RESEARCH ARTICLE OPEN ACCESS

Power Optimization of Battery Charging System Using FPGA Based Neural Network Controller

Ankita Dhakate*
*(Department of Electronics & Telecommunication, Symbiosis Institute of Technology, Pune-15

ABSTRACT
This paper involves designing a small scale battery charging system which is powered via a photovoltaic panel. This work aims at the usage of solar energy for charging the battery and optimizing the power of the system. Implementation is done using Artificial Neural Network (ANN) on FPGA. To develop this system an Artificial Neural Network is trained and its result is further used for the PWM technique. PWM pulse generation has been done using Papilio board which is based on XILINX Spartan 3E FPGA. The ANN with PWM technique is ported on FPGA which is programmed using VHDL. This able to automatically control the whole charging system operation without requirement of external sensory unit. The simulation results are achieved by using MATLAB and XILINX. These results allowed demonstrating the charging of the battery using proposed ANN and PWM technique.
Keywords- Photovoltaic battery charger, PWM, ANN, FPGA

I. INTRODUCTION

Renewable energy resources attract much more attention since today people are facing the problems of fossil fuel depletion and environmental imbalance associated with power generation. Among all the renewable resources, solar photovoltaic power generation is the most important and cleanest form of energy conversion available. Photovoltaic sources are fast growing and widely used in many applications such as battery charging, light sources, water pumping, satellite power systems, etc.

Power optimization is more in demand today than at any other time. This is because power demand is constantly growing & now outstripping supply. This produces resultant deterioration of power quality i.e. irregular voltage which is mostly too high & sometimes too low.

Photovoltaic system mainly consists of a PV panel which converts sunlight into direct current (D.C.) electricity. They have the advantage of being maintained and pollution free but their main drawbacks are high fabrication cost, low energy conversion efficiency, and nonlinear characteristics, a charging circuit for charging the battery and operation of the load, a charge controller is the heart of the PV systems. Traditionally battery have been used as a primary solution for power storage in solar power systems that are not connected to the electrical grid because off-grid homes need reliable power even at night, and solar panels are generally the most cost-effective way to generate it, but cannot provide on-demand power unless the sun is shining, which may not necessarily be when it is needed most. Therefore the solution is to capture it in batteries which can then be drawn upon later to provide power.

This paper represents a method to build FPGA based neural network controller which is capable of super wising the charging / discharging process in order to ensure a long battery life. However, this system uses simple and powerful Pulse Width Modulation technique and Artificial Neural Network. The implementation and simulation of the proposed method uses Field Programmable Gate Array. PWM pulse generation has been done on a Papilio one 250 K which is based on XILINX Spartan 3E FPGA using VHDL code. The pulse width modulated (PWM) adaptive intelligent system has been designed and developed where the input DC power stored in the battery obtained through PV source. The traditional analog method for generating PWM pulses uses the comparison of two signals i.e. a high frequency carrier signal and sinusoidal wave as reference signal to set the desired output frequency and thus needed two signals to produce PWM signal.

We can use Neural Network Controller to control the whole PV system for battery storage. The primary function of a FPGA based ANN charge controller in a stand-alone PV system is to maintain the battery at highest possible state of charge while protecting it from overcharge by the array and from over discharge by the loads.

II. LITERATURE SURVEY

In case of stand-alone system is usage, batteries are required for energy storage. Electricity generations of solar panels are strongly related with solar radiation intensity. However the intensity is not stable. Therefore, charge efficiency is a very important topic in solar systems. Charge controllers are designed to improve charge efficiency and safety.

The primary function of a charge controller is to protect the battery from overcharge and over discharge in a stand-alone PV system [1].

Ullah et al. (1996) focused on the design of a super-fast battery charger based on National's proprietary neural network based neural fuzzy technology. They compared their method with conventional fast chargers and indicate that their method reduce the charging time [2]. Masheleni and Carelse (1997) designed an intelligent charge controller, incorporating an SGS–Thompson microcontroller, ST62E20 and discussed the advantages of such charge controllers [3].

Hsieh et al. (2001) proposed a fuzzy-controlled active state of- charge controller (FC-ASCC) for improving the charging behavior of a lithium–ion (Li–ion) battery. In this method, a fuzzy-controlled algorithm is built with the predicted charger performance to program the charging trajectory faster and to remain the charge operation in a proposed safe-charge area (SCA). They increased the charging speed about 23% [4].

Yi et al. (2007) presented a novel switch-mode charger controller IC for improve the charging efficiency of valve regulated lead-acid (VRLA) battery and save its life. They achieved fast transient response and the precisions of both constant current and constant voltage charge modes met the specifications well [5]. Chiang et al. (2009) presented the modeling and controller design of the PV charger system implemented with the single-ended primary inductance converter (SEPIC) and gave a detailed modeling of the SEPIC with the PV module input and peak-current-mode control. The system has been proved to be effective in the MPPT and power balance control [6].

Tesfahunegn et al. (2011) proposed a new solar/battery charge controller that combines both MPPT and overvoltage controls as single control function. They conducted two case studies in Simulink /Simpower, first to evaluate the performance of the designed controller in terms of transient response and voltage overshoot. secondly, realistic irradiance data is used to evaluate the performance of the developed charge controller in terms of parameters such as PV energy utilization factor and overvoltage compared to the conventional hysteretic on/off controller. They achieved good transient response with only small voltage overshoot, better in terms PV energy utilization and same level of overvoltage control [7].

There are some applications which are use MPPT controller [8,9,10]. Dakkak and Hasan (2012) analyzed a charge controller based on microcontroller in stand-alone PV systems and they conclude that such systems reduce the power consumption for charging battery and give flexibility to the designer[11]. Karami et al. (2012) focused on the load type and suggest new methods to reach the MPP depending on the load state and the development of the PV array mathematical model. They analyzed the effect of temperature and irradiance on the battery charger and showed the difference between the direct-coupled and the indirect-coupled applications of a PV panel [12].

