Heuristics for Optimized Power Management in Nano-Grid Based Smart Homes

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MASTER'S THESIS WORK

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This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. The Thesis is also according to the format given by the university.

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Copyright Statement

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Dedicated to my exceptional parent

Abstract

With the growing demand for Electricity and alarming climate changes have obsessed the participants of the energy market to gain agreement on initiating the idea of "Smart Grid". Along with this,the concern for the production of fossil-fuel resources have paved the ways towards strong research to set up enhanced energy system with the assistance of DG resources like PV Power preserved by Energy Storage systems. Thus, this Research will provide heuristics by designing a Scheduler based on Look Ahead Approach through Direct Mapping Approach and Artificial Intelligence (Fuzzy Logic) Approach, all based on forecasting.to provide an optimized Power Flow Management in Smart Home. The main aims and objectives of this work are to provide the optimized Power scheduler that reduces the owner's energy bill over the period ,also to minimize the cost linked with acquiring from (or selling back to) the grid,while meeting the load demands and reducing the peak electricity buying from the Grid , thus providing an optimized smart power flow in an era of extensive blackouts and Critical peak pricing market issues. The Solution would help achieve the economic goal of providing Consistent Energy Power 24/7 at economic cost as compared to the conventional methods followed earlier.This solution would also help achieve and provide an optimized solution to the Energy Management in Nano Grid based smart Homes.

Key Words: *Distributed Generation (DG), Fuzzy Logic (FL),Fuzzy Logic Controller (FLC), Fuzzy Inference System (FIS), Energy Management System(EMS), Core Manager(CM),Nano-Grid (NG), Critical Peak Pricing (CPP), Distributed Energy Sources (DES),Fuzzy Inference (FI)*

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CHAPTER 1

INTRODUCTION

Increasing the efficiency of energy, raising the distribution of renewable/green energies, and decentralizing and diversifying the energy mix, are the three motivations that the Smart Grid/Smart House Project heads towards.

The Active interaction among the renewable energy sources and the load demand leads to serious problems of power quality and stability. Thus, organizing the energy flow is important to raise the operating life and to make sure of the consistent flow of energy. The growing number of green energy resources and the DG need newer approaches and plans for operations for keeping energy stability among utility grid /micro grid and the green energy sources. [1]

The Smart Grid has engrossed more and more consideration in past years in the power Industry. It basically consists of communication facilities, AMI (Advanced Metering Infrastructure), Effectual Strategies for energy management, also DG green energy powers are utilized as a substitute for fossil fuels to decrees carbon emission. Amongst the Green Energies being used widely, the PV system is one of the rapidly grown Renewable power producing alternative.The growth in the development of smart Grid is advantageous not only society as a whole ,but also to all that are involved in the electric power industry, its stakeholders and many customers

Because of the cheap Prices of PV module with regard to increasing Cots of fossil-fires, it is likely to have grid-parity soon in some areas of the world. PV production,therefore, would be one of the vital power resources. Conversely influenced by variations in the solar irradiation, output of PV Power is undispatchable and intermittent; a reality that might lead to power imbalances and difficulty in power dispatch. To effectively use the PV production, solar irradiation forecasting is required based upon partial information available. For EMS of Distributed energy sources, an accurate solar irradiation forecasting, with the power output of PV can decrease the uncertainty impact for the PV power Production, increase system reliability, preserve power quality and raise the penetration level of the PV Production system.

Incorporating residential PV power production and ESS (Electrical Energy Storage) system in Smart-Grid is an effective approach of using green energy power and decreasing the consumption of fossil-fuels. With the development of pricing models for Electricity energy, this has become an interesting issue, as electricity consumers can utilize PV Energy Production and ESS system for the peak-shaving based on their power demand profile from the Grid, and thus reducing electricity bills.

With the rising demand of electricity and concern for generation of fossil-fuel resources heads to strong research to use improved energy-systems with the help of DG (distributed Generation) resources ,for instance PV (photovoltaic) Power, wind, (FCs) Fuel cells maintained by ESS (Energy-Storage system).These works have eased utilization of renewable energy, thus minimizing costs of energy and fear above the collapse of natural sources while omitting the carbon footprints.

To utilize the renewable sources Grid-Connected and Stand-Alone Power systems have been proposed. The Stand-Alone system mainly incorporates only the Distributed generation sources and doesn't include the existing power of the Grid [1-6].This system type allows the provision of electricity free –of-cost to customers once to real constraints of sitting, environmental concern and sizing are overcome. This Research focuses on Residential based Grid-connected PV based system with financial benefits through operating and capital-cost required for installation is not added for evaluation. On the contrary, the Grid-connected system includes DG green sources e.g Powertized PV power to the Grid [1-6]. These systems have been frequently used by ESS comes out to be realistic for binding alternate energy because of stable supply power guaranteed. In this system, the customers are obliged to pay for the Grid; therefore the Plan for energy management should be beneficial. On the other hand, the current studies don't integrate systems for optimized scheduling of the Grid Power use and rather operate in following traditional procedure

- The System provides power generated by PV
- If extra PV power , then system use it in Battery charging
- If no other alternative power is available. Then system provides the Grid power.

This Scheduling pattern has been reasonably reflected over the past years as the occupants pay the electricity bill , depending upon the consumption they make irrespective of the timings of the day. Though many countries are planning to initiate imposing the critical peak pricing Time per day. Or real-time based pricing, also currently load shedding is the peak problem in several countries ,so forecast based look ahead approach could help make optimized load leveling energy storage and management system .Thus in order to achieve this, these aforementioned variable points should be considered to be integrated in the grid-connected system

1.1 Problem Statement

"Optimal Scheduling of Power Energy Sources to Get Cost Effective Power Energy Supply in the Current Era of Blackouts and CPP market "

The current major challenge of energy management system is the matching of Energy Power production with dynamic load demand, Critical Peak Pricing time and Load Shedding Pattern, to help provide optimized load balancing and 24/7 provision of electricity at economic cost.). The main intention of this thesis work is to derive several heuristics for optimized power flow management that can minimize the owners' energy bill for the system over the period under study in economic mode.Heuristics have been proposed that can provide a better optimized solution to the problem

1.2 Aims and Scope of thesis

The aim of this thesis is to provide possible heuristics that can help achieve:

- Optimized load leveling energy storage and management
- Money Saving (Net Metering)
- Load leveling under CPP and Blackouts
- Decentralizing and diversifying the energy mix
- Economic Energy Power Provision
- Energy Efficient System for Smart Homes
- Smart Handling and Distribution of Power Energy Sources(PV, Battery, Grid)
- Maximum Utilization of Renewable Energy Sources
- Stable Consistent Power Distribution
- Optimal Energy Management System for Smart Homes

1.3 Formation of Thesis

Further thesis is organized as follows:

Chapter 2 :Explains Distributed Generation system as a whole, also Grid connected PV Power

Systems, how it works, its applications and how PV power can be utilized effectively to get maximum power with minimum cost. Also Fuzzy Logic is explained in detail and how it could help achieve an optimized solution in the Energy Management domain.

Chapter 3 Details the amount of work done in the domain and the proposed solutions to optimal power management.

Chapter 4,Gives a brief overview of the fuzzy Logic Control and its different stages and how the fuzzification is done

In chapter 5, the proposed Heuristics are discussed. It includes the Look-ahead based Optimized Energy power flow management approach. Then the Artificial Intelligence approach is explained that includes the Fuzzy Logic and how it can provide an optimized solution to the problem

Chapter 7, Details the Results and the comparative analysis is explained briefly with the help of the graph results of the simulations.

Chapter 7contains the concluding remarks, Contribution of the work and Future work.

Research Contribution:

"Power Energy Management for a Grid-Connected PV System using Rule-Base Fuzzy Logic"

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CHAPTER 2

DISTRIBUTED GENERATION SYSTEM

The Distributed-Generation systems in the commercial and the residential building sectors refers to the on-spot energy generation, mostly electricity from green/renewable energy systems e.g. small wind turbines and Solar (PV). Numerous aspects persuade the market for DG, including Governmental Policies at the federal, state and the local level, and project costs that vary extensively depending upon the size, location, time and application.

Distributed-Generation minimizes the total of energy lost while doing electric power transmission since electric power is produced nearer to place it is consumed possibly to be in the same building. This reduces the size-number of power-lines to be made.

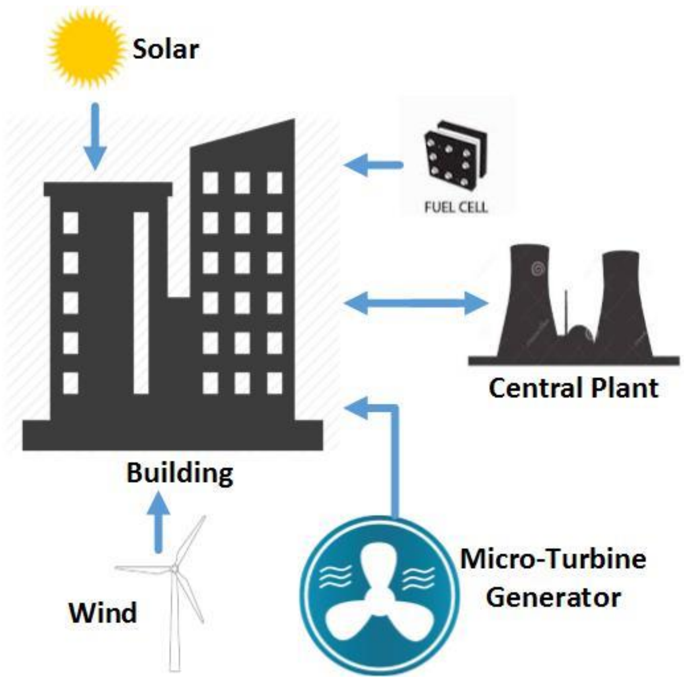

Figure 2.1:Distributed Generation Systems

In the Above Figure it can be seen that a building can get a power supply from Distributed Generation Power sources like from Solar (PV), Fuel Cells, Micro turbines,Wind, Central Power Plant

2.1 Distributed Energy Sources

DER systems generally utilize the green/renewable resources encompassing bio-mass, hydro, solar-Power, bio-gas, wind-Power and the geothermal Power .All these resources play a vital role in the Electricity Distribution system. Grid-Connected Energy Storage Device can be categorized also as DER system, and also mostly referred to as DESS (Distributed Energy-Storage system).In compliance with the interface, the DER systems can be coordinated, managed in Smart-Grid.DG and its Storage allows for the energy power from different sources and lower the impacts of environments and also enhance the supply security. Following are the different sources for Distributed Energy generation systems.

2.1.1 **CO-generation**

Distributed CO-generation source uses natural gas-fired fuel cells, steam turbines, repaying engines or micro-turbines to spin the generators .The hot drain is then utilized for heating of water or space, or to constrain an absorptive chiller for the purpose of cooling .e.g. air conditioning. Adding to the natural-gas systems, DG projects encompass green or low carbon-fuels covers bio-gas, bio-fuels, landfill gas, coal bed methane, sewage gas, associated petroleum gas and syngas.

Additionally, solid oxide fuel cells and molten carbonate fuel using natural-gas,for instance theone's form bloom energy server and fuel cell energy, or processes for waste-to-energy e.g. Gate-5 Energy-system is utilized as a DES.

2.1.2 Solar Energy Power

PV(Photovoltaic), considerably the vital Solar_Technology for DG of Solar Energy Power, utilizes solar-cells accumulated in the panels of solar in order to change the sun-light into the electric power. It is the rapidly-emerging technology raising its worldwide capacity in terms of installation in every passing year. PV system ranges from Residential, distributed and commercial building/rooftops, or constructing the incorporated installations towards big, centralized utility-scaled PV power-stations.

Recently, PV power has raised its efficiency in its sunlight to electric power conversion, also has reduced the per watt installation cost, also reduced EBPT (Energy pay-back-time), LCOE (levelized cost-of-Electricity), and also has attained the grid-parity in a minimum of 19 diverse markets in the year 2014. [7]

Contrary to most renewable sources, and in contrast to nuclear and coal, the PV solar power is non-dispatchable, variable ,however, has no fuel cost, mining-safety ,pollution operating , or issues of operating-safety. It generates Highest Peak-Power at the time of local noon per day and its capacity factor is round about 20%. [8]

2.1.3 Wind- Energy-Power

Another DG resource includes wind-turbines ,energy power. These resources have less pollution. Less maintenance and also have less cost. Still, as with solar power resource, wind resource is also non-dispatchable and variable .Wind generators and towers have considerable insurable milestones caused by high winds, however good operating-safety.

DG form Wind-hybrid-Power systems merge the Wind –Power with the other Distributed Energy resource systems. One of the related examples includes the integration of the wind-turbines into the solar-hybrid power systems, as wind synchronize with solar since the peak operating times for both systems are at different day and year times.

2.1.4 Hydro-Energy-Power

The most widely used renewable energy resource form is the Hydro-electricity power energy .Its likelihood has already been discovered to a great extent or it is been negotiated because of the issues of the impacts of environments on fisheries and raising recreational access demand. On the other hand, utilizing the 21^{st} century modern technology , e.g. wave-power, can produce huge amount of new hydro-power capacity to be available, with less environmental impact

2.1.5 Waste-To-Energy

Natural waste and MSW (Municipal solid waste) e.g. Food waste, sewage sludge and animal muck decomposes and discharge methane , including gas , which can be composed , utilized as fuel in micro-turbines or gas-turbines to generate electric power as DER.

2.1.6 Energy -Storage

DER is not only restricted to the electricity generation, but it also might include a device that can store the DE .The DESS (Distributed Energy-storage systems) applications contains pumped hydro, several kinds of batteries, compressed air and thermal energy storage. [9]

2.1.7 Vehicle-to-Grid

Forthcoming production of electrical-Vehicles could have competency of delivering battery power in Vehicle-To-Grid towards the Grid once required. An Electrical-Vehicle Network has likelihood to supplied as a DESS.

2.1.8 Fly-Wheels

An advanced FES (Flywheel energy storage) stores the electric power produced form DER in the form of angular Kinetic-energy by accelerating a flywheel to a higher speed of (20,000 rpm-50 000 rpm) in vacuum inclusion. Fly-Wheels can fastly react as it stores and give feedback electric power to the grid in minutes.

2.2 Grid Connected Distributed System

The core idea of installing Grid-connected DG system is the declaration to receive power from utility even when the system is not responding properly. This is vital for many green/renewable technologies, e.g. wind and solar, that produce irregular power and also for the systems that need to be closed for maintenance for some time.

Although few of the consumers install DG as a primary power source, others install it as a Support generation for the critical loads when the utility is not enough to produce power due to the blackouts, storms or any other unexpected events.

2.3 Grid-Connected Photovoltaic system

Grid-Connected Photovoltaic (PV) power system is an electricity producing solar system which is connected to Grid utility. This system consists of one or more inverters, solar panels, Equipment for grid connection and power conditioning unit. The system ranges from commercial and residential rooftop systems to the large scale-utility solar power stations. In contrast to stand-alone Power systems, a Grid-Connected system seldom incorporates a battery solution system, since they are expensive. When circumstances are right, the Grid system delivers the excess power, ahead of the consumption by the load connected, to the Grid utility

2.3.1 Operation

Grid-Connected Residential Rooftops systems with a capacity lesser than 10 KW meets the most consumers load. .The system can feed the excess power to utility Grid .This feedback is done via a smart meter that monitors the power transferred. In the case when PV wattage is less than the average load consumption, then in that case the consumers continue to buy the grid power energy but with less amount than previously.

In another case when the PV power considerably surpasses the average load consumption, then the PV power produced energy is enough for the load, with the surpass energy power sold back to the utility Grid. The consumers only have to pay for the electricity that is consumed less than the electricity generated that yields a negative number in case when more electricity is generated than being consumed.

2.3.2 Features

The Solar power captured by PV solar panels, projected for transferring to power Grid is processed for use and conditioned, through a Grid-Connected Inverter. Essentially an inverter converts the PV Input (DC) to (AC) voltage for the Grid. The inverter

- May Lie between the Grid and the solar array, then gets energy power form each
- Might be a huge stand-alone unit
- May be a collection of small inverters, each attached physically to individual solar panels

2.4 Smart Grid

The electric grid was conceived in the past year as a one way communication where the utility supplied the electricity to the customers., at that electric needs were easy, Generation of power was confined and constructed round communities .Most homes had little energy demands .This restricted one-way collaboration makes it complex for grid to respond dynamically to changing and expanding energy-demands.

Therefore , to add in to the solution of the complex situation, Smart Grid offers a two-way collaborative dialogue where electricity and the information data can be exchanged and shared between the customer and utility. It is developing a network of computers, communications, controls and new technologies and tools operating together to make grid more visioned, more secure and reliable. Smart-Grid enables advance technologies to be incorporated like wind energy power, solar energy power production.

2.4.1 What makes a Grid Smarter?

The digital Technology which provides two-way communication among its consumers and utility, also senses along lines of transmission is what makes grid smarter. Likewise Internet, Smart-Grid includes computers, controls, new technologies, automations and the tools and equipment's coordinating together, but in Smart-Grid case, these all work with electric-Grid in order to quickly respond to dynamically changing demand for electricity.

2.4.2 What Smart-Grid Executes?

The Smart-Grid symbolizes an exceptional prospect to move the energy industry towards a new age of availability, efficiency and reliability which adds to the environmental and economic health. Some of the advantages associated with the Smart-Grid include:

- Better Well-organized Electricity Transmission
- Faster Electricity Restoration after the Power troubleshoots
- Lesser Management and operation utilities costs and eventually lower costs at the consumers end
- Reduction in Peak Demand , leading to lower electricity rates
- Better Incorporation of large-scaled Renewable/green energy systems
- Improved Integration of owner-customer Power-Generation systems , encompassing green energy systems
- Better Efficient Security

Because of the smart-Grid's ability for two-way interaction, it allows the automatic re-routing when the equipment outages or failures occur. This reduces the outages and minimizes the impacts when they occur. When Power failure occurs, Smart-Grid highlights and separates the outages, having them before they turn into large-scaled Blackouts. The newer technology ensures that the electricity is recovered strategically and quickly just after an emergency, by routing the electricity to emergency-service first e.g. adding to it, the Smart-Grid takes greater benefit for the customer-owned Power-Generators to generate the power when the utilities cannot supply the Power.

CHAPTER 3

FUZZY LOGIC

3.1 Fuzzy Logic Concept

FL came from an inspiration to integrate logical,cognitive and spontaneous expert operator's decision making into mechanized system. The concept is to make resolutions depending upon the list of predefined or learned the rules, in spite of using mathematical calculations. FL integrates rules in order to make choices. But, before the rule-set utilization, input information ,data must be presented in a way so that it appears to be meaningful, however it still allows for operation and handling. Fuzzy Logic is a combination of rules depending upon the input variable situation with respective preferred output. A tool must be introduced so to make decisions as which particular output or group of outputs will be utilized as each rule might result into the different action output. FL can be seen as a substitute to the mapping of Input/output.

Rule Set representation of fuzzy is built on linguistics [10].Therefore, input is semantic variable that relate to the varying State considered. In FL control, "linguistic" term points to variable state that the designer of system is concerned. Fuzzy variable is labelled well as a linguistic fuzzy-qualifier. Once the Fuzzy variables and linguistics have stated, the complete Inference engine can be made to build FIS (Fuzzy Inference) system engine and apply it to the problem. The fuzzy Controller base Knowledge is an elementary part of FL control that is composed of steps mentioned below:

a. Fuzzifi-cation
b. Fuzzy Inference (Rules Evaluation)

3.1.1 Fuzzifi-cation

Fuzzifi-cation consist of transforming crisp input values into membership grades for semantic fuzzy set terms.The Member-ship function is required for association of grade to each semantic term.

3.1.2 Fuzzy Inference Method

This method is the configuring operation through which control output can be produced. Many Configuration methods like MAX-DOT and MAX-MIN have been suggested in literature. The frequently used method is the AND connection (MAX-MIN) as used in this research also. The output Member-ship function for each rule is set by operators minimum (MIN), maximum (MAX).

