The International Journal of Engineering and Science (IJES)
|| Volume || 6 || Issue || 10 || Pages || PP 78-88 || 2017 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Development of a Power Prediction Model and Integration with Maximum Power Point Tracking for Photovoltaic System Using Intelligent Techniques

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ABSTRACT

Among the renewable energy resources, the energy due to the photovoltaic (PV) has become increasingly popular as the desire for clean energy has grown. This study addresses the effect of weather variability in predicting solar PV power generation and is build based on the premise that performance can be improved when solar PV generation system is integrated by interfacing it with maximum power point tracking (MPPT) system. The power prediction model and the maximum power point tracking controller is designed using adaptive neuro – fuzzy inference system (ANFIS) and fuzzy logic (FL) respectively. The ANFIS based power prediction model incorporates a PV module, MPPT controller and a DC – DC boost converter. The output power from the PV module and the predicted power from the ANFIS are compared to obtain an error signal to serve as input to a fuzzy logic controller. The output of the controller is then used to regulate a boost converter to obtain a maximum power output. The ANFIS network was implemented using on-line weather data, comprising of three different set of inputs to asses and compare three different scenarios for a PV system with and without MPPT controller. The proposed approach was simulated to test its performance using MATLAB/Simulink The Simulated results indicate the accuracy of the proposed approach. For predicting PV power output, data set 2 in scenario 2 (hours of the day and hourly temperature) performs much better compared to data set 1 (hours of the day and Radiation) and data set 3 (hours of the day, Radiation and Temperature) in scenario 1 and scenario 3 respectively. The percentage of Power significantly increase from 43% minimum to 98% maximum for a PV system with MPPT controller than a PV system without MPPT controller.

Keywords: *Intelligent technique, Maximum power point tracking, Power Prediction model, Scenario*

Date of Submission: 06-10-2017 Date of Publication: 27-10-2017

I. INTRODUCTION

Solar energy is a fundamental source of energy, which is naturally replenished in a short period of time. For this reason, it is called "renewable energy" or "sustainable energy". Solar energy has a vast area of application such as electricity generation for distribution, pumping and heating water, lighting buildings and streets, crop drying etc. Due to the severity of global energy crisis and environmental pollution issues, the photovoltaic (PV) system has become one of the most important technologies for generating electrical energy. Conversion of solar energy into electricity has numerous advantages such as, short term duration of installation, simplicity, longer life of operation, maximum reserve, free from pollution and from geographical restrictions. Therefore, Continuous adoption and increased deployment of solar photovoltaic (PV) system is expected to have significant roles in power generation in the future, this is because photovoltaic system is being recognized as an alternate suitable option against conventional source of generating electricity [1]. Thus, PV technology becomes popular and receives wider acceptance and recognitions by governments, policy makers and has even become a popular research topic in academic institutions.

Photovoltaic technology used to describe the hardware that converts solar energy into electricity from sun light. The energy conversion mainly depends on whether variables such as, radiation, temperature, wind speed, humidity etc. Unfortunately, PV generation system have two major drawbacks: the conversion efficiency of solar energy into electric power is low, especially under varying irradiance and temperature conditions, and the amount of electric power generated by solar arrays changes continuously with weather conditions and time. Thus, the future energy generation of PV plant cannot be estimated with highest probability as this is not the case with conventional energy source. Subsequently, predicting the power output of a PV generator is necessary for the integration of this useful energy source for improving efficiency and maximizing utilization. A forecast or prediction is a statement of probability about outcome of a future events based on experience [2].

Due to the awareness on the advantages of solar energy, forecasting of photovoltaic power generation are playing bigger role, thus, deployment and research on solar PV systems is continuously increasing. Solar energy prediction is used to maximize usage of solar energy, provide accurate knowledge of the solar resource availability at any place it is required and generally manage uncertainty in solar power. Unlike conventional power source, future electricity supply cannot be planned beforehand. This is due to the fact that solar energy is highly dependent on weather conditions which make PV power dynamic or non – linear in nature. Therefore, energy generation using solar PV systems requires accurate prediction by applying suitable method and techniques to study and manage the weather variability effect.

Nowadays, various artificial intelligent (AI) techniques are introduced into photovoltaic systems to study and improve the utilization and application of solar energy generation. AI techniques such as, artificial neural network (ANN), Genetic algorithm (GA), Fuzzy logic (FL), Particle swam optimization (PSO) etc. has been viewed as a convenient and effective method of predicting PV power generation output without any complex and complicated mathematical calculations unlike the traditional methods [3]. Artificial intelligence techniques have proven their capability as one of the approach in managing the uncertainty associated in solar PV systems. Thus, one process of integrating solar, especially at utilization level is the maximization of PV power output by interfacing maximum power point tracking (MPPT) system with prediction model for reliable and efficient PV system. Maximum power point tracking, frequently referred to as MPPT, is an electronic system that operates the photovoltaic (PV) modules in a manner that allows the modules to produce all power they are capable to produce.