The paper [13] suggests method to charge lithium ion batteries by using solar power. MPPT control system is implemented which allows fast and safe charging by using pulse width modulator duty cycle ratio control. It provides better performance and efficiency. The voltage maximum power point tracking (VMPPT) algorithm was used to see the results for different conditions using MATLAB Simulink and Pspice. The solar charger prototype is designed by using PIC18F4585 microcontroller and IC SG3524. The results are obtained by observing system behavior for different conditions on load and environment conditions.

In [14] authors have implemented the improved PV module by using genetic algorithm. Artificial neural network (ANN) was used to train the genetic algorithm values. The maximum power point tracking (MPPT) algorithm was used. The proposed algorithm has been trained for different environment conditions. 0.05% to 4.46% error percentage has been observed which can be reduced by taking large number of training data for ANN.

The paper [15] suggested a maximum power point tracking algorithm using an artificial neural network for a solar power system. The three layers neural network and some simple activation functions have been used for tracking the maximum power point of the solar system. The overall design was implemented on a low-cost PIC16F876 RISC-microcontroller without external sensor unit requirement. The designed system provide above 90% efficiency. The proposed artificial neural network algorithm provides faster tracking speed as compared to conventional tracking system.

In paper [16] the authors suggested two different topologies of charger. The design is simulated by using Proteus professional software. Both the topologies were designed by using Atmega32 microcontroller. Pulse width modulation (PWM) will be implemented on a MCU to control duty cycle and voltage. The efficiency of designed system is depending on duty cycle and voltage. When a battery voltage reaches the regulation set point, the PWM algorithm slowly reduces the charging current to avoid heating of the battery. The designed system has many benefits like reduce battery heating, increase the charge acceptance of the battery etc.

In [17] the authors designed a solar power management system (SPMS) for an experimental unmanned aerial vehicle (UAV). The design consists of three stages. First stage is power management system, second stage is the battery management stage and the final stage is power conversion stage. The first stage is used to obtain maximum power from the solar panels. The second stage is used to control and monitor the charging and discharging process of battery. The last and final stage is used for power conversion. The overall power efficiency of the system is depending on the combination of the efficiency of all the three stages. The designed system is mainly suitable for low power applications.

In [18] battery charge control system for photovoltaic (PV) panel has been designed. Maximum power point tracking algorithm was used in the design which is used to solve the problem of mismatch between the PV panels and the battery. The system consists of microcontroller, buck bust converter, resistive load and battery. GUI has also been installed in the designed system.

Paper [19] describes battery charging system for solar battery management system. This system consists of buck-boost converter. Depending upon the supply voltages from the solar panels the system operates in different mode namely buck mode, buck boost mode, or the boost mode. The MATLAB Simulink simulation tool is used for verifying the results. The buck-boost converter with microcontroller is very important part of the designed power management system.

In paper [20] the authors have suggested method for the hybrid solar photovoltaic and wind power system in Battery management with artificial intelligence. Fuzzy logic and neural network are used to utilize maximum battery. A MATLAB Simulink model has been developed for power management system. Neural network is better as compared to fuzzy logic in battery power management system during charging and discharging process.

In [21] a new control algorithm for battery charging system has been developed by researchers. It consists of buck-type dc/dc converter. The proposed algorithm controls the charging and discharging process by transforming the input of buck-boost converter to the load controlled by microcontroller. The proposed algorithm is simple and flexible to use.

III. SYSTEM FLOWCHART

A flowchart of the major functions of the system is shown in fig 1.

3.1 System Process

The proposed system consists of seven units namely photovoltaic panel, charging circuit, battery, analog to digital converter, charge controller i.e. (ANN with FPGA), DC load, indicator unit, each with its own function. These units are connected in accordance with the block diagram presented in fig 1.

The first unit i.e solar photovoltaic panel has a rated power of 11 watt and rated voltage 17.2 volt, rated current of 0.63 Amp. When solar (PV) panel is placed in sunlight it gives maximum output. The output of solar photovoltaic panel is given to the second unit i.e. charging circuit which includes a DC-DC converter controlled by a PWM signal. DC/DC converter is formed by two switches. The output from the voltage divider in charging circuit goes to ADC.

The Second voltage divider circuit is used for sensing the battery voltage .The output of voltage divider goes to ADC. PWM signal is computed from the control unit.

Third unit is Analog to Digital converter. It is 8 bit 0809 ADC. Solar photovoltaic panel voltage and battery voltage is given as feedback to the analog to digital converter.

