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Fuzzy Logic Based Smart Home Energy Management System

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ABSTRACT
PowerdemandinIndiaandintheworldisincreasingdrasticallywhichultimatelyleadstothesupplydemand mismatch. The new demand management techniques areadopted in order to curtail the load demand during peak times.These demand side management techniques such as load basedcontrol and the price based control will hinder the freedom of theuser. Hence there is a necessity to develop a system which willdetect the peak times or supply power shortage times and do thenecessary action so that the consumer do not face any issue. Thesystem developed will address the problem discussed in order tobring down the supply demand mismatch. The system as a wholeconsists of two modules, a load forecasting module which willforecastthenextdayload ofthesmarthomeand an energycontrol module which will accept the inputs that are required forthecontinuouspowersupplyduringpowerfailurewithalsoeconomicutilizationoftheenergy.Thedevelopedfuzzylogicsystem is tested for the various conditions of the input in theMATLAB/Simulink environment with the varying input such aselectricitypriceoftheday,loadforecastedfromtheenergycontrol module, state of charge level in the battery and the supplypower availability. The outputs such as charging rate and supplyof power are obtained and compared with the normal residencewithout the energy management system. It was found that withthe implementation of the developed system, the user can enjoycontinuouspowersupplywith theeconomicutilization oftheenergyresulting inthereductionofelectricity cost.

Keywords:HomeEnergyManagementSystem,ChargingRate,StateofCharge,Fuzzy Logic,MembershipFunction

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I. INTRODUCTION

The power demand in India and the world is increasing in anexponentialfashionduetheadventandintrusionofmanyelectronic components in the lives of the people. The use ofelectronic gadgets will increase the demand for the supply asthe energy is required to charge the batteries of such devices.Thedemandforthesupplyoftheelectricalenergyisincreasing day by day whereas the generation of the electricalenergy is decreasing rapidly due to unavailability of the fossilfuels. The issue of supply demand mismatch is viewed as aseriousconcernbythe supplycompaniesas the demand onthe stationwillharm thegeneratingstationsif enoughfuelorinputisnotavailable at thetime required.

To combat these problems, the electricity supply companies inmanywesterncountrieshavestartedseveraldemandsidestrategieswhichwilleasethepressureonthegeneratingstations at the peak time when the demand exceeds the supplyimmensely. The demand side management which are carriedout by the ESCOMS (Electricity companies) are ranging fromtheDirectLoad ControltothePricebasedControl.

Price based control is a strategy where the consumers arecharged more than the fixed charges per unit during the peakdemand times and charge below or given incentives during theunutilizedorduringtheoffpeaktimehours.Hencetheconsumer needs to effectively use his loads during the peaktimeinordertoeconomicallyutilizetheelectricalenergywhichissuppliedbytheelectricitycompanies.

The main idea of this research is to build a control systemwhichwillmaintainacontinuouspowersupplyfortheuserandalso reduce the electricity cost by using the alternate form ofelectricalenergyduringthepeak time.

II. LITERATURE SURVEY

A. .LiteratureReviewonLoadForecasting

Load forecasting is a research theme which is mostly focusedfrom the generation aspect. Load forecasting is carried out inorder to understand the demand in the next five to six years sothattheadditionalequipmentcanbeaddedtothepowersystemtomeet the demand.

Inthepresentcontext,loadforecastingiscarriedoutinorderto charge the batteries in the energy control module only to therequired level. Also if load forecasting module can provide thevalues of the load of the household prior to twenty-four hours,the controller would be able to decide to switch the powersupply from the electricity board to the battery source in thetimesofpeakdemand inordertoavoidhighcharges.

In [1], load forecasting model is discussed to the dynamicpricing model power system which is also based on the factorof reducing the load on the power system and also economicusageofelectricalenergybytheconsumer.Theliteraturefirstdiscusses the pricing models like real time pricing, time of useprice and critical peak pricing in detail. Then the differentmethodsofloadforecastingsuchasstatisticalbasedloadforecasting and artificial intelligence-based load forecasting isdiscussed.

