International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

Improved Maximum Power Point Tracking for Solar PV Module using ANFIS

Ravinder K. Kharb[Ȧ*], S. L. Shimi[Ḃ] and S. Chatterji[Ḃ]

[Ȧ]Department of Electronics & Communication Engineering, Government Polytechnic Jhajjar, Haryana, India
[Ḃ]Department of Electrical Engineering, National Institute of Technical Teacher's Training and Research, Chandigarh, India

Accepted 25 November 2013, Available online 01 December 2013, **Vol.3, No.5 (December 2013)**

Abstract

The output power delivered by solar photovoltaic (PV) module depends on weather conditions and to obtain maximum they are required to operate at maximum available power point for different weather conditions. Maximum power point tracking (MPPT) controllers are usually employed in PV power systems to extract maximum power. Since the solar PV module characteristics are highly nonlinear, conventional control techniques could be inefficient for an optimal use of these systems. This paper presents an improved methodology for maximum power point tracking of a solar PV module using adaptive neuro fuzzy inference system (ANFIS). Mathematical modeling of a solar PV module has been done in sequential steps using Matlab/Simulink software package and ANFIS based maximum power point tracking scheme is developed to control the extraction of maximum power from this solar PV module. The proposed ANFIS based reference model is trained to generate maximum power corresponding to varying solar irradiance level and operating temperature. Simulation results reveals that the response of proposed ANFIS based MPPT method is more accurate and fast as compared to the conventional techniques like perturb & observation (P&O). The main advantage of proposed MPPT scheme is fast response and high gain even at lower value of solar irradiance level without oscillations near the point of maximum power. The analytical and simulation results of this research are presented to validate the concept.

Keywords: *Adaptive neuro fuzzy inference system (ANFIS), Maximum power point tracking (MPPT), Photovoltaic (PV) module, Perturb and Observation (P&O) technique, PI Controller.*

1. Introduction

In today's scenario of increasing energy demands and environmental concern, it is the need of time to investigate the alternatives of non-renewable and polluting fossil fuels. One such alternative is solar energy. Solar is one of the most talked-about alternative energy sources in the world today. The energy which comes from sun in one hour is sufficient to power the global population for a year. The enormous potential of solar energy can meet the world energy demand many times (M. Z. Jacobson, 2011). Sunlight is totally renewable resource, unlike oil, coal and natural gas. Various benefits of solar energy for different sectors are tabulated by (M. F. Ansari et al, 2013). Solar energy can be converted into electricity, directly using photovoltaic (PV) cells. Photovoltaic cells convert light energy into electric energy using the photoelectric effect. But the low efficiency and high capital cost of solar PV systems are the main barriers to implement solar power installations (M. Fahim Ansari et al, 2013). Although the solar power is environment friendly and it can help reduce the emission of greenhouse gases but still the market benefits of installing the current solar PV technology are much smaller than its costs (S. Borenstein, 2008). Although the costs of solar energy technologies have exhibited rapid declines in the recent past, the minimum values of levelized cost of any solar technologies would be higher than the maximum values of levelized costs of conventional technologies for power generation even if capital costs of solar energy technologies were reduced by 25% (R. Govinda et al, 2011). A typical solar PV module converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Moreover the output power of solar PV module also gets affected by some other factors like solar irradiance level, temperature and load conditions. So in order to improve the efficiency of solar PV system and enhance the solar power installations across the globe, maximum obtainable power from the solar PV module has to be extracted. A maximum power point tracker is used for extracting the maximum power from the solar PV module and transferring that power to the load.

1.1 Maximum Power Point Tracking – An Overview

Maximum Power Point Tracking (MPPT) is an electronic tracking, and has nothing to do with moving the solar PV modules with the position of Sun. Instead, the MPPT

*Corresponding author: **Ravinder K. Kharb**

controller looks at the output of the PV modules, and then figures out what is the best power that the PV module can put out to the connected load. Maximum power point tracking methods are used to improve the efficiency of the solar PV module. As per the theorem of maximum power transfer, the power output of a circuit is maximum when the source impedance of circuit matches with the load impedance. In solar PV system a DC-DC converter is inserted between solar PV module and load in order to match the impedance of two sides. By changing the duty cycle of the DC-DC converter appropriately we can match the source impedance with that of the load impedance. A maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar PV module and the load.