In recent years, several power forecasting studies related to PV plant have been published. The existing methods can be categorized as physical, statistical and hybrid based techniques [4]. Nevertheless, the presence of disturbance and model parameter uncertainties as a result of stochastic nature of renewable energy source brings about limited predictability and high variability, as a consequence, causes problem for estimating the amount of energy that a concrete power plant will produce with estimated meteorological data. Thus, one process that needs to be examined as an extension to PV generation forecasting is the maximization of the forecast output. It is not just enough to forecast, but after this there is a need to further improve on the short coming of a solar PV system. To fill this gap, a maximum power point tracking (MPPT) control system is incorporated to a forecast model with a view to answer this issue that has rarely been conducted. MPPT controller is essential in PV system for extracting maximum power, improving operational control of PV generator, and thereby increasing the efficiency of the system.

In this study an Adaptive Neuro – Fuzzy Inference System (ANFIS), a hybrid based artificial intelligence technique is applied to account for the non–linearity and periodicity associated in modeling PV power generation output by combining advantages of neural network and fuzzy logic. On-line hourly metrological data for Maiduguri weather conditions is considered for this study. Three different scenarios consisting of three data sets, which are hours of the day and hourly radiation, hours of the day and hourly temperature, and hours of the day, hourly temperature and hourly radiation for scenarios 1, 2 and 3 respectively, are investigated. The MPPT controller is also developed using fuzzy logic tool, the controller is intended to maximize the PV power output by interfacing it with the ANFIS PV power predictor. The motivating factor for embarking on this work using intelligent techniques is that, ANFIS combines the excellent training algorithm that neural network has and fuzzy logic capabilities to interpret in terms of linguistic variables, and both tools are model free estimators, share common ability to deal with uncertainties, conceptually simple and they consist of input stage, a processing stage and an output stage. A non-parametric modeling approach will be followed, which conceives the PV system as a black box. It does not consider any knowledge of internal characteristics and processes of the system, instead, it is a data driven model that estimates the behavior of the system from a historical time series of input and output. MATLAB/Simulink tool is used to simulate and study the response of the proposed system under the three different scenarios.

II. OVERVIEW OF PHOTOVOLTAIC POWER PREDICTION AND MAXIMUM POWER POINT TRACKING

2.1 Photovoltaic Power Prediction Approach

Many methods of photovoltaic power prediction have been proposed in several literatures. They are divided into direct and indirect approaches. Models based on the former approach use past values of measured data as input to the model both in training and operational stages, while indirect ones provide first a forecast of metrological variables which feeds a power conversion model. In this section therefore, some related PV power forecasting based on direct approach will be reviewed.

Regarding renewable energies technologies, in the last year's efforts done by researchers to present efficient and effective model to predict the behavior of their output have been significant. According to past literatures, two type of models, namely: linear and non - linear models are generally applied to a typical time series data in order to estimate future values of energy generation. The linear model such as AR (Autogressive), MA (Moving Average), ARMA (Autogressive Integrated moving average) are used to find a mathematical equation that approximately generate the historical patterns as linear function of its past value considering weather variables from metrological ground stations. Weather data from ground station might be feasible and accurate, but limitations such as instrument defect and failure, time, environmental conditions and human error attached to experiment will affect the performance of this type of model. Non - linear model such as artificial neural network (ANN), fuzzy logic etc., are artificial intelligent computing technique that is automatically adjusted, learn and adapt to a system. As it has been stated, linear model may be advantageous to understand the detail of the system and are easier to explain and implement. However, it needs rigorous mathematical computation, calibration and adjustment process which will take longer time to compute and prone to error. Therefore, in opposition to the linear model, the non - linear model can capture the stochastic structure, cater for sequential variation, more flexible and have fewer limitations in estimating the essential relationship between the past values of the time series and the future values [5] and these are the main motivational factor of this paper.

A survey of some recent publications on PV power forecasting and maximum power tracking is shown in table 1, indicating the limitations and drawbacks of the methods applied by different authors for predicting PV power generation and maximum power point tracking.

