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Artificial Intelligence - Smart Energy Distribution and Management System for small autonomous Photo-voltaic Systems

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***Abstract* – In today's world, with the decrease in the coal and other conventional sources of energy, the need of the hour for the use of other renewable sources of energy has arisen. The untapped potential of the renewable sources of energy like the wind and solar energy which when used to the full extent, have the potential to become a major boon to the ever increasing power demand. When used in combination with the newer trends of technology like Artificial Intelligence and neural networks, they can be used in the development of smart energy management systems that can be used in decreasing the energy expenditure.**

This paper analyses the design of a smart energy management system that is used to limit and conserve the excess power consumption from the grid by a domestic household by the use of a stand - alone solar panel system. The excess energy required by the system above a particular threshold value of consumption from the grid can be supplied by means of wireless transfer of power from the load along with the consumption by the standalone and the domestic systems being monitored by means of Power Line Communication (PLC) and Neural Network algorithm.

Keywords— Photo-Voltaic Generation System, Power Line Communication, Wireless Power Transmission, Deep Learning, Neural Networks, electric vehicles.

I. INTRODUCTION

In today's world, the renewable energy sources find applications ranging from acting as large sources of power such as solar or wind farms to small scale supplementary applications such as in hybrid vehicles. As such, a photo-voltaic system can be used both as an on-grid and off-grid (autonomous) system. The batteries form an integral part of the PV system since the excess power generated needs to be stored for later use. In case of large scale systems, the batteries are placed far away from either the load or the Photo-voltaic Generation System. As such there is a loss in the transmission of power. Furthermore, there is a need for the use of dedicated lines (or networks). But as mentioned above, the major disadvantage arises when it is being used for large systems where the length of the communication channel increases drastically due to the use of individual communication lines.

A Power Line Communication (PLC) system is proposed in order to avoid the the issue of dedicated wiring for communicating with these BMS by the use of Ziggbee modules to transmit the power transmission between the Master and Receiver (Transmission) modules. The Transmission module comprises of a separate solar panels which acts as supply to charge the Primary battery (as a supplement to it). This is controlled by the master module which is supplied by an individual supply. In case of an energy defect - Power shortage, the power in need can be supplied from the primary storage battery via Wireless Power Transmission using Radio waves. [6][12]

The availability of the charging charging stations is a major cause of concern or hurdle in today's development. Thus, the wireless transmission systems can be used as a solution for this problem by setting up autonomous PV charging stations operated wirelessly for electric and hybrid vehicles. Furthermore, it will be a major boon in the case of smart buildings and smart walls for supplementing the shortage of power Wirelessly between buildings as there is no separate wired setup that has to be fixed each time during transmission process. Another advantage is that the small household products like torches and lamps can be made smaller in size since the need of a separate storage element (battery) and wired connections are eliminated. [2]

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II. AI BASED SMART ENERGY MANAGEMENT SYSTEM

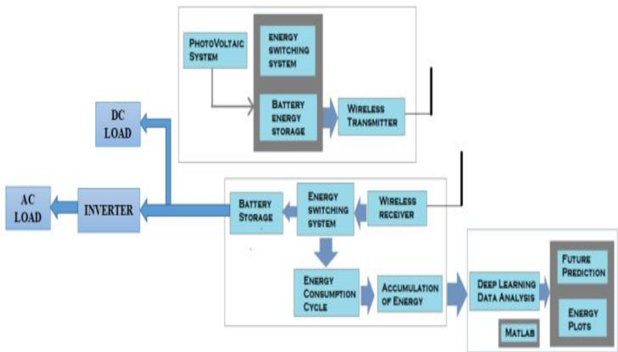

Fig. 1. Block Diagram of the Smart Energy Management System.

A. General Description of Solar Panels

Fig. 2. A typical 3W Solar Panel

A photo-voltaic system generally includes a panel or an array of solar modules, a solar electrical converter, and typically an electric battery and/or solar tracking device and interconnection wiring. A solar module will be able to solely generate a restricted quantity of power, most installations contain multiple modules. Most of modules use wafer-based crystalline semiconductor - Si cells or thin-film cells oriented cadmium telluride or semiconductor - Silicon.[1]

Cells must be protected against mechanical harm and wetness. Most solar modules are rigid, However, semi-flexible ones are on the market, based on thin-film cells. Electrical connections are created serially to realize the desired output voltage and/or in parallel to achieve the desired current capability.