3.2 Fuzzy-Logic-Controller

The FLC (Fuzzy Logic Controller) incorporates an interface for fuzzification, fuzzyinference engine, a knowledge-base and interface for defuzzi-fication. The elementary parts of each fuzzy-controller is shown in the figure below

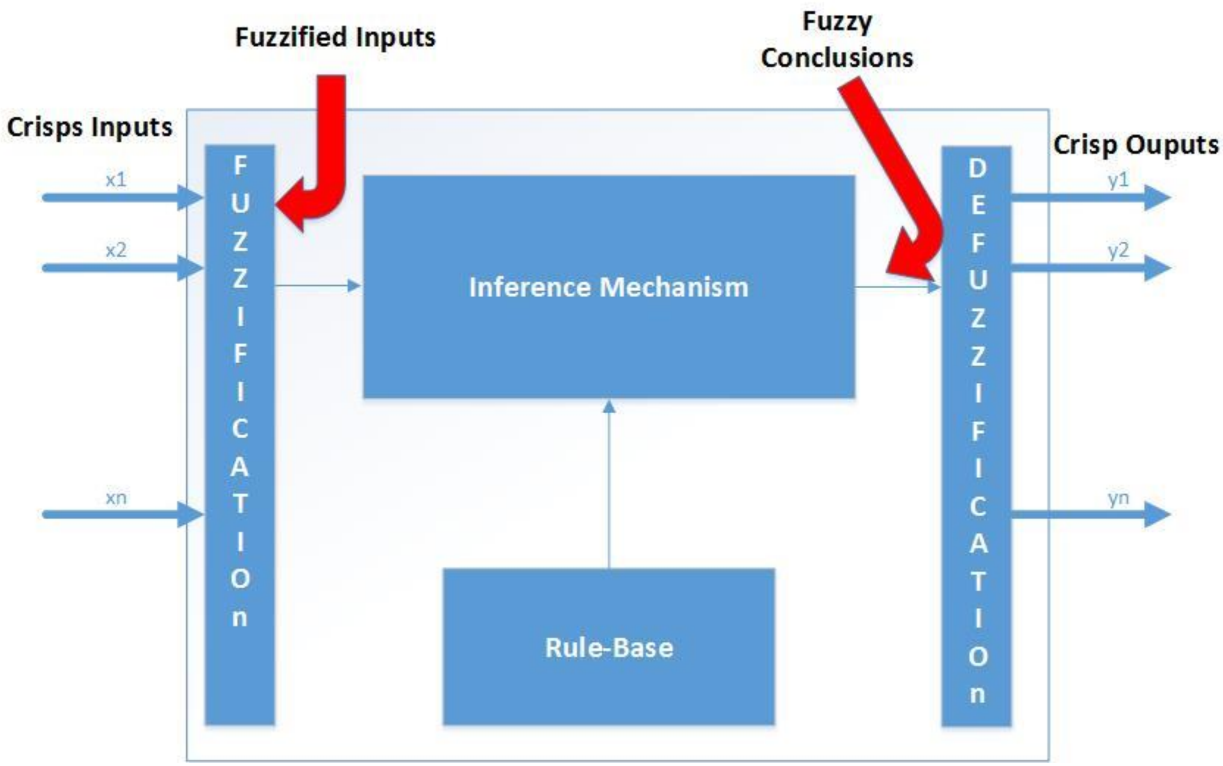

Figure 3.1:Fuzzy Controller Basic Parts

The Crisp Inputs are converted into a range of inputs under fuzzification then the inference (IF-THEN) rules are defined that the defuzification process is applied and the outputs are got. Each of the steps is explained briefly below

3.2.1 Fuzzification

Most Controller's input is a numerical definite value, but in FL control knowledge base,it is represented linguistically. The fuzzy system converts numerical values into some language statements and its correlated domains to permit interface for fuzzy engine. This kind of conversion is termed as fuzzification [11]

3.2.2 Knowledge Base

The inference base for FL control is the knowledge base. It describes all corresponding language control parameters and rules. The core of FL system is the knowledge base (integrating rule basis and databases)

3.2.3 Fuzzy Inference Method

Fuzzy-Inference Method implements the authentic process for decision-making and is considered to be most vital part of FL control.
The FI engine performs the actual resolution-making process and is considered the most vital part of fuzzy control.

3.2.4 Defuzzification

In Defuzzification process, it converts the FI engine output variables into corresponding guaranteed values, thus making the guaranteed values to confirm with the input values of the system. This procedure provides output control values to the controlled system.

CHAPTER 4

LITERATURE WORK

A Lot of work has been done in the domain of Energy Management of different Renewable energy sources in hybrid systems with the primary objective of minimization of the levelized energy cost while satisfying the load demands in an effective way.

The writers in [15] suggested a technique to help designers to regulate the hybrid solar-wind power system's optimal design. The Suggested analysis used linear programming method to reduce the average electricity cost while satisfying the load demand requirements in an effective reliable way. In [16], the researchers used Genetic algorithms to optimally size components of hybrid systems ,i.e. Choose the optimal PV power rated, wind turbine , battery storage energy and rating of the inverter .The key objective of the optimization was the reduction in energy the levelized cost of system over a whole project lifetime.

To raise the dispersion of PV generation into the grid, a confined hierarchical energy management control is proposed in [17].The proposed control system is shown as a control structure in multi-layer form, each layer having different functionality, and is dependent on optimized power management flow with the predictions, that consider the lookahead (day-ahead) and battery ageing method into the process for optimization. Though the exchange of data with smart grid, like grid capacity limitations is not taken into consideration. Further, because of prediction uncertainty and shortage of grid data ,information, the grid might be out of control.

An Energy management system was proposed in [18] based on microgrid hierarchical control. The system was ordered with diverse functionalities and was implemented in two diverse parts, customer side local management unit and microgrid side central energy management.PV active generator storage and PV-array as one element for microgrid. The system provides the power in accordance with the demand of smart grid and strategies of power balancing for microgrid is developed to follow the power orientation.

Some of the work has been done in the area of hybrid power systems energy management. Including are the work of [12], in which the researchers presented a strategy for power management for wind/PV/AC as linked hybrid energy system. Another strategy for power management was suggested by Ahmed et al. [19] that involved the study of fluctuations in power in a hybrid wind turbine/PV/FC power systems. A strategic algorithm for power management was proposed by Onar et al. [20] that dealt with hybrid power systems, including wind/PV/FC and ultra-capacitor bank. All the above mentioned power management strategies used traditional approaches to control hybrid systems , like PI linear controller that afterwards has proven its inconsistency to handle changes in climate conditions [21].The work in [14] proposed power management approach based on two scale dynamic programming that has problem of being non adaptive for inputs change and large time consumption issue. These all points leads to the urge to provide more robust Strategies having the ability to cope with varying changes by developing advanced management strategy criteria based on data information and environmental factor effects .

Since Fuzzy Logic deals with imprecise inputs, is robust and can handle non-linearity ,so this concept is also incorporated in the energy management domain and a lot of research work has used Fuzzy Logic Control in Hybrid Renewable Grid Systems to manage Power Optimally.

Grid-connected PV based system's simulation and modeling with MPPT (maximum power-point tracking) was performed in [22] through the use of unique FLC. The research work suggested FLC application as an expert MPPT technique for PV system under various interruptions. The performance for the particular FLC was assessed by the simulations and the outcome results turned out to be more effective and efficient in discovering the MPPT as compared to the traditional methods of incremental conductance in the case PV system is urged to certain deviations in condition (External) i.e. the temperature of the module and level of insulation.

A Power management strategy based on a FL controller design was suggested for Grid-connected HRES(Hybrid renewable energy sources) in [23].Control system based on two levels was implemented , including FLC, guarantinng the management of power among energy storage, intermittent Renewable Energy production, Grid, also wind unit ,local PV controllers. Simulations were run in SIMULIINK/MATLAB.FLC controlled the management of power among battery bank, PV array, wind generator and load. The results showed better performance of the suggested system. The results also showed that wind generator and PV have the capability to feed the load with the needed energy and can charge the battery with the required demand during the period of the night hours. During the period of daytime hours, PV generated power from system is got, because of the surplus power given to grid utility after battery is fully charged. The Fuzzy logic controller has 3 inputs that were demand, hybrid power and SOC .27 rules set, MAX-MIN and COG (center of Gravity) techniques were used.

Another work in [24], proposed FLC based on MPPT for Grid-connected PV based system to boost the robustness and efficiency of Solar PV power production, thus developed a model (Dynamic) for PV based grid -connected system by using the environment of SIMULINK/MATALB that mirrored the system characteristics accurately. Results of simulation produced ,validated the components of the model and the selected scheme for control. The block diagram of the system proposed is shown below.

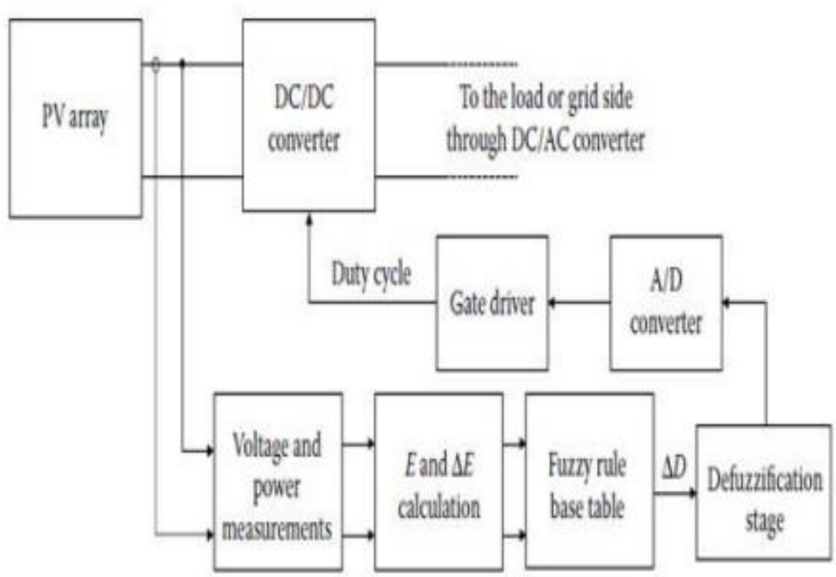

Figure 4.1:Block Diagram of Fuzzy Logic Based MPPT

A unique ExpertFLC for MPPT was proposed in [25] again for PV based Grid-connected system. The proposed methodology showed that the expert **FI**algorithm can be represented by equations which can be easily implemented in MCU chip and no fuzzy rules saving is required, also the factor of optimization in the Fuzzy equation for inference can be make fuzzy lines of rules to adjust on-line automatically in order to enhance the effect of system control that gave expert characteristics to the system.

CHAPTER 5

PROPOSED METHODOLOGY

This work details the look ahead based heuristics that can be utilized to provide an optimized power management in PV based Grid-connected system keeping the cost aspect as top priority to provide an optimized yet economical solution. The heuristics are made based on look-ahead approach to provide better optimized results than simple optimizing approaches.Initially a lookahead based Energy Management system is designed that is explained below

5.1 Look ahead EMS system

Model for perceived SkyPower Nano-Grid System tries to optimize availability of electricity while minimizing its cost. The model is structured in a way for its easy implementation in SW..
The system partitions load into critical and non-critical loads. The non-critical loads, if there are any, are directly connected to the grid so they are not considered as part of the model ,whereas the critical loads are given power with the hybrid system that may get power from Batteries, Grid or directly from the PVs. The system is grid tied; therefore there is a provision of feeding back the extra power to the grid and utilizing a provision of net metering in countries like Pakistan. The system while minimizing cost also considers variable pricing time per day where the electricity cost is predefined for peak hours or even real-time based pricing where the price dynamically changes with time.

The system also considers load shedding as it is rising as a major problem in several countries. In these scenarios the system schedules the charging in a way that the consumer gets uninterrupted power supply 24/7 for their critical loads.

These dimensioning of the system requires a forecast based look-ahead approach. This approach helps in making optimized load leveling energy storage and management system.
The model acts as an energy management system that matches the Energy Power production with dynamic load demand, Critical Peak Pricing time and Load Shedding Pattern to provide optimized load balancing and 24/7 provision of electricity at economic cost.

The proposed system structures a grid connected system under Time based criteria ,taking into consideration Critical Peak Pricing Time and Load shedding Times,to provide an optimized

Power Flow Management system in economic mode. The main objective of the system would be to provide stable ,consistent electricity at economic cost.

5.1.1 Logical Control View

The Control view of the system is shown below

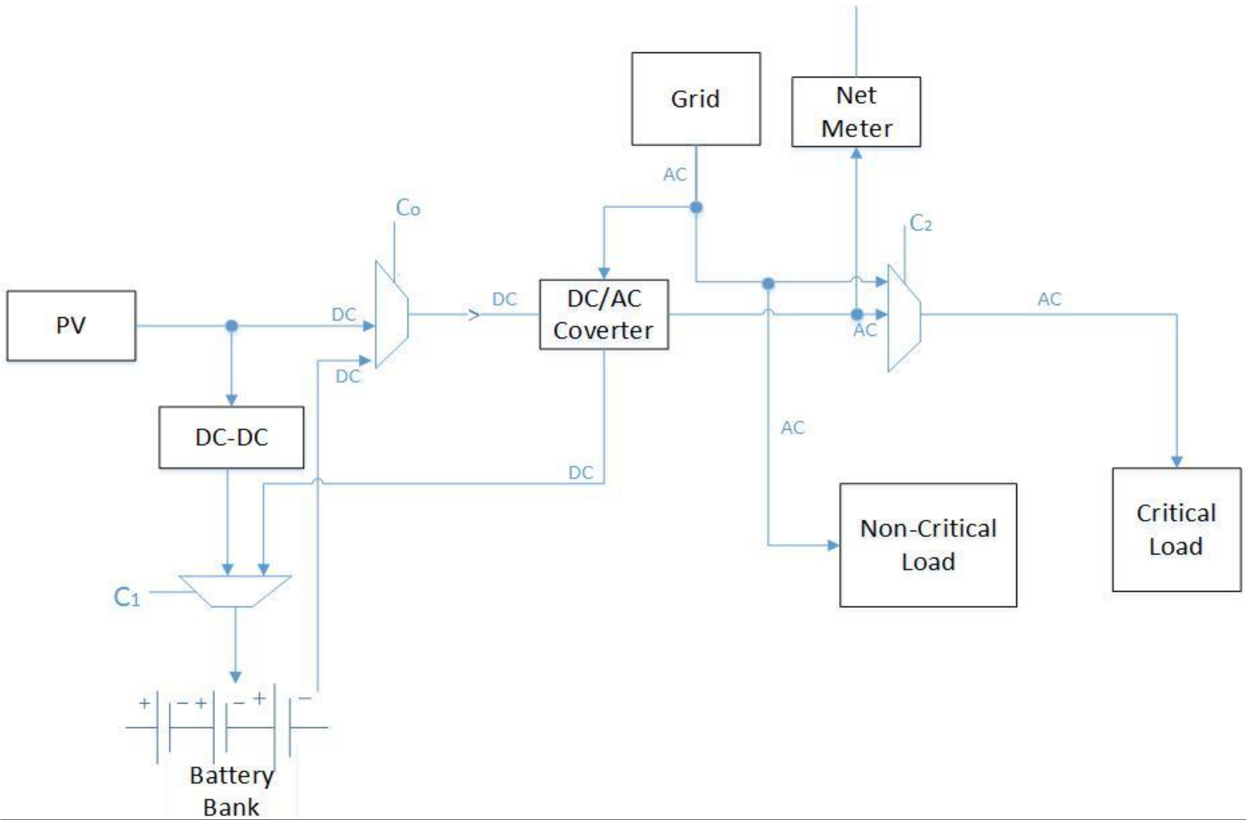

Figure 5.2: Control View

The diagram of the system above shows the battery that can be either charged from the PV panel or from the power from the grid, similarly the DC power from the Batteries or from the PV can be fed to the inverter for DC to AC conversion. The AC power, therefore ,can come from the grid, directly from the PV panels or from the batteries after conversion to AC. The surplus AC power can also be fed back to the grid taking benefit of Net metering.

5.1.2 Schematic System View

The Nano-grid controller mainly consist of one core Nano-Grid manager (providing stability in energy supply to Load demand) handling all the components and a number of sub mangers each for performing different task respectively.

The core Nano-Grid Manger works with the components and manages the generating sources. The Scheme initiates with the Prediction of the amount of PV generation, Load demand through the Forecasting Manger Component. The Forecasting would be done on an hourly basis but can be flexibly adjusted with the input data scanning rate. The Load demand is estimated under forecasting manger and Prediction is based on PV power generation by collecting the weather information from the cloud. Then next step is to determine the State-of-Charge (SOC) of battery with two criteria that are Peak Hours SOC Managers and Load Shedding SOC Managers respectively. The Model Diagram is shown below

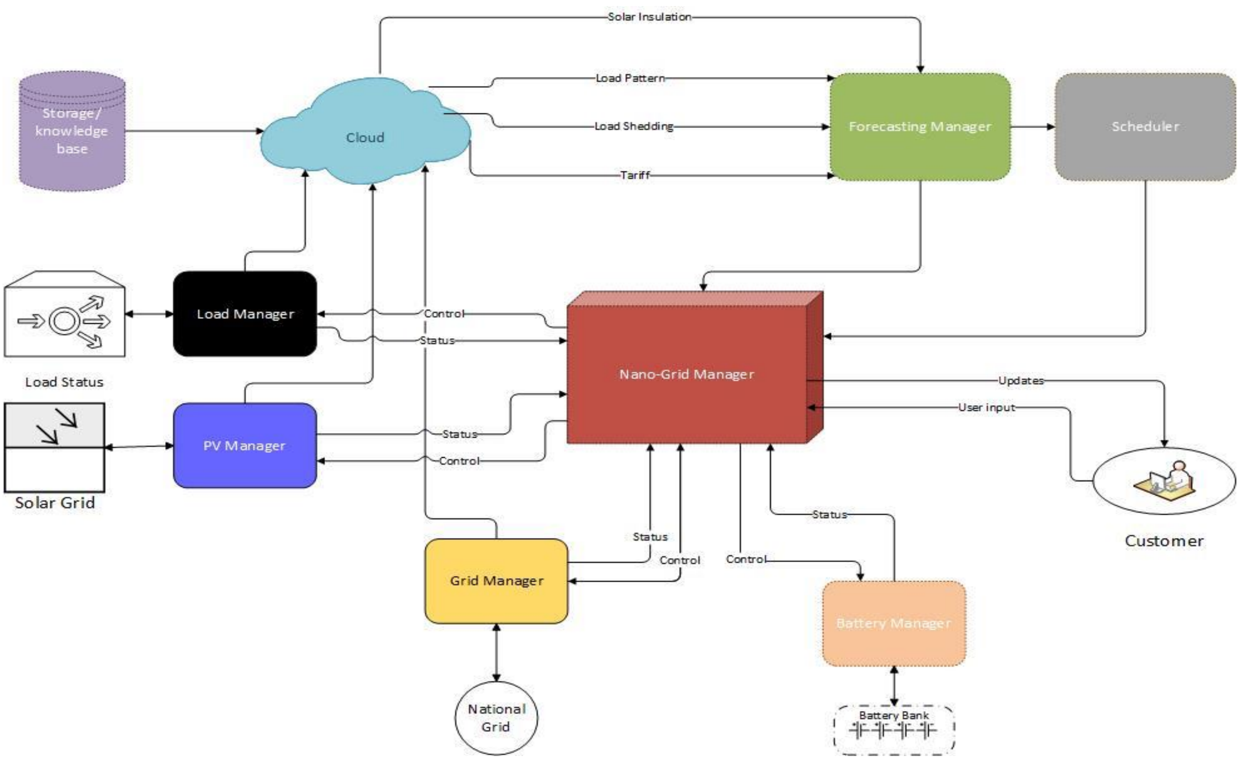

Figure 5.3: Model Diagram of EMS system

The Scheme initiates with the Prediction of the amount of PV generation, Load demand. Load Shedding patterns through the Forecasting Manger Component. The Forecastingwould be done on an hourly basis but can be flexibly adjusted with the input data scanning rate. The Load demand is estimated under forecasting manger and Prediction is based on PV energy power generation by gathering the climate information from the cloud or through sensors.

Then next step is to determine dynamically the State-of-Charge (SOC) of battery under two criteria that are Peak Hours SOC Managers and Load Shedding SOC Managers respectively. The system would consist of PV, Grid and battery power. The PV is considered to be the primary source of power for the system and battery is used for energy power storage. Grid Power is considered to be accessible all time ,therefore assuring stability and consistency in the supply of electricity power. The system Forecast and predicts the next day's load demand and facilitates usage of economic, energy power from battery, PV, cheap Grid power. The system enables the availability of economic cost electricity and providing smart Power Flow management system.

The system would also be embedded with climate sensors and RFID (Radio-frequency - Identification) sensors in order to get information on solar radiations, Total figures of people number in the household (Load Demand Patterns), Temperature, further Load shedding times and Peak pricing Times would also be got from Cloud to predict the Load shedding patterns and Peak timing patterns to manage the Seamless power supply throughout the day.

A CM (Core Manager) is intended to determine the flow of power in a system through Load predictions and PV power, with managing SOC of the battery under time based criteria's. The core manger commands the components of the system accordingly and order ,whether Battery power, PV power, or Grid power is to be used at the current time of operation. CM control and monitor the battery power E.g. if there is surplus PV power available (other than what is needed based on load) ,then CM observes the Battery SOC under both the Time based criteria's and start charging the battery as required.

In case when a large amount of power is required during the peak timings of usage and the grid power is at the economic level, so the system can start using the Grid power and in case of excess power available it can be used to charge the battery also for future peak Pricing Time. The system enables the availability of economic cost electricity and providing smart Power Flow management system.