Table 1: A survey of some PV- Power Forecasting and MPPT techniques

S/NO	METHOD	ADVANTAGE	LIMITATION	AUTHORS
1	Autogressive Integrated Moving Average(ARIMA)	Fast Processing of data	Unjustifiably Assumes Linear Relationship b/w Output and Weather data Input	Jeong Y, Lee S, Han K, Ryu D & Jun Y (2015)
2	Time Series	Simplicity in Structure	Limited Ability to Capture non Linear data	Larson D. P, Nonnenmadier L & Coimbra C. F. M (2016)
3	Fuzzy Logic	Fast Training Process, Works with Imprecise Input	Expert Experience is needed to generate Fuzzy rule and is usually Intuitive	Singh S, Mathew L & Shinin S. L (2013)
4	Artificial Neural Network (ANN)	The System can Continue Without any Problem because of their parallel nature	It needs Training to Operate	Saberian A, Hizan H, Radzi M. A. M, Abkadir M. Z. A & Mirzaei M (2014)
5	Neuro - Fuzzy	Deals with Non – Linear Relationship between Relative Factors	Needs Longer Training Time	Surendra U, Amruth R. T & Abhishek K (2015)
6	Perturb & Observe	Widely used in PV Application. Simple, it uses only one Sensor	Continue Oscillation around Maximum Power Point. Slow Tracking Speed	Atallah A. M, Abdelaziz A. Y & Jumaah (2014)
7	Microcontroller Based	High Accuracy in Tracking Maximum Power Point	Not Cost effective, requires complex Programming and control	Kute U. T & Ratnaparkh P.S (2013)
8	Incremental Conductance	Maximum Implementation Complexity	Unable to Track Maximum Power Under Partial Shading	Rothod G, Gorawar M, Revenkar P.P & Tewari P. G (2014)

Researchers have presented works focusing on achieving improved forecast performance using different method and tools. Numerous variants of each method have been proposed to overcome specific disadvantages in order to optimally manage the variability and uncertainty of solar power.

2.2. Maximum Power Point Tracking

Maximum power point tracking, frequently referred to as MPPT, is an electronic system that operates the photovoltaic (PV) modules in a manner that allows the modules to produce all power they are capable of. MPPT is not a mechanical tracking system that physically moves the modules to make them point directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power [14].

To utilize the maximum power produced by a solar cell at all times, the regulation system has to be equipped with a maximum power point tracker (MPPT). This is usually implemented in the DC-DC converter, but in systems without a DC-DC converter the MPPT is included in a DC-AC inverter control [15]. MPPT methods are used to improve the efficiency of a solar PV system. It is based on the theorem of maximum power transfer, that the power output of a circuit is maximal when the source impedance of circuit matches with the load impedance. In solar PV system a DC – DC converter is inserted between solar panel and load in order to match the impedance of the two sides by changing the duty circle of DC – DC converter, the source impedance will be merged to the load impedance.

Over the years numerous MPPT methods have been proposed, they differ in many aspects such as complexity, accuracy, sensors that are required, cost, efficiency and speed at which they track the point. There are many traditional MPPT techniques that are commonly applied for tracking maximum power point (MPP) in PV system, such as perturb and observe, hill climbing, incremental conductance, fractional short circuit current, fractional open circuit voltage, etc. [16]. Among these methods, perturb and observe and incremental conductance are commonly used due to their straight forward and low cost implementation. However, these methods did not respond correctly under rapidly changing atmospheric condition as was observed in [17], and this shows that they have low efficiency. Recently MPPT methods based on artificial intelligence techniques using artificial neural network, genetic algorithm and fuzzy logic systems have been emerged [18].

Intelligent techniques used in MPPT systems offer accurate and flexible nature on improving performance. Neural Network (NN) and fuzzy logic (FL) are mainly applied depending on specific applications. NN works as a black box model requires no detail description of the PV system [19] and on the other hand FL can transform linguistic terms into numerical value, relatively simple to design because they do not require knowledge of the exact system model [20]. However, they require correct fuzzy rules for satisfactory performance. Combining advantage of NN and fuzzy logic, an ANFIS model was formed recently as reported in [21] and [22]. The formation of ANFIS intelligent techniques which combines neural network (NN) and fuzzy logic (FL) capabilities have become a popular tool in tackling problems of non - linearity in PV power system, and was found that ANFIS is fast and accurate with few oscillations around the maximum power point.

It is clear from the literatures that artificial intelligent based MPPT techniques have their own drawbacks and their choice is highly application dependent. For example, for requirement of fast convergence to the MPPT and when using solar panels in residential purpose, the objective is to reduce the payback time. To do so it is important to constantly and quickly track the maximum power point with minimum oscillation so as to maximize output. Thus, intelligent technique such as fuzzy logic may be a good option because it is a user knowledge based MPPT technique.

2.3. DC-DC Converter

DC-DC converter is an electronic circuit which converts a source of direct current from one voltage level to another. Electronic switch-mode DC-DC converters operate by storing the input energy temporarily and then releasing that energy to the output at a different voltage and current.

Electronic mode DC – DC converters converts one DC voltage to another by temporarily storing the input energy and then realizing it at different level. The energy is stored in magnetic or electrical storage element (such as inductor and capacitors). These components are controlled by a transistor switch driven by an external signal. The signal is controlled by an algorithm programmed into an embedded control unit. The frequency and duty cycle of this signal relates the circuit impedance and output voltage. Taken together, the input signal, the switching algorithm, the storage element, and the circuit configuration are the four major parameters that characterize a given DC – DC converter.