Many MPPT algorithms and control schemes of solar PV system have been proposed in the literature (Joe-A. Jiang et al, 2005; V. Lingareddy et al, 2013; Saravana S. D., 2013; S. Gomathy et al, 2012; C. Chukwuka et al, 2013). As the output power of solar PV module is of dynamic nature, most of the presented MPPT methods suffer from the drawback of poor stability and can produce oscillations near the point of maximum power due to the highly non-linear characteristics of the PV modules. A comparative study between various MPPT algorithms has been presented by (T. Esram et al, 2007; D. P. Hohm et al, 2003; A. P. K. Yadav et al, 2012). Artificial intelligence (AI) techniques used for MPPT offer highly accurate and flexible nature of control to improve the dynamic performance of extracting maximum power from solar PV module (A. Chaouachi et al, 2010; M. F. Ansari et al, 2012; A. M. Zaki et al, 2012; R. Singh et al, 2013). The AI methods are mainly based on fuzzy logic controller and artificial neural networks. The Neural network is a powerful technique for mapping input-output relationship of non-linear system. . A neural network control lacks the heuristic sense and it operates like a black box model, requiring no detailed information about the PV system. On the other hand, fuzzy logic can transform the heuristic and linguistic terms into numerical values using a set of fuzzy rules and membership functions. Fuzzy logic controllers are robust and relatively simple to design because they do not require knowledge of the exact model. They use the expert knowledge for the development of rules of inference system. However, fuzzy logic requires correct fuzzy rules and membership functions for accurate fuzzy computation. The Adaptive neuro-fuzzy inference system (ANFIS) combines the advantages of neural network and fuzzy logic; hence this formation becomes the most powerful artificial intelligence technique to deal with non-linear system like solar PV system. Thus, in this paper, ANFIS technique is used to extract maximum power from solar PV module at a specific solar irradiance level and operating temperature. A PI controller is then used to eliminate the error in the actual power output and reference power. The effect of changing weather conditions like, solar irradiance level and temperature, on the output of solar PV module is further investigated and reported in this paper.

1.2 Organization of the Paper

This paper comprises of two parts; step by step mathematical modeling of a solar PV module in Matlab/Simulink environment and maximum power point tracking of this solar PV module using ANFIS based control scheme. In section 2, mathematical modeling of solar PV module is presented. Analysis of solar PV module characteristics is given in section 3. Designing of MPPT scheme using ANFIS is described in section 4. The results and discussion of this research are given in section 5, followed by conclusions and scope of future work in section 6.

2. Modeling of Solar PV module in Matlab/Simulink environment

MXS 60 PV Module is taken as the reference module for simulation and the data sheet details are given in table-1 (M. Abdulkadir et al, 2012). In addition to that, series resistance (Rs) of PV module is taken as 0.2Ω, band gap energy (Eg) of the semiconductor used is taken as 1.1 eV and ideality factor (A) of semiconductor is taken as 1.6.

Table 1 Key specification of MXS 60 PV module

Parameter	Variable	Value
Maximum power	Pm	60W
Maximum voltage	Vm	17.1 V
Current at max power	Im	3.5 A
Open circuit voltage	Voc	21.06 V
Short circuit current	Isc	3.74 A
Total No. of cells in Series	Ns	36
Total No. of cells in Parallel	Np	1

2.1 Equivalent Circuit of PV module

The ideal equivalent electrical circuit of a solar cell can be represented by a light generated current source, Iph, in parallel with a single-diode as shown in fig. 1 (A. Kane et al, 2013). Rs and Rsh are the series and shunt resistance of solar cell and they are usually neglected to simplify the analysis as the value of Rsh is very large and that of Rs is very small (N. Pandiarajan et al, 2012). Usually the output power of a solar cell is very less and of no practical use unless it is increased by some means. So in order to increase the output power of solar PV systems, the solar cells are connected in series and parallel configurations to form solar PV modules and arrays (M. S. Mahmodian et al, 2012).

2.2 Basic Equations of PV module

The current-voltage relationship of the PV module can be described mathematically using some basic equations from the theory of semiconductors and photovoltaic. These equations have been used in this paper for the step by step modeling of solar PV module using Matlab/Simulink software package.

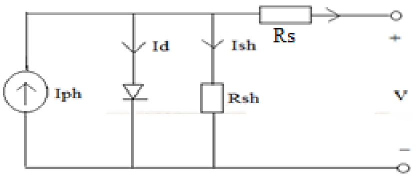

Fig. 1 Equivalent circuit of Solar Cell

2.2.1 Light Generated Photocurrent

The module photocurrent depends linearly on the solar irradiation level and is also influenced by the temperature according to the following equation

$$\mathrm{Iph} = [\mathrm{Isc} + \mathrm{Ki}(\mathrm{T} - \mathrm{Tr})] * \lambda \quad (1)$$

Where, Isc is the cell short-circuit current at a 25 °C and 1 kW/m^2; Ki is the cell short-circuit current temperature coefficient; T is cell working temperature; Tr is the cell reference temperature and λ is the solar irradiance level in kW/m^2.

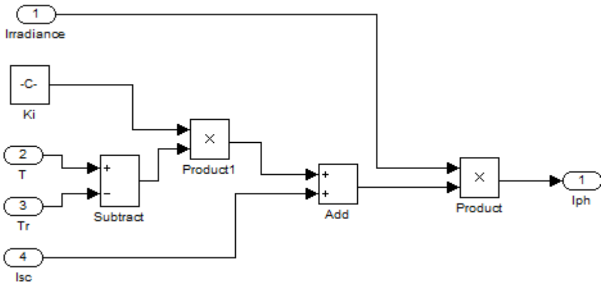

Fig.2 Simulink model of photocurrent using equation (1)

Matlab/Simulink model of photocurrent Iph using equation (1) is shown in figure 2. Value of photocurrent is measured for different irradiance level and temperatures and the result is given in table 2.