The detailed Model Diagram is shown below

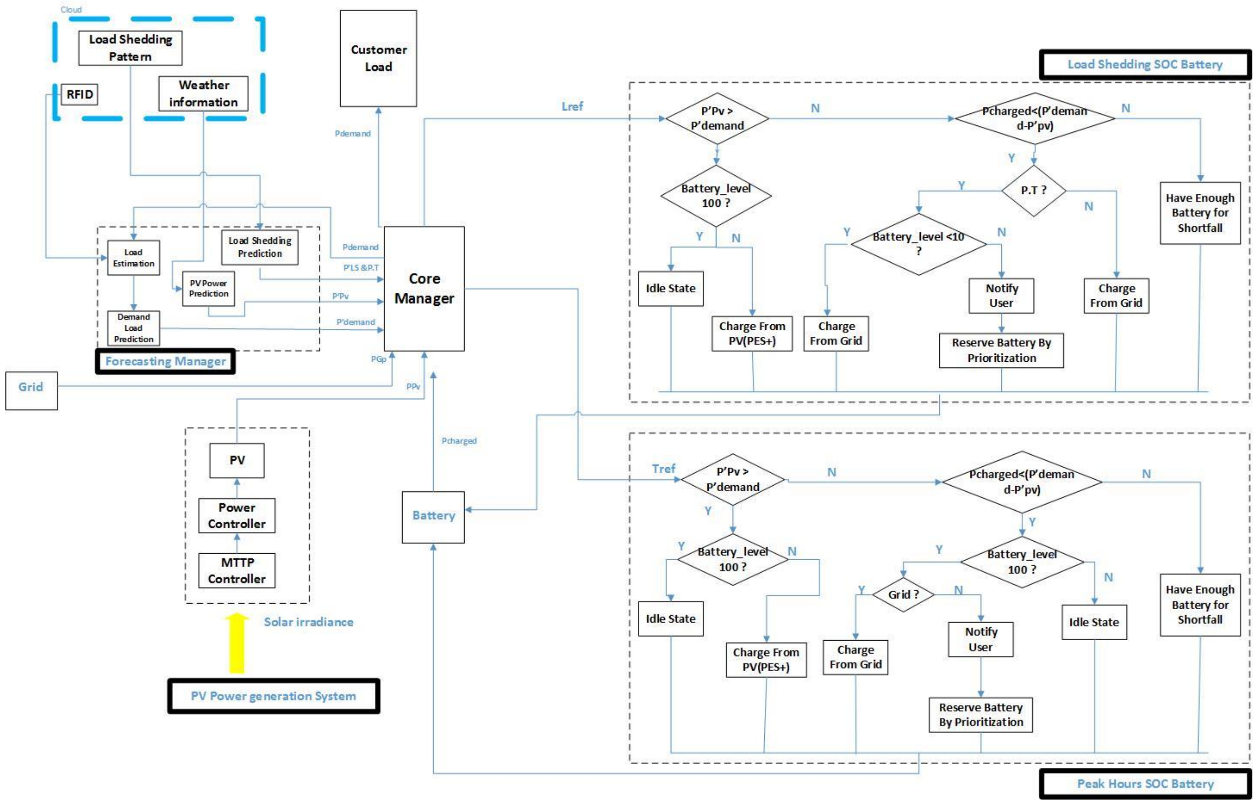

Figure 5.4: Detailed Model Diagram for Optimized EMS

Each of the sub manager's functionality is explained below

5.1.2.1 Forecasting Manager

The system begins with the Forecasting Manager that estimates the load demand form the data available and make predictions about it .The PV Power generation rate is also predicted and further Load shedding Patterns and Peak Pricing patterns are also forecasted under FM manager and FM forwards two variables , namely PLS(Pattern for Load Shedding) and P.T(Peak Times). Then the FM manager informs the Core Manager of all the predicted information respectively.

5.1.2.2 SOC Battery Managers

In the next step , System dynamically calculates the SOC of the battery in accordance with two criteria's (Load shedding and Peak Pricing times) .The CM based on Load Shedding and Peak pricing Hours patterns creates two related reference points ,namely Lref(Load Shedding reference) and tref (Peak Hour Reference) . Lref is set to be 2 hours prior to the load shedding hour and likewise tref is also set to 2 hours prior to Peak hours' time. The system overall finishes each curve of the estimation every 2 hours in advance of related time of operation and make optimized decisions for battery SOC.The PV is considered to be the primary source of power for the system, the battery is used for power energy storage. Grid Power is considered to be available with the consideration of Load shedding Hours. The system Forecast and predicts the current day's load demand and facilitates the usage of economic , energy power from battery, PV, cheap Grid power .Both SOC battery Mangers first calculate the power difference based on equation (1)

$$P_d = P'_{PV} - P'_{demand} \tag{1}$$

Where P_d is Power difference among the predicted PV power P'_{PV} and Load demad P'_{demand} For P_d>0 (+ve), assumptions would be having

1. High Predicted PV Power Available
2. Low predicted Load Demand

So in this way .Excess PV power can be utilized for battery charging. The excess power can be calculated using the equation (2)

$$P_{ES+} = P_{PV} - P_{demand} \tag{2}$$

P_{ES+}Would be the excess PV power available to charge the battery for future use. Where $P_{demand}$and P_{PV} are the Load demand of the occupants at current time t and PV power being generated

For P_d<0 (-ve), assumptions would be having

1. Low Predicted PV Power Available
2. High predicted Load Demand

In this case, the system first check for the current charge of the battery by equation (3)

$$P_{ES-} = (P'_{demand} - P'_{PV}) - P_{charged} \tag{3}$$

Here $P_{charged}$ is the current power in the battery

If P_{ES-}>0, it is assumed that $P_{charged}$ is less than the predicted load demand and PV Power available. So further it checks that whether currently Grid is available. If yes, then the battery is charged from grid to handle the future shortfall else if Grid is not available So in this case respective SOC manger commands for reserving the battery for future as Grid is not available and less PV power generation source is available and also notifying the core manager to use priority based power for coming shortfall.

If P_{ES-}<0, it is assumed that $P_{charged}$ is greater than the predicted load demand and predicted PV Power , so the system has enough battery to handle the future shortfall. So further it checks that the battery has any capacity to be charged if yes ,then it's charged from Grid in case of its availability otherwise battery has enough power to handle the shortfalls

In the third step, the CM selects power energy source from Grid, PV and battery options.PV is prioritized to be as primary power source, but if no PV power is available and the given operating hour is not within the peak Hours, then CM utilize the grid as a primary source. .Though, during the peak hours, the CM utilizes battery power first in a case when there is not future load shedding expected, else it uses Grid power even in Peak hours to reserve the battery for Loadshedding hours to avoid power shortage, grid is the last option in peak hours if no PV power is available and Load shedding is expected and batter power is not that sufficient to handle the shortfall.

5.2 Look-ahead Scheduler Design

The Look Ahead based scheduler Heuristics is designed.The flow chart of Heuristicsmethodology is given in the figure

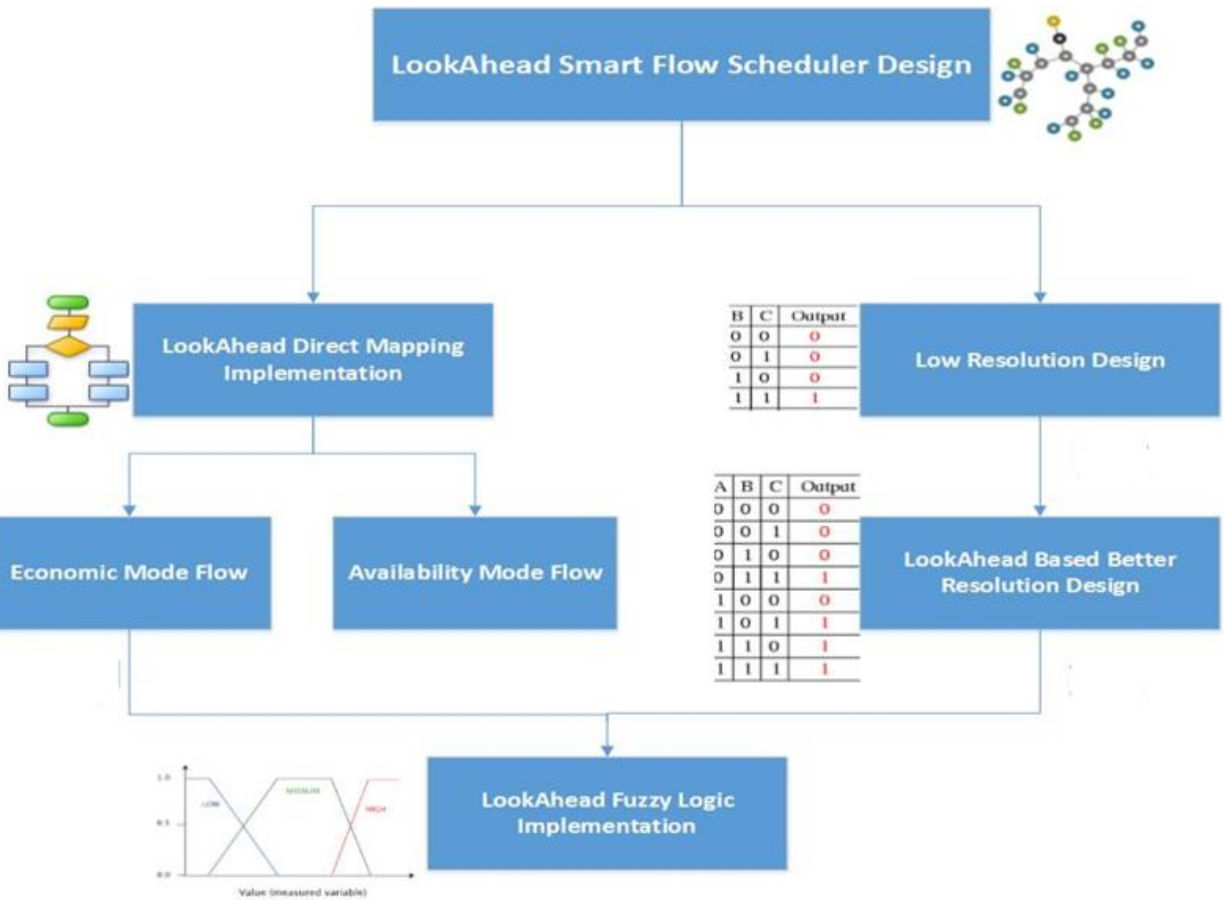

Figure 5.5: Proposed Heuristics Flow

The Heuristics is basically a hierarchical process one leads to another. It is further categorized into two steps

- Direct Mapping Implementation
- Low/High Level Resolution Design

Each of the Category is explained below

5.2.1 Direct Mapping Implementation

In this approach the inputs are mapped and provided by the flow of energy in different possible situation by following look ahead methodology. The situations were further divided into two different Modes as

1. Availability Mode
2. Economic Mode

The Difference among Two modes is the Min Battery level Threshold (T)

Availability	Economic
T=60 %	T=40 %

\

5.2.1.1 Availability Mode

The flow chart of this mode is shown below

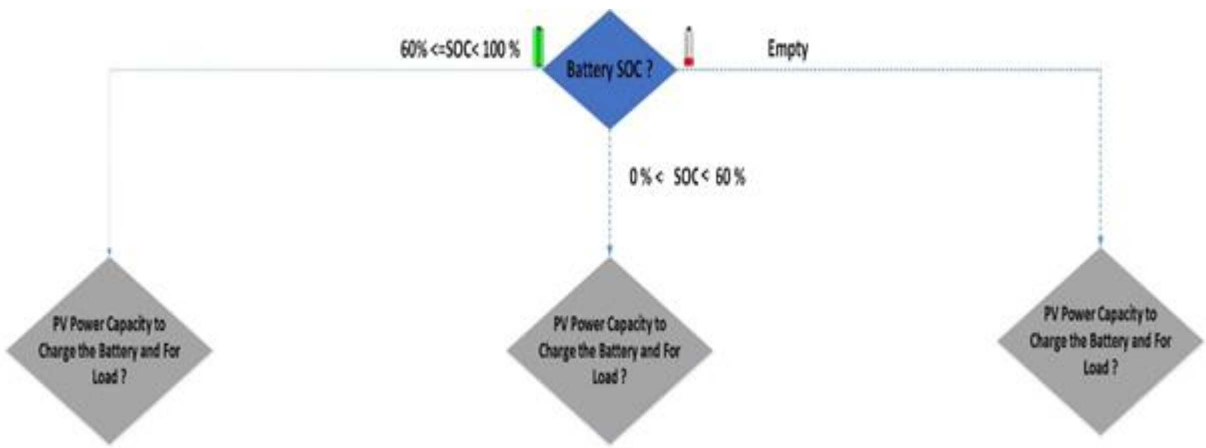

Figure 5.2: Availability Mode

At any Current Point the Battery SOC (State of Charge) can be in three different states in Economic Mode.

- 60% <= SOC <100%
- 0 % < SOC < 60 %
- Empty

When current battery SOC is Greater than 60 % but is not full then below are the possible decisions that needs to be taken.

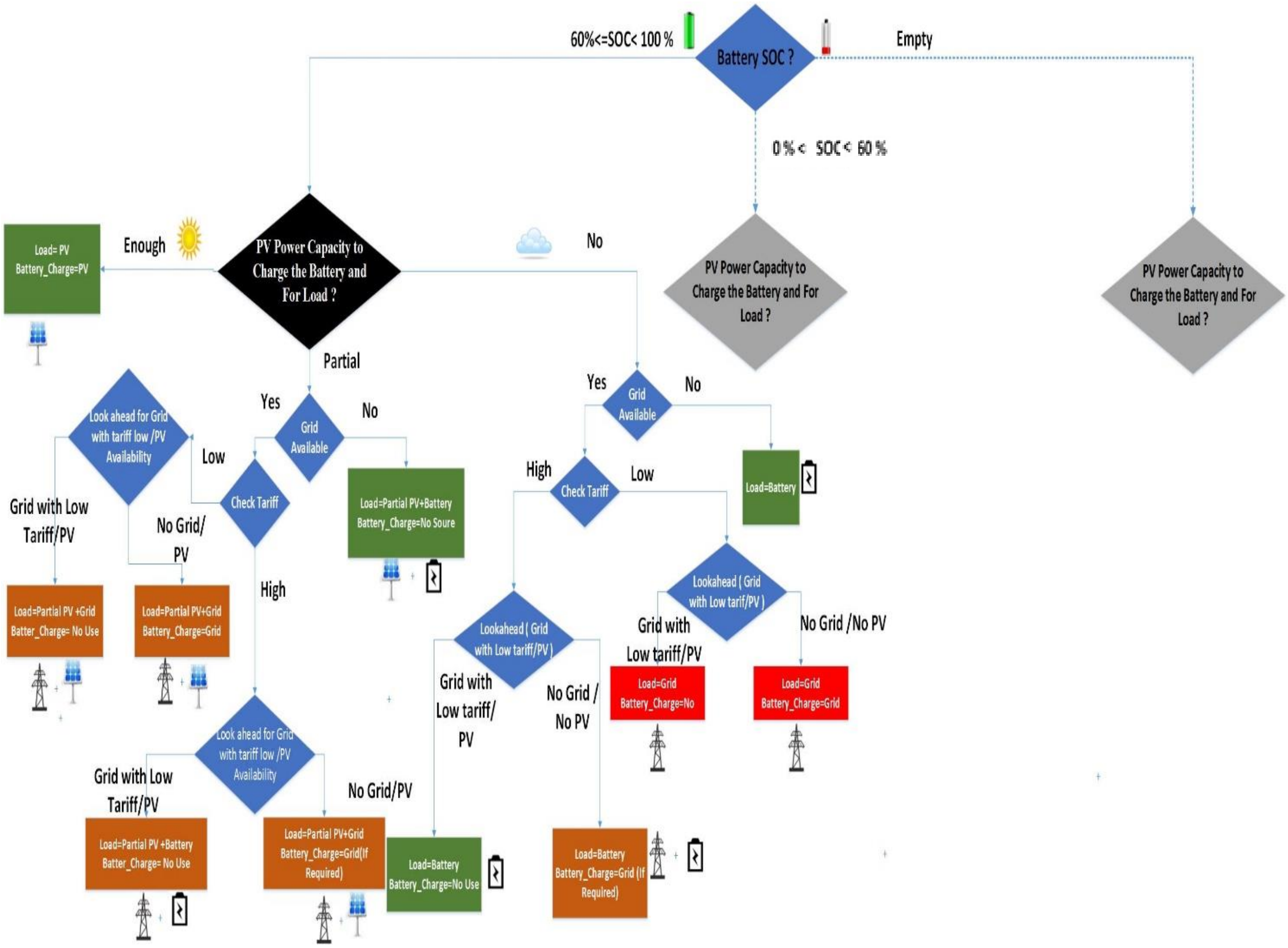

Figure 5.2a: Availability Path 1

If Currently PV Power is enough to handle the load and to charge the battery then PV would be used to feed the load and to charge the battery .In other case if PV Power is partial to feed the load then it further checks for the Grid availability .If its available then it checks for the tariff rates and if its high then lookahead based decisions are based that if in future the Grid with low tariff would be available then no need to charge the battery in current high tariff time , but in another case if Grid or PV is not available in future then battery needs to be charged form Grid to save it for any future shortfall. One of the Case can be when PV is not enough available then Grid would be the charging and load source, but battery Charging decisions can be made by lookahead inputs.

When current battery SOC is Greater than 0 % but less than 60 % then below are the possible decisions that needs to be taken.

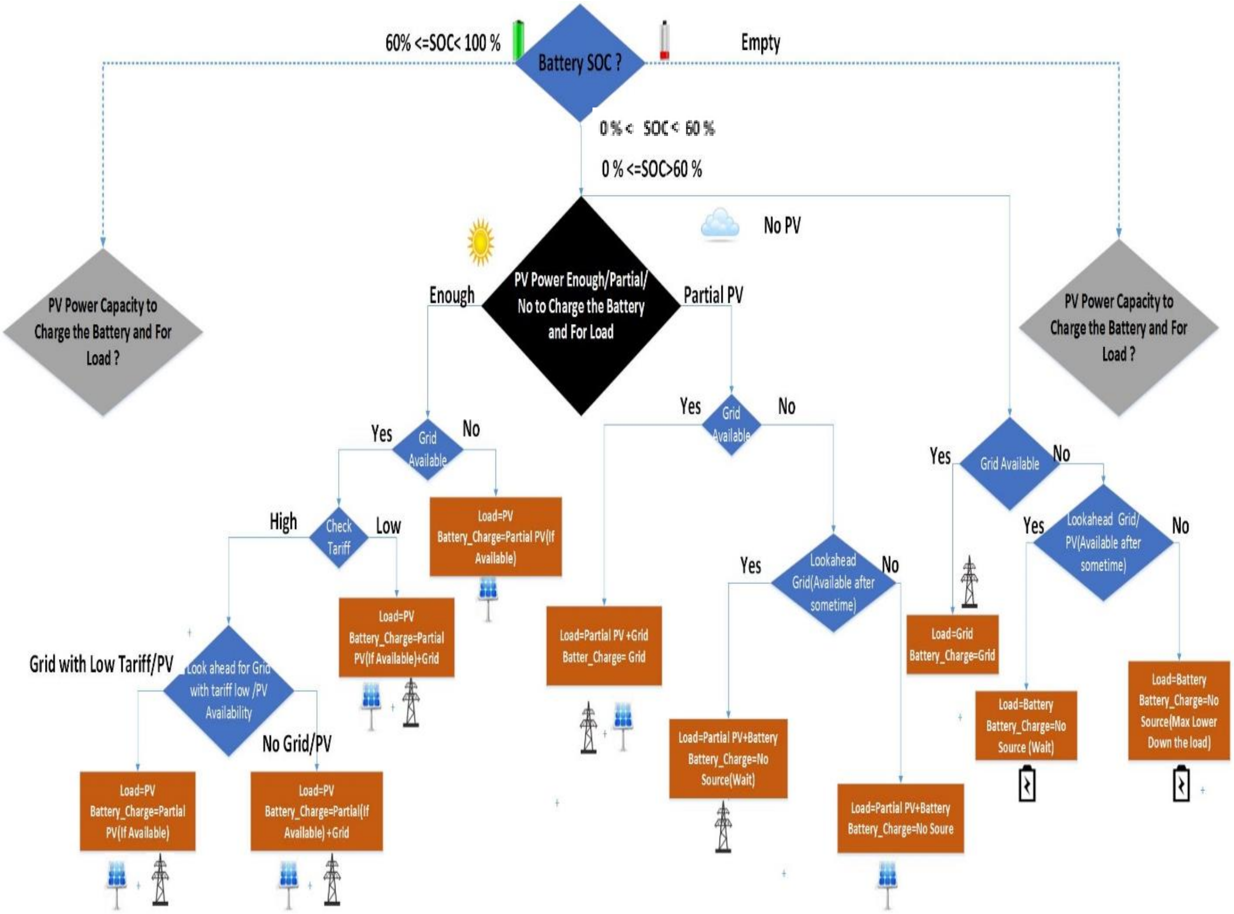

Figure 5.2b: Availability Path 2

If Currently PV Power is enough to handle the load and to charge the battery then PV would be used to feed the load and to charge the battery .In other case if PV Power is partial to feed the load and for battery charging ,then it further checks for the Grid availability .If Grid is available ,then battery is charged from Partial PV and grid since now Lookahead and tariff rates are not taken into account since the battery is less than the set 60 % threshold so battery should not be drained less than this and has to be charged from whatever source is available to keep the min threshold. In another case when PV is not enough available then Grid would be the charging and load source and lookahead based inputs will be used to give load reduction suggestions to users.

When current battery SOC is empty then below are the possible decisions that needs to be taken.