In[2],theauthortalksabouttheloadforecastingfortheHEMSapplication.Theloadforecastingishelpfulinschedulingthe operationoftheESS.Basedonthedataobtainedintheloadforecastingmodule,thecharginganddischarging of the batteries are done in order to reduce theelectricity cost and to continuously supply the electricity whenin high demand. The paper converses the different types offorecastingmethodsavailablefortheshorttimeloadforecasting taking into account of all the subsequent factorsintoaccountlikeaccuracy,timerequired tosolveetc.

In [3], the author has implemented a fuzzy based forecastingmodel for a power system based in the history data available.The fuzzy based system is used in the load forecasting modelasthedecisionstakenbytheloadforecastingmodelisdependent on the rules which are already formed in the rulebases. The rule base of the fuzzy systems can be formed by theexpert knowledge in the domain. The rules are firstformedand are entered into the fuzzy inference engine. Then the rulesare tested for all possible values of the input. If the outputobtained is not desirable, the rules are updated in the inferenceengine.

B. LiteratureReviewontheEnergyManagementTechniques

In [4], the HEMS is developed taken into the account of gridsupply availability, tariff of the electrical energy, SOC of thebattery andtheavailability of therenewableenergy sources.To carry out the research, the authors have built a model houseon 35 sq.mm plot which simulates the real life conditions forconsumption of the energy. The built house is equipped withthe roof top solar panel for the supply of the energy to thebattery. The loads are again classified into critical and non-critical where all the previous literature had done so far. Eachsimulation is carried out taking into account of the loadingprofileoftheequipmentandtheinputfactorswhichismentioned above.

In [5], the literature discusses the control of the energy flowduring peak and the off peak times through the grid and fromthe battery. The literature also discusses the integration of thePVand the storageina smarthome.

The PV cells are usedto charge the batteries during peakhours and during off peak hours, supply from the electricityboardisusedastheinputtothechargingofthebattery.Microcontroller based control system will take the decision ofcharging of the battery and the energy flow by taking intoaccount of the peak hours which is already communicated adaybefore.

In [6], the literature talks about the optimization of costconsidering the user comfort level into picture. The user haschoice to enter the criteria of selection of equipment accordingto theneed base. The various optimization algorithmslikegame theory, PSO, GA and MDP have been discussed in theliterature.

The literature also speaks about the conditions like on gridmode and off grid mode. In on grid mode, the HEMS eitherreceives or supplies energy. The off grid mode is a conditionwhen there are any outages and problems in the power systemand the HEMS is not able to communicate with the powersupply company. Hence the HEMS utilizes only the energysupplied by the renewable sources. The HEMS is implementedusingtheMDPalgorithmtakingTOUpricingmodelintoconsideration. The maximum charging rate of the batteries areconsidered tobe onetenthofitsratedcondition.

III.DESIGN OF SMART HOME ENERGY MANAGEMENT SYSTEM

A. FuzzyLogic

The block diagram in Fig.1 shows the fuzzy logic systemwhich contains all the modules required for obtaining a controlofaparticularsystem.Theinputsandtheoutputsofthesystemare always crisp inputs, but for processing inside the fuzzyinference engine the values are converted into the fuzzy inputsusingfuzzificationinterfaceanddefuzzificationblocks.

