Adaptive Neuro-Fuzzy Inference System based PV Energy Generation

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***Abstract*: The main point of this paper is to take bring out the maximum power for ever-increasing the efficiency of solar photovoltaic (PV) under unstable weather conditions. It is a method of hybrid small scale solar energy conversion system that use an adaptive neural fuzzy interface system (ANFIS). The conversion of solar energy, mostly depends on the irradiation and temperature. ANFIS is used to extract maximum feasible power under unstable solar irradiance and temperature by generating duty cycle through pulse width modulation (PWM). Duty cycle triggers the gate of DC-DC boost converter. This proposed system has been optimized by using MATLAB/Simulink software. The simulation results of the MPPT controller show that very effective and efficient than other ordinary conventional systems such as without MPPT system.**

***Keywords*: Adaptive neural fuzzy interface system (ANFIS); Maximum power point tracking (MPPT) system; DC to DC Boost converter; Solar energy.**

1. Introduction

Energy plays a vital role for our social life and economy [1]. Because of inanition of fossil fuel reserves, greenhouse effect, environmental degradation and high cost, the consumption of renewable energy sources is increasing day by day for electric power generation [1]. In order to meet up the ever-rising energy demand and overcome above problem, it is necessary on the way to the renewable energy sources such as wind, solar, tidal, sea wave, geothermal and hydro energy for maximum potential [2]. Al of them, solar energy is considered more reliable for Bangladesh mainly remote area [2]. This energy source is daily available, and environmentally friendly than other renewable source.

Bangladesh lies in the sunny regions of the world. The majority of the parts of Bangladesh receive 4–7 kWh of solar radiation per square meter per day. About 250–300 sunny day occurs in a year, which can mitigate the total load demand of a family in that's country [3]. On the other hand, solar energy systems usually suffer from their low efficiency. In order to rise above these drawbacks, MPPT techniques is a way to optimize greater efficiency for maximum power of PV panel. MPPT is a real-time control system that applied to the PV power converter in order to bring out the maximum possible power from the PV panel.

Artificial intelligence systems are a process which can take decision like a human brain by adjusting themselves. The situations and making correct decisions take automatically for future similar conditions [5]. An adaptive neural fuzzy inference system (ANFIS) is a type of artificial intelligence system that is based on Takagi–Sugeno fuzzy interface system. It is a combination both neural networks and fuzzy logic ideology [5]. Its inference system corresponds to a fuzzy set of IF-THEN rules based on training data that have learning ability to approximate nonlinear functions [6]. For using a hybrid learning procedure, ANFIS can build an input- output mapping based on both human knowledge and predetermined input-output data pairs which is more efficient and optimal way [6]. In this paper, designing and implementation of ANFIS based MPPT scheme which is interfaced with boost converter in MATLAB/Simulink.

2. Methodology

A. PV model

The system consists of PV module, a DC-DC boost converter, a control unit and load. Mainly, PV module depends on the solar irradiance and temperature as well as atmospheric condition. PV power is transferred to the load through boost converter.

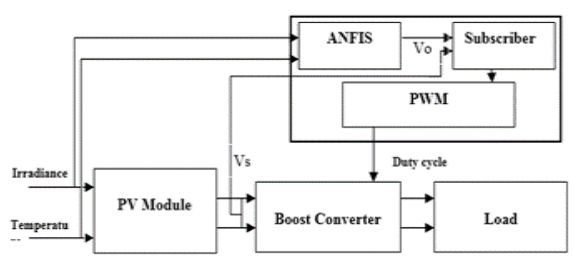

Fig. 1. Block diagram of proposed system.

Duty cycle to trigger the gate of the MOSFET switch is continuously adjusted to track the maximum power point. ANFIS is used as the control scheme which takes irradiance and temperature as input from change of PV power and voltage ratio. ANFIS gives duty ratio as output for maintaining the on and off time of the MOSFET switch through PWM shown in Fig. 1.

