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Real Time Simulation of Artificial Intelligence (AI) based MPPT of a Photo-Voltaic Array using Dspace

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ABSTRACT
This paper presents an Artificial Intelligent based Maximum Power Point Tracking (MPPT) of a Photo-Voltaic array implementation using Dspace with less number of sensors. The MPPT algorithms Perturb and Observe , Incremental Conductance, Neural Network and Adaptive Neuro Fuzzy Inference System (ANFIS) are discussed, implemented and compared. The modeling of the PV array is performed in MATLAB/SIMULINK. The performances are evaluated by means of MATLAB/SIMULINK simulations interfaced with Dspace control desk and ds1104.

***Keywords* -** Adaptive Neuro Fuzzy Inference System (ANFIS), Incremental Conductance, Maximum Power Point Tracking (MPPT), Neural Network Controller, Photo-Voltaic Array, Perturb and Observe.

I. INTRODUCTION

The limitation of the energy sources and power quality are the major concern of this century thus most of the literature discuss the problems of natural resource depletion, environment impact, the rising demand of new energy resources and challenging technologies to overcome these problems. At present, photovoltaic (PV) generation is assuming increased importance as a renewable energy source application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. Furthermore, the solar energy characterizes a clean, pollution free and inexhaustible energy source.

We know that the efficiency of the solar PV module is low about 13%. Since the module efficiency is low it is desirable to operate the module at the peak power point so that the maximum power can be delivered to the load under varying temperature and insolation conditions. Tracking the maximum power point (MPP) of a photovoltaic (PV) array is usually an essential part in order to increase the efficiency of the system. The problem considered by MPPT techniques is to automatically find the voltage VMPP or current IMPP at which a PV array should operate to obtain the maximum power output PMPP under a given temperature and irradiance. As such, many MPP tracking (MPPT) methods have been developed and implemented. The methods vary in complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, popularity, and in other respects.

There are two basic approaches in maximizing the power extraction:

(a) Using automatic sun tracker.
(b) Searching for the MPP conditions.

In automatic sun tracker systems, the solar panels are controlled to follow the movement of the sun (Rizk & Chaiko [1]). Due to the high cost and the energy consumption of the sun tracker, this approach may not be suitable for energy conversions at a small to medium power range.

In searching for the MPP condition, many methods have been tried. The perturb and observe (Eftichios ,Kostas & Voulgaris [2]; Eftichios Koutroulis, Kostas Kalaitzakis & Nicholas C. Voulgaris [3]; Leyva et al. [4]; Elgendy, Bashar & David [5]; Sharma & Purohit [6]; Abdalla, Zhang & Corda [7]; Brito, Sampaio, Luigi , Melo & Canesi [8]; Ansari , Chatterji & Iqbal [9]), incremental Conductance (Scarpa, Buso, & Spiazzi [10]; Altas & Sharaf [11] ;Siwakoti, Chhetri, Adhikary & Bista [12]; Guan, Hung, Cheng & Chi [13]) and current sweep are some of the fundamental approaches. Many other techniques like constant voltage (Elgendy, Zahawi & Atkinsou [14]), three points prediction Algorithm (Milea, Zafiu, Marin & Oltu [15]), linear reoriented coordinates method (LRCM) (Jung, Kim , Park , Choi

& Chung [16]), fractional-order incremental conductance method (FOICM) (Lin, Huang, Yi. & Chen [17]), open-circuit voltage and short-circuit current (Kumari & Babu [18]), dual module V and I method (Park, Ahn, Cho & Jong [19]), ON/OFF control method (Azab [20]), sensor less method (Kitano, Matsui, & Xu [21]), low cost method (Lopez, Penella, & Gasulla [22]) etc. are also reported. In all these methods the duty cycle of the dc-dc converter is adjusted to track the maximum power point (MPP).A smart optimal control of the dc-dc converter using GA techniques is proposed in (Elshaer , Mohamed A & Mohammed O [23]). Artificial Intelligent techniques algorithms like Fuzzy Logic (Balasubramanian & Singaravelu [24].; Wu & Widodo [25]) , Neural Network (Rai , Kaushika , Singh & Agarwal [26]), Neuro-Fuzzy (Putri & Rifa [27]; Kamel & K. Nagasaka [28]; Chaouachi , Kamel & Nagasaka [29]) and Adaptive Neuro Fuzzy Inference System (ANFIS) (Radianto [30]; Tarek & Benbouzid [31]) to estimate the MPP using the data collected from several experiments performed in different environmental conditions are also reported. A indirect methods has also been proposed where the, I-V curve is adjusted through optimization techniques like Partical Swarm Optimization (PSO) (Ishaque, Salam, Amjad & Mekhilef [32]). Comparison between different methods has been performed in (Esram & Chapman [33]).

Modeling and characteristics of PV module are described in section II. Maximum Power Point Tracking (MPPT) algorithms such as Perturb and Observe, Incremental Conductance, Neural Network based MPPT and ANFIS (Adaptive Neuro Fuzzy Inference System) based MPPT for a PV module is explained in section III. In section IV, the proposed hardware design is discussed. Simulated circuits and waveforms of this research are presented in section V followed by conclusions VI.

II. PV MODELING

Modeling of a solar cell is done by connecting a current source in parallel with an inverted diode along with a series and a parallel resistance as shown in Fig.1. The series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current. The single diode model shown in Fig 1 was adopted for simulating the PV module under different irradiance and temperature levels. PV modules are interconnected in a parallel-series configuration to form PV arrays as shown in Fig 2.