2.2.2 Reverse Saturation Current of PV module

The reverse saturation current, Irs, of module, at reference temperature is given by

$$\mathrm{Irs} = \frac{\mathrm{Isc}}{\exp\left[\frac{\mathrm{qVoc}}{\mathrm{NskAT}}\right] - 1} \quad (2)$$

Where, Voc is the PV open-circuit voltage at the reference temperature; q is the electron charge (1.6×10^{-19} C); k is Boltzmann constant (1.38×10^{-23} J/K); A is the ideal factor of cell dependent on PV technology and Ns is the number of cells connected in series. Detailed Simulink model of reverse saturation current using equation (2) is shown in figure 3.

Table 2 Photocurrent, Iph for different irradiance levels and temperatures

Irrad. W/m^2	Value of photocurrent (A)					
	15°C	25°C	35°C	45°C	55°C	65°C
200	0.7446	0.748	0.7514	0.7548	0.7582	0.7616
400	1.489	1.496	1.503	1.51	1.516	1.523
600	2.234	2.244	2.254	2.264	2.275	2.285
800	2.978	2.992	3.006	3.019	3.033	3.046
1000	3.723	3.74	3.757	3.774	3.791	3.808

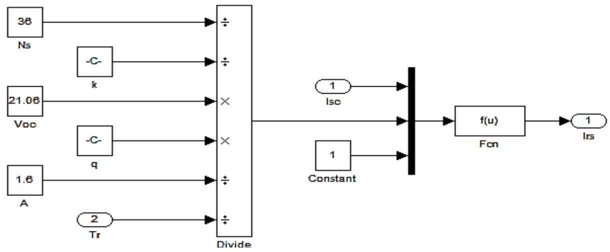

Fig. 3 Simulink model of reverse saturation current using equation (2)

Modules reverse saturation current changes with change in temperature as shown in table 3.

Table 3 Module reverse saturation current, Irs for different working temperatures

S.No.	Temperature °C	Module Reverse Saturation Current (A)
1.	15	$1.523*10^{(-006)}$
2.	25	$2.495*10^{(-006)}$
3.	35	$3.96*10^{(-006)}$
4.	45	$6.103*10^{(-006)}$
5.	55	$9.162*10^{(-006)}$
6.	65	$1.343*10^{(-005)}$

2.2.3 Module Saturation Current

The module saturation current, Is, varies with the cell temperature, which is given by

$$\mathrm{Is} = \mathrm{Irs}\left(\frac{\mathrm{T}}{\mathrm{Tr}}\right)^{3} \exp\left[\mathrm{q} * \mathrm{Eg}\,\frac{\frac{1}{\mathrm{Tr}} - \frac{1}{\mathrm{T}}}{\mathrm{kA}}\right] \quad (3)$$

Where, Irs is the module reverse saturation current; Eg is the band-gap energy of the semiconductor used in the cell. Matlab/Simulink model of equation (3) is shown in figure 4. The module operating temperature, reference temperature, and module reverse saturation current are taken as inputs. The module saturation current is calculated for different working temperatures and is given in table 4.

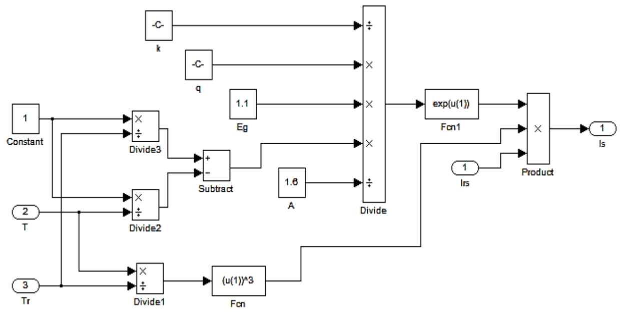

Fig.4 Simulink model of module saturation current using equation (3)

Table 4 Module saturation current, Is for different working temperatures

S.No.	Temperature °C	Module Reverse Saturation Current (A)
1.	15	$5.433*10^{(-007)}$
2.	25	$2.495*10^{(-006)}$
3.	35	$1.042*10^{(-005)}$
4.	45	$3.986*10^{(-005)}$
5.	55	0.000141
6.	65	0.0004639

2.2.4 Model of NsAkT product

Matlab/Simulink model of the product NsAkT is shown in figure 5. This model takes operating temperature in Kelvin and calculates the product NsAkT. The product NsAkT is used in the final simulink model of solar PV module.