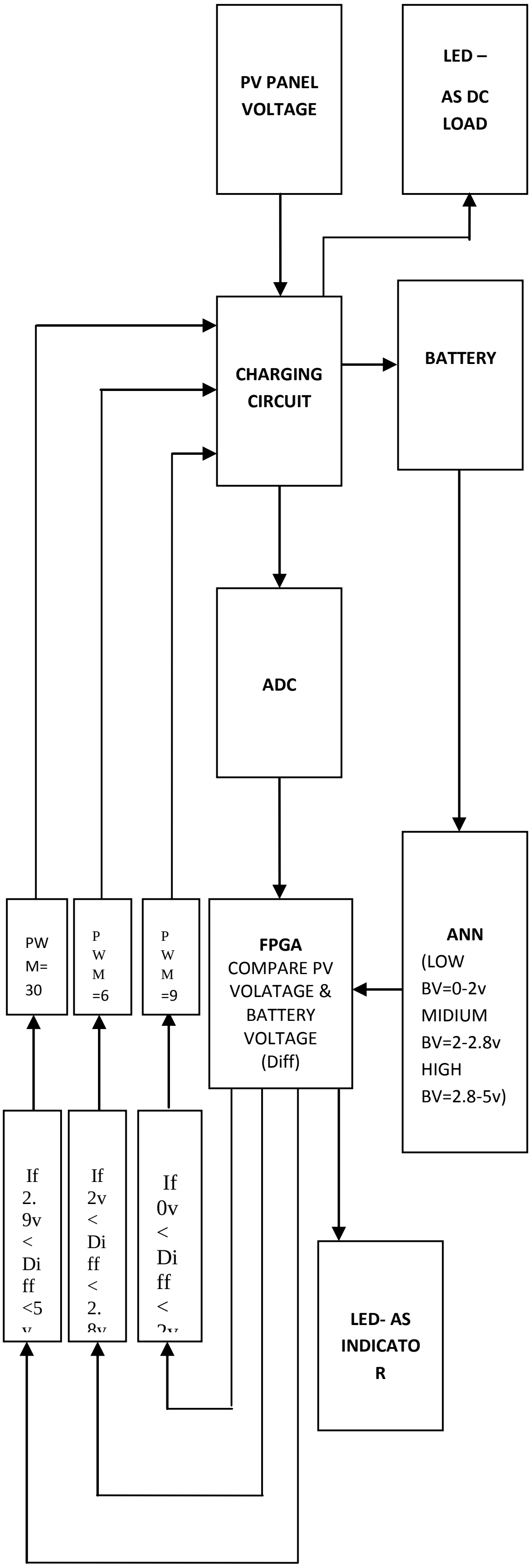

Fig.1. Proposed Block Diagram Of The System

Then ADC converts analog values into equivalent digital values. Then the fourth unit comes in the picture i.e. the control unit which consists of one the charger unit includes a DC/DC converter controlled by a PWM signal, ANN and FPGA. ANN has the input of battery voltages and it will send the desired value for generation of different PWM signals of duty cycle of 30%, 60% and 90 % to the FPGA, since ANN has the different range of the battery voltages. If the battery charge voltage lies within that particular range, according to the range it will send signal to FPGA. Then FPGA will received the signal from ANN according to received signal, it will generate PWM pulse of different duty cycles. The fifth unit includes a rechargeable sealed lead acid battery which is of 12 volt, 1.3 AH. Sixth unit is DC load. Three small sized one watt LED are used as a DC load. Seventh unit is indictor. Three LEDs are used for indication of battery charging status. i.e. whether the battery is fully charged, partially charged, or in charging mode. LED1 (red), LED2 (white), LED 3 (blue) are given to pin C_8, C11and C_9 of the Papilio board. LED1 (RED) is for low battery indication. LED 2 is for the indication of battery is in charging mode.LED 3 is used for full battery full indication. The resistors are used for limiting the current goes to LEDs.

IV. PROCESS IMPLEMENTATION

4.1. PULSE WIDTH MODULATION

Pulse Width Modulation (PWM) controls the duty ratio of the switches when the input changes to produce a constant output voltage. The direct current (DC) voltage is converted to a square-wave signal, which changes between fully on and zero. If analog circuits are controlled digitally then power consumption and system costs are reduced dramatically. There are two ways to control the PWM first is voltage control method and second is current controlled method. In voltage control method output voltage changes according to the duty cycle. Output voltage is then sensed and can be used as a feedback. If it has two stage regulations first it holds the voltage to a safe maximum for the battery to attain the full charge. Then it decreases the voltage lower to maintain "trickle" charge. In trickle charging of the battery voltage level is maintained and the current is reached to zero.

4.2. IMPLEMENTATION OF THE LEVENBERG–MARQUARDT ALGORITHM

Artificial neural network is nothing but a mathematical model inspired by biological neural networks. It consists of large number of processing elements called nodes or neurons which work in parallel. These artificial neurons are highly interconnected and are configured in regular architecture. Each computation link is associated with weights carrying the information about the input signal.ANN collective behavior is characterized by their ability to learn, recall and generalize training patterns or data similar to that of human brain. It is called as an adaptive system since it changes its structure during a learning phase and it is also used to model complex relationships between inputs and outputs or to find data pattern.

Function optimization problem is the difficulty of artificial neural network learning, where best network parameters i.e.(weights and biases) of the network have to be find out in order to decrease the network error. This means that some function optimization techniques from numerical linear algebra can be directly applied to network learning, one of these techniques being the Levenberg–Marquardt algorithm.

4.3. REASONS TO CHOOSE THE LEVENBERG–MARQUARDT ALGORITHM

1. It is a simple algorithm.
2. It does not require any external sensing units.
3. It is widely used for optimization.
4. By default, ANN network is train the data with this algorithm in MATLAB Artificial Neural Network Toolbox.

4.4 THE LEVENBERG – MARQUARDT ALGORITHM

It is another method of determining the minimum of a function to the Gauss-Newton method. It also provides a numerical solution to the nonlinear function minimizing problem over a space of parameters. An ANN is called as an adaptive system since it changes its structure based on external or internal information that flows through the network throughout the learning phase. The process of learning is used to find a set of connections **w** that gives a best mapping which means it fits the training set well. Additionally, artificial neural networks can be viewed as highly nonlinear functions which is given in following form

$$F(x, w) = y \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,
X is the input vector of the network,
W are the weights of the network
Y is the corresponding output vector approximated by the network.

4.4.1. Equations of Levenberg-Marquardt Algorithm

It is a very simple, but robust, method for approximating a function. Basically, it consists in solving the equation:

$$(J^tJ + \lambda I)\ \delta = J^tE \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where
J is the Jacobian matrix for the system
□ is the Levenberg's damping factor,
□ is the weight update vector that we want to find
E is the error vector containing the output errors for each input vector used on training the network.