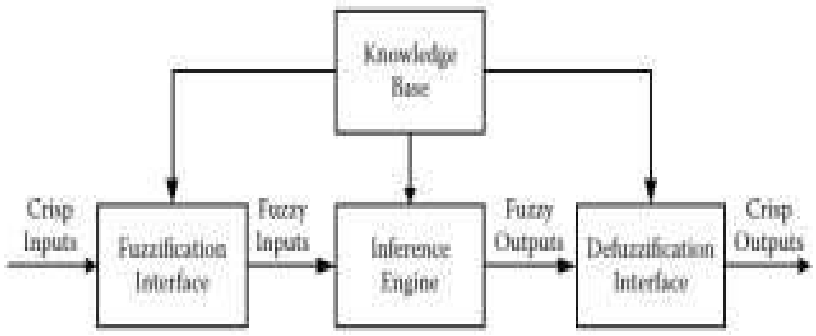

Fig:1Fuzzy LogicBlockDiagram

B. MembershipFunctions

Membershipfunctionsarethevalueswhichgivesthevalues of the degrees of the truthfulness to the universe ofdiscourseoftheinput.Theinputrangewhichisnormallyrepresented on the x axis is defined a relationship between thetruth and false value by using a membership functions. Thechoice,shapeandnumberofmembershipfunctionsareusuallya choiceofafuzzylogic designer.

Therearevariousshapesofthemembershipfunctionsavailablefortheusesuchassingleton,Gaussian,Gbell,Gaussian 2f etc. The curve which represents the membershipfunctionsaredenotedbytheGreekletterμ. Thedifferentmembershipfunctionsrequiredifferentparametertobedefined.

C. Fuzzification

The fuzzification is a process of converting the real valuedinputvariablesintothecrispvaluesusingthedefinedmembership functions. The fuzzification process is carried outby the fuzzifier which is at the input stage of the fuzzy system.Fuzzy sets have a set of boundary values without crisp values.Itcancontainelementsonlywithapartialdegreeofmembership.FuzzysetAofuniverseXisdefinedbyafunctionμ A(x),calledmembershipfunction, forsetA

$\mu A(x): X \rightarrow \{0, 1\}$, where $\mu A(x) = 1$ if x is totally in A;$\mu A(x)=0$ifxisnotin A;$0<\mu A(x)<1$ifxispartlyinA;

D. EvaluationofRules

Fuzzy logic operations are carried out based on the rules thatdefine the inputs. The fuzzy set rules are compliment to thenormal crisp operation rules. The normal crisp rules are AND,ORandNOTfunctions.Hencethereshouldbeafuzzyequivalent of the said functions which operate on the degree ofthe truthfulness. The equivalent rules for AND, OR and NOTfunctions are min, max and compliment functions. These canberepresentedbythefollowingequations as:-

$\mu AUB(x) = \max[\mu A(x), \mu B(x)]$

$\mu A\cap B(x) = \min[\mu A(x),\mu B(x)]\mu\bar{A}(x) = 1-\mu A(x)$

E. FuzzyBasedLoadForecastingMethod

This section discusses the design of a fuzzy logic system fortheloadforecastingmoduleoftheSmartHomeEnergyManagement System. The load forecasting module will acceptthe inputs such as previous day load, time of the day and thetemperature to predict the load of the next day. The nonlinearrelationship which exists between the inputs and the outputscan be modelled using the fuzzy logic system which can bemodelledusingthefuzzylogicrule base.

Load forecasting technique which is usually carried out inthe power system level takes into consideration the time of theday,temperatureandsimilardayloadconditionsintoconsiderationastheforecasteddaydependsonallthementioned factors.

As time and temperature increases, the load on the powersystem increases which is conventionally followed in manyhouse hold. As the temperature increases, people tend to usethe air conditioner more. Hence the load on the power systemincreasesrapidly.TofacilitatetheloadforecastingintheHEMS, same concept is used wherethe inputs to the systemremainssame as discussed above.

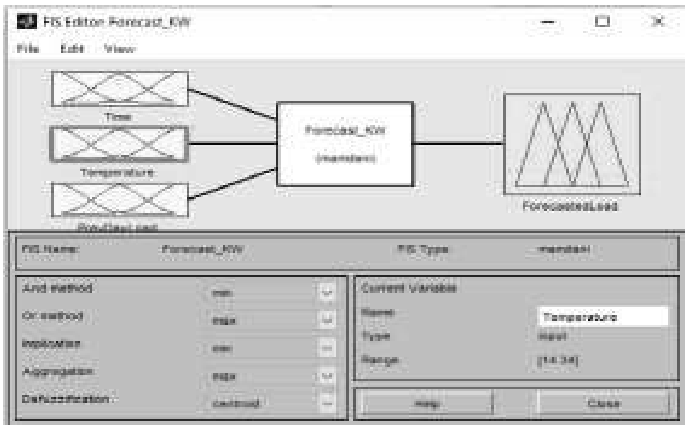

Fig:2DevelopedLoadForecastingModule

Theinputdataset,timeofthedayisdividedintofivemembership functions which are in the range of 0 hours to 23hours.