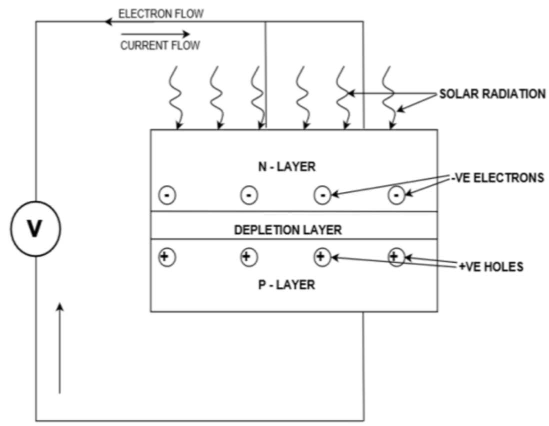

Fig. 3. Schematic diagram to represent the working of a Solar Cell

B. Power Line Communication

The process of communication between two nodes in a power line by the use of the power line itself is known as power line communication. This is achieved by the use of a separate transmitter and receiver module to transmit the RF signals across the line. The data is transmitted by the means of a particular encoding or communication protocols by varying the frequency of the RF signal. The RF signal is sent across the line by multiplexing it with the power signal at the transmitter end and de-multiplexing it at the receiver end. [15][19]

This mode of communication is standardized into different standards that specify the type of encoding used, frequency of the RF signal etc.

TABLE I. THE DIFFERENT STANDARDS OF PLC [1]

Standard	Technology	Frequncy Band	Bit Rate (kbps)
G3-PLC	OFDM	36-90.6KHz	5.6-45
PRIME	OFDM	42-89KHz	21.4-128.6
IEEE P1901.2	OFDM	9-500KHz	Coming soon
ANSI/EIA 709.1,.2	BPSK	86,131KHz	3.6-5.4
KNX	S-PSK	125-140KHz	1.2
IEC61334	S-PSK	CENELEC-A	2.4

TABLE II. NARROWBAND PLC FREQUENCY RANGES FOR VARIOUS REGIONS

Region	Regulatory Band	Frequency Band	Note
Europe	CENELEC	3-95KHz 95-125KHz 125-140KHz 140-148.5KHz	A-Energy providers B-Reserved for users C-Reserved for users,regulated CSMA access D-Reserved for users
Japan	ARIB	10-450KHz	
China	EPRI	3-90KHz 3-500KHz	Not Regulated
USA	FCC	10-490KHz	

Where:
CENELEC - European Committee for Electrotechnical Standardization.
ARIB – Association of Radio Industries & Businesses
EPRI – Electric Power Research Institute
FCC – Federal Communications Commission [1]

C. Wireless Power Transfer

The transfer of power between two points (or two circuits) wirelessly without the use of dedicated lines and any physical link between them is known as wireless Power transfer. This is achieved by the use of a transmitter which is driven by a separate source of power, that is transferred across the medium of space to the receiver which is used to extract the power and convert into a usable form that is used to drive the load (i.e. supply it).[14]

The techniques for the process of wireless power transfer are classified as
1. Near-Field or the Non - Radiative techniques that is used to transmit power for short distances by means of inductive or capacitive coupling.
2. Far-Field techniques that are more commonly called as Power Beaming which is used to transmit power to longer distances via electromagnetic radiation like microwave or lasers.[8]
Among these methods of the transmission of power, the resonant coupling is found to be the most efficient one. In this case, the power is transferred between two coils that are magnetically coupled to each other and are operated in the resonant condition. However, maximum transfer of power and efficiency is achieved only when the two coils are placed at such a distance that is less than the total diameter of the coils and the coils must be aligned to each other i.e the are placed one above the other. [10][11][13]

In a sense, the act similar to a transformer with air core medium - like an Air Core Transformer. The major advantage of the wireless power transmission are
• The need for dedicated wiring is reduced or removed completely.
• The size of the batteries and other power storage elements is decreased since the can be charged wirelessly and hence reduce cost of production.