B. PV Model

Solar PV systems use PV modules and arrays which directly convert to electric energy from solar energy through semiconductor material [6]. When semiconductor substances consisting of Silicon are exposed to mild, the some of the photons of light ray are absorbed by using the semiconductor crystal which reasons substantial range of free electrons inside the crystal. This is the primary purpose of manufacturing strength because of the photovoltaic effect [3], [6]. The following mathematical model has been described for estimating the output power of PV cell. Fig. 2 represent an equivalent circuit of a PV cell by including a current source, a diode, a series resistance and a shunt resistance.

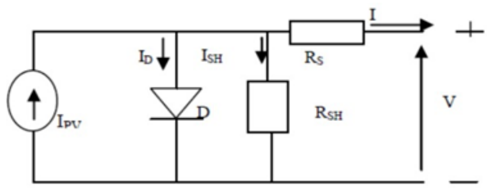

Fig. 2. Equivalent Circuit if PV Model

According to the equivalent circuit of the PV cell, current flow through the load can be expressed as [6]:

$$I = I_{PV} - I_d - I_{sh} \quad (1)$$

Where, I_d -diode current in amp, I_{PV} - PV cell current in amp, I_{Sh}- shunt resistor current in the amp. The voltage across theshunt resistor is [7].

$$V_{sh} = V + IR_s \quad (2)$$

Where, V-Voltage across the load in volt and R_s- series resistance in Ω

Current flow through the shunt resistor is [6]

$$I_{sh} = \frac{V_{sh}}{R_{sh}} = (V + (R_s I)/R_{sh} \quad (3)$$

R_{sh}- Shunt resistance in Ω

Current flow through the diode is [7]

$$I_d = I_o e^{\frac{V_{sh}}{n V_T}} - 1 \quad (4)$$

$$\text{Where } V_T = \frac{KT}{q} \quad (5)$$

V_T -Thermal voltage in volt, n-linearity factor, q-Electron charge = $1.6 * 10^{-19}$C

Light generated current can be express as following equation (7)

$$I_{pv} = [I_{sc} + K\,(T - 298)] * \frac{G}{1000} \quad (6)$$

Where, I_{SC} is the short circuit current in amp at 25 ^{0}C temperature and 1000W/m^2 solar radiation, K is the short-circuit current temperature co-efficient, T is the solar module working temperature in Kelvin, G is the PV module illumination in W/m^2.

Module reverses saturation current which can be expressed as: (7)

$$I_{rs} = I_{sc}\left(e^{q\,V_{oc}}\right) - 1 \quad (7)$$

Where, open circuit voltage is V_{oc}in volt, Number of series connected cell is N_s, k is the Boltzmann constant.

The physical behavior of the PV cell depends on I_{pv}, R_s and R_{sh} as well as some environmental parameters like temperature and solar radiation. The output power of a PV module is changing with radiation and temperature. The three most important characteristics of PV panel are the short circuit current, open circuit voltage and the MPP that is a function depends on temperature and irradiance. The operation and the performance of PV cell depend on its maximum power shown in Fig. 3.

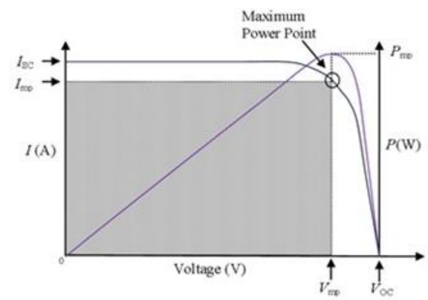

Fig. 3. MPPT curve of PV module [8]

The PV module specification has been given in Table 1 for the proposed system.