As stated earlier, the Levenberg-Marquardt consists basically in solving (2) with different □values until the sum of squared error decreases. So, each learning iteration (epoch) consist of following basic steps:

1. Compute the Jacobian (by using finite differences or the chain rule)
2. Compute the error gradient $g = J^tE$
3. Approximate the Hessian using the cross product Jacobian equation i.e. $H = J^tJ$
4. Solve $(H + \lambda I)\delta = g$ to find □
5. Update the network weights **w** using □
6. Recalculate the sum of squared errors using the updated weights
7. If the sum of squared errors has not decreased, then discard the new weights, and increase □using **v** and go to step 4.
8. Else decrease □using **v** and stop.

The same method implemented internally by the MATLAB Neural Network Toolbox **.**

4.4.2 TRAINING USING LM ALGORITHM IN MATLAB

MATLAB i.e. matrix laboratory is a multi paradigm numerical computing environment used for matrix manipulations, plotting of functions and data, implementation of algorithms. Its ANN toolbox is used for training the large number of data, testing, classification of the training data. Battery voltage range is selected as input. Target range is nothing but the PWM signals which ANN has to be send to the FPGA.

For training and testing, code is written in MATLAB (ANN Toolbox). In neural network training, we have assign an input range from 0 to 5 (volt) varying with difference of 0.4 and target values varies with difference of 1.This set of input and target is forwarded to neural network for training. For training purpose we are using a LM algorithm. To train the data weight, bias, number of hidden layers are assigned. Two hidden layers and ten hidden neurons have been defined and the data is train with LM algorithm. After training the mean square error is calculated and response is shown. After training data with LM algorithm we get range of various output voltages.

Next step is to classify the range into three classes i.e. low charge, medium charge and high voltage charge of the battery. For this purpose we set offset voltage and according to offset classify voltage output into three classes i.e. 0v-2v, 2v-2.8 v, 2.8v-5v voltage. The output of ANN is given to FPGA.

Detailed flow of ANN Algorithm is carried out with the following steps shown in the below figure 2. and results are obtained are given in the result section.

V. WORKING OF CHARGE CONTROLLER

The FPGA receives signals from artificial neural network for generation of PWM signals of different duty cycles. In FPGA, the maximum voltage which can be obtained from solar cell is set as reference voltage. At first, the charge controller i.e FPGA will check the solar photovoltaic panel voltage and compare it with battery voltage, if it is greater then the FPGA will starts sending pulse width modulation (PWM) signals to the MOSFET in order to charge the battery .When the solar photovoltaic panel voltage is below the battery voltage, this PWM signals will not send by FPGA.

Then next, the FPGA will check the battery voltage, if the battery voltage is below 2V volts and reference voltage is more then the battery will be charged in boost mode ,that means the battery will be charged with maximum amperage, this boost mode of charging will be done by sending pulse width modulation signals with 90% duty cycle. When the battery voltage reaches up to 2.8 V and if reference voltage is more than the battery voltage then again the battery is in charging mode, PWM of 60 % duty cycle is generated. When the battery voltage is greater than 2.8 V and reference voltage is more than that, then the charging mode will turn as absorption mode from boost mode, this was done by changing the duty cycle 30%.This absorption mode will keep the battery fully charged. LED indicators glow according to the charge controller action.

VI. IMPLEMENTATION OF VHDL CODE

VHDL is used for generating the PWM signals of different duty cycles 30%, 60%, 90% by FPGA. There are different processes are defined using VHDL in ISE i.e. Integrated Software Environment. Basically Xilinx ISE design suit is a software tool produced by Xilinx. It is used for synthesis and analysis of hardware description language (HDL) designs. It enables the developer for compiling their designs and performing the timing analysis. It also allows to observe register transfer level i.e. RTL diagrams and simulate a design's reaction to different stimuli, and configuring the target device with the programmer.

Fig 3. shows the state diagram of analog to digital converter. In Papilio board there is 32 MHz oscillator. Therefore, ADC clock of 500 KHz is generated from 32 MHz Initially as per the ADC timing diagram, small timing delay. Then initially START = 0 and ALE is set at 1. Then in initial state START is set to 1 then ALE is set to zero. After few delays START is again set to zero then move to the conversion state.

In the conversion state, few microsecond delays are created for converting the analog data into digital. If the conversion is completed by ADC, then it will send EOC to FPGA that the conversion is completed. Then OE is set to 1.Then ADC sends the digitized data to FPGA. Papilio loader is a software which has been used to download the VHDL code into the FPGA development kit i.e. FPGA.