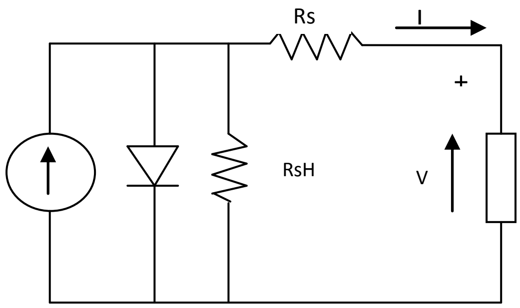

Fig 1: Single Diode Model of a PV Cell

It has non-linear characteristics, and the basic mathematical model can be expressed as:

—— --------- (1)

where,
I and V are the PV array output current and voltage respectively,
Iph is the photo-current that is equal to shortcircuit current Isc,
$I0$ is the reverse saturation current,
np is the number of modules connected in parallel,
ns is the number of modules connected in series,
q is the charge of an electron
k is Boltzmann's constant,
a is the p-n junction ideality factor, $1< a < 5$ ($a = 1$ being the ideal value),
and T is the cell temperature.

Practical arrays composed of several connected photovoltaic cells require the inclusion of additional parameters to the basic equation :

—— —— ---- (2)

where, Iph and $I0$ are the photovoltaic and saturation currents of the array and
$Vt = NskT/q$ is the thermal voltage of the array with Ns cells connected in series.
Rs and Rp are equivalent series and parallel array resistances. The light generated current (Ipv) of the solar cells, depends on the series and parallel resistances. Datasheets only provides the nominal short-circuit current (Isc,n), which is the maximum current available at the terminals of the practical device. The assumption $Isc \approx Ipv$ is generally used in photovoltaic models because in practical devices the series resistance is low and the parallel resistance is high. The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation:

— -----------------(3)

where *Ipv,n* is the light-generated current at the nominal condition (usually 25 ^{0}C and 1000W/m2), *T* and *Tn* are the actual and nominal temperatures, *S* and *Sn* are actual and nominal radiation and the short-circuit current/temperature coefficient (*KI*). Diode saturation currents (*I0*) also depend on the solar radiation and the cell temperature as:

— — — – -------------(4)

where, *Eg* is the bandgap energy of the semiconductor and *I0,n* is the nominal saturation current:

—— ----------------(5)

with *Vt,n* being the thermal voltage of *Ns* series-connected cells at the nominal temperature *Tn*. At normal levels of solar irradiance, the short-circuit current can be considered equivalent to the photocurrent *Iph*, i.e. proportional to the solar irradiance *S* (W/m2). But this may result in some deviation from the experimental result, so a power law having exponent *a* is introduced in equation 4 to account for the non-linear effect that the photocurrent depends on. The short-circuit current *Isc* of the PV modules is not strongly temperature dependent. It tends to increase slightly with increase of the module temperature. For the purposes of PV module performance, modeling this variation can be considered.

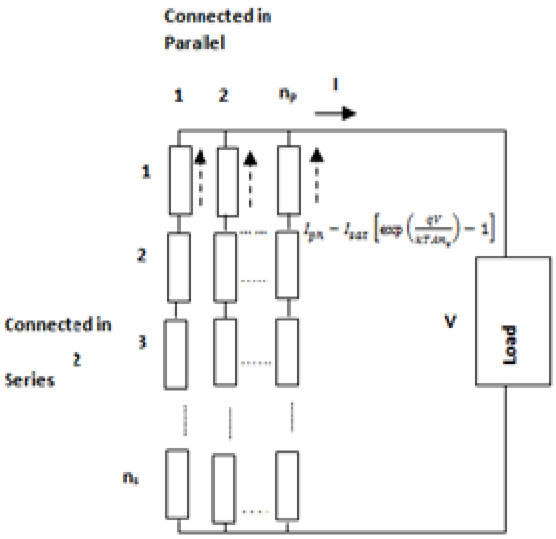

Fig 2: Equivalent Circuit of PV Module

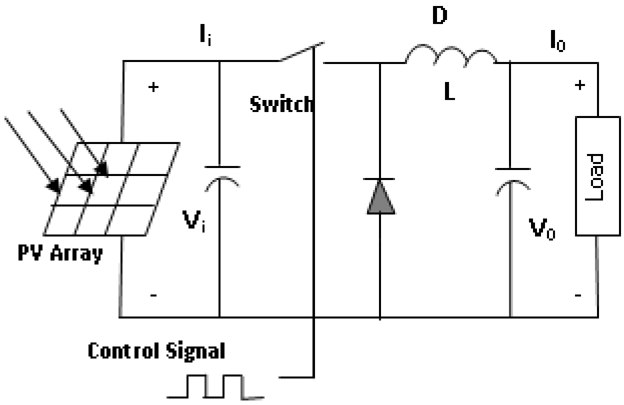

Fig 3: Buck Converter Configuration

Fig.3 shows use of buck converter for elevating the output voltage *Vo* respect to the input voltage *Vin* by fixing the duty cycle *D* (with a pulse width modulator) according to the following relation :

--(6)

The modeling of the PV cell was done in MATLAB/SIMULINK by writing the code in the embedded block. The solar irradiance and temperature were the input to the PV module and the voltage and current were the output of the module. The PV array subsystems were modeled and connected to the MPPT controller and boost converter. In literature a number of approaches and models can be found to analyze the behavior of PVs (U. Boke [35]; Arias & Rivera [36]; Ramaprabha & Mathur [37]).
The PV cell model used in this work is based on the single diode cell. The VI characteristics (in green) of a typical solar cell are as shown in the Fig 4.