Table 1
PV modules specification [8]

Parameter	Rating
Maximum power (MPPT)	80W
Open circuit voltage (Voc)	21.6 V
Voltage at MPP (Vmp)	17.3 V
Short circuit current (Isc)	5.16 A
Current at MPP (Imp)	4.63 A
Temp coefficient for MPPT	-40^{0}C to +90^{0}C
No. of cells (NS)	36
Module efficiency	12.40 %

C. ANFIS based efficient MPPT Model scheme

MPPT technique is used to optimize maximum power depends on real time data [9]. Various technologies have been developed for MMPT system. Through effective way for this system, Adaptive Neural Fuzzy Inference System (ANFIS) approach is used to optimize the Maximum Power Point [9]. The generated power is transferred to the load through Boost converter. The gate of boost converter is switched by duty cycle is continuing to bring out the maximum power. It is delivered into the PV panel through ANFIS controller at a given irradiance and temperature. Fig. 4 represents ANFIS based MPPT schematic diagram for the proposed system. The schematic diagram of boost converter is consists with inductor L, controlled switch SW, diode Dm, filter capacitor C, and load resistance R shown in Fig. 11. ANFIS is used to generate a duty ratio by comparing supply voltage and operating voltage (Vs) according to equation 10. The boost converter's voltage gain can be express as [10]

$$D = 1 - \frac{V_o}{V_s} \tag{8}$$

Where, D - duty cycle of the pulse width modulation (PWM) signal used to control the ON and OFF states of MOSFET, Vs- DC input voltage source which generates from PV module, Vo is output voltage from FLC as well as ANFIS.

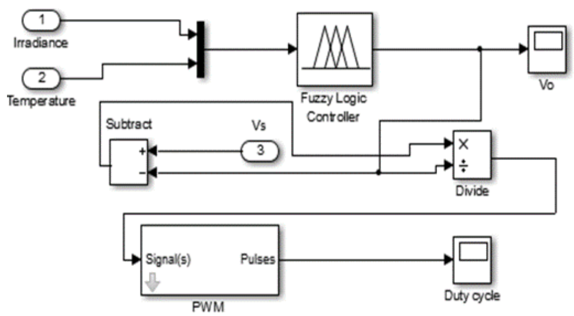

Fig. 4. PV MPPT model, based on ANFIS

D. Data collection and optimizing for MPPT

ANFIS is able to develop the input-output mapping by adjusting themselves on training data for sufficient number of periods. ANFIS create membership function based on training data. ANFIS generates fuzzy rules in order to make the appropriate output by adjusting the values of membership functions. The parameters of membership functions are changed till the error is reduced for all real time value. After adjusting all parameters of membership function, the ANFIS model becomes a learning model which is prepared to be used in the MPPT control scheme. Before using the ANFIS learning model for MPPT control, its results are checked by using testing data. Some training data has been given in Table.

First eighteen data have been used as training data and other are used as test data.

By training data in adaptive neural fuzzy interface system (ANFIS), we get two membership functions as inputs based on solar irradiance and temperature in Fig. 7 & 8. For optimum operating voltage the temperature is varied from 12 ^{0}C to 30 ^{0}C and at the same time solar irradiance level is varied from 100 W/m2 to 950 W/m^2 in Table II. Fig. 5 & 6 represents ANFIS training errors versus epochs and MPPT structure of ANFIS. Fig. 9 & 10 represents the rule view and surface view of MPPT model based on ANFIS.

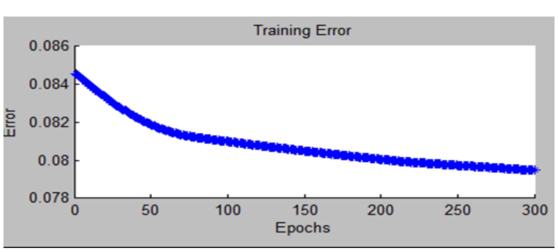

Fig. 5. ANFIS training errors

Table 2
Training and testing data for ANFIS [1]