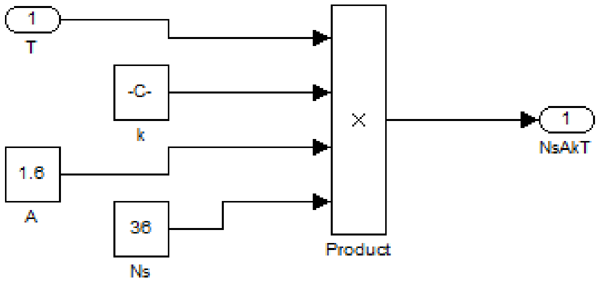

Fig.5. Simulink model of the product NsAkT

2.2.5 Model of Temperature Conversion

As the temperature used in the mathematical equations of solar PV module is in Kelvin units, figure 6 is used to convert the operating temperature from degree Celsius units to Kelvin units using equation (4).

$$T_{(K)} = T_{(°C)} + 273 \tag{4}$$

Where, $T_{(K)}$ is temperature in Kelvin and $T_{(°C)}$ is temperature in degree Celsius.

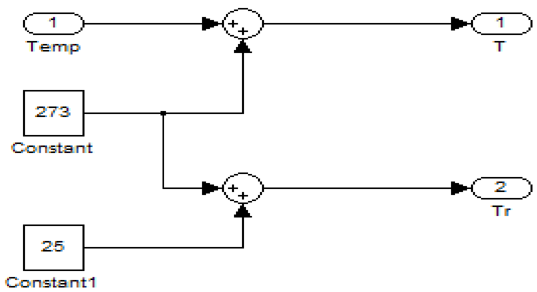

Fig.6. Simulink model of the temperature conversion from degree Celsius unit to Kelvin unit

2.2.6 Output Current of PV module

The output current, I, of PV module is given as

$$\mathrm{I} = \mathrm{Np} * \mathrm{Iph} - \mathrm{Np} * \mathrm{Is}\left[\exp\frac{\mathrm{q(V+IRs)}}{\mathrm{Ns*kTA}} - 1\right] \tag{5}$$

Where, Rs is the series resistance of solar cell; V is the output voltage which is equal to Voc at standard test conditions of 1000 W/m^2 irradiance level and 25°C temperature; Np is the number of cells connected in parallel.

The solution of equation (5) can be found out using iterative process and it needs to solve an algebraic loop in the simulink model of output current. In order to avoid the problem of algebraic loop, the functional models are used in PV research for modeling of solar PV modules [46]. For the purpose of successful simulink modeling of output current, proper care has to be taken of the feedback loop to get the faster convergence to a definite answer. In this paper the problem of algebraic loop is solved by including in the feedback path, the saturation block and transport delay block from simulink library of matlab software package. The iterative Matlab/Simulink model of equation (5) is shown in figure 7.

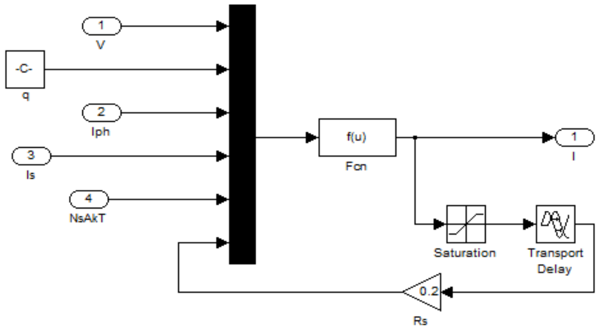

Fig.7. Simulink model of the module output current using equation (5)

2.3 Simulink Model of PV module

All the above six simulink models are masked and interconnected to get the simulink model of PV module as shown in figure 8. This model takes irradiance level, operating temperature and module voltage as input and gives the output current, I. Module voltage is varied from 0 to 22 V.

3. Analysis of PV module Characteristics

Current versus voltage and power voltage curves of solar PV module represent its electrical characteristics. Simulated model in figure 8is used to derive the I-V and P-V curves of solar PV module and results are shown in figures 9-11

Figure 9 shows the I-V characteristics of solar PV module under varying irradiance level with constant temperatures. It is observed that the solar PV module output current increases rapidly with irradiance level and there is moderate increase in output voltage also, which result in net increase in output power with rise in irradiance level. Figure 10 shows the I-V characteristics of solar PV module under constant irradiance level with varying temperature. It is depicted that the output current increases marginally and output voltage decreases drastically with increase in temperature, which result in net reduction in power output.

Figure 11 shows the P-V output characteristics of the solar PV module under varying irradiance level with constant temperatures. From the curve it is observed that when the irradiance level increases, the output current and voltage increases. This result indicate that there is net increase in output power with an increase in irradiance level at constant temperatures and the maximum power point (MPP) keeps on moving with it. It is also observed that the P-V characteristics of solar PV module are fixed for each irradiance level without any intersection.