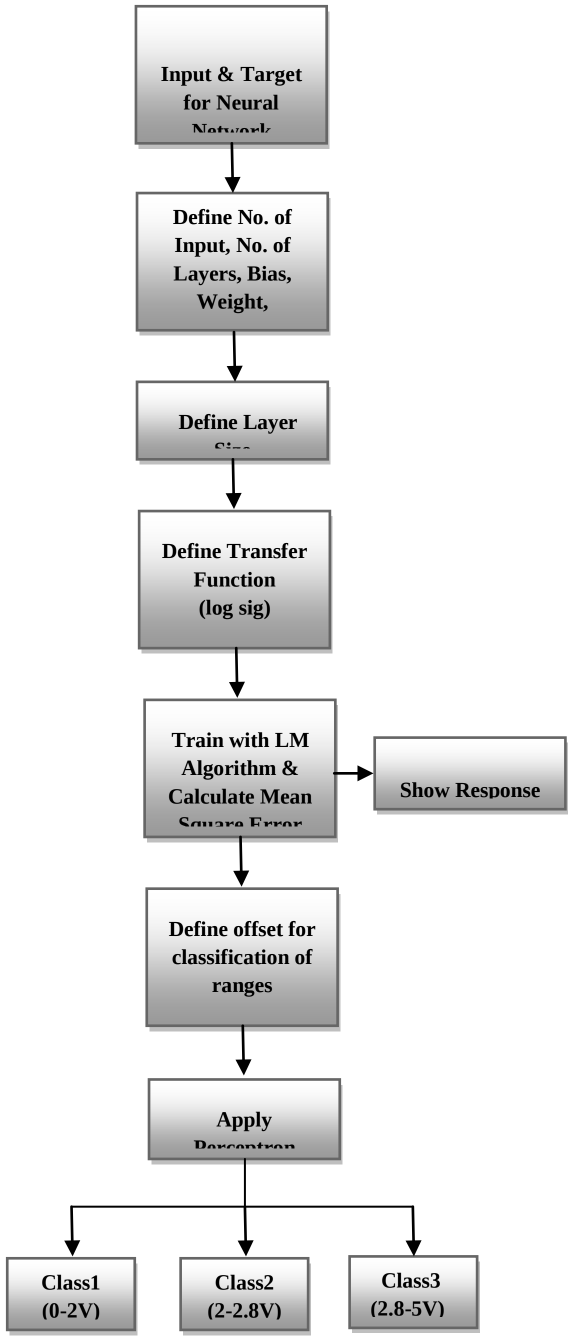

Fig.2. ANN Implementation In MATLAB

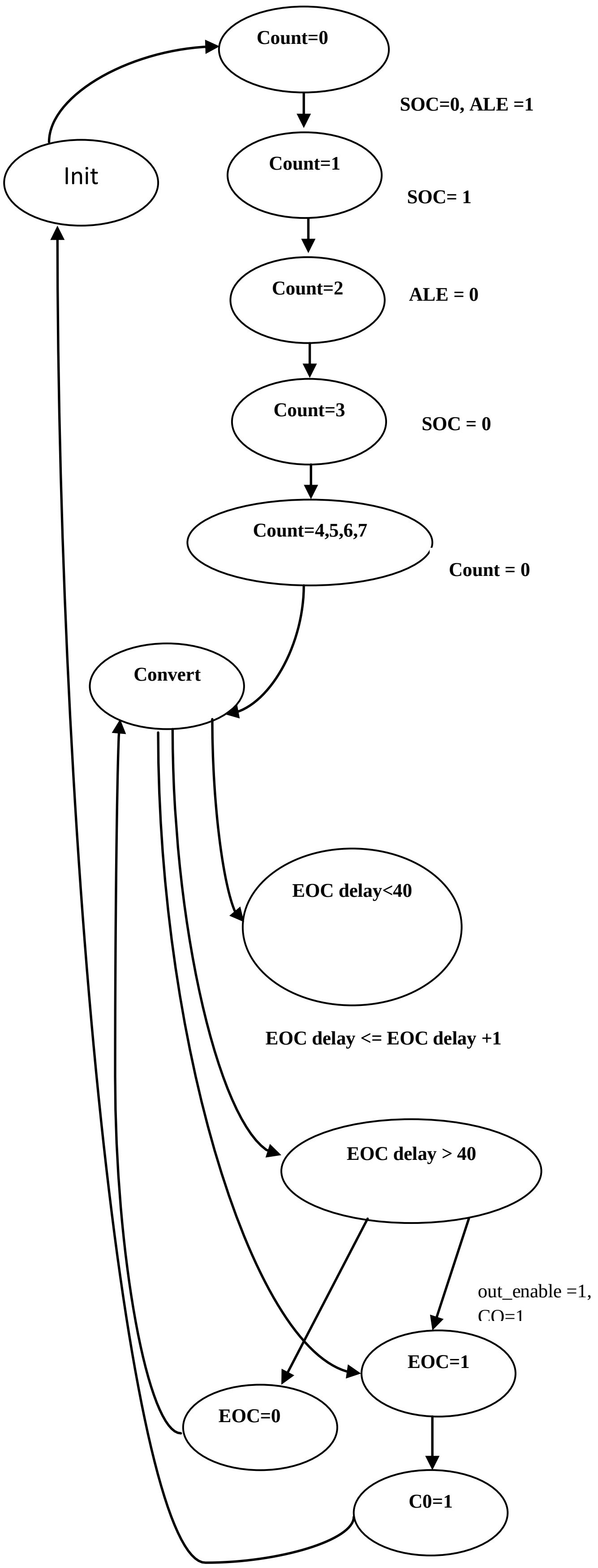

Fig.3. State diagram of ADC

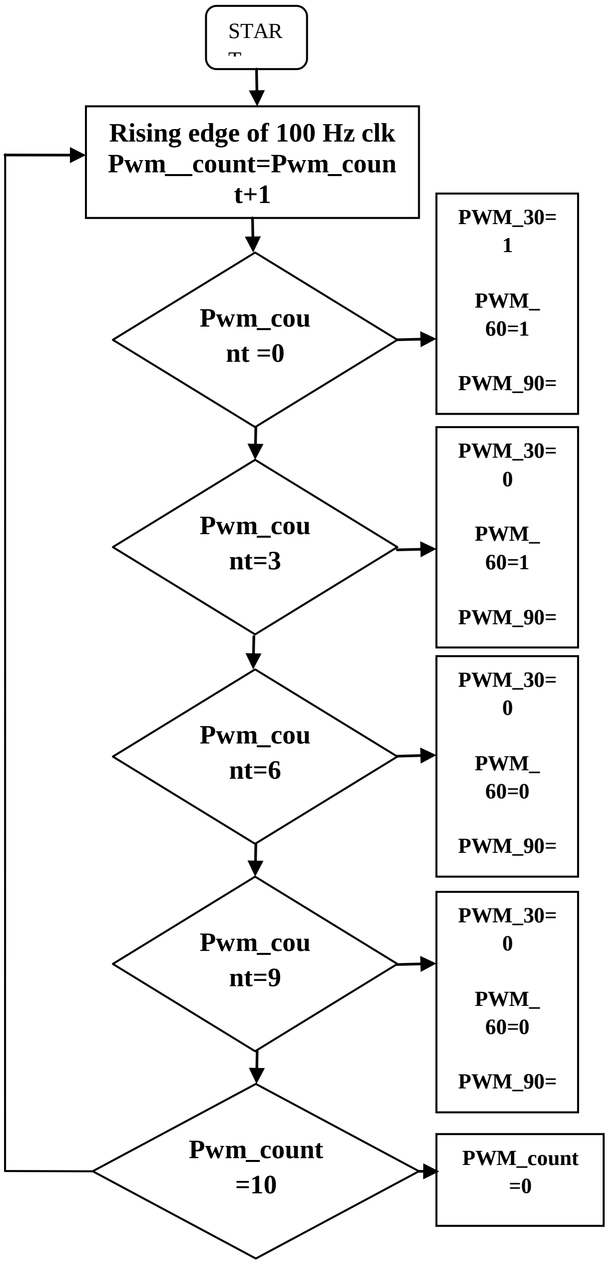

Fig.4. Flowchart for PWM

VII. FLOWCHART OF PWM DECISIONS

In this fig 4 show how the PWM counter is set for different duty cycle is shown in figure. Clock is divided to 100 Hz from 32 MHz for creating PWM signals (32MHz is the on board frequency of the Papilio one 250 k board).

VIII. FLOWCHART OF COMPARISON BETWEEN BATTERY & SOLAR PANEL VOLTAGES

This flowchart shows decision making on the basis of comparison between battery voltage and solar panel voltage. For charging and controlling the battery, the ANN logic is used. According to that, conditions will be applied for indication of the LEDs and to switch on the load.