Radia	Temperature	Optimum operating voltage
100	15	21.22
150	16	21.69
200	23	23
250	16	22.21
300	17	22.37
350	18	22.49
400	20	22.58
450	22	22.65
500	23	22.71
550	22	22.74
600	25	22.77
650	22	22.79
700	30	22.8
750	12	22.8
800	15	22.8
850	16	22.79
900	24	22.78
950	22	22.76
950	25	22
950	30	22.9

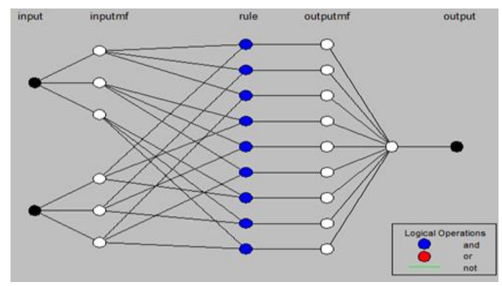

Fig. 6. MPPT structure of ANFIS

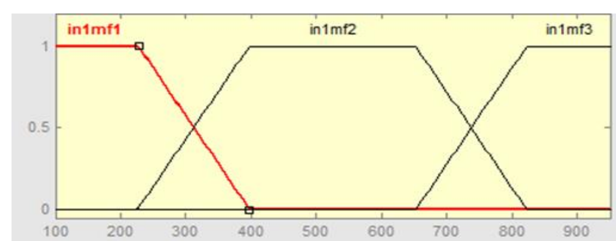

Fig. 7. Membership function of solar radiation

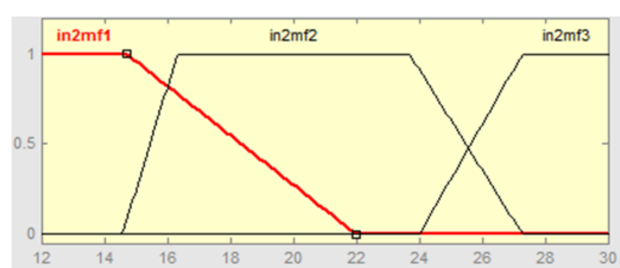

Fig. 8. Membership function of temperature

The proposed system has been developed in MATLAB/Simulink. The system consists of PV module, DC to DC boost converter, ANFIS based MPPT control unit and load shown in Fig. 11. In this paper, the ANFIS based PV MPPT system depends on irradiance and temperature, which gives duty ratio for triggering the gate of DC to DC boost converter. If an inaccuracy formed is more than the most wanted value, parameters of membership functions are adjusted to carry out the error and gives maximum value. DC-DC boost converter is designed to be placed between solar PV module and load.