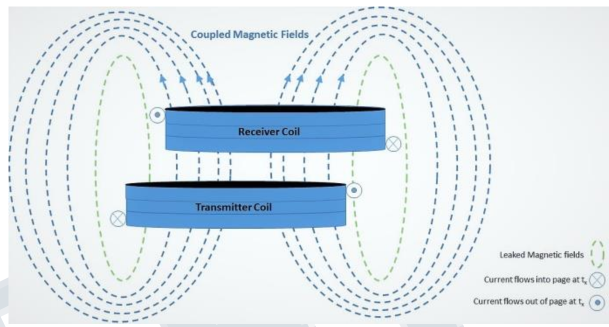

Fig. 4. Wireless Power Transmission between two coils.

D. Neural Networks And Deep Learning

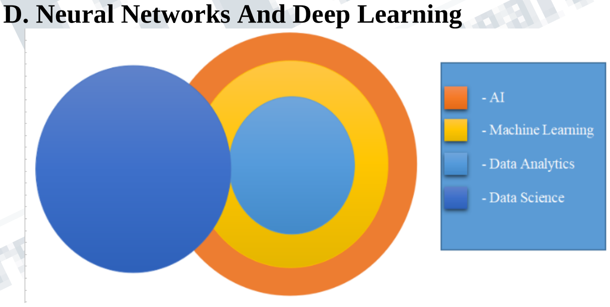

Fig. 5 . The relationship between Data Science, AI, Machine Learn and Data Analytics.

A neural network is a computing model whose layered structure resembles the networked structure of neurons in the brain, with layers of connected nodes. In a sense, it is the branch of computer science that aims to create intelligent machines that can think, behave and act like human beings i.e. replicate the functions of the human brain and is a part of Data Analytics. In a broad sense, it includes the ability to learn from data—so it can be trained to recognize patterns, classify data, and forecast future events — store process and analyse huge amounts of data in very short duration of time (in the order of a few milliseconds) which is made possible by the access to large sources or pools of data and the ability to store huge quantities of data - cloud computing. [4][5]
The branch of computer science that aims to create intelligent machines that can think, behave and act like

human beings I.e. replicate the functions of the human brain. In a broad sense, it includes the ability to store process and analyse huge amounts of data in very short duration of time (in the order of a few milliseconds) which is made possible by the access to large sources or pools of data and the ability to store huge quantities of data - cloud computing.

The ability of the machines to learn and parse large quantities of data to modify the algorithms to make informed decisions is known as Machine Learning and is a subdivision of the AI Technology i.e. the process of doing the job or function given to it consequently getting better at it.

In a modern sense, the Neural network is a network composed of artificial neurons or node that are used in the process of solving complex Problems inspired by the the human and animal intelligence i.e. the biological nervous system tends to process information. Like the living beings, the Artificial Neural Networks learn by examples i.e. they become more efficient as they solve more and more problems. As in the case of biological systems, the neural networks also comprises of a system of synapses of a large number of interconnected processing elements known as neurons that work together in order to solve the given problems. [5]

E. Various Steps involved Neural Network Analysis

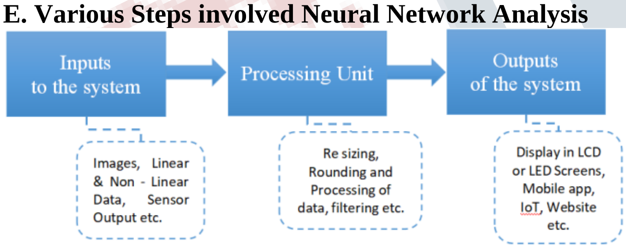

Fig. 6 . Various Steps involved Neural Network Analysis

The two steps involved in this process are:

i. Pre-processing:

This involves the conversion of raw data into a more suitable formate that can be used as input to the Processing units (i.e. Analytic Network). The major processes involved are:

a) Resizing: The size of the inout is reduced to a more smaller format more compatible with the system for easier analysis. (say 600 points of data to 100 points of data or so)

b) Rounding up of data (say 6.8548 to 7)

c) Processing of data

1. Matrix Method:

Used for processing the images. The images are generally available in the form of a 3x3 matrix which is processed or converted into a 2x2 "RBG" based matrix system for easier analysis purpose.