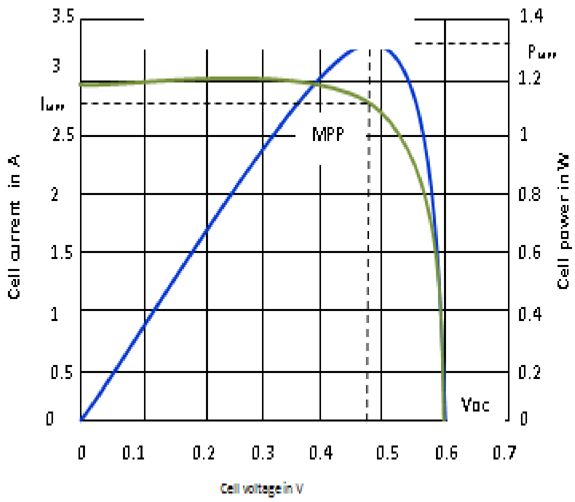

Fig 4: V-I and P-V Characteristics of PV Cell

When the voltage and the current characteristics are multiplied we get the P-V characteristics (in blue) as shown in Fig. 4. The point highlighted as MPP is the point at which the panel power output is maximum (Marcelo, Gazoli & Filho [38]).

III. MPPT ALGORITHMS

The electrical power generated by a photovoltaic system depends on solar irradiance , temperature and cloud cover. The current and voltage at which a solar module generates the maximum power is known as the maximum power point which is not known in advance. The maximum power point tracking (MPPT) system basically controls the voltage and the current of the PV array independently of the connected load. It is found that the P&O technique is the most extensively used in commercial MPPT systems because it is straight forward, accurate, and easy to implement .MPPT algorithms Perturb and Observe, Incremental Conductance, Neural Network and Adaptive Neuro Fuzzy Inference System (ANFIS) which are implemented on the PV array are described below (Ansari , Chatterji & Iqbal [39]).

3.1Perturb and Observe

In this method a slight perturbation is introduced in the system. Thus, the power of the module alters. Due to the perturbation if the power enhances, then the perturbation is carried on in the same direction. After the maximum power is accomplished, the power at the next instant decrements and hence the perturbation reverses. As in this method only one voltage and current sensor is used the error due to change in irradiance is introduced.

3.2 Incremental Conductance Method

Incremental conductance method senses both the voltage and current of the PV array simultaneously thus the error due to change in irradiance is eradicated. At MPP the slope of the PV curve is 0.

(dP/dV)MPP=d(VI)/dV
0=I+VdI/dVMPP
dI/dVMPP = - I/V ---------- (7)

The left hand side of equation 7 is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the PV array then MPP is reached. This method is more complex and the cost of implementation is also high and this method is suitable for a highly elaborated system.

3.3 Neural Network based MPPT

Neural network architecture gives the appropriate solution for the non-linear and complex systems. Among its types, there is the back propagation network which is more widespread, important and useful. The function and results of artificial neural network (ANN) are determined by its architecture that has different kinds. The simpler architecture contains two layers as shown in Fig. 7.

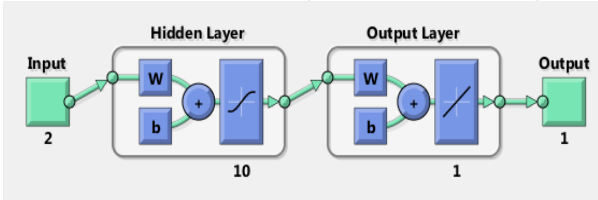

Fig 7: Neural Network Model

The input region receives the extern data. The first layer, hidden layer, contains several hidden neurons which receive data from the input region and send them to the second layer, output layer.

In this paper, to map the relationship between the emulated MPP locus (EML) parameter sets and the parameters available from the datasheet, a two layer feed-forward ANN as shown in Fig 7 is utilized. The input layer in this case consists of PV voltage and current recorded under different irradiations and temperatures from a real time system. The number of hidden layer nodes is 10. The relationships between the inputs and outputs are given as follows (Chiu, Luo, Huang & Liu [40]):

Neurons in input layer only act as buffers for distributing the input signals. The net input of the j^{th} hidden unit is

------- (8)

where is the weighting on the connection from the i^{th} input unit, represent the bias for the hidden layer neurons.

The output of the neurons in the hidden layer is

----(9)

and the net input to the neurons in the output layer can be written as

----------(10)

where is the weighting on the connection from the j^{th} input unit, represent the bias for the second layer neurons.

The output of the second layer, , is the network outputs of interest, and these outputs are labeled y_k .

x (11)

The collected data is first processed by MATLAB to obtain the corresponding emulated MPP locus (EML) parameter set. Using the collected data as input of artificial neural network (ANN) and the obtained emulated MPP locus (EML) parameter as output of artificial neural network (ANN), the proposed artificial neural network (ANN) can be trained using the Neural Network Toolbox in MATLAB (Anitha & Prabha [41]).

A two-layer feed-forward network with sigmoid hidden neurons and linear output neurons , can fit multi-dimensional mapping problems arbitrarily well, given consistent data and enough neurons in its hidden layer. The network was trained with Levenberg-Marquardt backpropagation algorithm .

Function fitting is the process of training a neural network on a set of inputs in order to produce an associated set of target outputs. Once the neural network has fit the data, it forms a generalization of the input-output relationship and can be used to generate outputs for inputs it was not trained on.