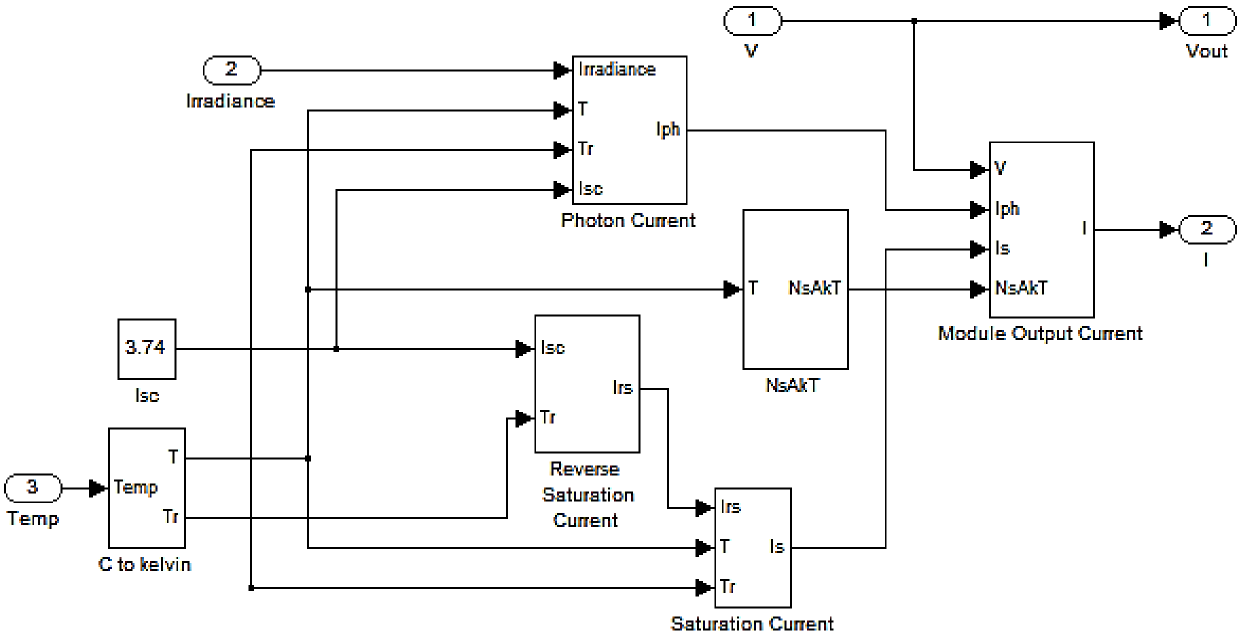

Fig.8.This simulink model interconnect all the six models

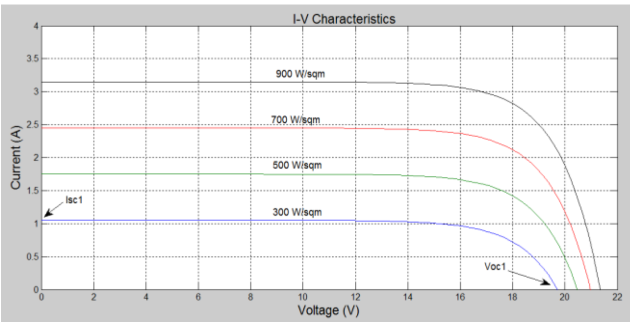

Fig.9 I-V characteristics under varying irradiance level with constant temperature

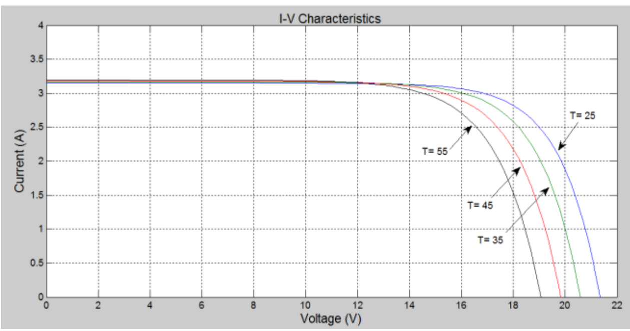

Fig. 10. I-V characteristics under constant irradiance level with varying temperature

4. Design of ANFIS based MPPT Scheme

Artificial intelligence systems are those systems which can make decisions like humans by adapting themselves to the situations and taking correct decisions automatically for future similar situations. Neural networks, fuzzy systems, and neuro-fuzzy systems are the examples of the artificial intelligence systems. Among different artificial intelligence systems, adaptive neuro fuzzy inference system (ANFIS) is most suitable for non-linear systems as it has advantages of both fuzzy systems and neural networks. The neuro-adaptive learning techniques provide a method for the fuzzy modeling procedure to learn information about data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input-output data. ANFIS constructs an input-output mapping based on both human knowledge and simulated input output data pairs. ANFIS constructs the set of fuzzy rules with appropriate membership functions in order to generate the input output pairs. The parameters associated with the membership functions are open to change through the learning process. The adjustment of these parameters is facilitated using a hybrid learning algorithm.