The basic operating principle of a converter consists of the two distinct states. In ON state, switch is closed, resulting in an increase in the inductor current. In OFF state, switch is open, resulting in decrease in the inductor current [23]. Generally, their operations depend on the tendency of an inductor to resist the changes in current induced by the transistor switch. In order to resist, the inductor will either absorb energy (charge) or release energy (discharge). The discharge voltage is proportional to the rate of current charge. This mechanism allows an output voltage to be different from the input voltage. There are several different types of DC – DC converters such as buck, boost, buck – boost and cuk topologies, as reported in literatures to meet specific applications and demand. They are defined as follows:

i. Bulk Converter: This is a converter whose output voltage is smaller than the input voltage and output current is larger than the input current.

ii. Boost Converter: This is a converter whose output voltage is greater than the input voltage and output current is smaller than the input current.
iii. Buck – Boost Converter: Is a type of converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude.
iv. CUK Converter: This is a converter where a negative polarity output may be desired with respect to the common terminals of the input voltage and the average output is either higher or lower than the DC input voltage.

III. MATERIALS AND METHODS

3.1. PV Power Forecast Model and MPPT Control Scheme

This section describes and presents the materials and methods employed to design and create ANFIS PV power forecasting system and fuzzy logic maximum power point tracking system using MATLAB/ Simulink environment.

A schematic diagram representation of the PV power forecasting system and MPPT scheme is shown in figure 1.0 and the simulink block of the complete design is shown in figure 2.0. The setup consists of a PV module, ANFIS PV Power predictor, Fuzzy logic MPPT controller with a DC – DC boost converter. The output power from the PV module and the predicted power from the ANFIS are compared to obtain an error and change in error which serves as inputs to a fuzzy logic controller based MPPT. After designing the controller, the output of the controller (duty cycle) is used to regulate a boost converter to obtain a maximum power output. The converter is a step up DC power supply for which its output voltage is greater than input voltage and is determined by the duty cycle or duty ratio of the fuzzy logic controller's output.

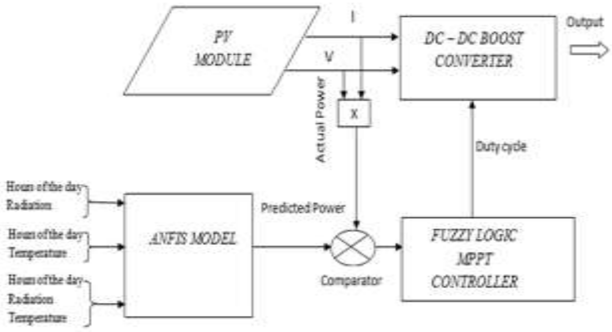

Figure 1: Schematic Representation of the PV Power Forecasting system with MPPT Controller