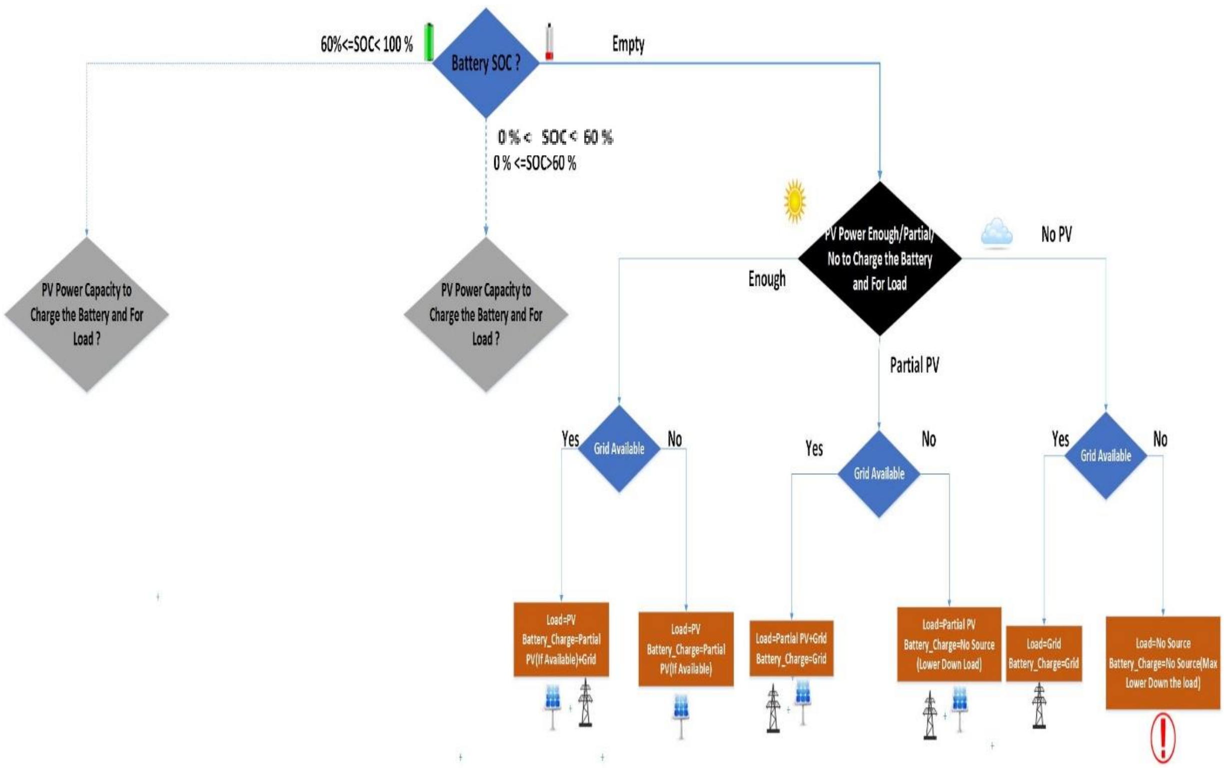

Figure 5.2c: Availability Path 3

If Currently PV Power is enough to handle the load and to charge the battery then PV would be used to feed the load and to charge the battery .In other case if PV Power is partial to feed the load and for battery charging ,then it further checks for the Grid availability .If Grid is available ,then battery is charged from Partial PV and grid since now Lookahead and tariff rates are not taken into account since the battery is empty so battery SOC should be maintained to min threshold and has to be charged from whatever source is available to keep the min threshold. In another case when PV is not enough ,then Grid would be the charging and load source and worst case when no PV , no battery power and no Grid is available then no possible decisions can be taken instead of maximum lowering down of the load. But the lookahead based decisions will not let the user to come in this worst case scenario.

2.1.1.1 Economic Mode

The flow chart of this Economic Mode is shown below

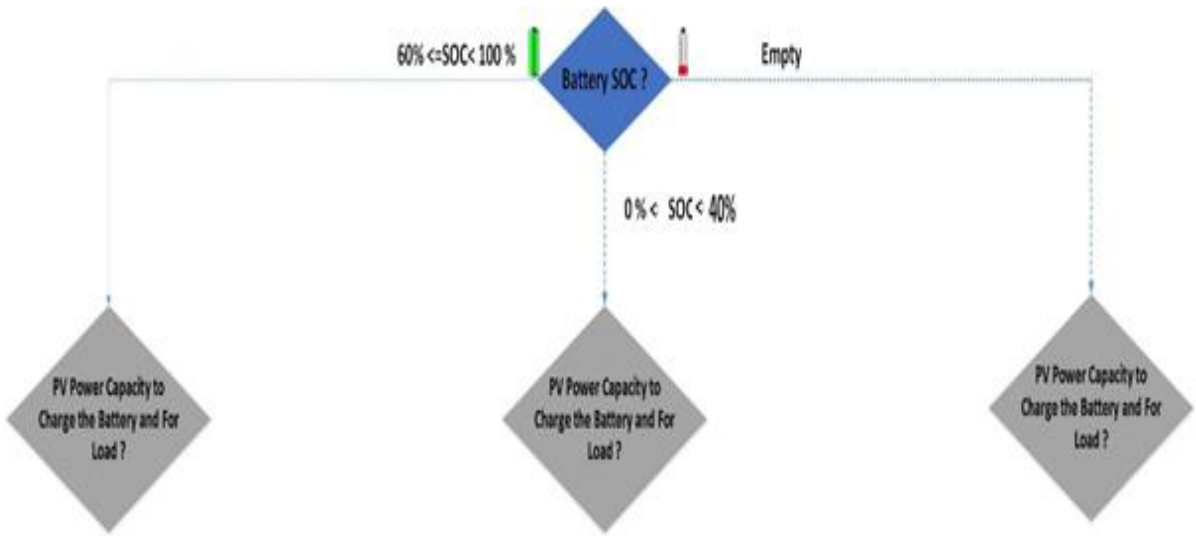

Figure 5.3: Economic Mode

At any Current Point the Battery SOC (State of Charge) can be in three different states in Economic Mode.

- 40% <= SOC <100%
- 0 % < SOC < 40 %
- Empty

When current battery SOC is Greater than 40 % but is not full then below are the possible decisions that needs to be taken.

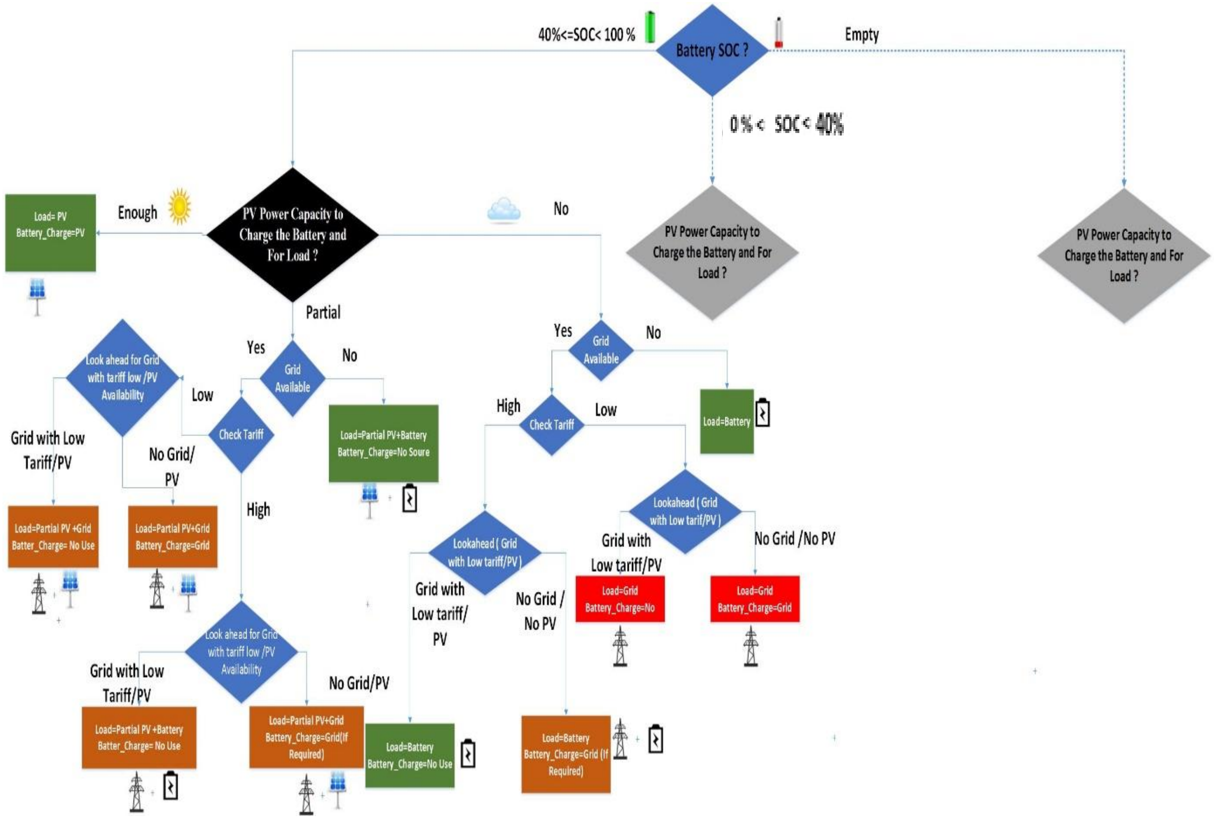

Figure 5.3a: Economic Path 1

If Currently PV Power is enough to handle the load and to charge the battery then PV would be used to feed the load and to charge the battery .In other case if PV Power is partial to feed the load then it further checks for the Grid availability .If its available then it checks for the tariff rates and if its high then lookahead based decisions are based that if in future the Grid with low tariff would be available then no need to charge the battery in current high tariff time , but in another case if Grid or PV is not available in future then battery needs to be charged form Grid to save it for any future shortfall. One of the Case can be when PV is not enough available then Grid would be the charging and load source, but battery Charging decisions can be made by lookahead inputs.

When current battery SOC is Greater than 0 % but less than 40 % then below are the possible decisions that needs to be taken.

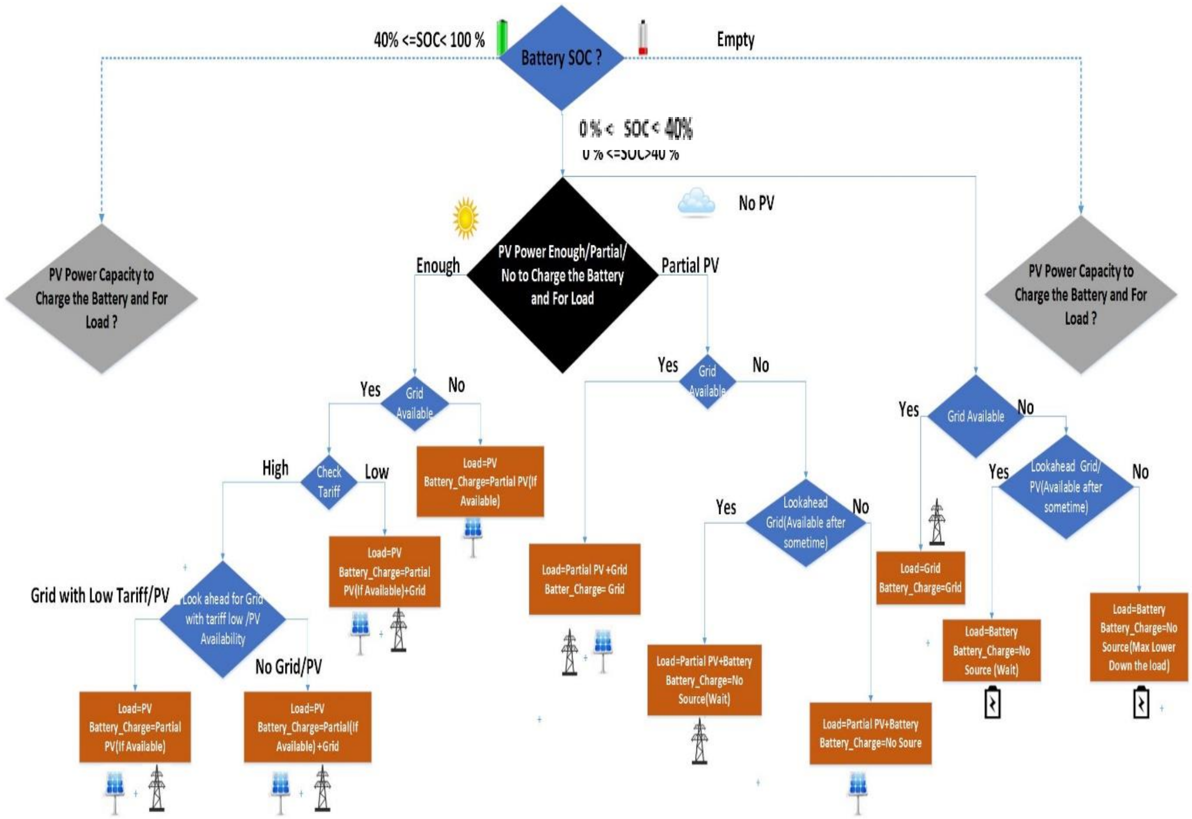

Figure 5.3b: Economic Path 2

If Currently PV Power is enough to handle the load and to charge the battery then PV would be used to feed the load and to charge the battery .In other case if PV Power is partial to feed the load and for battery charging ,then it further checks for the Grid availability .If Grid is available ,then battery is charged from Partial PV and grid since now Lookahead and tariff rates are not taken into account since the battery is less than the set 60 % threshold so battery should not be drained less than this and has to be charged from whatever source is available to keep the min threshold. In another case when PV is not enough available then Grid would be the charging and load source and lookahead based inputs will be used to give load reduction suggestions to users.

When current battery SOC is empty then below are the possible decisions that needs to be taken.

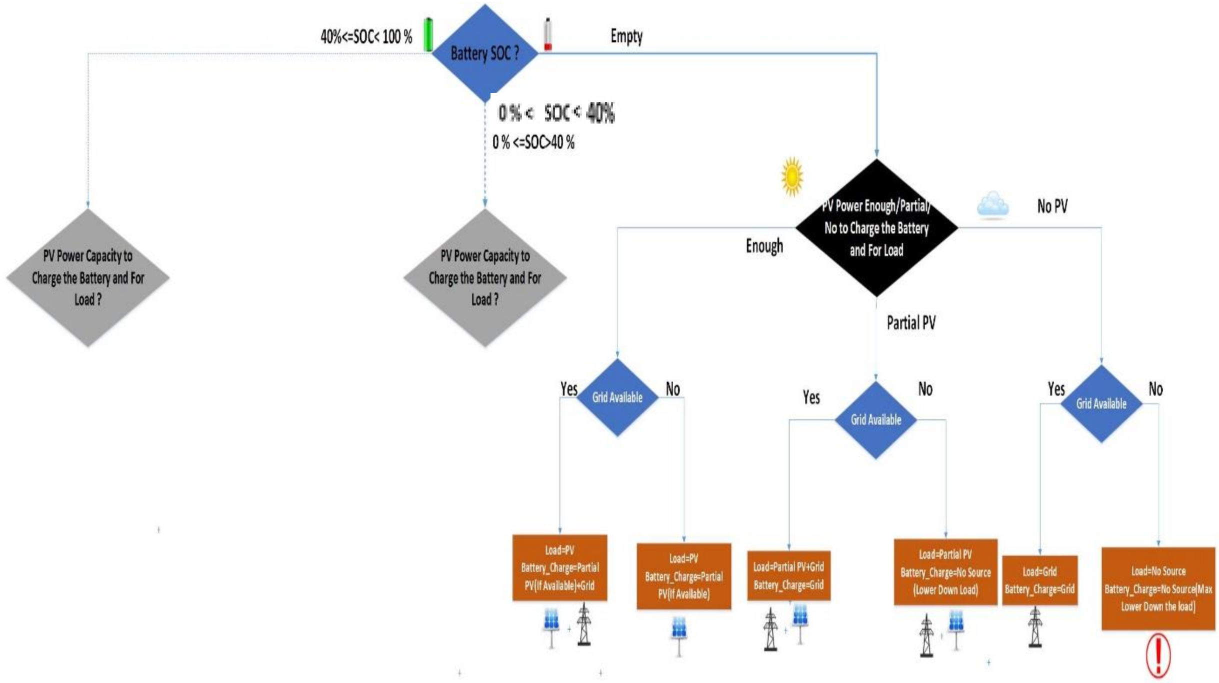

Figure 5.3c: Economic Path 3

If Currently PV Power is enough to handle the load and to charge the battery then PV would be used to feed the load and to charge the battery .In other case if PV Power is partial to feed the load and for battery charging ,then it further checks for the Grid availability .If Grid is available ,then battery is charged from Partial PV and grid since now Lookahead and tariff rates are not taken into account since the battery is empty so battery SOC should be maintained to min threshold and has to be charged from whatever source is available to keep the min threshold. In another case when PV is not enough ,then Grid would be the charging and load source and worst case when no PV , no battery power and no Grid is available then no possible decisions can be taken instead of maximum lowering down of the load. But the lookahead based decisions will not let the user to come in this worst case scenario.

5.2.2 Low/High Level Resolution Design

The low and high resolution design are illustrated below

5.2.2.1 Low Resolution Design

Table 5-1:(2 Bit) PV Output

PV	Output
00	Low or no
01	Low medium
10	High medium
11	High

PV capacity for charging in the next time interval (the interval resolution defined as 15 min or can be half an hour, T). There will be two values, one is the current output PV_C and the other is the predicted value for time interval PV_t where $t = 0,1,2, \dots, N$ for every T min for one day of operation starting from 12 am in the morning as PV_0. The PV_t will be provided by the Forecast Manager for the next three hours of scheduling.

Table 5-2: (2 Bit) Load Shedding Hours

LS	Output
00	No
01	Less than one hour
10	More than one and less than two hours
11	Three or more hours

Similarly the Forecast Manager (FM) would give forecasting about the load shedding for the next three hours of operation as LSp as a vector with 15 min or T resolution. The current status of the load shedding LS_C will also be fed as a binary variable.

Similarly the tables for Usage Pattern Prediction, Battery Charge Status and Tariff are given here.

Table 5-3: (2 Bit)User Load

LD	**Load**
00	Low or no load
01	Low medium
10	High medium
11	High

Table 5-4:(2 Bit)Battery Charge Status Output

BS	Output
00	Low or no charge
01	Low medium
10	High medium
11	High

Table 5-5:(2 Bit)Tariff

TF	Price
00	Low
01	Low medium
10	High medium
11	High

The output of the scheduler will generate the following output at the same resolution T.

Table 5-6:(2 Bit)Power Source

PS	Power Source
00	No Power
01	PV
10	Battery
11	Grid

Table 5-7:(2 Bit)Battery Charging

BC	Source for Charging
00	No charging
01	PV
10	Grid
11	Any other source

The system will also suggest the user to reduce the load and in economy mode, shall automatically shutt down lower priority loads, if already specified by the user.

Table 5-8:(2 Bit)Load Reduction Suggestions

LR	Reduce Load Suggestion
00	As is

01	Reduce little
10	Reduce more
11	Maximum reduction

5.2.2.2 High Resolution Design

Table 5-9:(3 bit) PV Output Lookahead

PV Power	Output Condition
000	(Not Available) for Next 3 hrs
001	(Not Available) for Next 2 hr
010	(Not Available) for Next 1hr
011	(Not Available) for Next ½ hr
100	(Available) for Next 3 hrs
101	(Available) for Next 2 hrs
110	(Available) for Next 1 hr
111	(Available) for Next ½ hr

Table 5-10:(3 bit) LoadShedding Lookahead

Load Shedding	Output Condition
000	(No Load Shedding) for Next 3 hrs
001	(No Load Shedding) for Next 2 hr
010	(No Load Shedding) for Next 1 hr
011	(No Load Shedding) for Next ½ hr
100	(Load Shedding) for Next 3 hrs
101	(Load Shedding) for Next 2 hrs
110	(Load Shedding) for Next 1 hr
111	(Load Shedding) for Next ½ hr

Table 5-11:(3 bit) Tariff Lookahead

Tariffs	Output Condition
000	(Tariff Low)for Next 3 hrs
001	(Tariff Low)for Next 2 hrs
010	(Tariff Low)for Next 1 hr
011	(Tariff Low)for Next ½ hr
100	(Tariff High)for Next 3 hrs
101	(Tariff High)for Next 2 hrs
110	(Tariff High)for Next 1 hr
111	(Tariff High)for Next ½ hrs

The scheduler is a lookup table that can be intelligently filled and can be extended by fuzzification of the input variables and defining fuzzy rules. The defuzzification shall then generate the required output. For economic mode, following table will be used for Different cases as shown below

5.2.2.2.1 When Only PV Power is Available

Below are the Possible Input Combination for the case when the only PV Power is available for load and for charging the battery.

Table 5-12:PV Power Possible Input Cases

PV	**LS**	**Tariff**	**BS**		**Power Source**	**Battery Charge**	**LR**
111	100	Whatever is tariff rate	Low		PV	PV	Max Reduction
111	101	000	Low		PV	PV	Reduce More
111	101	001/010/011/100/ 101/110/111	Low		PV	PV	Max Reduction
111	110	000/001/011/010/ 110/111	Low		PV	PV	Reduce Little
111	110	100/101	Low		PV	PV	Reduce More
111	111	000/001/111	Low		PV	PV	As is
111	111	010/110	Low		PV	PV	Reduce Little
111	111	011/100/101	Low		PV	PV	Reduce More
110	101	Whatever is tariff rate	Low		PV	PV	Reduce More
110	110	000/001/110/111	Low		PV	PV	As is
110	110/111	010/011/101	Low		PV	PV	Reduce Little
110	110/111	100	Low		PV	PV	Reduce More
110	111	000/001/110/111	Low		PV	PV	As is
100	Whatever is Load shedding times	Whatever is tariff rate	Low		PV	PV	As is
101	100/101	Whatever is tariff rate	Low		PV	PV	Reduce Little
101	110/111	000	Low		PV	PV	As is

5.2.2.2.2 When Only Grid Power is Available

Below are the Possible Input Combination for the case when only the Gid Power is available for load and for charging the battery.