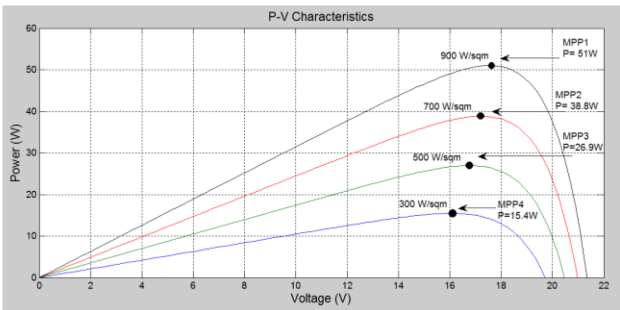

Fig.11. P-V Characteristics under constant temprature with varying irradiance level

4.1 ANFIS Reference model

The proposed ANFIS reference model directly takes in operating temperature and irradiance level as inputs, to find out the maximum available output power of solar PV module. In order to generate ANFIS reference model, the developed Matlab/Simulink model of solar PV module in section 2, is used to collect the training data. The operating temperature is varied from 15° C to 65° C in a step of 5°C and the solar irradiance level is varied from 100 W/m^2 to 1000 W/m^2 in a step of 50 W/m^2, to get the training data sets for ANFIS. For each pair of operating temperature and irradiance level the corresponding maximum available power is recorded. A sample of training data set for ANFIS is shown in table 5. In total 209 training data sets and 2000 epochs are used to train the ANFIS. The training error is reduced to approximately 6%. By using given input/output data set, the ANFIS constructs a fuzzy inference system (FIS) in which value of membership functions are tuned using the hybrid optimization method of training the FIS.

4.2 Implementation of ANFIS based MPPT Scheme

In this paper the maximum power point tracking using ANFIS is designed in Matlab/Simulink environment as shown in figure 12. The complete system is designed using user friendly icons from simulink library of Matlab software package. An optimal load of 5.4 Ω, which closely matches the maximum power point of the solar PV module at standard test conditions of 1000 W/m^2 irradiance level and 25°C temperature, is connected at the output.

Table 5 Training data sample

S.No.	Irradiance Level (W/m^2)	Temperature (°C)	Output Power (W)
1.	100	15	5.084
2.	100	20	4.926
3.	100	25	4.769
4.	100	30	4.611
5.	100	35	4.453
6.	100	40	4.296
7.	100	45	4.138
8.	100	50	3.981
9	100	55	3.824
10.	100	60	3.667

An IGBT is chosen as the switching element of DC-DC boost converter to vary its duty cycle. Gating signals to the IGBT are provided by a high carrier frequency pulse width modulator (PWM) block. Maximum available output power of PV module at a specific irradiance level and temperature is taken from the ANFIS reference model. At the same irradiance level and temperature, the actual output power of PV module is taken from the simulated model of PV module. Both the output powers are compared and the resultant error signal is processed by a proportional-integral (PI) controller. The output control signal from the PI controller is given to the PWM block which adjusts the pulse width to maintain the output power at maximum value. The PWM signal is generated using high frequency of carrier signal as compared to the control or modulating signal. The frequency of carrier signal used is 50 kHz. The PWM signal thus produced controls the switching frequency of IGBT and hence the duty cycle of DC-DC boost converter as per the changing irradiance level and temperature, so as to maximize the output power of solar PV module.

5. Results and Discussion

The Matlab/Simulink model of solar PV module, developed in section 2, is used to test the proposed ANFIS based MPPT control scheme. One DC-DC boost converter is connected between solar PV module and a resistive load for impedance matching and transfer of maximum power between solar PV module and resistive load. ANFIS based control scheme is used here to vary the duty cycle of boost converter, so that maximum available power can be transferred to load. For comparing the results of ANFIS based control scheme, same solar PV module is connected directly to the load without any controller.

5.1 Simulated Results under varying irradiance level with constant temperature

Various results obtained for different values of irradiance level and constant temperature are given in table 6. When the irradiance level is increased, a uniform increase in the output power with ANFIS based MPPT control scheme is observed in table 6. Starting from 34% to 100% increase in output power is obtained when the irradiance level is increased from 200 W/m^2 to 900 W/m^2. Maximum increase of 100% in the output power is achieved for irradiance level of 900 W/m^2.

Table 6: Output power for different irradiance levels and constant temperature of 25^{o}C

S.No.	Irradiance Level (W/m^2)	Output Power (W) (Without MPPT)	Output Power (W) (With MPPT)	% Increase
1.	200	2.662	3.579	34%
2.	300	5.988	8.929	49%
3.	400	10.64	17.72	66%
4.	500	16.62	30.47	83%
5.	600	23.87	47.12	97%
6.	700	32.10	63.29	97%
7.	800	41.31	81.39	97%
8.	900	50.13	100.6	100%

5.2 Simulated Results under varying temperature with constant irradiance level

The output power of PV module for different operating temperature and constant irradiance level is given in table 7. It is observed from table 7 that the increase in output power remains almost constant with varying operating temperature, clearly depicting the successful extraction of maximum power of PV module.