2. Vectors Method:

Used for signals based analysis.

d) Application of Filters: The filters are applied to remove the unwanted signals such as noise that is obtained as input along with the data and also for the process of fine tuning the data. The 3 most common types of filtering are:

1. Median filters
2. Integral filters
3. Digital filters:
4. Discrete Cosine Transform based (dct filters)
5. Discrete Sine Transform based (dst filters)
6. Fast Fourier Transforms based (fft filters)

ii. Feature Extraction

a. Harris Feature Extraction Technique
b. Feature Discriptus Technique
c. Fast Feature Extraction Technique
d. SIFT Technique
e. Webber Descriptive Extraction Technique
f. Multinodal Feature Extraction Technique

iii. Deep Learning Analysis

These are used to find the hidden info in the inputs. The hidden characteristics may refer to the information that is being carried by the inputs.

a. Random Forest Model
b. Linear Regression Model
c. Back Propagation
d. Feed Forward Model
e. Decision Tree
f. LTSM
g. Regressive Model

In case of neural networks and deep learning analysis, there are two types of vectors that are used in the analysis purpose of the stored data in the database which comprises of the reference datum as well as the input data. [3][5]

There are two types of vectors used:

a) Training Vector: The unit info of the input is provided.

b) Featured Vector: The unit info of the input that is saved as a vector here.

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III. SYSTEM DESIGN

TABLE III. THE BASIC COMPONENTS OF THE HARDWARE PROPOSED

S.No.	Component	Rating / Specifications	Quantity
1.	Solar Panels	Current: 0.34A Voltage: 12V	1
2.	Batteries		2
3.	Zigbee Module	-	2
4.	ATMEL Microprocessor	OpF - 20MHz FM. - 8Kb DM. - 368 bytes EM. - 256 bytes	1
5.	LCD Display	16 x 4 Display	1
6.	Current Sensors	-	2
7.	Current Regulator		2

Abbreviations Used:

OpF: Operating Frequency
FM: Flash Memory
DM: Direct Memory
EM: EEPROM Data Memory

The System Comprises of two individual modules - The Transmission module (Slave) and The Receiver (Master) forming a Master - Slave relationship with both of them supplied by a separate power source. The transmission module is supplied by a Solar panel array system. In general, both the modules operate as separate unit independent of each other. However, at the time of need of additional power, the power can be transmitted between the modules wirelessly. When, the shortage of power occurs, then the transmission signal is enabled by the Master - Receiver module which sends the command to the Slave. Furthermore, the modules are connected to each other wirelessly via Wireless Power-line Communication (w-PLC) using Zigbee Modules. [16][24] The w-PLC can be used to monitor the state of charge of the two batteries in the modules and thereby act as a preventive measure against energy theft. The data so collected can be fed into a separate datalog file that can be used as input to the Neural Network Program.[7][9] This can be used to analyse the user consumption analysis pattern and further be used to predict the future consumption. This data so obtained can also be fed into the online database to run monitor the data remotely via IoT (Internet Of Things).[17][18]

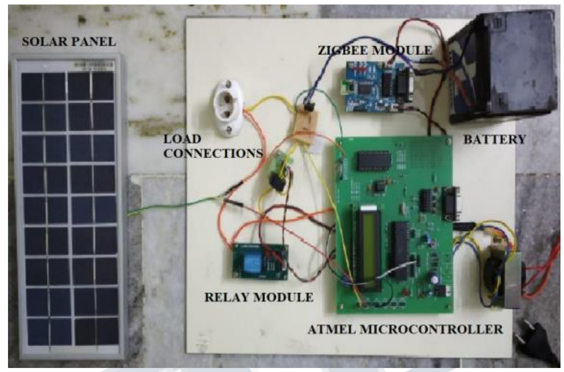

Fig. 5. Stand-alone Solar powered Transmission circuit.

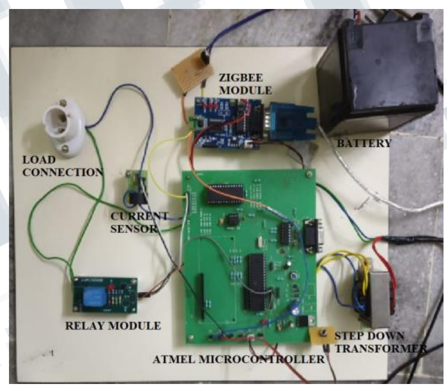

Fig. 6. The Receiver system that acts as the load in the prototype

IV. NEURAL NETWORK ALGORITHM FOR THE SMART ENERGY MANAGEMENT SYSTEM

There are various different steps involved in the processing of the data by the use of the MATLAB Neural Network program. [3][4]

STEP 1: The power consumption data is monitored via wireless power line communication and is sent to a computer and stored as a text file.

STEP 2: The text file is used as the input to the MATLAB Neural Network software program.