Table 5-13: Grid Power Possible Input Cases

PV	LS	Tariff	BS		Power Source	Battery Charge	LR
011	001	000/001/010/011	Low		Grid	Grid	As is
011	001	100/101/110/111	Low		Grid	Grid	Reduce Little
011	010	000/001/010/011	Low		Grid	Grid	As is
011	010	100/101/110/111	Low		Grid	Grid	Reduce Little
011	011	000/001/010/011	Low		Grid	Grid	As is
011	011	100/101/110/111	Low		Grid	Grid	Reduce Little
010	010	100	Low		Grid	Grid	Max Reduction
010	010	101/110	Low		Grid	Grid	Reduce More
010	011	000/001/010/011	Low		Grid	Grid	As is
010	011	100/101/110/111	Low		Grid	Grid	Reduce Little
010	001	010/110/111			Grid	Grid	Reduce Little
010	001	011/101	Low		Grid	Grid	Reduce More
010	001	100	Low		Grid	Grid	Max Reduction
010	010	000/001/010	Low		Grid	Grid	As is
010	010	011/111	Low		Grid	Grid	Reduce Little
001	010	000	Low		Grid	Grid	As is
001	010	001/111	Low		Grid	Grid	Reduce little
001	010	010/101/110	Low		Grid	Grid	Reduce More
001	010	011/100	Low		Grid	Grid	Max Reduction
001	011	000/011	Low		Grid	Grid	Reduce Little
001	011	001/010/101/	Low		Grid	Grid	Reduce More

001	011	100/111	Low		Grid	Grid	Max Reduction
001	011	110	Low		Grid	Grid	Reduce More
010	001	000/001	Low		Grid	Grid	As is
001	001	010/111	Low		Grid	Grid	Reduce Little
001	001	011/101/110	Low		Grid	Grid	Reduce More
001	001	100	Low		Grid	Grid	Max Reduction
001	001	000/010	Low		Grid	Grid	As is
001	001	001	Low		Grid	Grid	As is /Reduce Little
010	010	010	Low		Grid	Grid	As is /Reduce Little
011	011	011	Low		Grid	Grid	Reduce More
001/00 /011	000	000	Low		Grid	Grid	As is
000	000/01	000	Low		Grid	Grid	As is
000	010	000	Low		Grid	Grid	Reduce little
000	011	000	Low		Grid	Grid	Reduce More
000	000	101/110/010	Low		Grid	Grid	Reduce More
000	000	001/111/110	Low		Grid	Grid	Reduce little
000	000	011/100	Low		Grid	Grid	Max Reduction

5.2.2.2.3 When Only Battery Power is Available

Below are the Possible Input Combination for the case when only the Battery Power is available for load.

Table 5-14: Battery Power Possible Input Cases

PV	**LS**	**Tariff**	**BS**		**Power Source**	**Battery Charge**	**LR**
000/001/0	100	Whatever are	High		Battery	No Source	As is

10/011		tariff rates					
000	101/110/1 11	Whatever are tariff rates	High		Battery	No Source	As is
001	101/110/1 11	Whatever are tariff rates	High		Battery	No Source	As is
010	101/110/1 11	Whatever are tariff rates	High		Battery	No Source	As is
011	101/110/1 11	Whatever are tariff rates	High		Battery	No Source	As is
000	100/101/1 10/111	Whatever are tariff rates	High		Battery	No Source	As is
001	100/101/1 10/111	Whatever are tariff rates	High		Battery	No Source	As is
010	100/101/1 10/111	Whatever are tariff rates	High		Battery	No Source	As is
011	100/101/1 10/111	Whatever are tariff rates	High		Battery	No Source	As is
000	100	Whatever are tariff rates	Medium		Battery	No Source	Max Reduction
000	101	000/001/010/0 11/101/110/11 1	Medium		Battery	No Source	Reduce More
000	101	100	Medium		Battery	No Source	Max Reduction
000	110	000/001/110/1 11	Medium		Battery	No Source	As is
000	110	010/011/100/1 01	Medium		Battery	No Source	Reduce Little
000	111	000/001/010/0 11/110/111	Medium		Battery	No Source	As is
000	111	100/101	Medium		Battery	No Source	Reduce Little
001	100	Whatever are tariff rates	Medium		Battery	No Source	Reduce Little
010	100/1010/ 110/111	Whatever are tariff rates	Medium		Battery	No Source	As is
011	Whatever	Whatever are	Medium		Battery	No Source	As is

	the load shedding time	tariff rates					

5.2.2.2.4 When PV+Grid Power is Available

Below are the Possible Input Combination for the case when PV and Grid Power are available for load and for charging the battery.

Table 5-15: PV+Grid Power Possible Input Cases

PV	**LS**	**Tariff**	**BS**		**Power Source**	**Battery Charge**	**LR**
111	001	000/001/111	Low		PV/Grid	PV/Grid	As is
111	001	010/110	Low		PV/Grid	PV/Grid	Reduce Little
111	001	011/101	Low		PV/Grid	PV/Grid	Reduce More
111	001	100	Low		PV/Grid	PV/Grid	Max Reduction
111	010	000/001			PV/Grid	PV/Grid	As is
111	010	010/011/101/110 /111	Low		PV/Grid	PV/Grid	Reduce Little
111	010	100	Low		PV/Grid	PV/Grid	Reduce More
111	011	Whatever is tariff rate	Low		PV/Grid	PV/Grid	Reduce More
110	011	Whatever is tariff rate	Low		PV/Grid	PV/Grid	Reduce Little
101	001/010/ 011/101	Whatever is tariff rate	Low		PV/Grid	PV/Grid	As is
110	001	000/001/111	Low		PV/Grid	PV/Grid	As is
110	001	010/011/100/110	Low		PV/Grid	PV/Grid	Reduce Little
110	001	101	Low		PV/Grid	PV/Grid	As is/Reduce Little
110	010	000/001/010/110	Low		PV/Grid	PV/Grid	As is
110	010	011/101/111	Low		PV/Grid	PV/Grid	Reduce Little

110	010	100	Low		PV/Grid	PV/Grid	Reduce More
110	000	000	Low		PV/Grid	PV/Grid	Reduce More/Little
111	000	000	Low		PV/Grid	PV/Grid	Reduce More
100	000/001/ 010/010/ 011	000	Low		PV/Grid	PV/Grid	As is

5.2.2.2.5 When PV+Battery Power is Available

Below are the Possible Input Combination for the case when PV and Battery Power are available for load and PV for charging the battery.

Table 5-16: PV+Battery Power Possible Input Cases

PV	LS	Tariff	BS		Power Source	Battery Charge	LR
100	100	100	Medium		Battery/PV	PV	As is/Reduce Little
101	101	101	Medium		Battery/PV	PV	As is/Reduce Little
110	110	110	Medium		Battery/PV	PV	As is/Reduce Little
111	111	111	Medium		Battery/PV	PV	As is/Reduce Little
100	100	100	High		Battery/PV	PV	As is
101	101	101	High		Battery/PV	PV	As is
110	110	110	High		Battery/PV	PV	As is
111	111	111	High		Battery/PV	PV	As is

5.2.2.2.6 When Battery+Grid Power is Available

Below are the Possible Input Combination for the case when Battery and Grid Power are available for load and Grid for charging the battery.

Table 5-17: Battery+Grid Power Possible Input Cases

PV	LS	Tariff	BS		Power Source	Battery Charge	LR
000	000	000	Medium		Grid/Battery	Grid	As is
000	000	001/111/110	Medium		Grid/Battery	Grid	Reduce little
000	000	011/100	Medium		Grid/Battery	Grid	Max Reduction
000	000	010/101	Medium		Grid/Battery	Grid	Reduce more
000	000	000	High		Grid/Battery	Grid	As is
000	000	100/011	High		Battery/Grid	Grid	Max Reduction
000	000	010/101	High		Battery/Grid	Grid	Reduce More
000	000	001//111/110	High		Battery/Grid	Grid	Reduce Little
000	100	000	Low		Grid/Battery	Grid	Max Reduction
000	001	000	Medium		Grid/Battery	Grid	As is
000	010/110/111	000	Medium		Grid/Battery	Grid	Reduce little
000	011/101	000	Medium		Grid/Battery	Grid	Reduce More
000	100	000	Medium		Grid/Battery	Grid	Max Reduction
000	001/010/011	000	High		Grid/Battery	Grid	As is
001/010/011	000	000	Medium		Battery/Grid	Grid	As is
001/010/011	000	000	High		Battery /Grid	Grid	As is
001/010/011	001	001	Medium		Battery/Grid	Grid	As is /Reduce Little
010	010	010	Medium		Battery/Grid	Grid	As is /Reduce Little

011	011	011	Medium		Battery/Grid	Grid	Reduce More
001	001	001	High		Battery/Grid	Grid	As is
010	010	010	High		Battery/Grid	Grid	As is
001	001	001	High		Battery/Grid	Grid	As is /Reduce Little
010	010	010	High		Battery/Grid	Grid	As is /Reduce Little

5.2.2.2.7 When PV+Battery+Grid Power is Available

Below are the Possible Input Combination for the case all Power Sourcesare available for load and for charging the battery.

Table 5-18: PV+Battery+Grid Power Possible Input Cases

PV	**LS**	**Tariff**	**BS**		**Power Source**	**Battery Charge**	**LR**
100/101/110/111	000/001/010/011	Whatever the tariff rates	Medium /High		PV/Battery /Grid	PV/Grid	As is

5.2.2.2.8 When No Power is Available

Below are the Possible Input Combination for the case when no Power is available for load and PV for charging the battery.

Table 5-19: No Power Possible Input Cases

PV	**LS**	**Tariff**	**BS**		**Power Source**	**Battery Charge**	**LR**
011	110/111	Whatever is tariff rate	Low		No Power	No Source	Reduce More
011	100/101	Whatever is tariff rate	Low		No Power	No Source	Max Reduction
010	111	000/001/111	Low		No Power	No Source	Reduce Little
010	111	011/100/101/11	Low		No Power	No	Reduce More

		0/010				Source	
010	100/101 /1 10	Whatever is tariff rate ?	Low		No Power	No Source	Reduce More
001	100	Whatever is the tarif rate	Low		No Power	No Source	Max Reduction
001	101	Whatever is the tarif rate	Low		No Power	No Source	Reduce More
001	110	Whatever is the tarif rate	Low		No Power	No Source	Reduce More
001	111	Whatever is the tarif rate	Low		No Power	No Source	Reduce More
000	110/111	000	Low		No Power	No Source	Reduce More
000	101	000	Low		No Power	No Source	Reduce More
000	100	Whatever is the tarif rate	Low		No Power	No Source	Max Reduction

5.2.3 Fuzzy Logic Implementation

The strategy for energy management must control the power split between Grid, PV and battery. However ,fulfilling the load requirements also. Power Demand is varied and inconsistent in nature, so the load demand profile is inescapable .By adding this to any non-linear subsystems, the system would become more complex .Therefore an expert fuzzy system in accordance with this variation in climate (PV Power), Load demand profile, Battery SOC is proposed. The Fuzzy Intelligent system is designed by integrating the high and low resolution design inputs and adding the non-linearity aspect to its solution by presenting a modified solution by shifting from crisp inputs to range of inputs. The proposed fuzzy expert system also includes 3 hours look ahead inputs for both PV and the Grid availability so as help achieves optimized economic results, also inputs and the outputs are dependent on each other. The main input /Output Control block is shown below

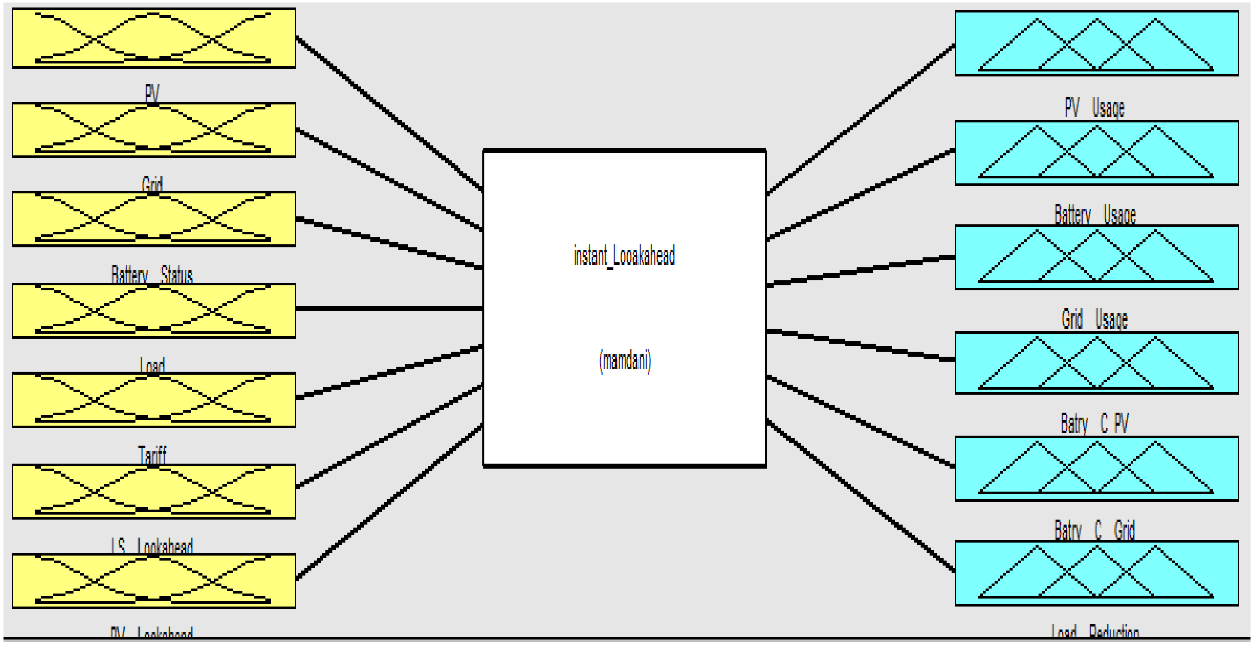

Figure 5.9: Input/Output Main Fuzzy Control

The fuzzy input variables are

1. PV (Instant)
2. Grid (Instant)
3. Battery_Status(Instant)
4. Tariff (Instant)
5. Load(Instant
6. LoadShedding_Lookahead
7. PV_Lookahead

The Output variables are

1. PV__Usage,
2. Grid__Usage
3. Battery Usage
4. Batter_Charge_PV
5. Battery_Charge_Grid
6. Load__Reduction

5.2.3.1 Fuzzification

The membership functions for each input and output is shown below

a) PV

The membership Functions for PV are categorized based on its capacity as No, Very_Low, Low, Medium_Low, Medium, Medium_High, High and Max at the current time slot.

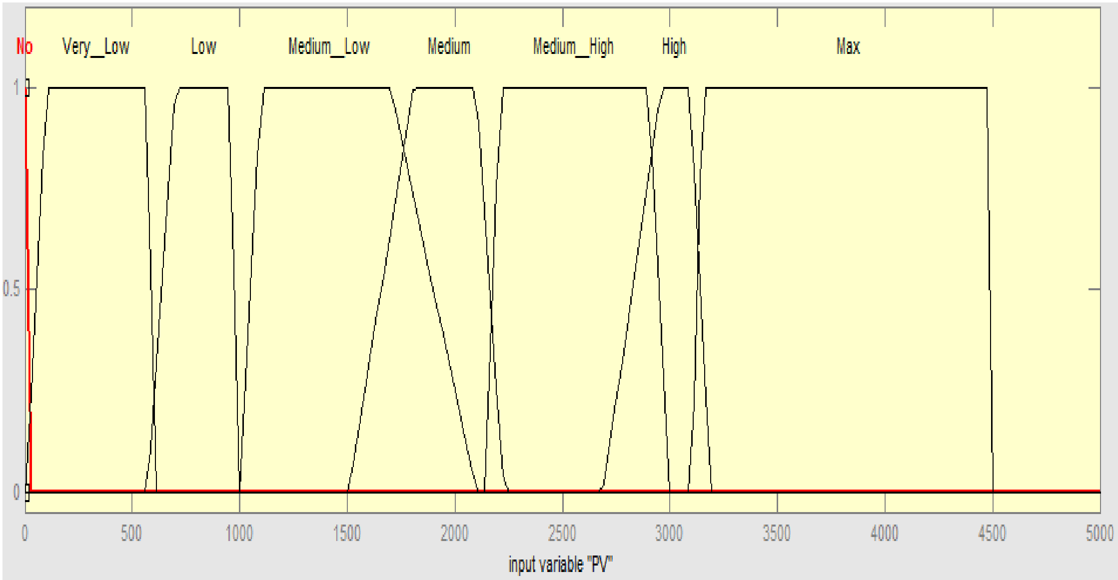

Figure 5.10: PV Membership Functions

b) Grid

The membership Functions for Grid in terms of availability are categorized as 0 for Not available and 1 for availability of Grid at the current time slot.

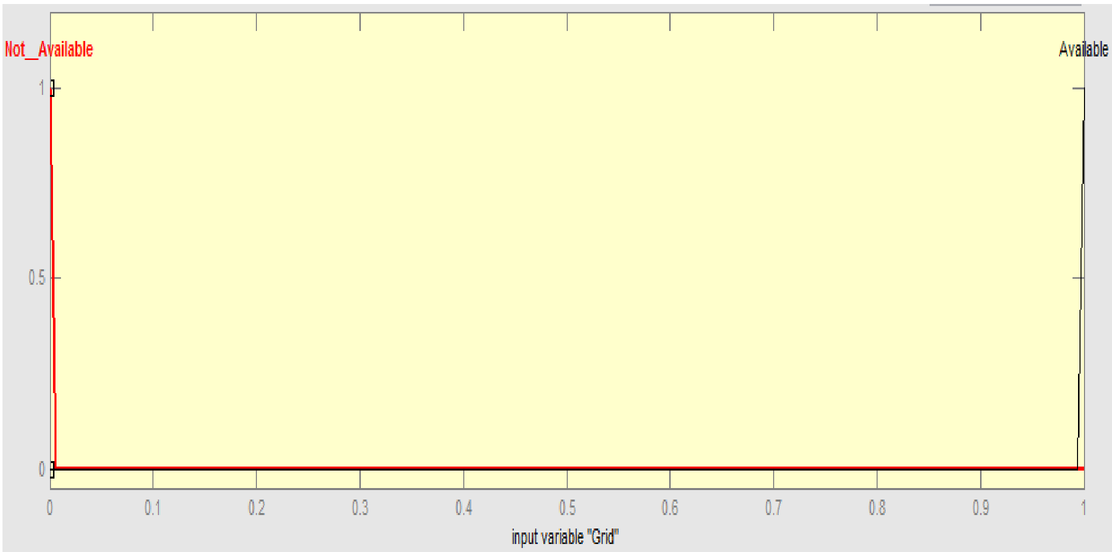

Figure 5.11: Grid Membership Functions

c) Battery

The membership Functions for battery SOC are categorized based on its capacity in percentage as Low, Medium,, Medium High, High and Full at the current time slot.

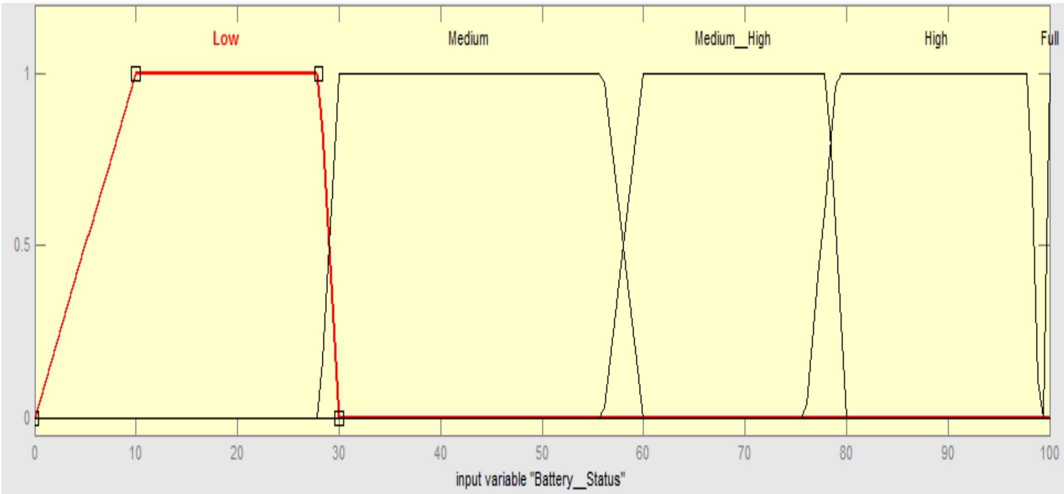

Figure 5.12: Battery Membership Functions

d) Tariff

The membership Functions for tariff rates are categorized as 0 for Low Tariff and 1 for High tariff at the current time slot.