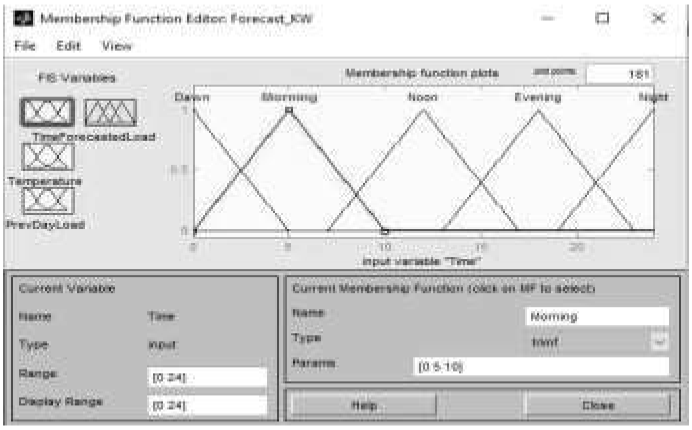

Fig:3MembershipFunctionofTime

The next input data set, temperature is also divided into fivemembershipfunctionsfromtherangeof14to34degreeCelsius

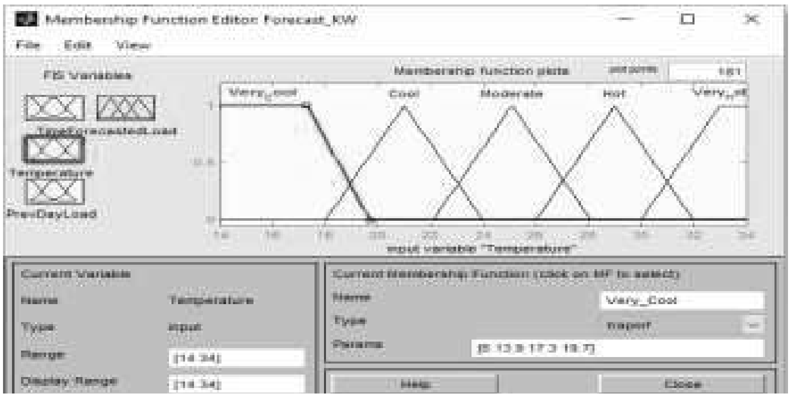

Fig:4MembershipFunctionofTemperature

The last input data set which is similar day load is ranging from the 800 Watts to the 2400 Watts is divided into the five membership function

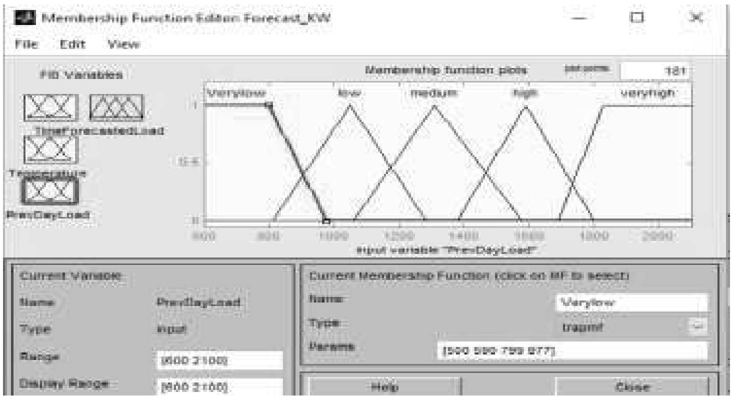

Fig:5MembershipFunctionofPreviousDayLoad

Theoutputdatasetwhichneedstobeobtainedfromthecombination of the input data set is as also in the similar rangeas of the input similar day load and is also divided into fivemembershipfunction.