Training data These are presented to the network during training, and the network is adjusted according to its error.

Validation data These are used to measure network generalization, and to halt training when generalization stops improving.

Testing data These have no effect on training and so provide an independent measure of network performance during and after training.

A total of 7609 samples were collected from real time system out of which 5327 samples (ie) 70% was used as training data, 1141 samples (ie) 15% was used as validation data and remaining 1141 samples (ie) 15% was used as testing data.

The mean square error(MSE) and regression of the ANN model developed is given in Table 1.

Table 1: ANN Data Set, Mean Square Error and Regression

	Samples	**MSE**	**Regression**
Training	5327	2.92492e-9	1.90887e-1
Validation	1141	2.82180e-9	1.93351e-1
Testing	1141	2.88905e-9	1.79767e-1

To validate the ANN model the error histogram and regression plot are shown in Fig 8 and Fig 9.

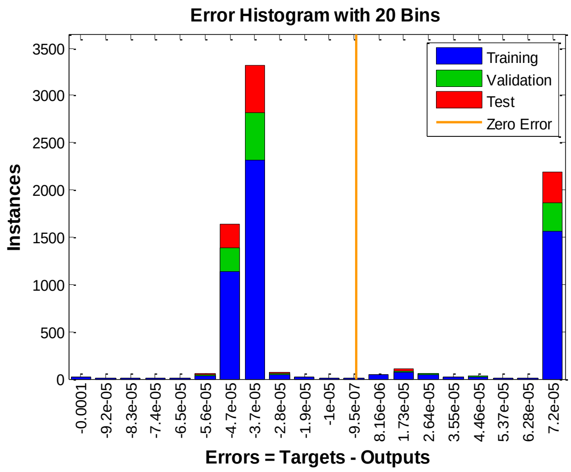

Fig 8: Validation of the ANN model (Error Histogram)

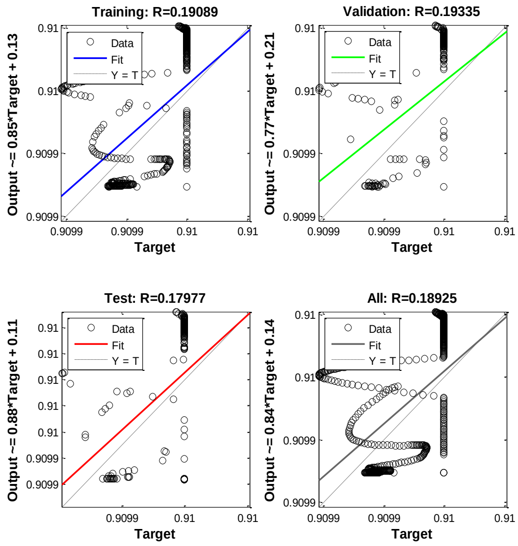

Fig 9: Validation of the ANN model (Regression Plot)

Mean Squared Error (MSE) is the average squared difference between outputs and targets. Lower values are better. Zero means no error.

Regression (R) Values measure the correlation between outputs and targets. A R value of 1 means a close relationship, 0 a random relationship.

The two-layer feed-forward network with sigmoid hidden neurons and linear output neurons based artificial neural network (ANN) model developed using MATLAB/SIMULINK is shown in Fig.10.

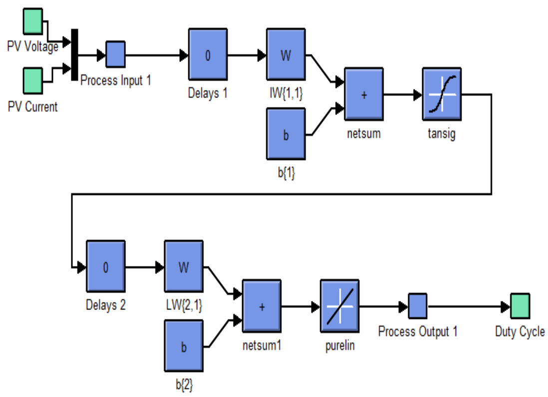

Fig 10: MATLAB/SIMULINK ANN Model

3.4 ANFIS (Adaptive Neuro Fuzzy Inference System)

Intelligent control is the viable alternative to conventional control schemes. The uncertain or unknown variations in plant parameters can be dealt more effectively by using artificial intelligent techniques such as fuzzy logic and neural network. Hence the robustness of the control system can be improved. The multilayer feed forward network has nodes which performs a particular function on incoming signals. Each node has different formula. The links in the adaptive network just indicate the signal flow direction (Liu & Huang [42]; Jang [43]; Shimi, Thilak, Jagdish & Chatterji [44]). The Investigators have developed an Adaptive Neuro Fuzzy Inference System (ANFIS) based algorithm for Maximum Power Point Tracking (MPPT). Voltage , current and the duty cycle was recorded under different irradiations and temperatures from a real time system. This real time data was used to train the Adaptive Neuro Fuzzy Inference System (ANFIS) model using MATLAB/SIMULINK (Fig. 11).

