequency control and voltage control etc. Intelligent agents are not only concerned with the monitoring and control of smart grid but they can also add to the improvement of the security of grid, hence reducing the risk of external attacks leading to a large failures due to its distributed nature of making decision locally.

9.2 FUTURE GOALS

Story about agents and smart grids does not end up here at this point. This thesis just gives us a direction to a new horizon but the main applications and implementations of these agents in smart grid in reality is yet to be done. Most complex algorithms for fault handling and energy usage management can be simplified by the proper implementation of intelligent agents. The topic ***"Agents in Smart Grids"*** demands a bridge between many fields of engineering, so the researches must be continued to find efficient ways and means to make dream of the smart grid come true.

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