A. FuzzyBasedEnergyControlModule

Oncetheforecastedloadisgeneratedfortheparticularresidence for the next day, the electricity price for the same isalso obtained from the electricity supply board. The pricingmodeladoptedhereisassumedtobeofdynamicpricingmodel type and the prices of the next day is already availabletothe userprior totwenty-four hours.

Theinputstothefuzzylogicsystemisasfollows:-

1) ElectricityPrice
2) ForecastedLoadDemand
3) Stateofcharge ofthe Battery
4) SupplyPoweravailableatthebattery

Theoutputsofthedesignedfuzzylogicsystemaregivenbelow: -

1) Chargingrateofthebattery
2) Switchtoelectricitysupplyboardpower
3) Switchtobatterysource

As the system should take decisions for the charging thebatteries before in hand to switch from the electricity boards,future values are taken in the inputs for the load demand andthesupplypoweravailability.Todecidetheamountofhourstobe taken as the future input of the system, batteries are takenintoconsideration.

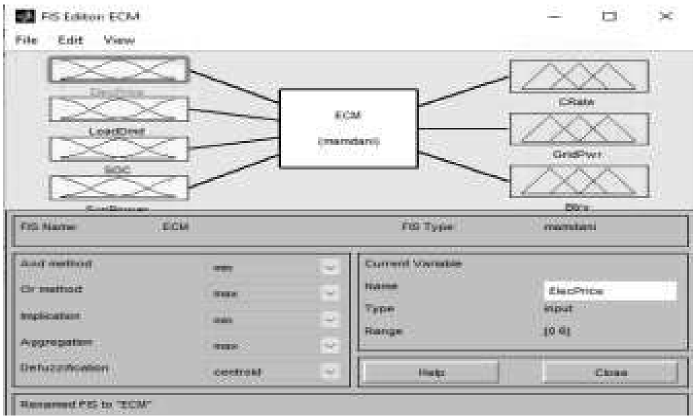

Fig:6DevelopedEnergyControlModuleusingFuzzy

Theinputelectricitypriceisdividedintothreemembershipfunctionsas low,mediumand high.