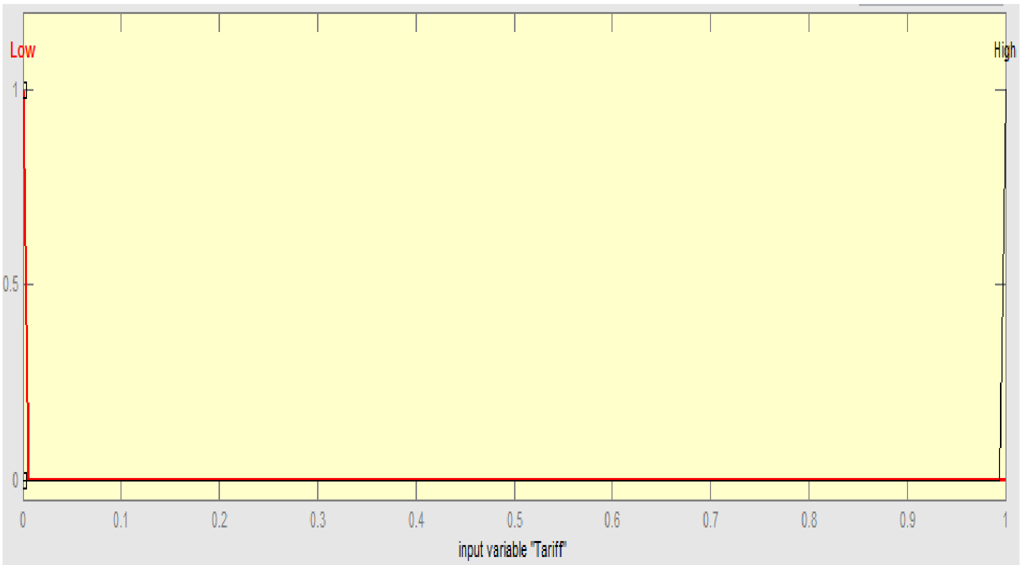

Figure 5.13: Tariff Membership Functions

e) Load

The membership Functions for Load Demand are categorized based on its capacity in KW as No Load, Little load, Medium Load, max Load at the current time slot.

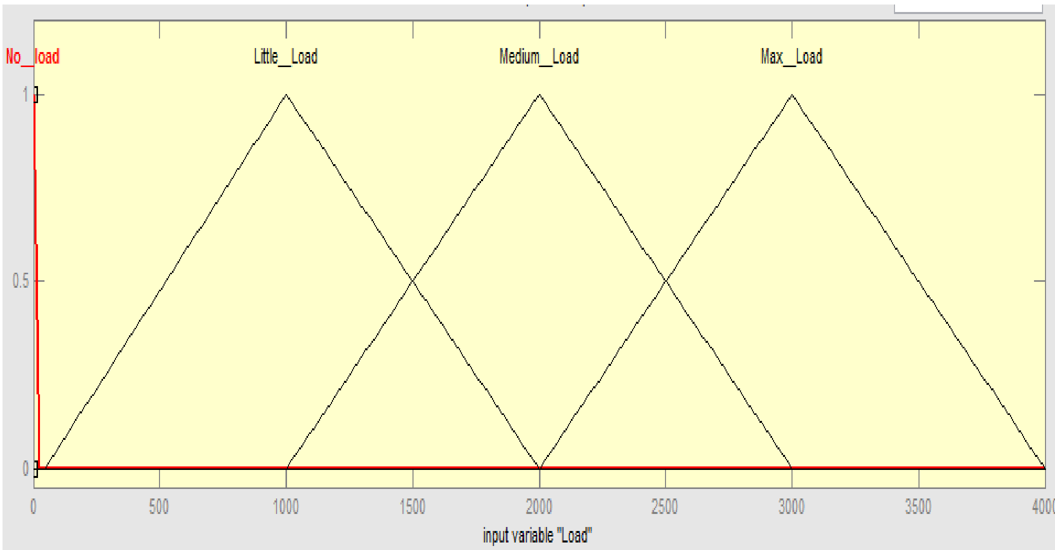

Figure 5.14: Load Membership Functions

f) LoadShedding_Looakahead

The membership Functions for Load Shedding lookahead was indexed with 15 min time slot interval following the load shedding pattern of 1 hour load Shedding after every 3 hour (3-1-3).Indexing starts from 0 (Not Available for Next 1 Hour) till 15(Available for Next 3 hour).

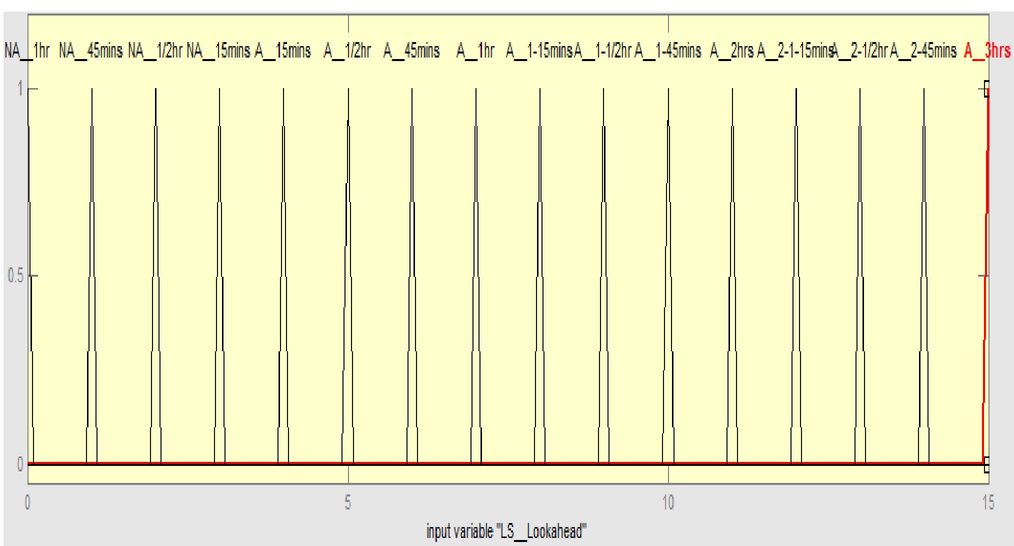

Figure 5.15:LoadShedding_Looakahead Membership Functions

g) PV_Looakahead

The membership Functions for PV Availability lookahead was indexed with 15 min time slot interval Indexing starts from 0 (Not Available for Next 3 Hour) till 23(Available for Next 3 hours).

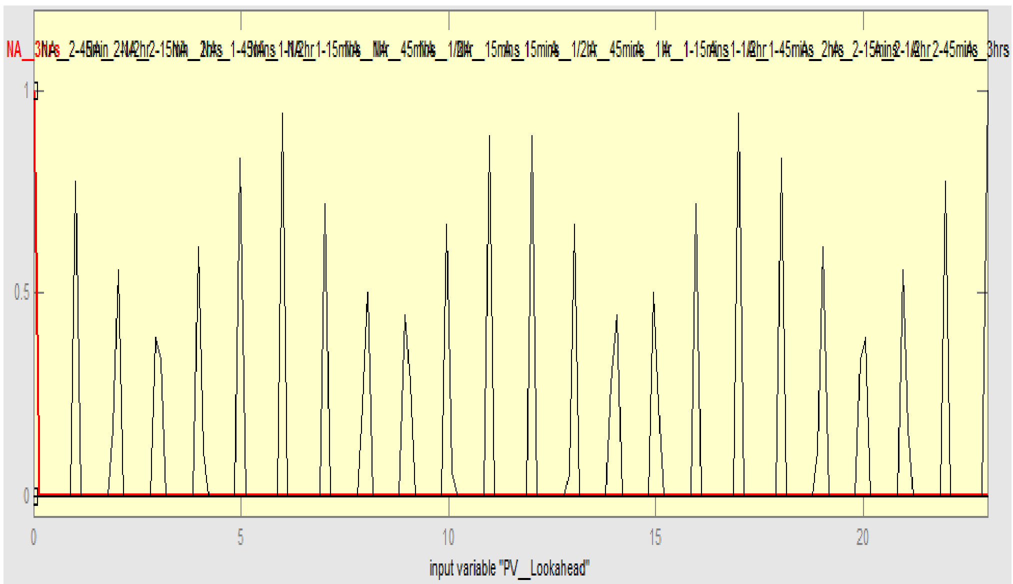

Figure 5.16: PV_Looakahead Membership Functions

Output membership Functions are listed below

a) PV_Usage

The membership Functions for PV Usage are categorized based on its usage capacity as No Use, Very Less Use , Less Use, Medium Use, Medium High Use, High Use and Max use at the current time slot based on input data.

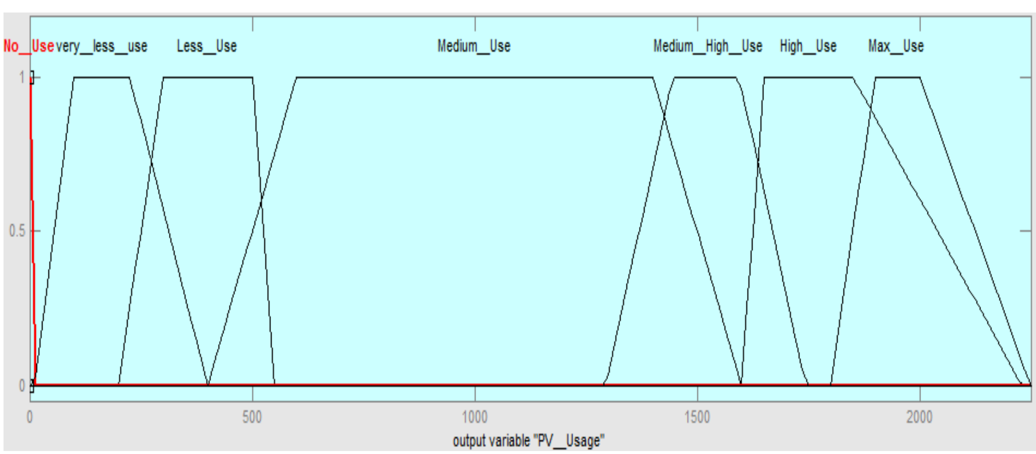

Figure 5.17: PV_Usage Membership Function

b) Grid_Usage

The membership Functions for Grid Usage are categorized based on its usage capacity as No Use, Less Use, Medium Use, Medium High Use, High Use and Max use at the current time slot based on input data.

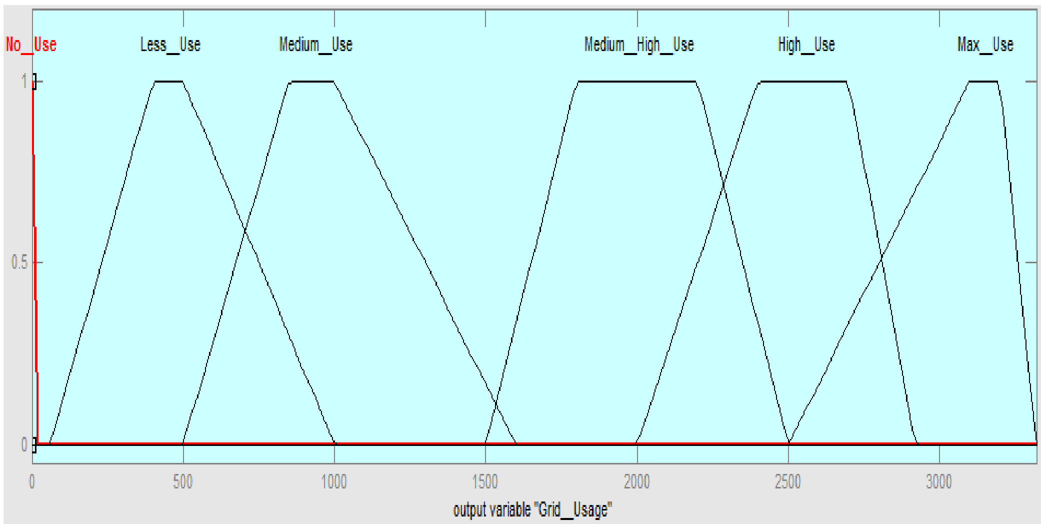

Figure 5.18: Grid_Usage Membership Functions

c) Battery_Usage

The membership Functions for Battery Usage are categorized based on its usage capacity as No Use, Very less use ,Less Use, Medium Use, Medium High Use, High Use and Max use at the current time slot based on input data.

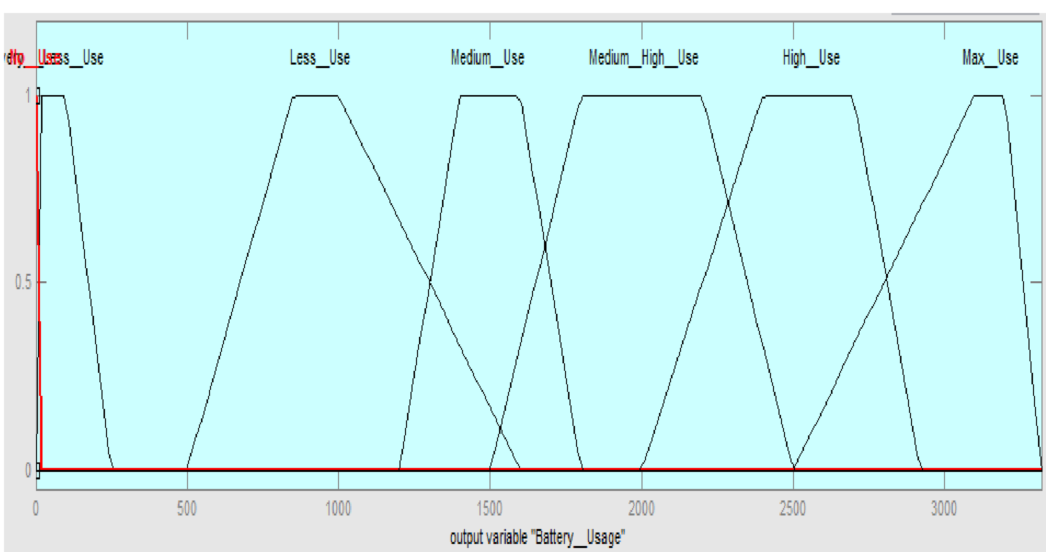

Figure 5.19: Battery_Usage Membership Functions

d) Battery_Charge_PV

The membership Functions for PV Usage in Battery Charging are categorized based on PV usage for charging the Battery as No Use, Very less use ,Less Use, Medium Use, Medium High Use, High Use and Max use at the current time slot based on input data.

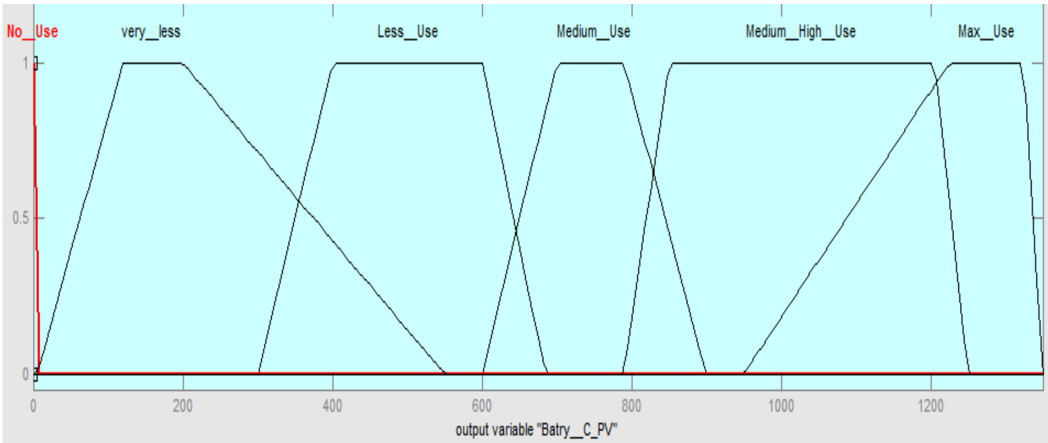

Figure 5.20: Battery_Charge_PVMembership Functions

e) Battery_Charge_Grid

The membership Functions for Grid Usage in Battery Charging are categorized based on Grid usage for charging the Battery as No Use, Partial use and Max use at the current time slot based on input data.

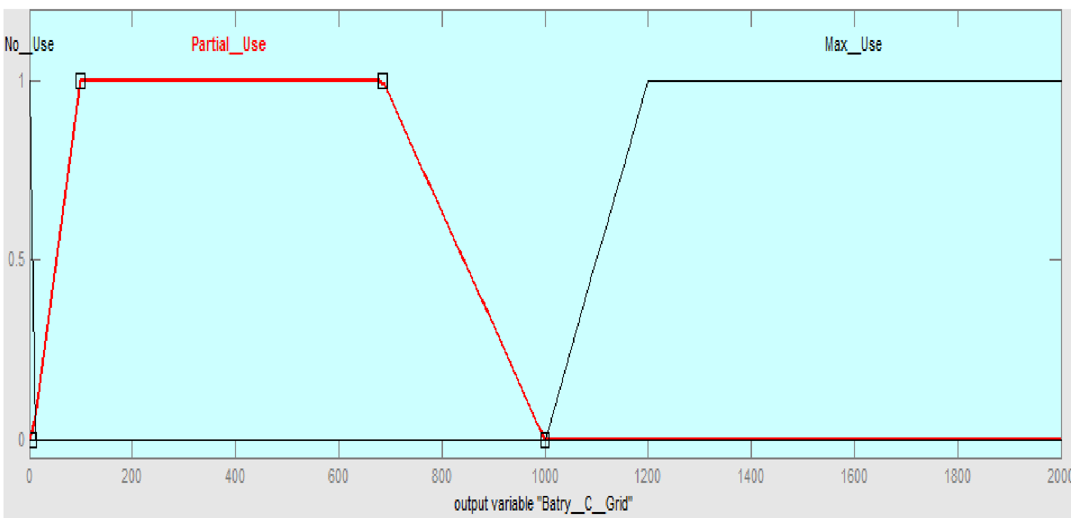

Figure 5.21: Battery_Charge_GridMembership Functions

f) Load_Reduction

The membership Functions for Load Reduction Suggestions are categorized (based on the Source Availability for load Demand) as As is, Reduce little, Reduce More and Max Reduction.

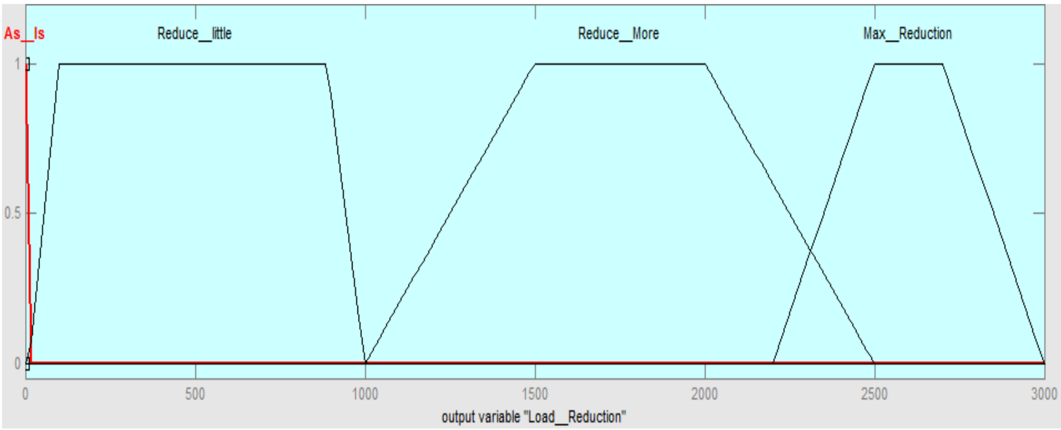

Figure 5.22: Load_ReductionMembership Functions

5.2.3.2 Inference

The table below shows the IF-THEN rules for 24-hours Fuzzy Expert system

Table 5-20: Fuzzy IF-THEN Rules for 24 Hours

Rules No.	If-Then Parts
1.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__3hrs) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
2.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
3.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is

	Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
4.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1-15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
5.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2hrs) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
6.	. If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1-45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
7.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1-1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
8.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1-15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
9.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
10.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)

11.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
12.	If (PV is No) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
13.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__1hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
14.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
15.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
16.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Medium__High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
17.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__3hrs) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
18.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-45mins) and (PV__Lookahead

	is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
19.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1/2hr) and (PV__Lookahead is NA__2-45min) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
20.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1-15mins) and (PV__Lookahead is NA__2-1/2hr) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
21.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__2hrs) and (PV__Lookahead is NA__2-15min) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
22.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1-45mins) and (PV__Lookahead is NA__2hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
23.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1-1/2hr) and (PV__Lookahead is NA__1-45mins) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
24.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1-15mins) and (PV__Lookahead is NA__1-1/2hr) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
25.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1hr) and (PV__Lookahead is NA__1-15mins) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is

	As__Is)
26.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__45mins) and (PV__Lookahead is NA__1hr) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
27.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1/2hr) and (PV__Lookahead is NA__45mins) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
28.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__15mins) and (PV__Lookahead is NA__1/2hr) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
29.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is NA__1hr) and (PV__Lookahead is NA__15mins) then (PV__Usage is No__Use)(Battery__Usage is Less__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
30.	If (PV is Very__Low) and (Grid is Not__Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is NA__45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is very__less__use)(Battery__Usage is Less__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
31.	If (PV is Very__Low) and (Grid is Not__Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is NA__1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is very__less__use)(Battery__Usage is Less__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
32.	If (PV is Very__Low) and (Grid is Not__Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is NA__15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is very__less__use)(Battery__Usage is Less__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
33.	If (PV is Low) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__3hrs) and (PV__Lookahead is A__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is Medium__Use)(Batry__C__Grid is No__Use)(Load__Reduction

	is As__Is)
34.	If (PV is Low) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__2-45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is Medium__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
35.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
36.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1-15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is very__less)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
37.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__2hrs) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Less__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
38.	If (PV is Medium) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1-45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Less__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
39.	If (PV is Medium) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1-1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Medium__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
40.	If (PV is Medium) and (Grid is Available) and (Battery__Status is Medium) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1-15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Medium__High__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
41.	If (PV is Medium__High) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
42.	If (PV is Medium__High) and (Grid is Available) and (Battery__Status is Medium__High) and