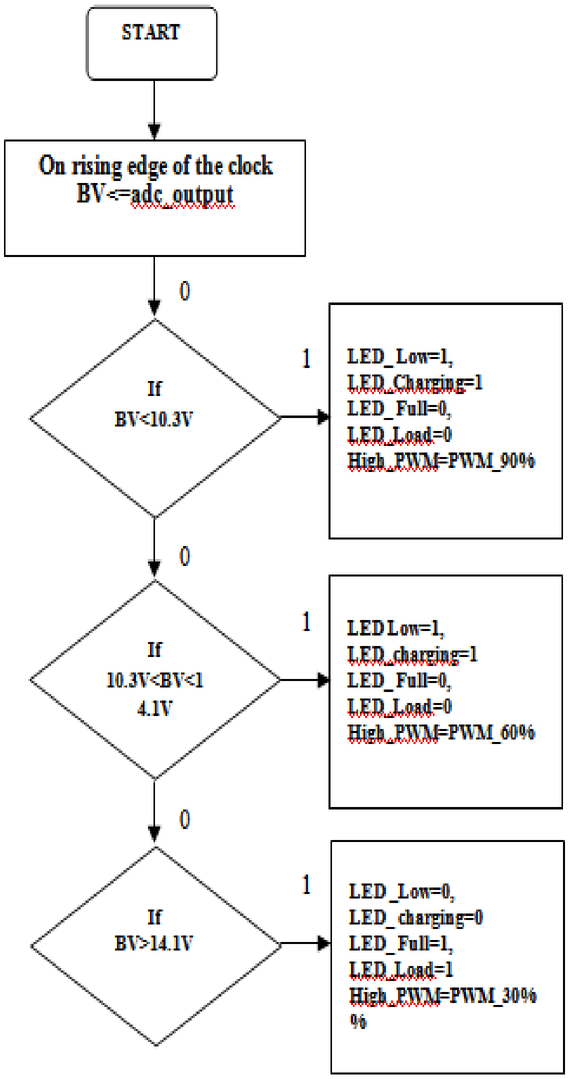

Fig.5. Comparison between Battery and solar panel voltage

IX. RESULTS

9.1 RESULTS OF ANN

Fig 6 shows initial block diagram of the artificial neural network having two hidden layers with zero hidden neurons in MATLAB artificial neural network toolbox.

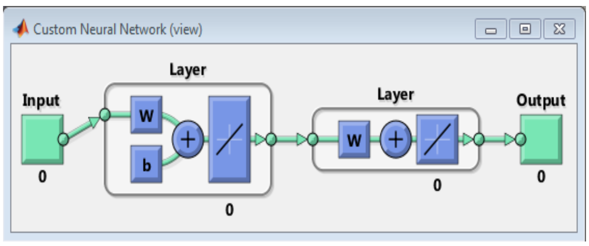

Fig.6. Initial Block diagram of ANN

Fig 7 shows the custom neural network (view) having two hidden layers and ten hidden neurons are selected since it gives best performing network.

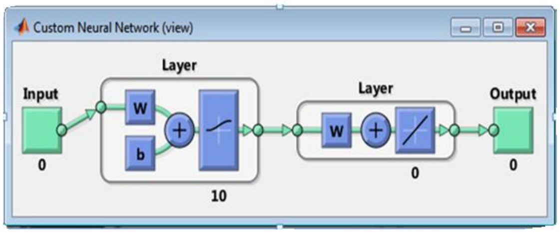

Fig.7. ANN block diagram with 10 hidden neurons

Fig 8 shows Neural network Training using Levenberg Marquardt Algorithm.