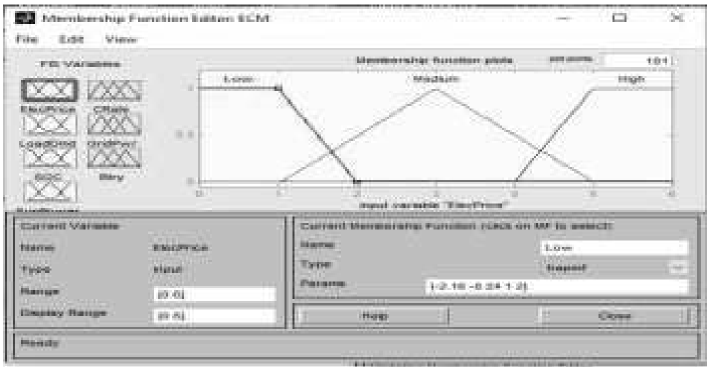

Fig:7Membershipfunction ofElectricityPrice

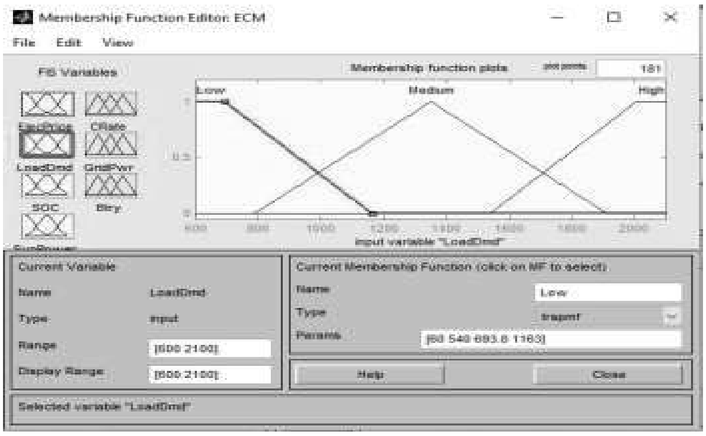

Fig:8MembershipFunctionofLoadDemand

Thefourthinputthesystemisthesupplypoweravailability. The electricity company gives information for thesame before in hand for the consumer. As the possible valuesofpoweravailabilitycaneitherbe1or0,thesingletonmembership function is used at two values of 1 and 0. Thesameis shownintheFig.9.

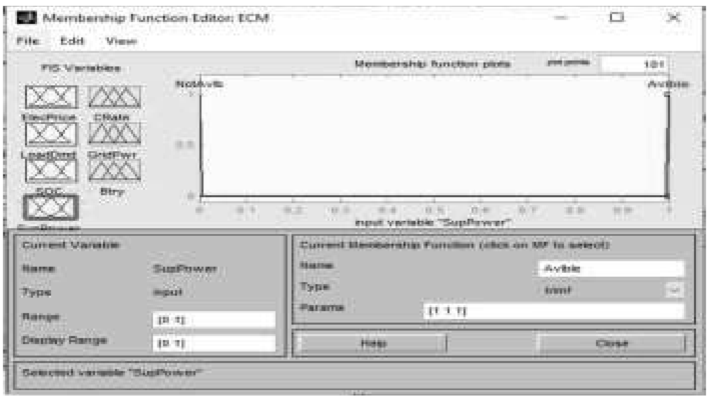

Fig:9MFofSupplyPoweravailability

The outputs of the system are the rate of charging thebatteries,connectionfromthegridandtheconnectionfromthebattery. Its membership functions are as shown in the belowFig.10and11.

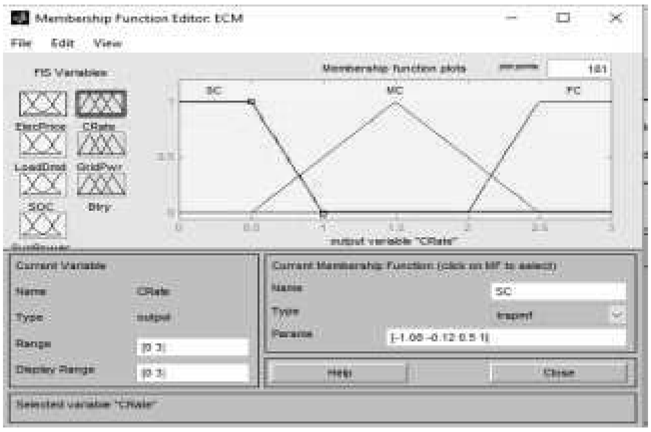

Fig:10MembershipFunctionofChargingRate

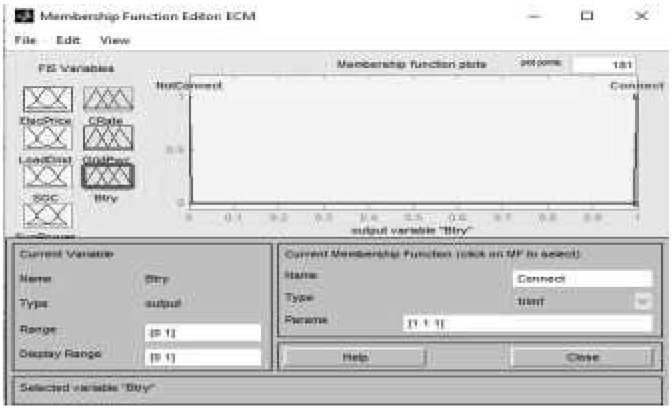

Fig:11MembershipFunctionofConnectiontoBatteryPower

III. TESTING OF DEVELOPED SYSTEM

The load forecasting model which is designed in the fuzzylogictoolboxistestedusingtheSimulinksoftware.Theinputsto the system is provided using the constant blocks and theoutput of the system is obtained using the display block as inFig. 12. The data for testing the load forecasting model such asprevious day load and time has been taken reference from the[7].