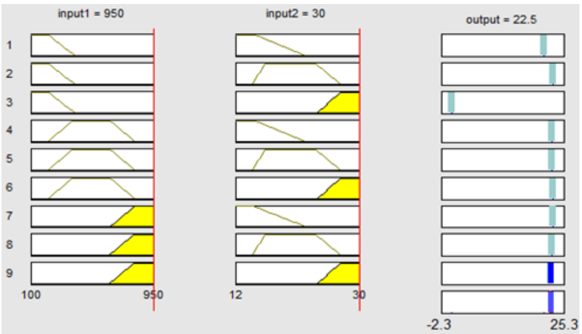

Fig. 9. Rule view at particular movement

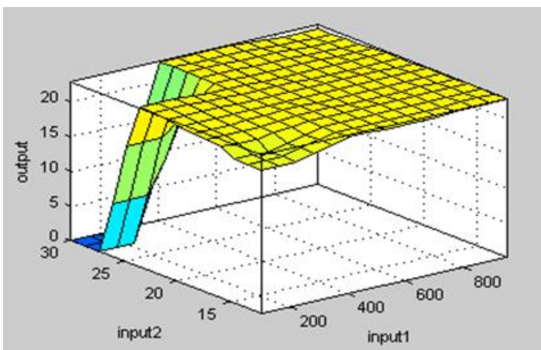

Fig. 10. Surface view for duty cycle from ANFIS

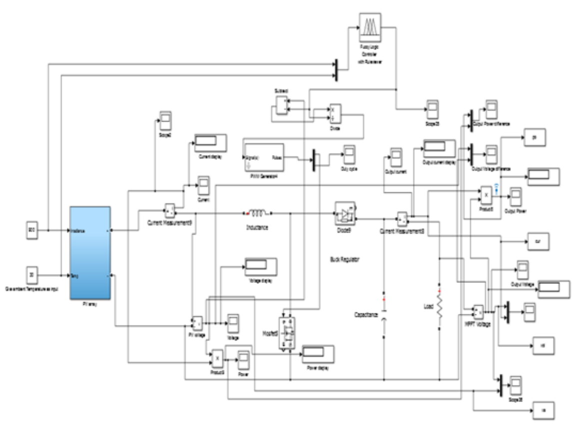
Fig. 11. Schematic diagram of proposed system

3. Results and discussion

Fig. 12 shows the Simulation result for the ANFIS based MPPT system and without MPPT system. Table 3 compares the maximum power produced by the proposed ANFIS based MPPT and direct conventional system such as without MPPT system. Simulation result has been collected from designed system for operating temperature 15 ^{0}C to 30 ^{0}C in a step of 5 ^{0}C and the solar irradiance level 650 W/m^2 to 900 W/m^2 in a step of 50 W/m2 and 200 W/m^2. Simulation results demonstrate higher efficiency than ordinary system.

Table 3
Output power compared with MPPT and without MPPT.

Radiation	Temperature	Without MPPT	With MPPT
650	15	49.51	56.47
700	15	53.14	62.71
900	15	55.47	73.55
650	20	49.43	56.21
700	20	53.10	62.31
900	20	53.42	72.27
650	25	49.16	56
700	25	53.00	62
900	25	52.74	71.94
650	30	49.08	55.84
700	30	52.09	61.71
900	30	52.41	70.86

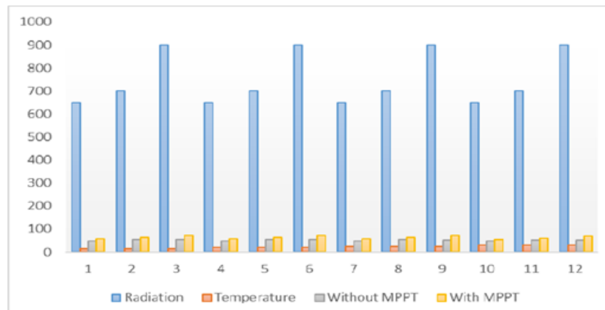

Fig. 12. Power difference between ANFIS MPPT and without MPPT

Fig. 13 & 14 represent the power and voltage difference between MPPT and without MPPT at radiation 650 and temperature 15^0. From the figure it is clear that ANFIS based MPPT power and voltage are greater than the ordinary system such as without an MPPT control system.

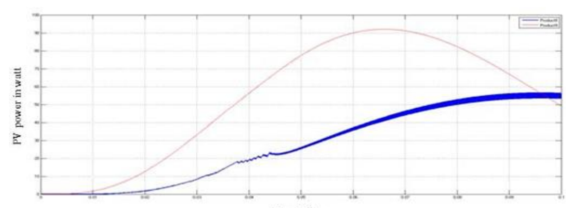

Fig. 13. Power difference between MPPT and without MPPT at radiation 650 and temperature 15^0

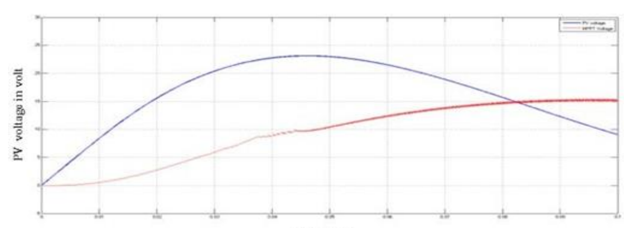

Fig. 14. Voltage difference between MPPT and without MPPT at radiation 650 and temperature 15^0

Fig. 15 & 16 represent Power and voltage difference between MPPT and without MPPT at radiation 700 and temperature 20^0. The output power and voltage of ANFIS based PV MPPT structure are higher than conventional system such as without an MPPT control system.