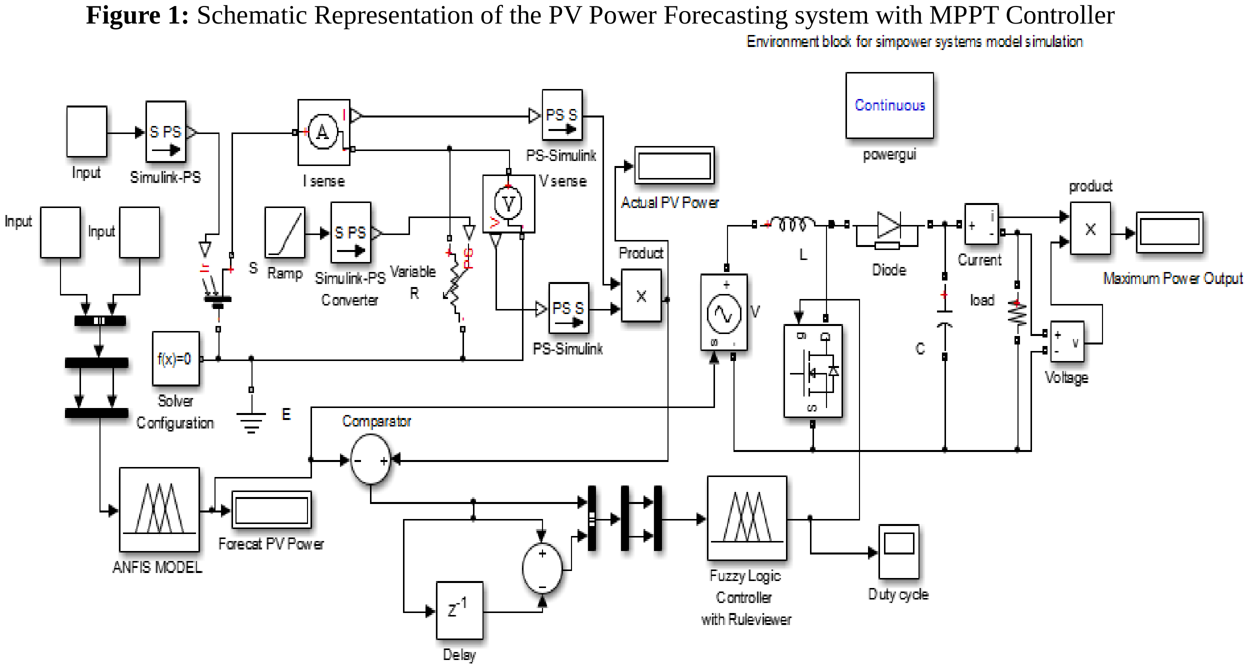

Figure 2: Simulink PV power prediction model with MPPT controller

ANFIS and fuzzy logic tools will be used to design the predictor and the MPPT controller respectively. The ANFIS predictor consists of three (3) different data set (hours of the day and radiation; hours of the day and temperature; hours of the day, radiation and temperature). These data sets will be used to develop three different prediction models for PV power prediction.

3.2. Data Collection and Presentation

To design an ANFIS model, input and output data is required to train and test the model. Accordingly, weather variables including; solar radiation, temperature and time were considered as a fundamental input data. Hourly power output data of PV plant is also considered as the output data. The data of Maiduguri weather condition was accessed from the world online web portal (www.worldweatheronline.com/maiduguri-weather history/Borno/NG.aspx). The data was manually stored in Microsoft excel worksheets and later imported to MATLAB environment using the command "xlsread".

The dataset will consider the effect of hours of the day and radiation, hours of the day and temperature and hours of the day and radiation/temperature as input variables. An adaptive neuro-fuzzy based inference system applied for training and testing the ANFIS Network, where suitable training rate, linguistic and membership functions will be determined based on the combination of neural network properties and fuzzy logic rules to have a combined single structure. The degree of membership function for the input data is defined by partitioning the input space equally and extracting fuzzy rules from the data using grid partitioning method. This is used to generate the rules and works automatically by enumerating all possible combinations of the membership functions of the input.

3.3. Design of the ANFIS Based Prediction Model

Designing the ANFIS based prediction model made consideration of the effect of hourly radiation and temperature.

The criterion chosen for the design of the ANFIS model was based on the selection of the following

i. Membership function type
ii. Number of membership function
iii. Learning algorithm
iv. Epoch size
v. Data size
vi. FIS type
vii. Output type and
viii. Number of inputs

3.5 Design of Fuzzy logic MPPT Scheme

The maximum power point control system consists of a fuzzy controller and a DC-DC converter. A boost converter or a step – up converter is used in this research to be controlled by fuzzy logic output signal in order to adjust and maximize power produced. The converter can be used as a switching mode regulator.

3.5.1 Fuzzy logic MPPT Controller

The error signal as a result of the difference between the actual and the predicted power will be used to compute duty cycle to switch a boost DC-DC converter. This will be achieved by use of fuzzy logic. Two input variables of error e (k) and error rate or change in error Δ e (k) will serve as inputs to the controller. Where, e (k) is an error signal that is expected to produce by a comparator between the power from the PV cell model (actual power) and the estimated or forecasted power from the ANFIS model. The two controller's inputs are defined by the following equations:

$$e(k) = p_{actual} - p_{forecast} \quad (1)$$

$$\Delta e(k) = e(k) - e(k-1) \quad (2)$$

The three stages of fuzzification, rule base and defuzzification will be followed for implementation of the fuzzy controller.

3.5.2 DC – DC Boost Converter

A boost converter is a switch mode power supply for which output voltage is greater than input voltage. Here, metal oxide field effect transistor (MOSFET) was chosen as a switch, because of its high switching frequency. The control strategy lies on the fuzzy logic controller output signal (duty cycle) for switching the converter's switch for adjusting the output at maximum value. Figure 3 shows a continuous current typical model of a DC-DC boost converter. It consists of an inductor, switch, diode, capacitor and a resistor (www.blueskynergyine.com).When the switch is closed the current flows in the first loop only; the current through the inductor grows. The switch then opens, and the voltage across the inductor and the input combine in series to charge up the output capacitor to a higher voltage than the input.

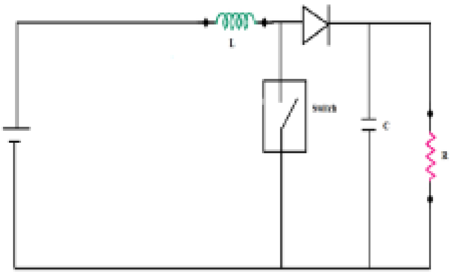

Figure 3: DC-DC Boost Converter

The conversion ratio is given by:

$$\frac{V_o}{V_{in}} = \frac{I_{in}}{I_o} = \frac{1}{1-D} \qquad (3)$$

Where, D is the duty cycle of the converter.
The expected maximum output voltage is defined by

$$V_0 = \frac{V_{in} - V_{transD}}{1-D} - V_d \qquad (4)$$

Where,
V_{trains}, is the voltage drop across the converter switch.
V_d, is the voltage drop across the diode in the system.