	(Load is Little__Load) and (LS__Lookahead is A__45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
43.	If (PV is Medium__High) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
44.	If (PV is Medium__High) and (Grid is Available) and (Battery__Status is Medium__High) and (Load is Little__Load) and (Tariff is Low) and (LS__Lookahead is A__15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
45.	If (PV is High) and (Grid is Not__Available) and (Battery__Status is Medium__High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__1hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Medium__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
46.	If (PV is Max) and (Grid is Not__Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Medium__High__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
47.	If (PV is Max) and (Grid is Not__Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
48.	If (PV is Max) and (Grid is Not__Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
49.	If (PV is Max) and (Grid is Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__3hrs) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
50.	If (PV is Max) and (Grid is Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV

	is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
51.	If (PV is Max) and (Grid is Available) and (Battery__Status is High) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is Max__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
52.	If (PV is Max) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1-15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
53.	If (PV is Max) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2hrs) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
54.	If (PV is Max) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1-45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
55.	If (PV is Max) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1-1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
56.	If (PV is Max) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1-15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
57.	If (PV is Max) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is) (1
58.	If (PV is Max) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
59.	If (PV is Medium__High) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)

60.	If (PV is Medium__High) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
61.	If (PV is High) and (Grid is Not__Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__1hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
62.	If (PV is Medium__High) and (Grid is Not__Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
63.	If (PV is Medium__High) and (Grid is Not__Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__1/2hr) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
64.	If (PV is Medium__High) and (Grid is Not__Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__15mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
65.	If (PV is Medium__High) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__3hrs) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
66.	If (PV is Medium) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-45mins) and (PV__Lookahead is A__3hrs) then (PV__Usage is Max__Use)(Battery__Usage is No__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
67.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1/2hr) and (PV__Lookahead is A__2-45mins) then (PV__Usage is High__Use)(Battery__Usage is very___Less__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
68.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is A__2-1-15mins) and (PV__Lookahead is A__2-1/2hr) then (PV__Usage is Medium__High__Use)(Battery__Usage is No__Use)(Grid__Usage is Less__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is

	No__Use)(Load__Reduction is As__Is)
69.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__2hrs) and (PV__Lookahead is A__2-15mins) then (PV__Usage is Medium__High__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
70.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__1-45mins) and (PV__Lookahead is A__2hrs) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Grid__Usage is Medium__High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
71.	If (PV is Medium__Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__1-1/2hr) and (PV__Lookahead is A__1-45mins) then (PV__Usage is Medium__Use)(Battery__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
72.	If (PV is Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__1-15mins) and (PV__Lookahead is A__1-1/2hr) then (PV__Usage is Less__Use)(Battery__Usage is No__Use)(Grid__Usage is High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
73.	If (PV is Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__1hr) and (PV__Lookahead is A__1-15mins) then (PV__Usage is Less__Use)(Battery__Usage is No__Use)(Grid__Usage is High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
74.	If (PV is Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__45mins) and (PV__Lookahead is A__1hr) then (PV__Usage is Less__Use)(Battery__Usage is No__Use)(Grid__Usage is High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is) (1
75.	If (PV is Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__1/2hr) and (PV__Lookahead is A__45mins) then (PV__Usage is Less__Use)(Battery__Usage is No__Use)(Grid__Usage is High__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
76.	If (PV is Very__Low) and (Grid is Available) and (Battery__Status is Full) and (Load is Max__Load) and (Tariff is Low) and (LS__Lookahead is A__15mins) and (PV__Lookahead is A__1/2hr) then (PV__Usage is very__less__use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
77.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Full) and (Load is Max__Load)

	and (Tariff is High) and (LS__Lookahead is NA__1hr) and (PV__Lookahead is A__15mins) then (PV__Usage is No__Use)(Battery__Usage is Max__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
78.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is High) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is NA__45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Max__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
79.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Medium__High) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is NA__1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Max__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
80.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Medium__High) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is NA__15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Max__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
81.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__3hrs) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
82.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__2-45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
83.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__2-1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
84.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__2-1-15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
85.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__2hrs) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
86.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__1-45mins) and (PV__Lookahead is NA__3hrs) then

	(PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
87.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__1-1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
88.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__1-15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
89.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__1hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
90.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
91.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
92.	If (PV is No) and (Grid is Available) and (Battery__Status is Medium) and (Load is Max__Load) and (Tariff is High) and (LS__Lookahead is A__15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is No__Use)(Grid__Usage is Max__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
93.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Medium) and (Load is Medium__Load) and (Tariff is High) and (LS__Lookahead is NA__1hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
94.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Medium) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__45mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
95.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Medium) and (Load is

	Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__1/2hr) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)
96.	If (PV is No) and (Grid is Not__Available) and (Battery__Status is Low) and (Load is Medium__Load) and (Tariff is Low) and (LS__Lookahead is NA__15mins) and (PV__Lookahead is NA__3hrs) then (PV__Usage is No__Use)(Battery__Usage is Medium__High__Use)(Grid__Usage is No__Use)(Batry__C_PV is No__Use)(Batry__C__Grid is No__Use)(Load__Reduction is As__Is)

The Fuzzy Logic Controller maps the inputs with the corresponding outputs by using list of if-then rule statements. The if portion of rules explains the Regions (Fuzzy sets) of the input variable. In this Research work, the degree of membership are estimated to get the controller output. And THEN portion of rules are weighted, averaged by respective membership degree.

CHAPTER 6

EXPERIMENTAL RESULTS

6.1 Datasets

The 24 hour Test Vector Data set was generated for 24 hour period with 15 mints with the following input patterns for Load Grid and PV data.

6.1.1. PV Power Pattern

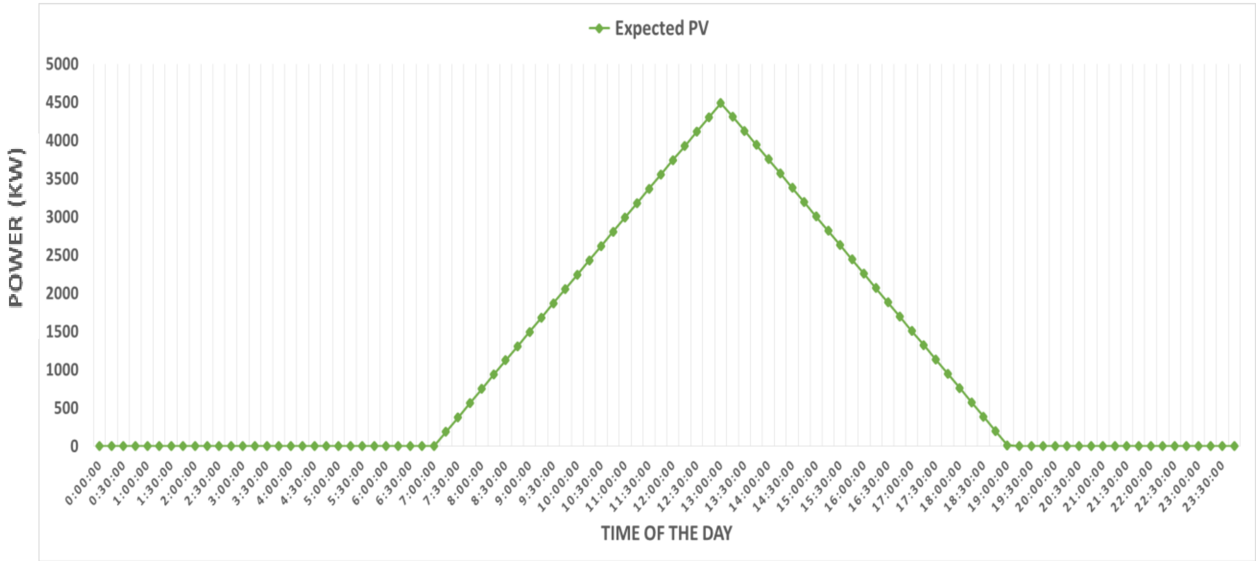

Figure 6.1: PV Power Pattern for 24 Hours

24 hour Test Vector PV Power data were generated as an input (based on capacity in KW) for lookahead based decisions for 24 hours with 15 mints Time slots .From the Fig above the pattern shows that from 00:00 A.M to 7:00 A.M the PV power is 0 kW, from 7:00 A.M to 1:00 PM PV power is in rising state and reaches its peak at 1 :00 PM and from there the falling period of PV power start that ends at 7:00 P.M .From 7:00 P.M to 12:00 Noon the PV power is 0 KW at night.

6.1.2. PV Availability lookahead Pattern

PV Lookahead (LS) indexing (15 mins Interval for 24 Hour Total Period) is illustrated below

0:Not Available for Next 3 hour12:Available for Next 15 min

1:NotAvailable for Next 2 hours 45min13: Available for Next ½ hour

2: Not Available for Next 2 -1/2hour14:Available for Next 45 min

3: Not Available for Next 2 hours 15 min15: Available for Next 1 hour

4: Not Available for Next 2 hours16:Available for Next 1 hour 15 min

5: Not Available for Next 1 hour 45 min17: Available for Next 1 -1/2 hour

6: Not Available for 1 -1/2 hour 18: Available for Next 1-45 min

7: Not Available for Next 1 hour 15 min19: Available for Next 2 hours

8: Not Available for Next 1 hour20: Available for Next 2 hours 15 min

9: Not Available for Next 45 min21: Available for Next 2-1/2 hour

10: Not Available for Next ½ hour22: Available for Next 2 hours 45 min

11:Not Available for Next 15 min23: Available for Next 3 Hours

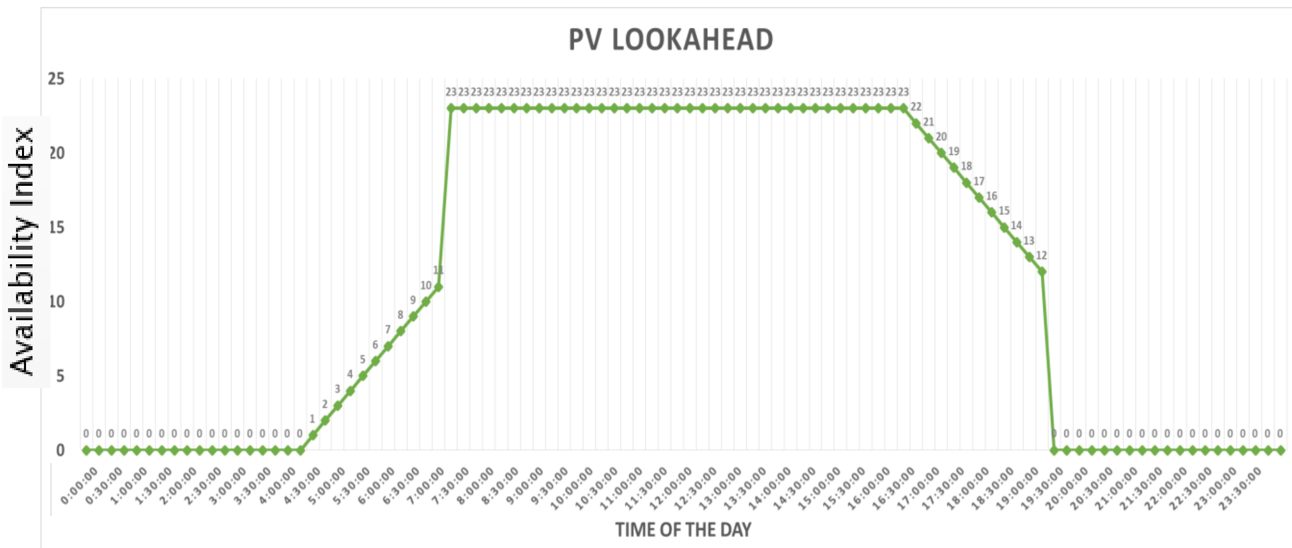

Figure 6.2: PV LookAhead for 24 Hours

6.1.3. Load Pattern

The Figure above shows the Domestic Load Profile of typical household .The load Demand profile is measured in KW for 24 hour Period. Form the Fig above loads vary for different times of the day. From 00:00 A.M to 5:00 A.M the load demand is 2000 KW, from 5:00 A.M till 11:00 A.M the load demands is 1000 KW, from 11:00 A.M to 5:00 P.M the load demands gets to 2000 KW, From 5:00 P.M to 11:00 P.M there is high load demand of 3000 KW that get lower to 2000 KW from 11:00 P.M onwards again.

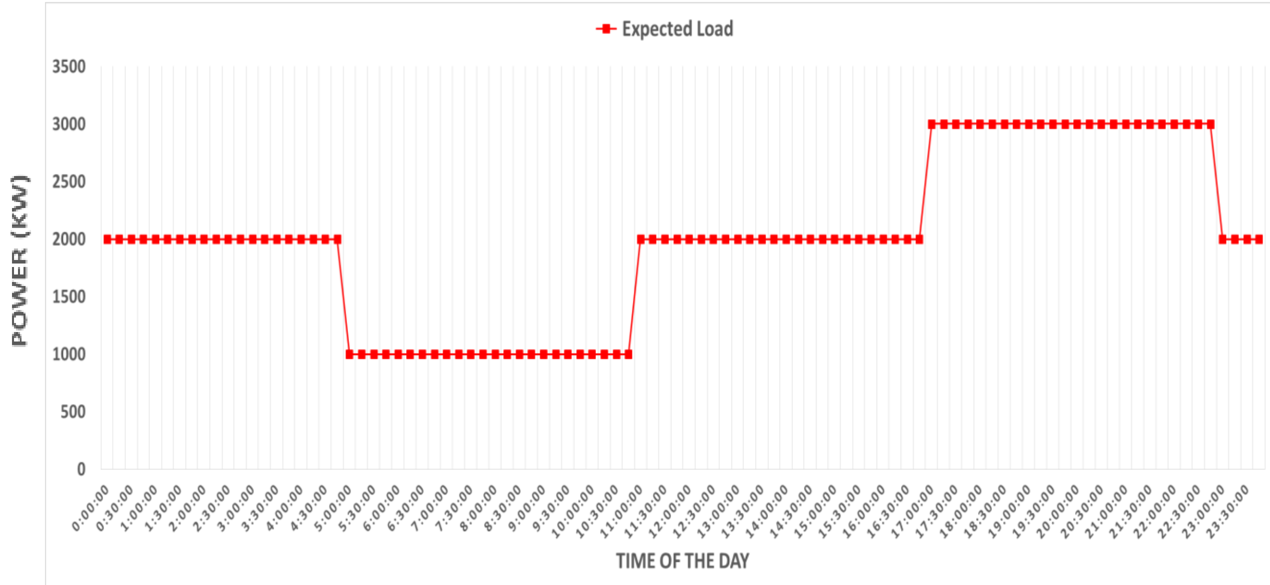

Figure 6.3: Load Profile for 24 Hours

6.1.4. Grid Pattern

The Figure above shows the Grid Availability pattern for 24 hour Period .The Grid Availability follows the pattern of 1 hour Load Shedding after every 3 hours (3-1-3). In fig above '1' represents the Availability of Grid at the current time slot while' 0' shows the non-Availability of Grid at current time slot.

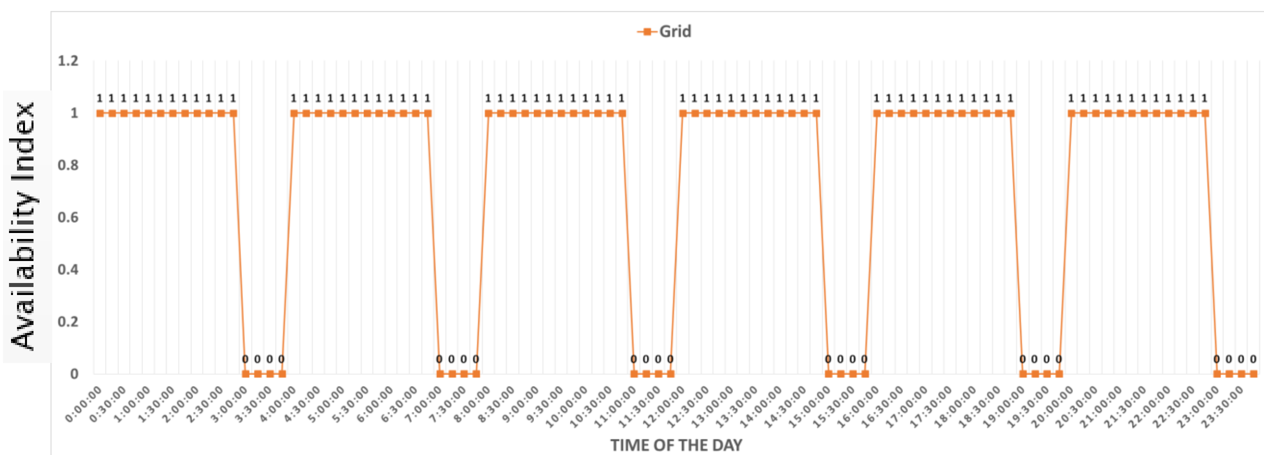

Figure 6.4:Grid Pattern for 24 Hours

6.1.5. LoadShedding Lookahead Pattern

LoadShedding Lookahead (LS) indexing (15 mins Interval for 24 Hour Total Period) is listed below

7. 0: Not Available for Next 1 hour
8. 1: Not Available for Next 45 min
9. 2: Not Available for Next ½ hour
10. 3: Not Available for Next 15 min
11. 4: Available for Next 15 min
12. 5: Available for Next 1/2hour
13. 6: Available for Next 45 min
14. 7: Available for Next 1 hour

8: Available for Next 1 hour 15 min
9: Available for Next 1 -1/2hour
10: Available for Next 1 hour 45 min
11: Available for Next 2 hours
12: Available for Next 2 hours 15 min
13: Available for Next 2 -1/2hour
14: Available for Next 2 hours 45 min

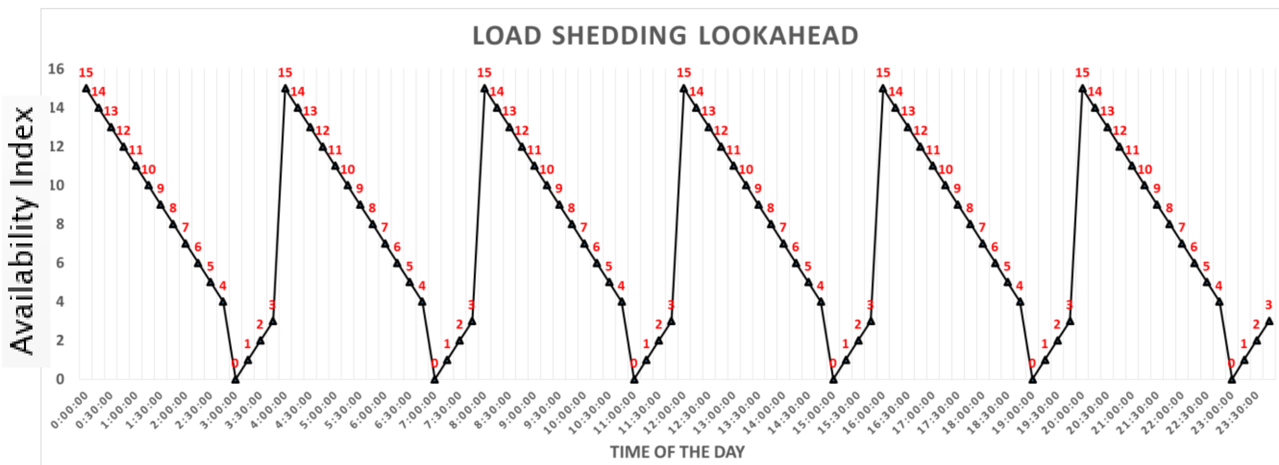

Figure 6.5: Load Shedding Lookahead for 24 Hours

6.2 Results Comparisons

These all test vector patterns are tested for each Economic, Availability mode also simulated in the lookahead based fuzzy Expert system. The results are then compared with that of the without lookahead case.