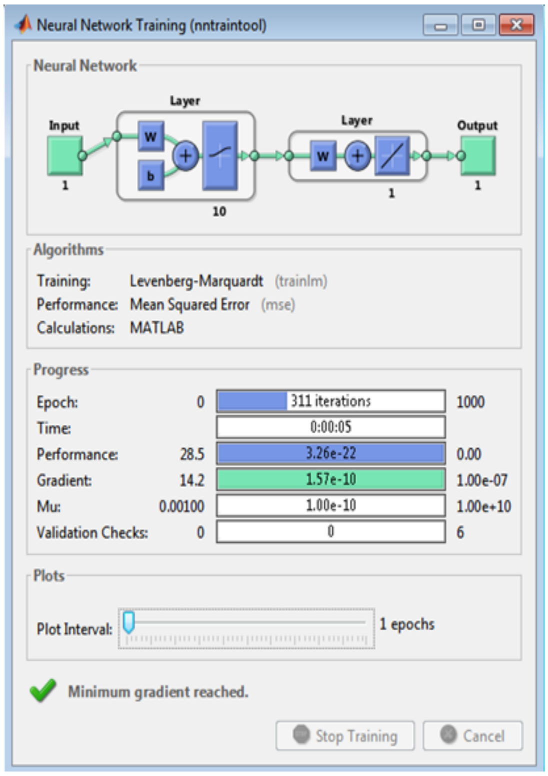

Fig.8. Training of ANN

Fig 9 shows the classification of data (Battery voltages). Class A is for battery low voltage range. Class B is for battery medium voltage range. Class C is for battery high voltage range.

Fig 10. shows the perceptron view of the network.

Fig 11. shows the neural library for creating the SIMULINK diagram of the network.

Fig 12. shows the Simulink diagram of the network which is used to generate VHD files from MATLAB files.

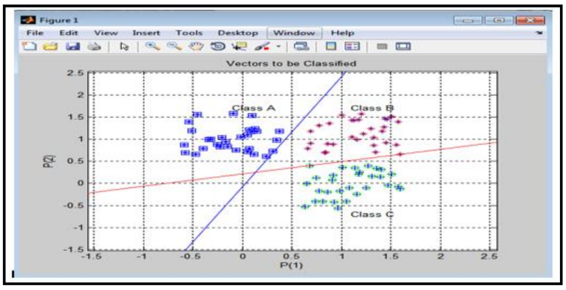

Fig.9. Classifications of battery range

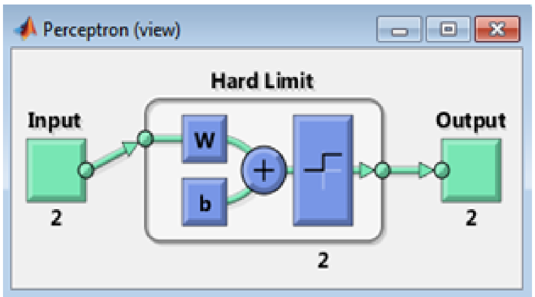

Fig.10. Perceptron (view)

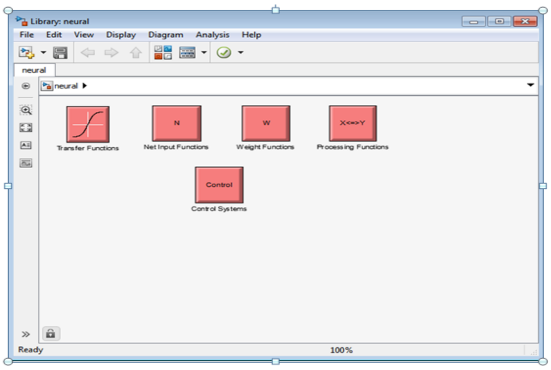

Fig.11. Neural library

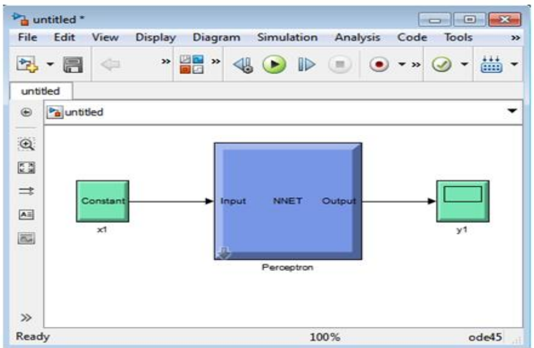

Fig.12. Simulink diagram of the network

9.2 FPGA RESULT

Fig 13 shows the PWM signals of duty cycle 30%,60% 90% in the waveform window.

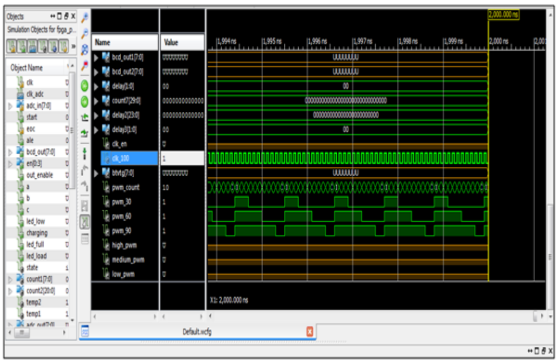

Fig.13. Observed PWM signals in the Xilinx waveform window

10.3 POWER COMPARISON BETWEEN PROPOSED AND CONVENTIONAL SYSTEM

The power consumption of the conventional system i.e solar powered battery charging system without FPGA is shown in table 1

Table 1: Power consumption without FPGA

Time	Battery voltage (volt)	Battery current (mA)	Power (W)
10:00 am	5.5	8.40	0.04
12:00 pm	7.2	13.85	0.10
2:00 pm	9.8	21.1	0.18

The power consumption of the proposed system i.e solar powered battery charging system using FPGA based neural network controller is shown in table 2

Table 2: Power Optimization with FPGA

Time	Battery voltage (volt)	Battery current (mA)	Power (W)
10:00 am	5.5	9.45	0.05
12:00 pm	9.1	15.20	0.13
2:00 pm	12.9	21.1	0.27

X. CONCLUSION & FUTURE SCOPE

In this paper battery charging system via a photovoltaic panel has been discussed. The proposed system has been simulated in MATLAB-SIMULINK environment with less number of artificial neural network training data set. Also the use of FPGA technology to generate PWM pulses for the charging system using VHDL programming language has been implemented in the present study and the results are verified experimentally.