IV. RESULTS AND DISCUSSION

The MATLAB/Simulink model designed in figure 2 is used to test the proposed ANFIS based PV power prediction system and fuzzy logic MPPT control scheme. A DC – DC boost converter is connected between the predition model and MPPT controller for transfer of maximum power. Fuzzy logic control scheme is used here to vary the output of the controller or the duty cycle of the boost converter. Various simulation scenarious showing results for the three different set of input variables for prediction of PV power output without and with MPPT controller is observed and recorded in tables 2.

Figure 4 depicts the waveform of the fuzzy logic MPPT controller's output signal (duty cycle). As the power changes, the controller adjust the duty cycle and applies to the switch of the DC-DC boost convertert to output a maximum power. It can be observed that the waveform increases every 1 second until 5 seconds depending on the set output range of the fuzzy logic controller. The duty cycle changes and increases every equal time interval and continuous to increases again due to the controller's action. The change in duty cycle indicates the impact of the weather variables in PV power generation, and the PV power out increases as a result of the MPPT control system.

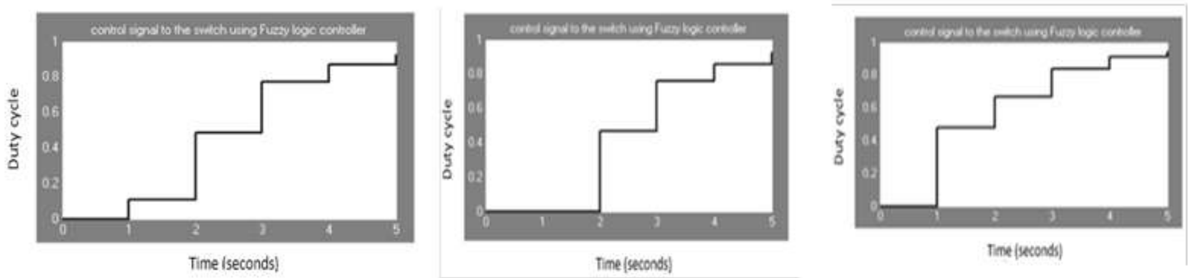

Figure 4: Fuzzy logic MPPT controller output signal

Table 2: Predicted Power Output with and without MPPT Controller

SCENARIO 1						SCENARIO 2						SCENARIO 3				
Hours of the day	Actual Power (KVA)	Predicted Power (KVA) Without MPPT	Predicted Power (KVA) With MPPT	% Increase		Hours of the day	Actual Power (KVA)	Predicted Power (KVA) Without MPPT	Predicted Power (KVA) With MPPT	% Increase		Hours of the day	Actual Power (KVA)	Predicted Power (KVA) Without MPPT	Predicted Power (KVA) With MPPT	% Increase
7	0.525	0.609	1.180	94		7	0.450	0.359	0.630	75		7	0.175	0.180	0.190	84
8	0.300	0.804	1.300	62		8	0.600	0.556	1.000	80		8	0.175	0.183	0.340	86
9	0.600	0.799	1.250	56		9	0.500	0.471	0.900	91		9	0.875	0.723	1.220	69
10	0.565	0.575	1.120	95		10	0.550	0.528	1.020	93		10	0.325	0.280	0.500	79
11	0.825	0.851	1.430	68		11	0.540	0.538	1.030	91		11	0.500	0.550	1.011	94
12	1.275	1.331	1.900	43		12	0.520	0.478	0.920	92		12	0.500	0.500	1.120	84
1	0.885	0.776	1.401	81		1	0.400	0.311	0.610	96		1	0.600	0.500	0.660	66
2	1.285	1.146	1.990	74		2	0.551	0.514	1.010	95		2	0.525	0.538	1.070	98
3	0.375	0.550	1.010	84		3	0.280	0.312	0.310	62		3	0.530	0.535	1.051	96
4	0.825	0.807	1.310	62		4	0.475	0.390	0.700	79		4	0	0.111	0.290	35
5	0.595	0.600	1.101	84		5	0.574	0.501	1.190	73		5	0.400	0.381	0.610	60
6	0.584	0.536	1.011	89		6	0.501	0.500	1.000	72		6	0.850	0.792	1.130	43

In order to validate the performance of ANFIS PV power prediction system integrated with MPPT, a graphical representation of the simulated results is presented for comparisons in figure 5 and 6 between the actual and predicted power without and with MPPT controller. These figures illustrate comparison between scenario 1, scenario 2 and scenario 3. As it can be seen from the figures it is possible to observe the correlation between actual PV power and power output obtained from the prediction, the maximized power as a result of MPPT controller and the percentage of the power increase by the MPPT.