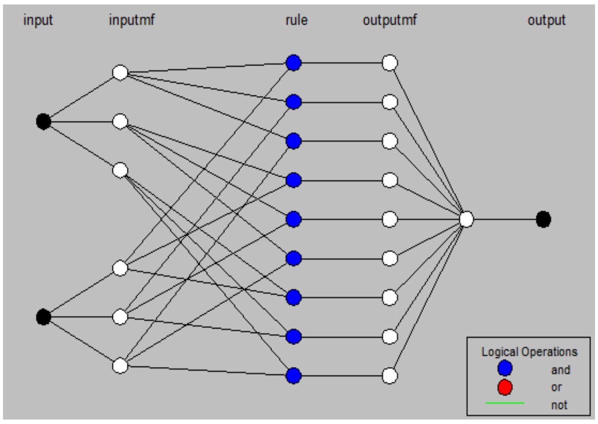

Fig. 11. MATLAB/SIMULINK ANFIS Model

IV. PROPOSED DESIGN

In this proposed method the photovoltaic system uses a MPPT system which automatically varies the duty cycle of the buck converter in order to generate the required voltage to extract maximum power.

The most popularly used MPPT algorithms Perturb and Observe ,Incremental Conductance, Neural Network based MPPT and ANFIS based MPPT algorithms are used for generating the duty cycle of the buck converter. The block diagram of the proposed scheme is shown in Fig.12. Voltage and Current sensors are used to acquire the input PV voltage and Current and is fed as input to the real time interface unit ds1104. Dspace 1104 is interfaced with MATLAB/SIMULINK in PC, which generates the firing pulse of required duty cycle to fire the buck converter.

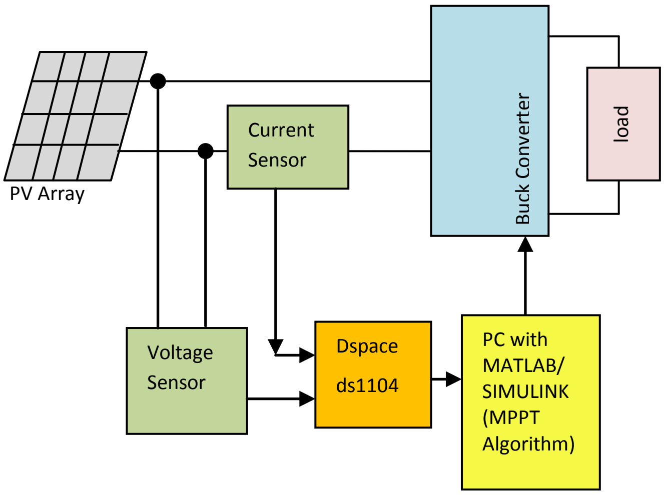

Fig. 12. Block Diagram of the Proposed System

V. SIMULATED CIRCUITS AND WAVEFORM

To verify the correctness of the proposed maximum power point tracking (MPPT) methods, a 37 W prototyping circuit is implemented from which simulations and experiments are carried out accordingly.

Eldora Micro Series 36 Cell Multicrystalline PV Module was used for experimentation. The parameters of the utilized PV panel is given in Table2.

Table 2 Parameters of the utilized PV panel

P_{max} (W)	**37**
V_{mpp} (V)	18.1
I_{mpp} (A)	2.1
V_{oc} (V)	21.77
I_{sc} (A)	2.26
Efficiency (%)	12.01

The buck converter inductance and capacitance design was done using the following equations

—— --------------------------------(12)

—— --------------------------------(13)

for a switching frequency of 80KHz and inductance current ripple of 10% the and are approximated as 1mH and 100µF respectively.

The validation of the system developed was done experimentally using the prototype of the P&O,INC, ANN and ANFIS based maximum power point tracking (MPPT) system shown in Fig.13 and Fig. 14.

Fig.13 Prototype of the P&O, INC, ANN and ANFIS based MPPT

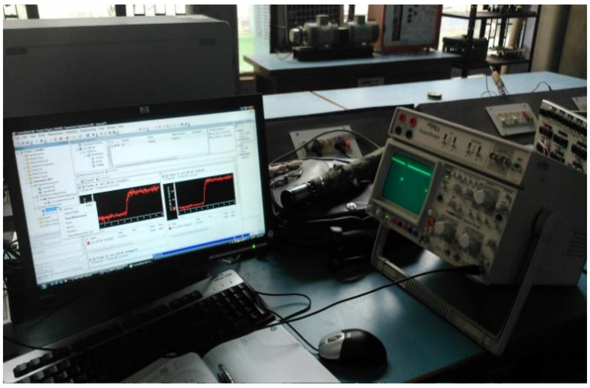

Fig. 14 P&O output waveforms on control desk

The MATLAB/SIMULINK implementation of the Perturb and Observe and Incremental Conductance MPPT subsystems are shown in Fig 15 and Fig 16 respectively.

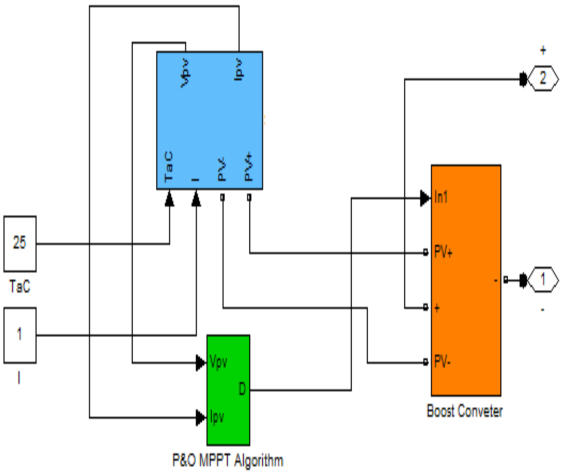

Fig 15: Perturb and Observe MPPT Algorithm

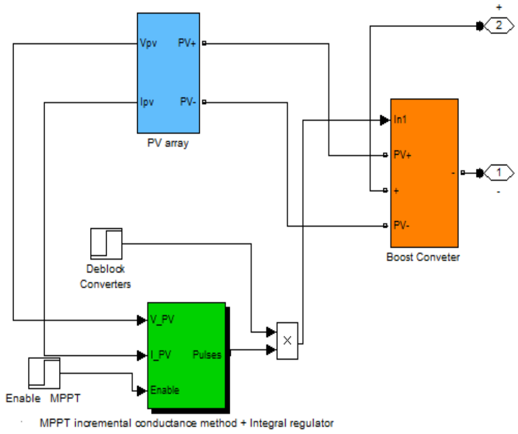

Fig 16: Incremental Conductance MPPT Algorithm

The real time data acquisition was done using Dspace and the simulated circuit is as shown in Fig 17