Figure 13 depicts the output power of solar PV module with and without MPPT scheme at irradiance level of 200 W/m^2 and operating temperature of 25°C. It is clearly seen

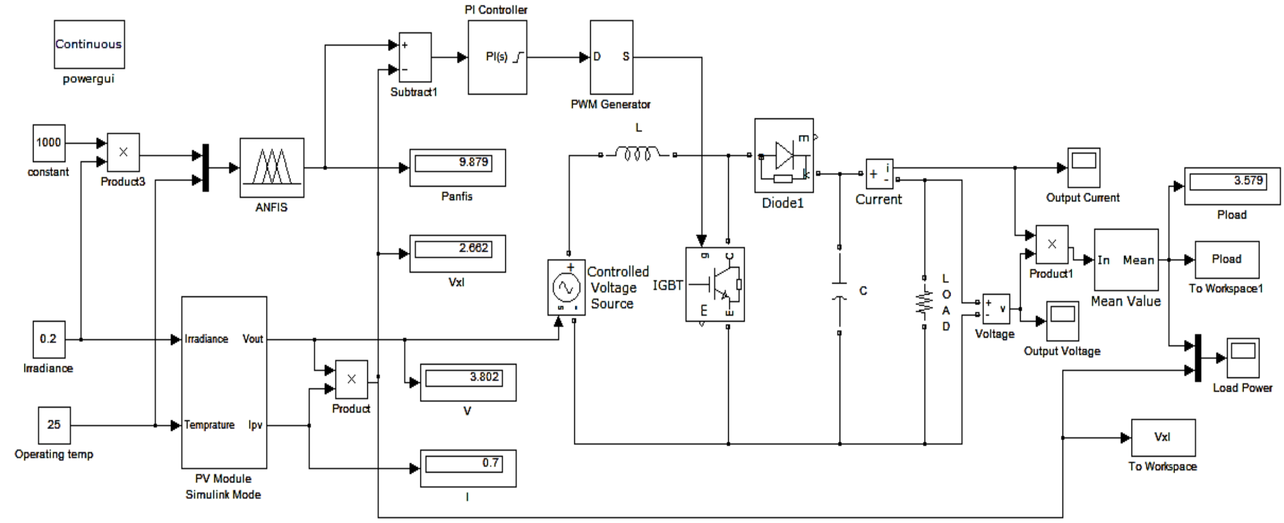

Fig.12. Simulink model of ANFIS based MPPT scheme

that the output power of solar PV module is increased by 34% with ANFIS based control scheme.

Table 7 Output power for varying temperatures and constant irradiance level of 600 W/m^2

S.No.	Operating Temperature (^{o}C)	Output Power (W) (Without MPPT)	Output Power (W) (With MPPT)	% Increase
1.	15	23.68	46.47	96%
2.	25	23.87	47.12	97%
3.	35	24.01	47.56	98%
4.	45	24.06	47.47	97%
5.	55	23.99	47.42	97%
6.	65	23.72	46.53	96%

The resulting waveform also depict that even at lower value of irradiance level output power quickly attains its maximum value, showing quick response of ANFIS based MPPT control scheme.

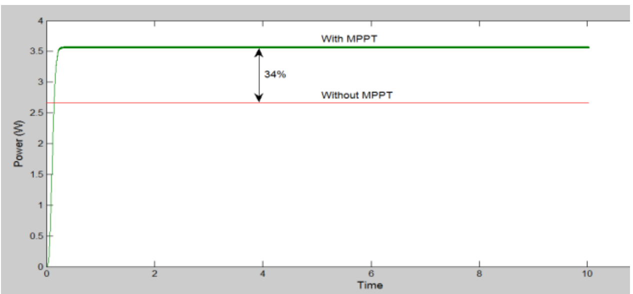

Fig.13. Power vs time with and without MPPT for 200 W/m^2 irradiance and 25°C temperature

6. Conclusions

In this paper the simulated model of solar PV module and ANFIS based MPPT control scheme are designed in Matlab/Simulink environment. After a proper training of proposed ANFIS reference model, the ANFIS based MPPT control scheme has successfully tracked the maximum available power at different weather conditions. The operation of ANFIS based MPPT scheme is investigated under varying irradiance level and operating temperature. Output power of the solar PV module improves up to 100% (double) with the MPPT scheme than it was without MPPT scheme. Output power of solar PV module remains almost constant under varying operating temperature with presented ANFIS based MPPT control scheme.

In the resulting waveforms of output power the maximum value is reached in quick time with high gain, which depicts that the response of presented ANFIS based MPPT controller is extremely fast with good dynamics and the gain in the output power is significantly higher at all solar irradiance conditions. Even at low value of irradiance level there is no oscillations near the maximum power point in the output power unlike conventional perturb & observation (P & O) technique. So, the ANFIS based control is an effective tool to track and extract maximum power from solar PV module.