STEP 3: Among the different values of power data available,the input is reduced to 100 values that are chosen in random.

STEP 4: This is done to generate four different training sets.

STEP 5: These are used in the generation of power target.

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STEP 6: This is create the pattern recognition network.
STEP 7:The pattern recognition network with Hidden layers of 3 cells thick is generated.
STEP 8: The given data (power target) and input is given to the network.
STEP 9: The input and output functions are defined.
STEP 10: The data samples are divided randomly.
STEP 11: The algorithm is run according to the test , value and train ratios.
STEP 12: The training method is initiated according to the coding given as scaled conjugate grid and the performance function as Mean Squares ratio (according to the program).
STEP 13: The various graphs are plotted.
STEP 14: The training , validation and test performance are recalculated.
STEP 15: The data is used to calculate the percentage of power consumption.
STEP 16: The consumption is displayed as `Proper Consumption' / `Warning: Improper Consumption' according to the data given as input.
STEP 17: When the consumption by the load reaches beyond a certain limit, then the excess power required br the load can be supplied from the solar powered storage unit wirelessly (As in the case of smart buildings).
STEP 18: Thus, the consumption pattern is regulated to a certain limit. However, when the maximum capacity of the solar powered unit is reached, then the supply is again switched back to the grid.

V. SYSTEM APPLICATION ANALYSIS

The effect of the application of the proposed setup in an individual system has been analyzed for a domestic system. 15 of its bi-monthly bills have been considered by comparing the power consumption before and after the application of the proposed support setup. A 400 watt solar panel system has been used for this analysis.
If the panels are assumed to be working for a period of 16 hours per day for 61 days (i.e. for 2 months to be considered for the bi-monthly billing period), then as a whole, it can by itself supply up-to a power of P = 400 x 16 x 61 = 3,90,400 watt-hours = 390.4 units (or) KW-hr.
However, on assuming the actual efficiency of about 65% for the actual simple setup, a power of about 250 units (or) KW-hr can be produced/supplied. This energy in general can be used to supply for the other devices (i.e. operated as a stand alone system) until the consumption of the household reaches a particular limit of consumption (say 500 units). When this condition is satisfied, then the excess power generated by the system is supplied by the solar power setup. The power consumption of the domestic system from the grid and the local tariff has been shown in the below table.

TABLE IV. DATA ANALYSIS ABOUT THE POWER CONSUMPTION AND TARIFF

S. No.	Power consumption without Panels (in KW-hr)	Power consumption (in KW-hr)	Tariff w/o panels (in Rs)	Tariff with panels (in Rs)
1	460	460	1210	1210
2	500	500	1330	1330
3	600	550	2780	2450
4	780	550	3960	2450
5	880	630	4628	2978
6	640	550	3044	2450
7	400	400	1030	1030
8	487	487	1291	1291
9	500	500	1330	1330
10	660	550	3176	2450
11	550	550	2450	2450
12	480	480	1270	1270
13	500	500	1330	1330
14	520	520	2252	2252
15	490	490	1300	1300
Total	8447 KW-hr	7717 KW-hr	₹ 32381	₹ 27571

TOTAL POWER SAVING (% in power)
: (8447-7717)/8447
: 8.642%
TOTAL DECREASE IN TARIFF (% in Rupees)
: (32381-27571)/32381
: 14.854%