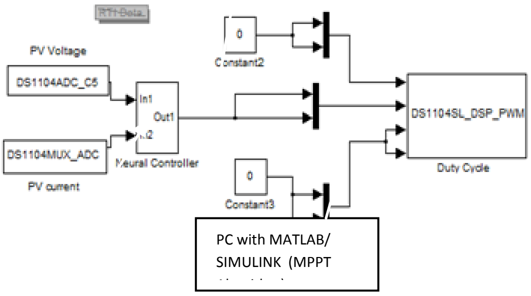

Fig 17: Real Time Data Acquisition

During the experimentation the irradiation was changed from 450W/m^2 to 910 W/m2 and the experiment was carried out with different algorithms such as Perturb and Observe , Incremental Conductance, Neural Network and adaptive neuro fuzzy inference system (ANFIS). The power Vs time plot for all the algorithms are as shown in Fig 18. The slope for all the curves was also calculated as shown in Fig 19. By observation it was found that Perturb and Observe (P&O) algorithm has poor response and lot of oscillations. Using the linear regression equation y=a+bx, where the intercept (a) was equated to zero then the equation becomes y=bx, where b is the slope. From the results it was found that the maximum b value resulted in adaptive neuro fuzzy inference system (ANFIS) which was 15.81. Thus it was conclude that ANFIS model gave fast response and fewer oscillations compared to Perturb and Observe, Incremental Conductance, Neural Network models. Next to adaptive neuro fuzzy inference system (ANFIS) the artificial neural network (ANN) model showed a better result with a slope 15.69. The incremental conductance model response shows a initial dip and thus the response the poor.

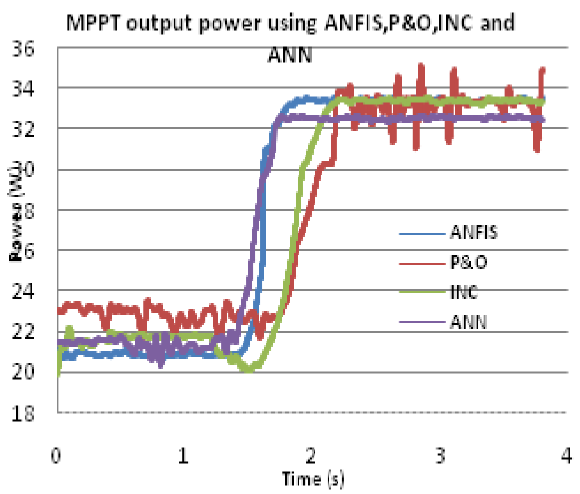

Fig 18: Comparison of MPPT Alogrithms

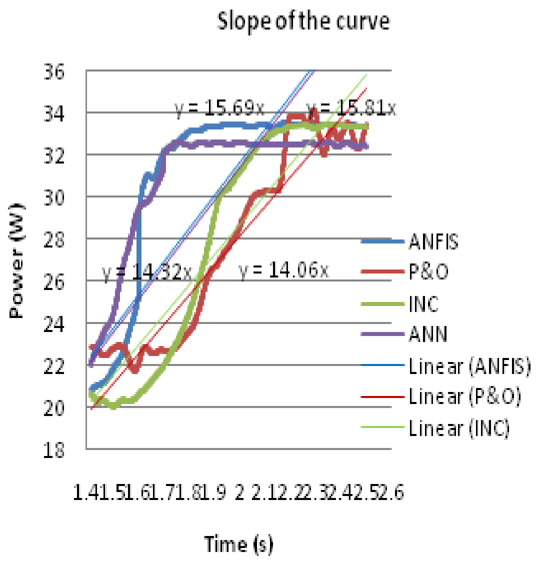

Fig 19: Comparison of Output Power Slope

VI. CONCLUSION

The Artificial Intelligent based Maximum Power Point Tracking (MPPT) of a Photo-Voltaic array was implementation using Dspace . The MPPT algorithms Perturb and Observe, Incremental Conductance, Neural Network and Adaptive Neuro Fuzzy Inference System (ANFIS) were discussed, implemented and compared. The modeling of the PV array was performed in MATLAB/SIMULINK. It was conclude that ANFIS model gave fast response and fewer oscillations compared to Perturb and Observe, Incremental Conductance and Neural Network models. The proposed ANFIS model is a well trained system and uses only two sensors and thus making the system cheaper and faster compared to the ANFIS model discussed in literature. Next to adaptive neuro fuzzy inference system (ANFIS) the artificial neural network (ANN) model showed a better result. The performances were evaluated by means of MATLAB/SIMULINK simulations interfaced with Dspace control desk and ds1104.