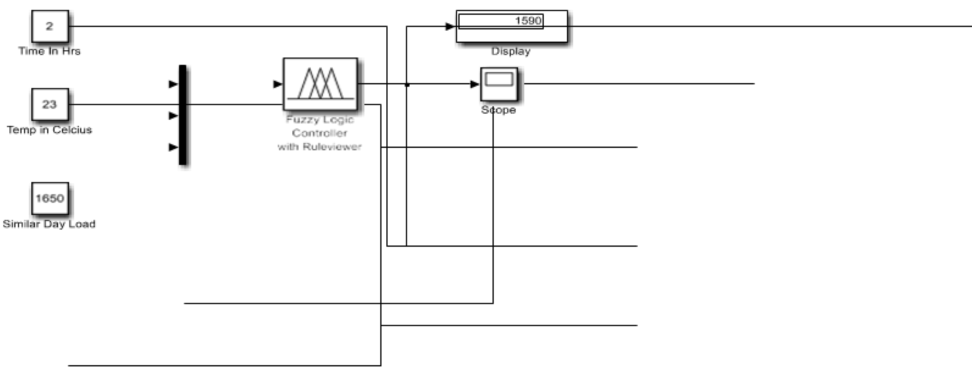

Fig:12 TestingofLoadforecastingModule

The testing of the energy control module is also done using theSimulink where all the inputs are given as the constant blocksandtheoutputsareobtainedusingthedisplayblock. The SimulinkblockdiagramdesignedinordertotestthefuzzylogicdiagramisasshowninthefollowingFig.13.

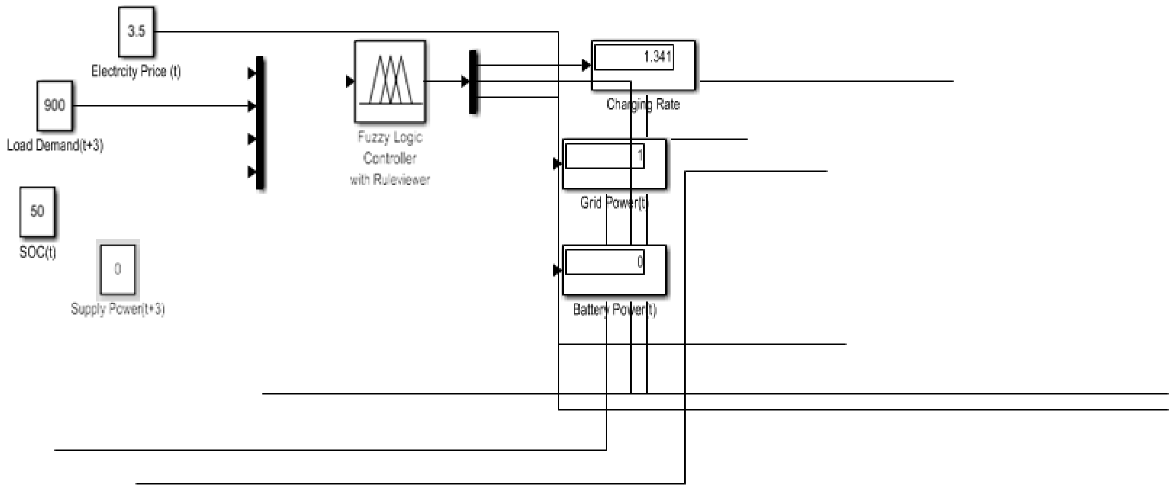

Fig:13 TestingofEnergyControlModule

Theinputdataset,theelectricitypriceandthesupplypowerisobtainedfromtheelectricitycompanyandisshowninthebelowFig.14.