6.1 Scope of Future Research

Hardware implementation of the proposed ANFIS based MPPT control scheme for solar PV module, can be applied by interfacing Matlab with solar PV module and boost converter using parallel ports. A complete solar photovoltaic system including ANFIS based MPPT control scheme and inverter can be developed for grid connectivity. Microcontroller based maximum power point tracking controller for solar PV module based on present control scheme can be developed. Such an embedded controller will be of low cost, small size and efficient device.

References

M. F. Ansari, R. K. Kharb, S. Luthra, S. L. Shimmi and S. Chatterji (2013), Analysis of barriers to implement solar power installations in India using interpretive structural modeling technique, *Renewable and Sustainable Energy Reviews 27, 163–174.*

M. Z. Jacobson and M. A. Delucchi, (2011), Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials, *Energy Policy 39 (2011) 1154–1169.*

S. Borenstein, (2008), The Market Value and Cost of Solar Photovoltaic Electricity Production. *Center for the Study of Energy Markets (CSEM) Working Paper176.*

Govinda R. T., L.Kurdgelashvili and Patrick A. N. (2011), A Review of Solar Energy: Markets, Economics and Policies, *Policy Research Working Paper 5845, The World Bank Research Group.*

Joe-A. Jiang, Tsong-L. Huang, Ying-T. Hsiao and Chia-H. Chen (2005), Maximum Power Tracking for Photovoltaic Power Systems, *Tamkang Journal of Science and Engineering, Vol. 8, No 2, pp. 147_153.*

V. Lingareddy, G. Ravichandra and P. K. Maddukrui (2013), Effective Strategy for MPPT in PV/Wind Hybrid Electric Power System Interconnected with Electrical Utility Grid, *International Journal of Advanced Research in Computer Science and Software Engineering. Volume 3, Issue 7.*

Saravana S. D., (2013), Modeling and Simulation of Incremental Conductance MPPT Algorithm for Photovoltaic Applications, *International Journal of Scientific Engineering and Technology, ISSN: 2277-1581, Volume No.2, Issue No.7, pp: 681-685.*

S. Gomathy, S. Saravanan and Dr. S. Thangavel (2012), Design and Implementation of Maximum Power Point Tracking (MPPT) Algorithm for a Standalone PV System, *International Journal of Scientific & Engineering Research, Vol. 3, Issue 3, ISSN 2229 5518.*

C. Chukwuka and K. A. Folly (2013), Technical and Economic Modeling of the 2.5kW Grid-Tie Residential Photovoltaic System, *International Journal of Renewable Energy Research. Vol.3, No.2.*

T. Esram and P. L. Chapman (2007), Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, *IEEE transactions on energy conversion, Vol. 22, no. 2.*

D. P. Hohm and M. E. Ropp (2003), Comparative Study of Maximum Power Point Tracking Algorithms, *Progress in Photovoltaics: Research and Applications, 11:47–62 (DOI: 10.1002/pip.459).*

A. P. K. Yadav, S.Thirumaliah and G.Haritha (2012), Comparison of MPPT Algorithms for DC-DC Converters Based PV Systems, *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 1, Issue 1.*

A. Chaouachi, R. M. Kamel and K. Nagasaka (2010), A Novel Multi-Model Neuro-Fuzzy-based MPPT for Three-Phase grid-connected Photovoltaic System, *Elsevier Ltd., science Direct, Solar Energy, 2219–2229*

M. F. Ansari, B. C. Sharma and P. Saini (2012), Maximum Power Point Tracking of A Solar PV Module using ANFIS, *The 3rd IEEE International Conference on Sustainable Energy Technologies, Nepal*

A. M. Zaki, S. I. Amer and M. Mostafa (2012), Maximum Power Point Tracking for PV System Using Advanced Neural Networks Technique, *International Journal of Emerging Technology and Advanced Engineering, Vol. 2, Issue 12.*

R. Singh and M. Pandit (2013), Controlling Output Voltage of Photovoltaic Cells using ANFIS and Interfacing it with Closed Loop Boost Converter, *International Journal of Current Engineering and Technology. ISSN 2277 – 4106, Vol. 3, No.2*

M. Abdulkadir, A. S. Samosir and A. H. M. Yatim (2012), Modeling and Simulation Based Approach of Photovoltaic System in Simulink Model, *ARPN Journal of Engineering and Applied Sciences, VOL. 7, NO. 5*

A. Kane and Dr. V. Verma (2013), Performance Enhancement of Building Integrated Photovoltaic Module using Thermoelectric Cooling, *International Journal of Renewable Energy Research, Vol.3, No.2.*

N. Pandiarajan, R. Ramaprabha and R. Muthu (2012), Application of Circuit Model for Photovoltaic Energy Conversion System, *Hindawi Publishing Corporation. International Journal of Photoenergy. doi:10.1155/2012/410401*.

M. S. Mahmodian, R. Rahmani, E. Taslimi and S. Mekhilef (2012), Step By Step Analyzing, Modeling and Simulation of Single and Double Array PV system in Different Environmental Variability, *International Conference on Future Environment and Energy IPCBEE vol.28, Singapoore.*