REFERENCES

[1] J. Rizk, and Y. Chaiko , "Solar Tracking System: More Efficient Use of Solar Panels", *World Academy of Science, Engineering and Technology, 43, 2008, 314-322.*

[2] Tiberiu Tudorache, Constantin Daniel Oancea, Liviu Kreindler, "Performance Evaluation of a Solar Tracking PV Panel", *U.P.B. Sci. Bull., Series C, 74 (1), 2012, 3-10.*

[3] Eftichios Koutroulis, Kostas Kalaitzakis and Nicholas C. Voulgaris,"Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System*", IEEE transactions on power electronics, 16 (1), 2001, 46-54.*

[4] R. Leyva, C. Alonso, I. Queinnec, A. Cid-Pastor, D. Lagrange and L. Martínez-Salamero, "MPPT of Photovoltaic Systems using Extremum–Seeking Control", *IEEE transactions on aerospace and electronic systems*, 42(1), 2006, 249-258.

[5] Mohammed A. Elgendy, Bashar Zahawi, and David J. Atkinson,"Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications", *IEEE Transactions On Sustainable Energy*, *3(1), 2012, 21-32* .

[6] D. K. Sharma & G. Purohit, "Advanced Perturbation and Observation (P&O) Based Maximum Power Point Tracking (MPPT) of a Solar Photo-Voltaic System", *proceeding of 5th International Conference on Power Electronics (IICPE), IEEE, 6(8), 2012, 1-5.*

[7] I. Abdalla, L. Zhang, J. Corda, "Voltage-Hold Perturbation & Observation Maximum Power Point Tracking Algorithm (VH-P&O MPPT) for Improved Tracking over the Transient Atmospheric Changes", *proceeding of European Conference on Power Electronics and Applications (EPE), 2011, 1-10.*

[8] Moacyr A. G. de Brito, Leonardo P. Sampaio, Luigi G. Jr., Guilherme A. e Melo and Carlos A. Canesi , "Comparative Analysis of MPPT Techniques for PV Applications", *proceeding of International Conference on Clean Electrical Power (ICCEP), Ischia, 2011, 99–104.*

[9] Md Fahim Ansari , S. Chatterji & Atif Iqba , “Automatic maximum power point tracker for solar PV modules using dSPACE software”, *International Journal of Sustainable Energy, 29 (3), 2010, 151-163.*

[10] Vladimir V. R. Scarpa, Simone Buso, Giorgio Spiazzi, “Low-Complexity MPPT Technique Exploiting the PV Module MPP Locus Characterization”, *IEEE transactions on industrial electronics, 56 (5) , 2009, 1531-1538*.

[11] I.H Altas and A.M Sharaf, “A Novel On-Line MPP Search Algorithm for PV Arrays”, *IEEE Transaction on Energy Conversion, 11(4), 1996, 748-754.*

[12] Siwakoti Y.P., Chhetri, B.B. Adhikary, B Bista, D, “Microcontroller Based Intelligent dc/dc Converter To Track Maximum Power Point For Solar Photovoltaic Module”, *IEEE Conference on Innovative Thechnologies for an efficient and Reliable Electricity Supply, 2010, 94-101.*

[13] Guan-Chyun Hsieh, Hung-I Hsieh, Cheng-Yuan Tsai, and Chi-Hao Wang, “Photovoltaic Power Increment Aided Incremental Conductance MPPT With Two Phased Tracking”, *IEEE Transactions On Power Electronics,* 28(6), 2013, 2895-2911.

[14] M.A Elgendy, B.Zahawi & SlidD.J. Atkinsou, “Comparison of directly connected and constant voltage controlled photovoltaic pumping systems “, *IEEE Transactions On Sustainable Energy, 1 (3), 2010, 184-192.*

[15] Petru Lucian Milea, Adrian Zafiu, Marin Dragulinescu & Orest Oltu,”MPP Tracking Method for PV Systems, Based on a Three Points Prediction Algorithm”, *U.P.B. Sci. Bull., Series C, 72 (4),2010, 149-160*.

[16] Jung-Sik Choi and Do-Yeon Kim and Ki-Tae Park & Jung-Hoon Choi and Dong-Hwa Chung, “Tracking system and MPPT Control for Efficiency Improvement of Photovoltaic”, *proceeding of International Conference on Control, Automation and Systems, COEX, Seoul, Korea, 2008, 1341-1344.*

[17] Lin C., Huang C., Duc Yi. & Chen J,” Maximum Photovoltaic Power Tracking For The PV Array Using The Fractional-Order Incremental Conductance Method”, *Elsevier Journal on Applied Energy, 88, 2011, 4840–4847.*

[18] J.S. Kumari & Ch. S. Babu, “Comparison of Maximum Power Point Tracking Algorithms for Photovoltaic System”, *International Journal of Advances in Engineering and Technology, 1(5), 2011, 133-148.*

[19] Joung-Hu Park, Jun-Youn Ahn, Bo-Hyung Cho and Gwon-Jong Yu, “Dual-Module-Based Maximum Power Point Tracking Control of Photovoltaic Systems”, *IEEE Transactions On Industrial Electronics,* 53 (4), 2006, 1036-1047.

[20] Mohamed Azab, “A New Maximum Power Point Tracking for Photovoltaic Systems”, *International Journal of Electrical and Electronics Engineering,* 3(11), 2009, 702-705.

[21] T. Kitano, M. Matsui, and D.-h. Xu, “Power sensor-less MPPT control scheme utilizing power balance at dc link-system design to ensure stability and response”, *proceeding of 27th Annual Conference of the IEEE Industrial Electronics Society, IECON, 2001,1309-1314.*

[22] Lopez-Lapena O, Penella, M.T and Gasulla M , “A New MPPT Method for Low-Power Solar Energy Harvesting”, IEEE Transactions on Industrial Electronics, 57 (9), 2010, 3129-3138.