When a battery voltage reaches the regulation set point, the PWM algorithm slowly reduces the charging current to avoid heating and gassing of the battery. In addition, this method of solar battery charging promises benefits from the PWM pulsing such as: it reduces battery heating and automatically adjusts battery aging and temperature effects in solar systems.

In the present system, stationary solar panel is used which gives less output and hence decrease the efficiency. But by making use of solar tracker, we can increase the efficiency of solar system. In this proposed system fixed load is used but in the future scope we can connect this system to variable loads and verify the system results in terms of power consumption and battery charge timing also we can develop this prototype with large number of ANN training data.

REFERENCES

Journal Papers

[1] S. Harrington, J. Dunlop, *Battery charge controller characteristics in photovoltaic systems, aerospace and Electronic Systems Magazine, IEEE, Volume: 7, Issue: 8, p, 15 – 21, 1992.*

[2] Z. Ullah, B. Burford, S. Rahman, *Fast Intelligent battery charging: neural-fuzzy approach,* WESCON/'95. *Conference record. 'Microelectronics Communications Technology Producing Quality Products Mobile and Portable Power Emerging Technologies', 1995.*

[3] H. Masheleni and X. F. Carelse, *Microcontroller-Based Charge Controller for Stand-Alone Photovoltaic Systems*, Solar Energy, *Vol. 61, No. 4, pp. 225–230, 1997.*

[4] G. C. Hsieh L. R. Chen and K. S. Huang, *Fuzzy-Controlled Li–Ion Battery Charge System with Active State-of-Charge Controller, IEEE Transactions On Industrial Electronics, Vol. 48, No. 3, 2001.*

[5] Z. Yi, W. Xiaobo, Y. Xiaolang and H. Shiming, *A Novel Switch- Mode Charger Controller IC for VRLA Batteries, The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON), Taipei, Taiwan, 2007.*

[6] S. J. Chiang, H.J. Shieh and M. C. Chen, *Modeling and Control of PV Charger System with SEPIC Converter*, IEEE Transactions on Industrial Electronics, vol. 56, no.11, 2009.

[7] S. G. Tesfahunegn, P.J.S. Vie, O. Ulleberg and T.M. Undeland, *A simplified battery charge controller for safety and increased utilization in standalone PV applications*, International Conference on Clean Electrical Power (ICCEP), 2011.

[8] C. Hua, J. Lin, C. Shen, *Implementation of a DSP-Controlled Photovoltaic System with Peak Power Tracking,* IEEE Transactions On Industrial Electronics, V. 45, No. 1, 1998.

[9] C. R. Sullivan, M. J. Powers, *A High-Efficiency Maximum Power Point Tracker for Photovoltaic Arrays in a Solar-Powered Race Vehicle*, Power Electronics Specialists Conference, 1993.

[10] D. P. Hohm, M. E. Ropp, *Comparative Study of Maximum Power Point Tracking Algorithms Using an Experimental, Programmable*, Maximum Power Point Tracking Test Bed, Photovoltaic Specialists Conference, 2000.

[11] M. Dakkaka and A. Hasana, "*A charge Controller Based on Microcontroller In Stand-alone Photovoltaic Systems*", Energy Procedia V. 19, pp. 87 – 90, 2012

[12] N. Karami, N. Moubayed and R. Outbib, *Analysis and implementation of an adaptative PV based battery floating charger*, Solar Energy, (Accepted: 7 May 2012)

[13] Carlos Manuel Ferreira Santos, *Optimized Photovoltaic Solar Charger With Voltage Maximum Power Point Tracking*, PhD diss., Universidade Técnica de Lisboa, 2008.

[14] R. Ramaprabha, B.L. Mathur, *Intelligent Controller based Maximum Power Point Tracking for Solar PV System*, International Journal of Computer Applications (0975 – 8887) Volume 12– No.10, January 2011

[15] Panom Petchjatuporn, Phaophak Sirisuk, *A Solar-powered Battery Charger with Neural Network Maximum Power Point Tracking Implemented on a Low-Cost PIC-microcontroller*, IEEE Power Electronics and Drives Systems, 2005. Pp.507-510.

[16] Mohammed Shoaib1, V Nagaraj2, *Novel Battery Charging Control System for Batteries Using On/Off and PWM Controllers for Stand Alone Power Systems*, IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 6, Issue 3 (May. - Jun. 2013), PP 44-52

[17] Jaw-Kuen Shiau, Member, *Design of a Solar Power Management System for an Experimental UAV*, IEEE der-ming ma pin-ying yang geng-feng wang jhij hua gong Tamkang University,

[18] Çınar, S. M., & Akarslan, E. (2012), *Design of an Intelligent Battery Charge Controller for PV Panels,* Journal of Engineering Science and Technology Review, 5(4), 30-34.

[19] Shiau, J. K., & Ma, C. W. (2013), Li-ion *battery charging with a buck-boost power converter for a solar powered battery management system*. Energies, 6(3), 1669-1699

[20] Raju, P., & Vijayan, S. Artificial *Intelligence based Battery Power Management for Solar PV And Wind Hybrid Power System*.

[21] Lee, J. H., H. S. Bae, and Bo-Hyung Cho., *Resistive control for a photovoltaic battery charging system using a microcontroller*, Industrial Electronics, IEEE Transactions on 55.7 (2008): 2767-2775.

Books:

[22] Samir Palnitkar, "*Verilog HDL A Guide to Digital Design and Synthesis Second Edition"* Pearson Publication India, IEEE 1364-2001 Compliant.

[23] Muhammad H. Rashid, "*Power Electronics Circuits Devices And Applications Third Edition*" Pearson Publication India.