6.2.1. Battery Level

Battery level comparison is done Between the Economic Mode, Availability Mode, Fuzzy Lookahead and without lookahead mode and results are got for 24 hours that are illustrated below

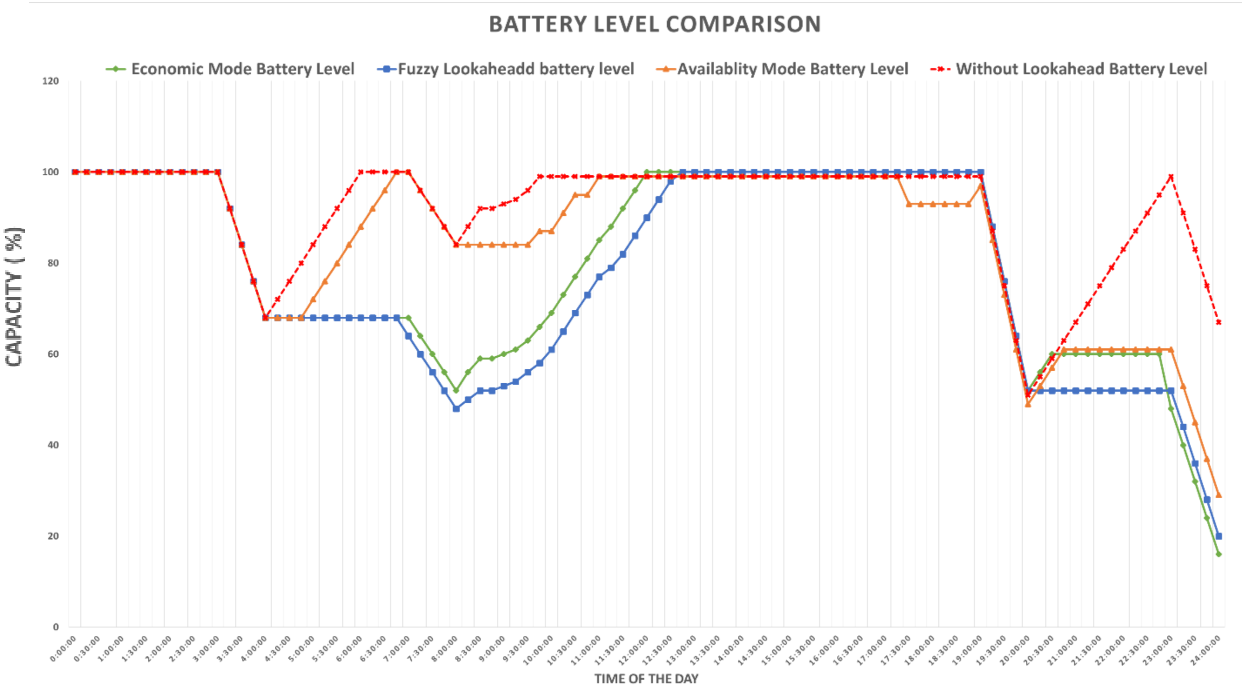

Figure 6.6: Battery Level Comparison for 24 Hours

The Battery Ending level in Economic Mode =16 %

The Battery Ending level in Availability Mode=29 %

The Battery Ending level in Fuzzy LookAhead=20%

Battery Ending level in Without Lookahead = 67 %

The battery is maximum utilized in proposed Heuristics while putting less load on Grid leading to reduction in Cost.

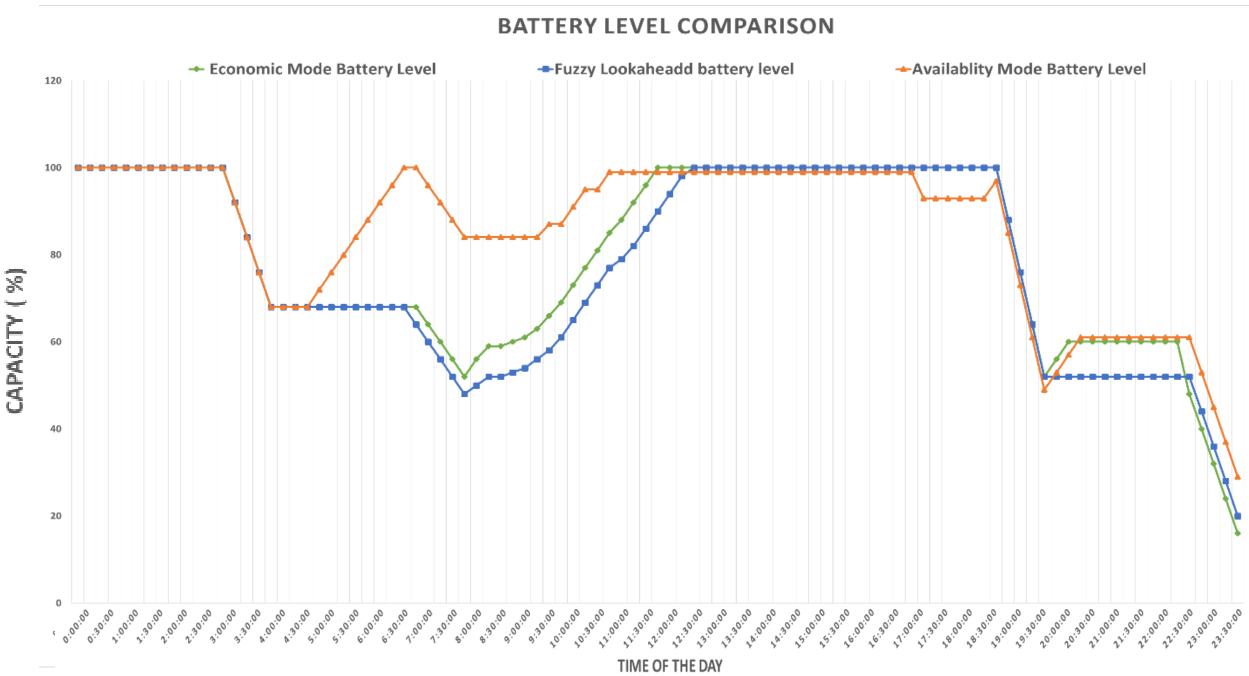

Figure 6.7: Heuristics Battery Level Comparison for 24 Hours

When comparison is done among the proposed heuristics the Maximum battery utilization is done in economic mode (ends at 16 % with minimum cost and Maximum Battery utilization).Minimum Battery Utilization is done under availability mode.

6.2.2. Electricity Cost

Grid Electricity Cost comparison is done Between the Economic Mode, Availability Mode, Fuzzy Lookahead and without lookahead mode and results are got for 24 hours that are illustrated below

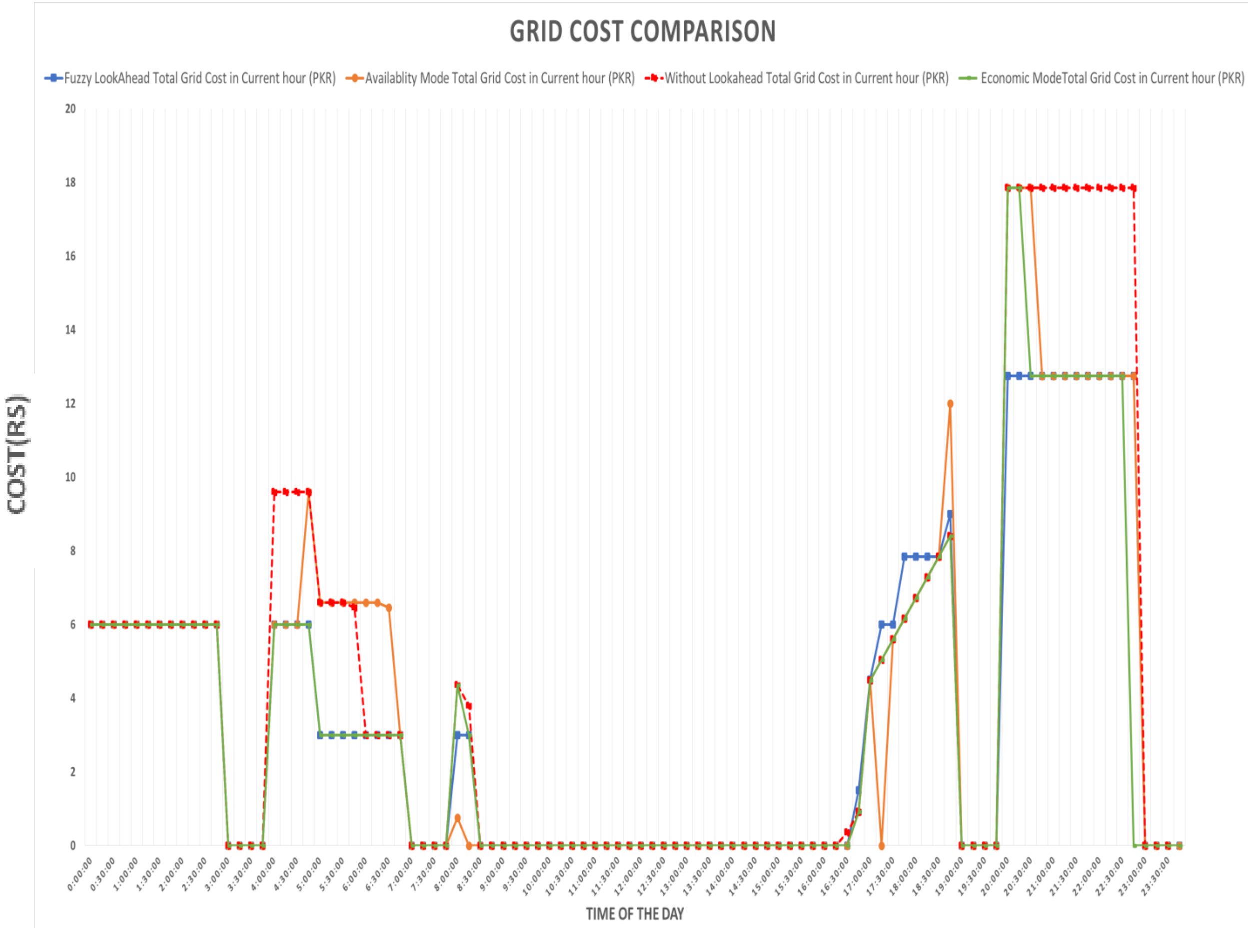

Figure 6.8: Grid Cost Comparison for 24 Hours

The Economic Mode Cost =Rs.330.237

The Availability Mode Cost=Rs.368.706

The Fuzzy LookAhead Cost=Rs. 337.368

Without Lookahead Cost= Rs.423.792

From the above Results it can be concluded that the lookahead based heuristics produce better cost effective results as compared to without lookahead approach results.

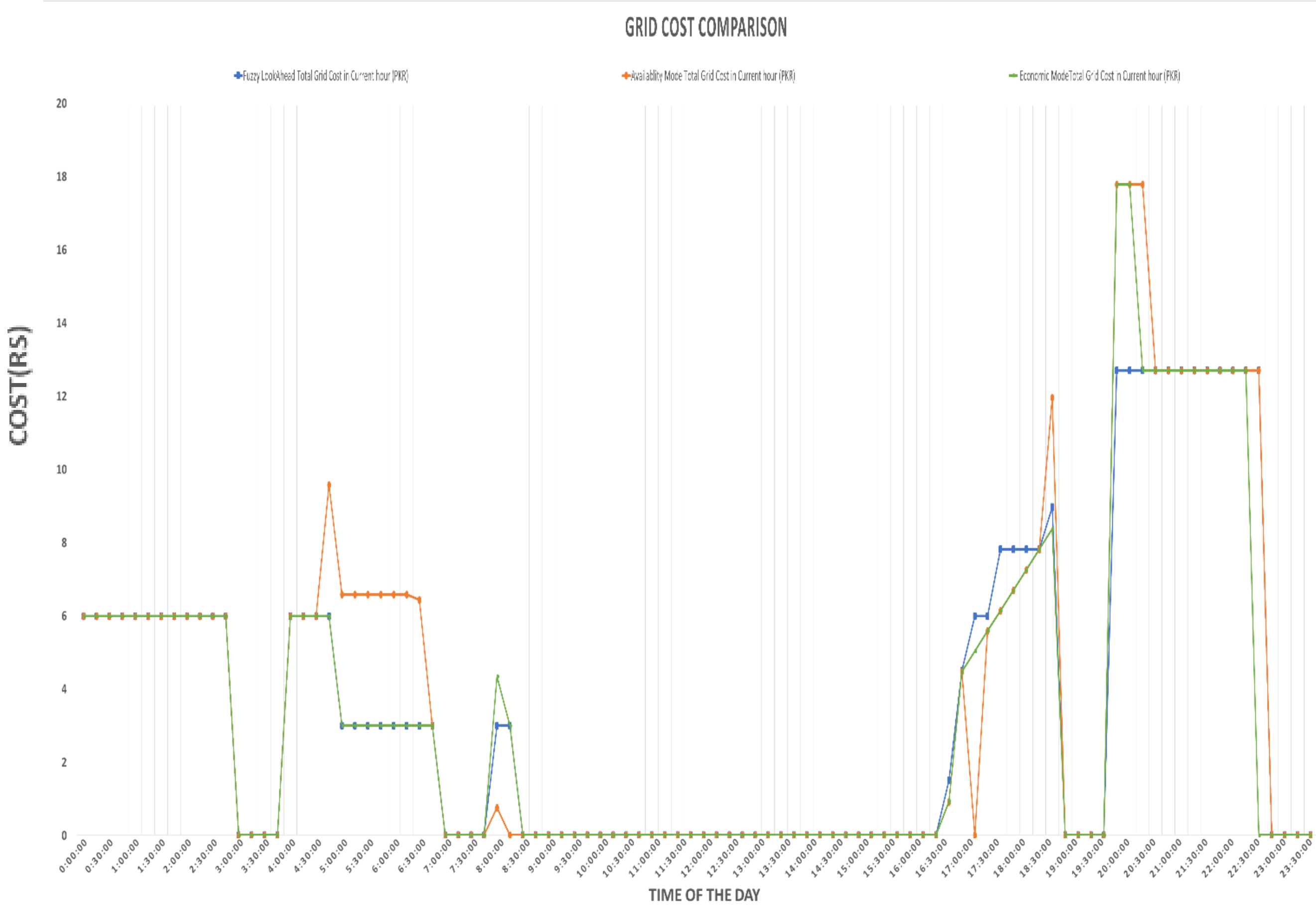

Figure 6.9: Heuristics Grid Cost Comparison for 24 Hours

When comparing among all the proposed Heuristics the Economic Mode gives the best optimal results with minimum cost and max availability and is the best Heuristics to be considered in Smart Flow Power Management in Nano Grid Homes

6.2.3. Grid_Usage Comparison of Best Heuristics with WithoutLookAhead

The figure below clearly shows that the Economic Mode Puts less on Grid as compared to Non Lookahead based approach that leads to cost effective results of economic mode

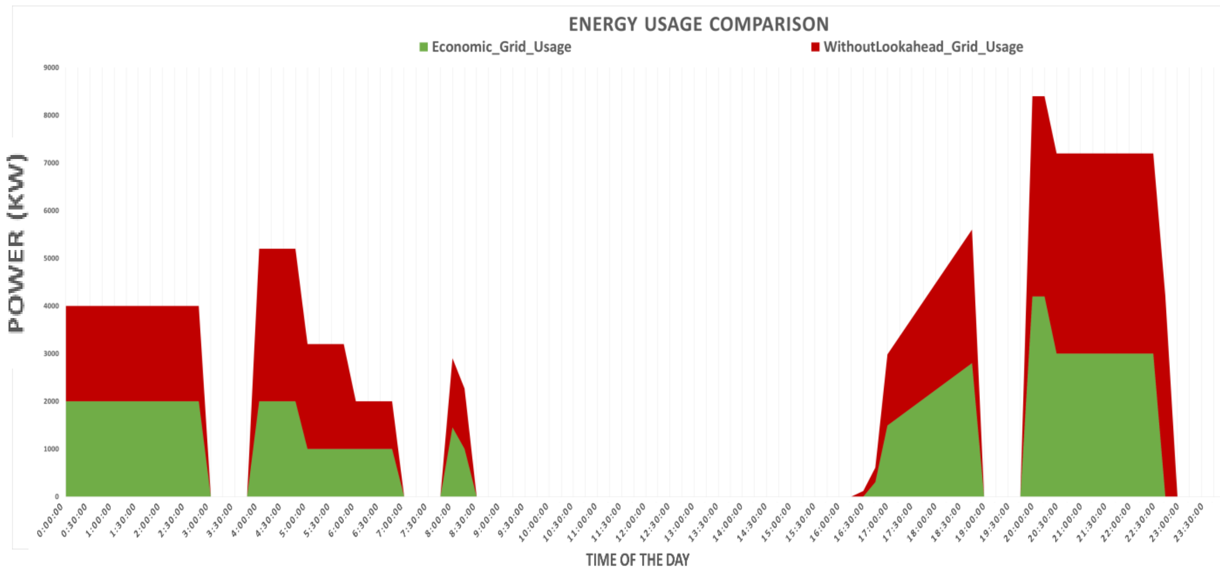

Figure 6.10: Grid_Usage Comparison of Heuristics with WithoutLookAhead for 24 Hours

6.2.4. Free_Energy_Usage Comparison of Best Heuristics with WithoutLookAhead

The figure below shows the Free Energy (PV+Battery) usage comparison among the Economic Mode and non Lookahead mode ,which clearly shows the max utilization of the free energy sources under economic mode.

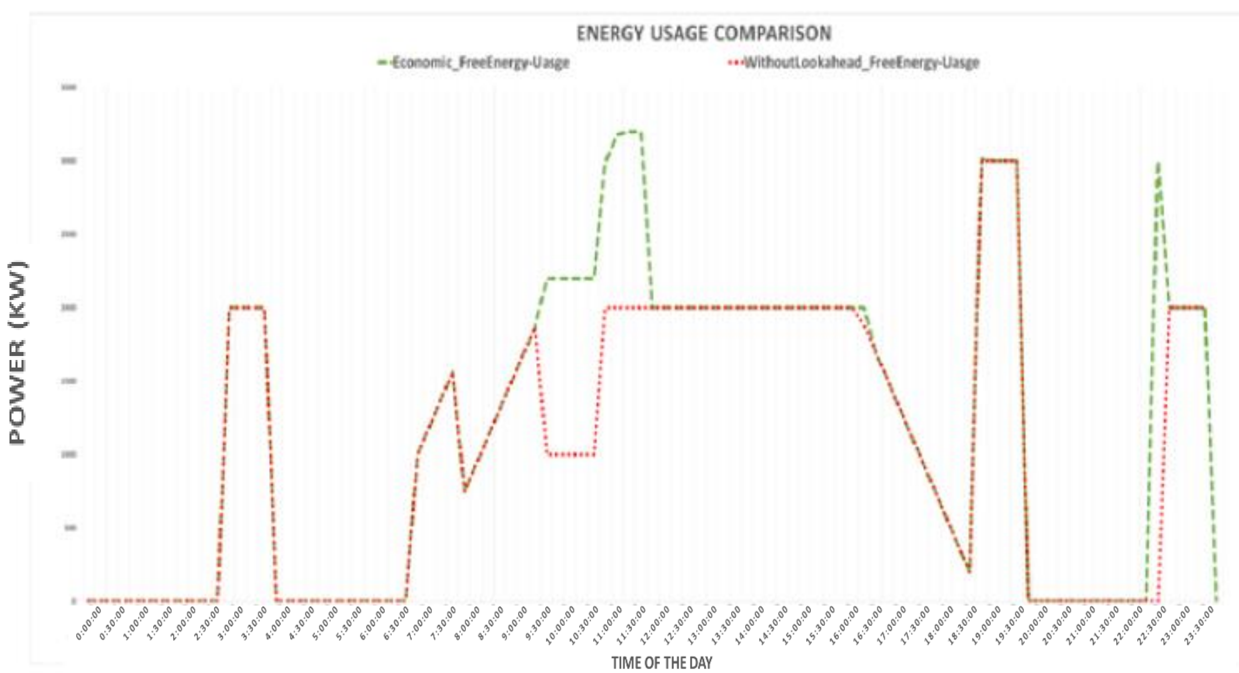

Figure 6.11: Free_Energy_Usage Comparison of Heuristics with WithoutLookAhead for 24 Hour

CHAPTER 7

CONCLUSION

7.1 Conclusions

With the growing electricity demand and concern for the production of fossil-fuel resources have paved the ways towards strong research to set up enhanced energy system with the assistance of DG resources like PV Power preserved by Energy Storage systems. The main aim of this work was to provide the optimized power scheduling that reduces the owner's energy bill over the period and provided an optimized smart flow also.The objective was to minimize the cost linked with acquiring from (or selling back to) the grid,while meeting the load demands and reducing the peak electricity buying from the Grid.

Thus Research suggested the heuristics based on Look Ahead Approach by Direct Mapping Approach Implementation including Availability Mode, Economic Mode and also Artificial Intelligence (Fuzzy Logic) Approach, all based on forecasting provides an optimized Power Flow Management in Smart House while keeping into consideration the two major issues faced that are Peak Pricing Hours and Load Shedding Hours (Most Common in Pakistan) The results of this work showed that the proposed Look-ahead based heuristics for Energy Flow management helps achieve the economic goal for providing Consistent Energy Power 24/7 at economic cost as compared to the conventional methods followed earlier.

The effectiveness of these Heuristicsstrategies has been tested by using Test vector data set implemented and tested in Java and the results showed that the lookahead based approach can provide better cost effective results as compared to the conventional non-lookahead approach by optimally utilizing the Battery Energy and PV power and putting less load on the Grid .The solution would help achieve and provide an optimized solution to the Energy Management in Nano Grid based smart Homes. The results also demonstrate that the proposed system producescost effective savings while providing reliable electricity service in era of extensive blackouts and Critical peak pricing market issues.

7.2 Contributions

The main contributions of this thesis are

- It provided Lookahead based Heuristic Strategies to optimally handle the Energy Power Flow for Smart Grid House.

- Effectively handled the Critical Peak Pricing and load Shedding market issues
- Provided Better Cost Effective Results by providing 24/7 Electricity at economic cost
- Comparison with the conventional without lookahead approach is also carried out.

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Publications

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