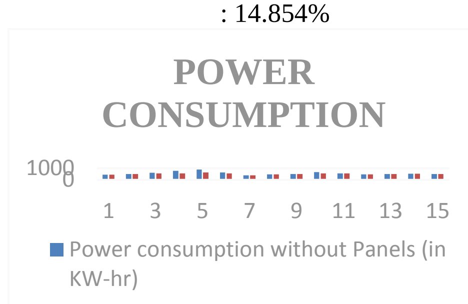

Fig. 7. The Graph depicting the Energy Consumption plot for the analysis

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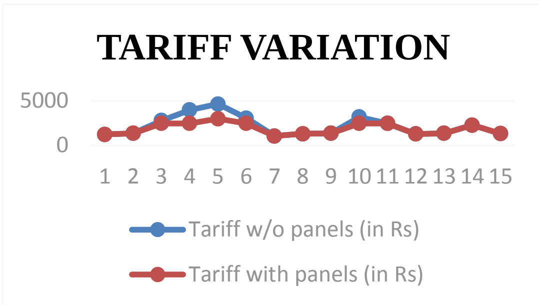
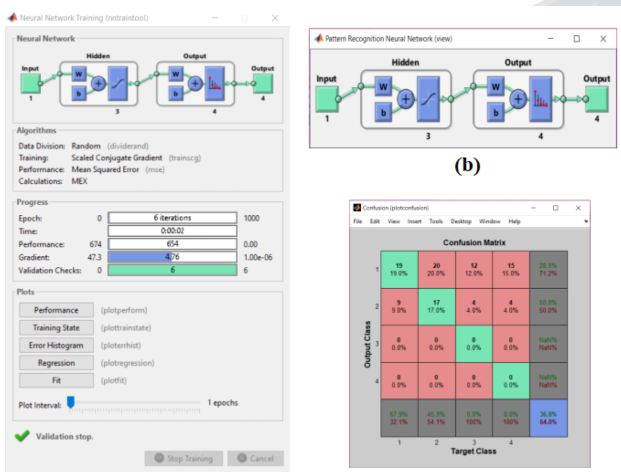


Fig. 8. The Graph depicting the Tariff plot for the analysis

VI. RESULTS AND DISCUSSIONS

The w-PLC can be successfully implemented to reduce the chances of energy theft by monitoring the power transmission between two points as well as view the power consumption remotely via IoT platform - Thingspeak.



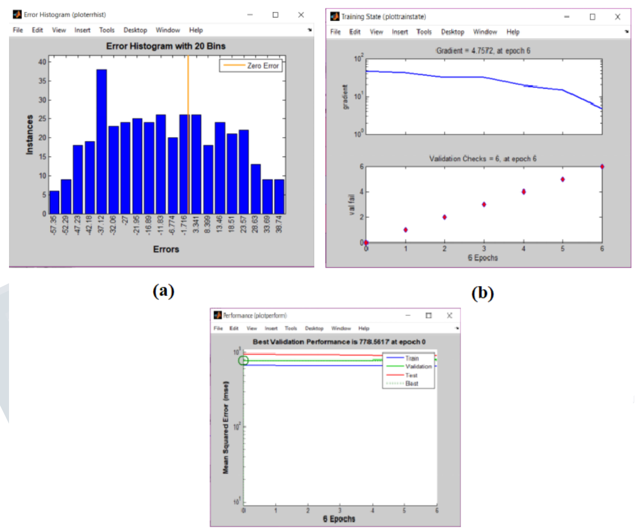
(b)

(a) (c)

Fig. 9. (a) Characteristic Details for analysing the algorithm (b) Pattern Recognition Neural Network View (c) Confusion Plotforthe algorithm

The Figure 9 is obtained on running the Neural Network algorithm on MATLAB software. It displays the displays the information about the various characteristics of the algorithm like the number of iterations that has taken place, Type of training method used, performance etc. Here Scaled Conjugate gradient is used as the training method and the performance is measured by using Mean Square Error technique.

The data from the prototype is give as input to the MATLAB program in the form of the text file and the algorithm is processed by using the various graphs as shown in Figure 9 and Figure 10 (Shown below). The confusion plot in Figure 9 (c) is used to analyse the accuracy of the algorithm by determining its ability to distinguish various types of inputs or the states that is given to the MATLAB file.



(a) (b)

(c)

Fig. 10. (a) Error Histogram,(b) Training State Plot (c) Performance Plot

The Error histogram 10 (a) is used to measure the error the in output prediction of the algorithm in each instances or epoch and performance plot 10 (c) is used to analyse the performance characteristics by comparing the Test, Validation and Training States of the algorithm and the training state 10 (b) is used to analyse the training characteristics of the algorithm.

VII. CONCLUSION

With the ever increasing demand of power in today's world, the use of Smart Energy Systems have become the solution to limit the consumption of power from the grid and act as a supplement to growing need. With the limited supply of fossil fuels in our planet, the need of the hour for the use of alternative sources of power has arisen. The use of the Smart Energy Management Systems decrease the stress on the Grid and focuses on the more renewable forms of energy along with decreasing the energy consumption.[20] On the implementation of a miniature Solar Powered Energy management system comprising of a 400 Watts panel itself may lead to a decrease in the power consumption from the grid - with that the stress on the grid - by about 8.6% in a bimonthly period and the cost by as much as 14.8% thereby leading to a more efficient use of solar power and energy savings as shown by the graph.

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