Plots of predicted power output without MPPT is shown in figure 5 for scenario 1, scenario 2 and scenario 3. The difference between the predicted and actual power is not much for each of the three scenarios. But it can be observed that, there was a very little difference which is negligible between the predicted and actual power indicated in scenario 1 and scenario 2, and this shows that there was a good correlation between the two input variables (hours of the day and radiation) and (hours of the day and temperature) in scenario 1 and scenario 2 respectively. And this also shows that they have greater influence in PV power prediction. Similarly, scenario 3 having (hourly radiation and hourly temperature) together as data set indicates small difference between the actual and the predicted power. Though there is some negligible difference between the actual and the predicted values it still has significant impact in predicting PV power output. In comparison, prediction using data set of hours of the day and hourly temperature observed in scenario 2 is much more satisfactory because correlation between these data set and PV power is even stronger compared to scenario 1 and scenario 3 having data sets of hours of the day and hourly radiation, and radiation and temperature respectively, which indicates that the pattern or trend in the early hour in scenario 1 and afternoon hour in scenario 3
are not quite similar.

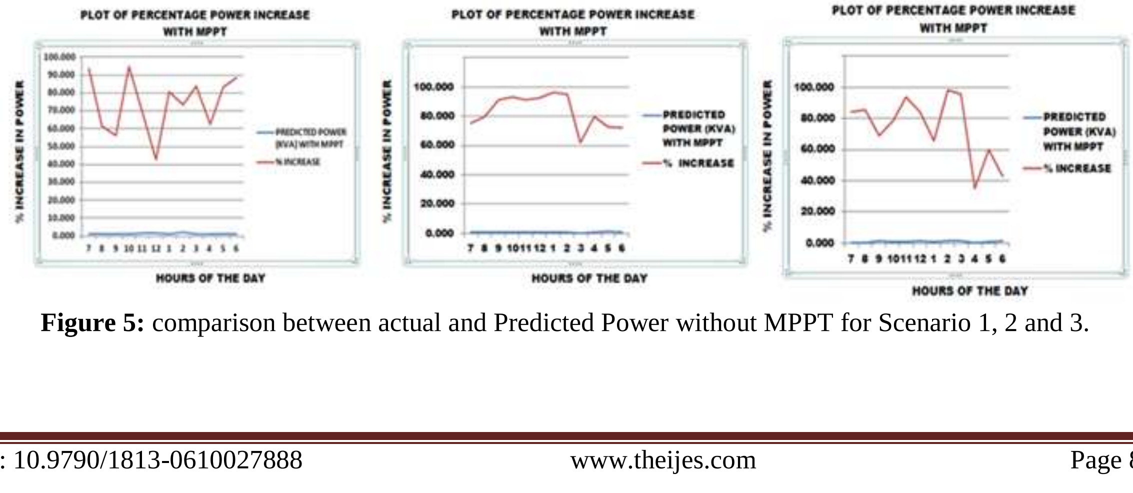

Figure 5: comparison between actual and Predicted Power without MPPT for Scenario 1, 2 and 3.

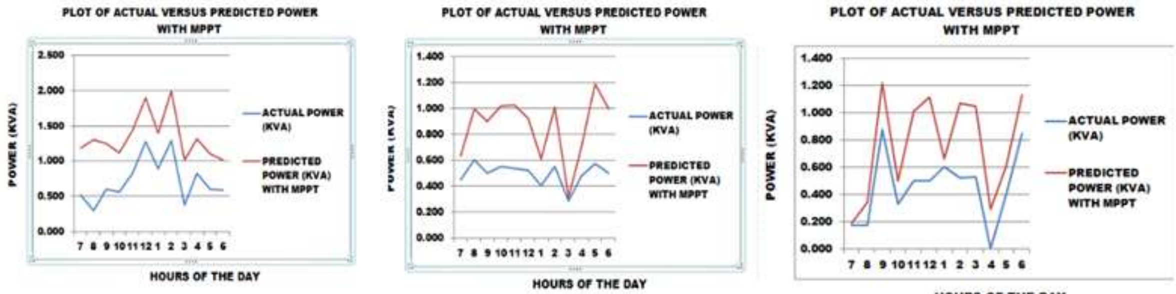

Figure 6: comparison between actual and Predicted Power with MPPT for Scenario 1, 2 and 3.

Figure 6 shows the plots of predicted power output with MPPT controller for scenario1, scenario 2 and scenario 3. It is observed that increase in power output occurs as a result of the effect of controller action together with boost converter. The output power increased to different levels, this clearly indicates the extraction of maximum power of a PV system, maximizing output power. The resulting graph also depicts that even at the morning hours of the day where the input variables (radiation and temperature) are lower, significant increase in power output is recorded, showing better response of the MPPT system. Consequently, in the resulting plots of power output with MPPT, scenario 2 gives significantly higher values and maintains some closer percentage in power increased compared to scenario 1 and scenario 3.