Fig:14DayAheadElectricityPriceobtainedfromEB

ThemaincriteriaoftheHEMSdesignedistosupplycontinuous electricity supply keeping energy cost in mind inthedynamicpricingmodel[8].Thesystemshouldalsoeconomically charge the batteries and make it ready in theperiods of non-availability of the electricity or periods of highpeaktime.

Fig:15ElectricityConsumptionwithoutSHEMS

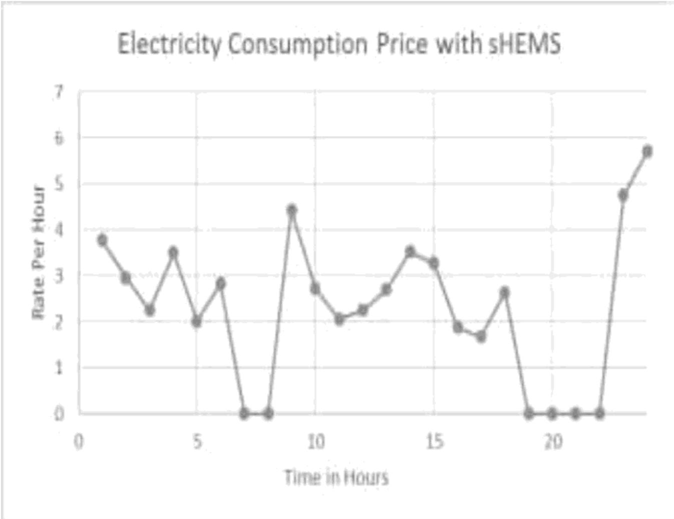

Fig:16ElectricityConsumptionpricewithSHEMS

It can be clearly compared from the above Fig. 15 and 16that the electricity consumption rate is zero in the periods ofhighpeakenergyprofileasthesystemwillswitchtothebatteryconsumptionasperthealgorithmdesigned.

The charging rate of the battery is also considered to be invariableaspertheelectricitypriceandthesupplypoweravailability.Asdiscussedearlier,thechargingrateofthebatteryisvariableandhencethelifetimeofthebatteryincreases.

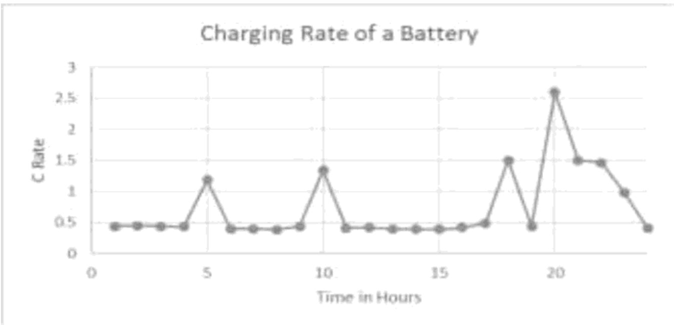

Fig:17ChargingrateoftheBattery

TheFig.17showsthereductionintheelectricitypricebyatleast40%inthehouseholds whichemploytheSHEMS.

IV. CONCLUSION

The smart home energy management system is necessary inthe field of Indian domestic energy consumption where theconcept of dynamic pricing model is yet to be introduced. Theenergy management system should also be able to guaranteethe supply at all the times. The load forecasting module is firstdevelopedusingthefuzzylogicsystemwhichtakesinputfrom the past history and generates the future load curve of thehouse. The data which is obtained from the load forecastingmodule is then taken as a reference with other inputs to theenergycontrolsystemwhichwillcontroltheflowoftheenergyinthe smarthome.

Thesmarthomeenergymanagementsystemtakesintoconsideration of nonlinear system of inputs and takes action insupplyingtheelectricalenergycontinuouslywhilealso reducing the cost. This is performed using the energy storagesystemavailableinthesmarthomeandthuschargingthebatteryonlyto the requiredlevel.

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