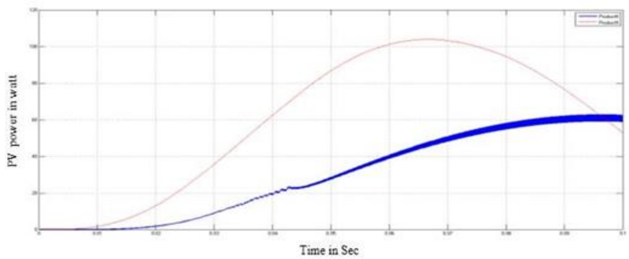

Fig. 15. Power difference between MPPT and without MPPT at radiation 700 and temperature 20^0

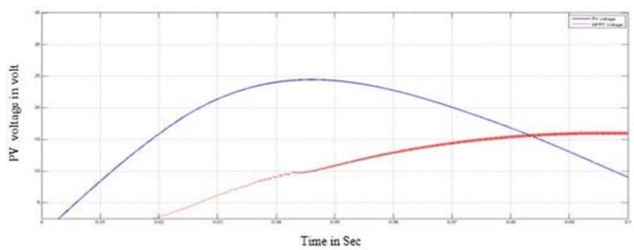

Fig. 16. Power difference between MPPT and without MPPT at radiation 900 and temperature 20^0

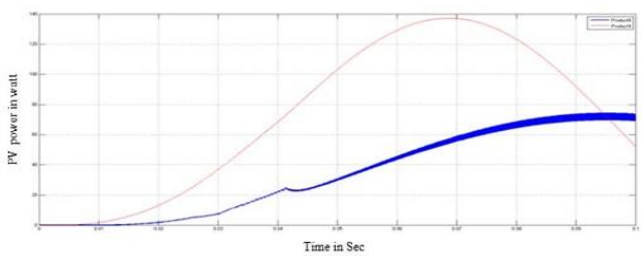

Fig. 17. Power difference between MPPT and without MPPT at radiation 900 and temperature 25^0

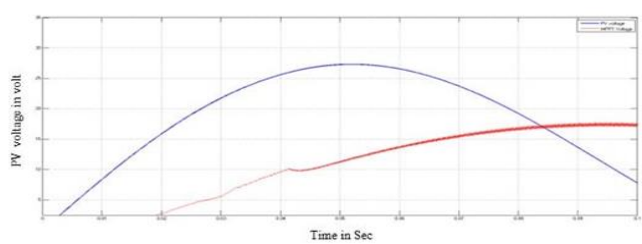

Fig. 18. Voltage difference between MPPT and without MPPT at radiation 900 and temperature 25^0

Fig. 17 & 18 represent the power and voltage difference between MPPT and without MPPT at radiation 900 and temperature 25^0. The output power and voltage of ANFIS based PV MPPT structure is higher than above case. This paper is completing for 80 Watt solar PV module which gives maximum output power at standard temperature 25 ^{0}C and 1000 W/m^2. Simulation output power of PV MPPT system is also close proximity to maximum output power which is 71.94 Watt. ANFIS controller has been increased the output voltage and power by triggering MOSFET switch of DC TO DC boost converter to find out maximum power point tracking structure.

4. Conclusions

The performance of the proposed system has been compared with conventional system such as without MPPT system. Results indicate that the ANFIS-based MPPT model is higher accuracy and more effective than without MPPT system. Simulation graph has been shown for various weather conditions. Moreover, the graph of simulation results of the developed ANFIS based MPPT system shows that output power and voltage are high and effective than the other ordinary conventional system. The system is excellent performance under various operating conditions.

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