The percentage of power increase with MPPT is as shown in figure 7 for scenario 1, scenario 2 and scenario 3 respectively. Increase in percentage of power ranges from 43% minimum to 94% maximum in scenario 1, 72% maximum to 96% maximum in scenario 2 and 35% minimum to 98% maximum in scenario 3. It can be deduced that the power output with MPPT scheme improves up to almost 100% than it was without MPPT scheme. However, the PV power output which is mainly influenced by radiation and temperature does not remain constant, little variations was observed due to weak strength of association between input variables and actual power during early hours in scenario 1 and late hours in scenario 3 as indicated in figure 6 (scenarios 1 and 3) hence, the reason for not recording constant percentage increase in power output in both scenario 1 and scenario 3. However, scenario 3 gives relatively stable and closer percentage, this is as a result of using radiation and temperature together as input variables. In each case the output power with MPPT has significantly improved at any condition and scenarios compared to PV system without MPPT scheme.

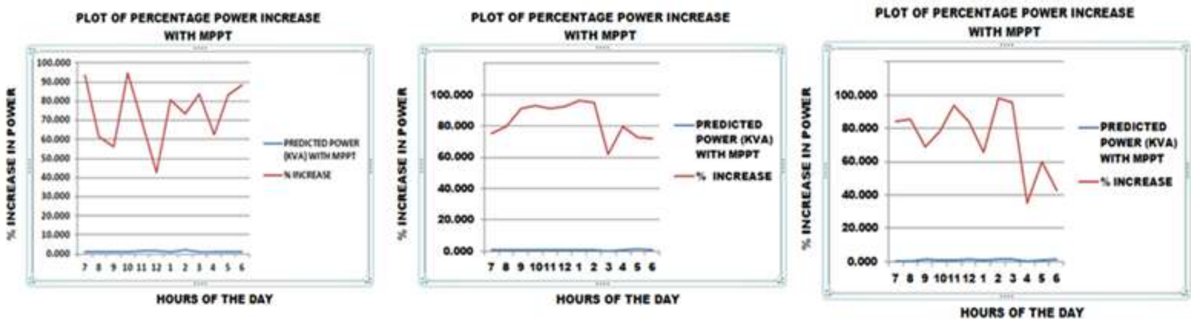

Figure 7: Percentage Power increase with MPPT for Scenarios 1, 2 and 3.

V. CONCLUSION

This study has shown three different ANFIS model for predicting PV power output and analysis of the relationship between metrological factors. The prediction model is being integrated by interfacing it with MPPT system and simulated results are compared. The following conclusions were made:

Through the analysis of data that influences the generation of solar PV power output, and by applications of intelligent technique, the aim of this proposed study was achieved. An ANFIS based approach for predicting solar PV power output and MPPT controller has been developed. The benefit of this approach is that it does not require complex modeling and complicated calculations. The test results represent the performance and effectiveness of the proposed approach; the proposed approach can be used to predict the power output of PV system effectively. Based on the observed scenarios, data set consisting of weather variable hours of the day and temperature (scenario 2) performs better and therefore is more satisfactory for predicting PV power.

The developed ANFIS PV power predictor has been successfully interfaced with fuzzy logic based MPPT controller. The MPPT scheme can be included into a power prediction program for integrating and promoting the application and utilization of solar energy. Thus, this promotes and improves the power production using solar PV technology. The Output power of the PV system improves significantly with the interfacing of the MPPT scheme. So, fuzzy logic based MPPT control is one of the effective tool for integrating solar PV system.

The Simulated results proved the accuracy of the proposed approach; in the resulting plots, the output Power of PV system improves significantly with the MPPT scheme than it was without MPPT scheme, indicating that output of a PV system can be increase to a higher value with the aid of a MPPT system. For this reason, introduction of MPPT controller into a PV system will greatly enhance the performance and efficiency in harvesting solar energy at any potential location.

VI. RECOMMENDATIONS

i. One-year data was used in this work. Larger data set consisting of two, three or four years could be used for training, to further improve the performance of the network. Also, incorporating additional information such as seasons of the year and other parameters like wind speed, humidity, cloud cover etc. into the network will allow for more representative power prediction and study under different scenarios.

ii. The designed MPPT controller is not an adaptive one. An adaptive fuzzy logic controller can be developed by introducing gain updating factor based on the present control scheme, such a controller performs much better when put to use in practice. Also, Hardware implementation of such a controller will be of small size and efficient device.

iii. Study can be undertaking by using other artificial intelligence technique like Genetic Algorithm, particle swarm optimization, neural network etc. to further make comparison with the result of the proposed approach.

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