[23] Elshaer and Mohamed A. and Mohammed O, “Smart Optimal Control of DC-DC Boost Converter in PV Systems”, *IEEE/PES Transmission and Distribution Conference and Exposition, Latin America, 2010, 403-410.*

[24] G. Balasubramanian & S. Singaravelu, “Fuzzy logic controller for the maximum power point tracking in photovoltaic system”, *International Journal of Computer Applications, 41(12), 2012, 22-28.*

[25] M.K. Wu & S. Widodo, “Single Input Cerebellar Model Articulation Controller (CMAC) based Maximum Power Point Tracking for Photovoltaic System”, *International Symposium on Computer, Communication, Control and Automation, IEEE, 2010, 439-442*.

[26] Rai A., Kaushika N., SinghB & Agarwal N, “Simulation Model Of ANN Based Maximum Power Point Tracking Controller For Solar PV System”, *Elsevier Journal on Solar Energy Materials & Solar Cells,* 95, 2011, 773–778.

[27] R. I. Putri & M. Rifa I, “Maximum Power Point Tracking Control for Photovoltaic System Using Neural Fuzzy”, *International Journal of Computer and Electrical Engineering,* 4(1), 2012, 75-81.

[28] R. M. Kamel & K. Nagasaka, “MPPT Operation for PV Grid-Connected System using RBFNN and Fuzzy Classification”, *World Academy of Science, Engineering and Technology, 41, 2010 97-105.*

[29] Aymen Chaouachi , Rashad M. Kamel and Ken Nagasaka, "A Novel Multi-Model Neuro-Fuzzy-based MPPT for Three-Phase grid-connected Photovoltaic System", *Elsevier Ltd., Science Direct, Solar Energy*,84(12), 2010, 2219–2229.

[30] Donny Radianto, " Partial Shading Detection and MPPT Controller for Total Cross Tied Photovoltaic using ANFIS", *ACEEE International Journal on Electrical and Power Engineering, 03(2), 2012, 1-5.*

[31] Boutabba Tarek, Drid said,M.E.H. Benbouzid, "Maximum Power Point Tracking Control for Photovoltaic System Using Adaptive Neuro- Fuzzy "ANFIS" ", *Eighth International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER), 2013, 1-7.*

[32] Kashif Ishaque, Zainal Salam, Muhammad Amjad & Saad Mekhilef," An Improved Particle Swarm Optimization (PSO)–Based MPPT for PV With Reduced Steady-State Oscillation", *IEEE Transactions on Power Electronics, 27 (8). 2012 , 3627-3638.*

[33] Trihan Esram & Patrick L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", *IEEE Transactions on Energy Conversion*, 22(2), 2007, 439-449.

[34] F. Filho, L. M. Tolbert, B. Ozpineci & Y. Cao, "Real Time Selective Harmonic Minimization for Multilevel Inverters Connected to Solar Panels Using Artificial Neural Network Angle Generation", *IEEE Transactions on Industry Applications*, 47(5), 2011, 2117-2124.

[35] U. Boke, "A simple model of photovoltaic module electric characteristics", *European Conference on Power Electronics and Applications*, 2007, 1-8.

[36] O. Gil-Arias & E. I. Ortiz-Rivera, "A general purpose tool for simulating the behavior of PV solar cells, modules and arrays", *11th Workshop on Control and Modeling for Power Electronics, 2008, 1-5.*

[37] R. Ramaprabha & B. L.Mathur, "MATLAB based modelling to study the influence of shading on series connected SPVA", *2nd International Conference on Emerging Trends in Engineering and Technology, 2009, 30-34.*

[38] Marcelo G, Gazoli J. & Filho E, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays", *IEEE Transactions On Power Electronics, 24(5), 2009, 1198-1208.*

[39] Md Fahim Ansari , S. Chatterji & Atif Iqbal, "Fuzzy logic-based MPPT controllers for three-phase grid-connected inverters", International *Journal of Sustainable Energy, 2011, 186-195.*

[40] Yi-Hsun Chiu, Yi-Feng Luo, Jia-Wei Huang and Yi-Hua Liu," An ANN-based Maximum Power Point Tracking Method for Fast Changing Environments", *SCIS-ISIS , Kobe, Japan, 2012, 715- 720.*

[41] S. D. Anitha & S. Berclin Jeya Prabha, "Artificial Neural Network based Maximum Power Point Tracker for Photovoltaic system", *proceeding of 2nd International Conference on Sustainable Energy and Intelligent System, organized by Dr. M.G.R. University, Maduravoyal, Chennai, Tamil Nadu, India, 2011, 130-136.*

[42] Y. H. Liu & J. W. Huang , A fast and low cost analog maximum power point tracking method for low power photovoltaic systems," *Elsevier Solar Energy*,85(5), 2011, 2771–2780.

[43] J. S. R. Jang," ANFIS: Adaptive Network-Based-Fuzzy Inference System", *IEEE Transactions On Systems, Man And Cybernetics, 23(3), 1993, 665-685.*

[44] Shimi S.L, Dr. Thilak Thakur , Dr. Jagdish Kumar, Dr. S Chatterji," ANFIS Controller For Solar Powered Cascade Multilevel Inverter", *International Journal of Electrical Engineering & Technology, 3(3), 2012, 234-240.*