APPLICATION OF SOLAR ENERGY USING ARTIFICIAL NEURAL NETWORK AND PARTICLE SWARM OPTIMIZATION

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ABSTRACT

Solar energy is rapidly gaining notoriety as an important means of expanding renewable energy resources. More energy is produced by tracking the solar panel to remain aligned to the sun at a right angle to the rays of light. Now-a-days various artificial techniques are introduced into photovoltaic (PV) system for utilisation of renewable energy. it is essential to track the generated power of the PV system and utilise the collected solar energy optimally. Artificial Neural Network (ANN) is initially used to forecast the solar insolation level and followed by the Particle Swarm Optimisation (PSO) to optimise the power generation of the PV system based on the solar insolation level, cell temperature, efficiency of PV panel and output voltage requirements. This paper proposes an integrated offline PSO and ANN algorithms to track the solar power optimally based on various operation conditions due to the uncertain climate change. The proposed approach has the capability to estimate the amount of generated PV power at a specific time. The ANN based solar insolation forecast has shown satisfactory results with minimal error and the generated PV power has been optimised significantly with the aids of the PSO algorithm.

KEYWORDS: *Solar Energy, Photovoltaic system, Particle Swarm Optimization, Artificial neural Network*

I. INTRODUCTION

Artificial Intelligence is a combination of computer science, physiology, and philosophy. AI is a broad topic, consisting of different fields, from machine vision to expert systems. The element that the fields of AI have in common is the creation of machines that can "think”. In order to classify machines as "thinking", it is necessary to define intelligence. To what degree does intelligence consist of, for example, solving complex problems, or making generalizations and relationships and what about perception and comprehension. Researches into the areas of learning, of language, and of sensory perception have aided scientists in building intelligent machines. One of the most challenging approaches facing experts is building systems that mimic the behaviour of the human brain, made up of billions of neurons, and arguably the most complex matter in the universe. Perhaps the best way to gauge the intelligence of a machine is British computer scientist Alan Turing's test. He stated that a computer would deserve to be called intelligent if it could deceive a human into believing that it was human.
Various Artificial Intelligence techniques are used. They are as follows:

1.1 Genetic Algorithm (GA):-

GA is a global search technique based on mechanics of natural Selection and genetics. It is a general purpose optimization algorithm that is distinguished from conventional optimization techniques by the use of concepts of population genetics to guide the optimization search. Instead of point to point search, GA searches from population to population. The advantages of GA over traditional techniques is that it needs only rough information of the objective function and places no restriction such as differentiability and convexity on the objective function, the method works with a set of solutions from one generation to next, and not a single solution, thus making it less likely to converge on local minima, and the solutions developed are randomly based on the probability rate of the genetic operators such as mutation and crossover; the initial solutions thus would not dictate the search direction of GA.A major disadvantage of GA method is that it requires tremendously high time.

1.2 Tabu Search Algorithms:-

Tabu search (TS) algorithm was originally proposed as an optimization tool by Glover in 1977. It is a conceptually simple and an elegant iterative technique for finding good solutions to optimization problems. In general terms, TS is characterized by its ability to escape local optima by using a short term memory of recent solutions called the tabu list. Moreover, tabu search permits back tracking to previous solutions by using the aspiration criterion. Reference, a tabu search algorithm has been addressed for robust tuning of power system stabilizers in multi-machine power systems, operating at different loading conditions.

1.3 Simulated Annealing Algorithms:-

In the last few years, Simulated Annealing (SA) algorithm appeared as a promising heuristic algorithm for handling the combinatorial optimization problems. It has been theoretically proved that the SA algorithm converges to the optimum solution. The SA algorithm is robust i.e. the final solution quality does not strongly depend on the choice of the initial solution. Therefore, the algorithm can be used to improve the solution of other methods. Another strong feature of SA algorithm is that a complicated mathematical model is not needed and the constraints can be easily incorporated unlike the gradient descent technique, SA is a derivative free optimization algorithm and no sensitivity analysis is required to evaluate the objective function. This feature simplifies the constraints imposed on the objective function considered.

1.4 Particle Swarm Optimization (PSO) Algorithms:-

Recently, Particle Swarm Optimization (PSO) algorithm appeared as a promising algorithm for handling the optimization problems. PSO shares many similarities with GA optimization technique, like initialization of population of random solutions and search for the optimal by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. One of the most promising advantages of PSO over GA is its algorithmic simplicity as it uses a few parameters and easy to implement. In PSO, the potential solutions, called particle, fly through the problem space by following the current optimum particles.

1.5 Fuzzy logic (FL) Algorithms:-

Fuzzy logic was developed by Zadeh in 1964 to address uncertainty and imprecision which widely exist in the engineering problems and it was first introduced in 1979 for solving power system problems. Fuzzy set theory can be considered as a generation of the classical set theory. In classical set theory an element of the universe either belongs to or does not belong to the set. Thus the degree of associations of an element is crisp. In a fuzzy set theory the association of an element can be continuously varying. Mathematically, a fuzzy set is a mapping (known as membership function) from the universe of discourse to the closed interval. The membership function is usually designed by taking into consideration the requirement and constraints of the problem. Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules.

A detailed data is required as it designates an interest for potential location with the highest solar energy measurement. Due to the demand growth in solar energy, a proper modelling and forecasting of solar insolation is required. This method maximise the usage of solar energy as it improve the operation control and energy optimisation in PV system. Potential location with highest solar measurement does not guarantee the maximum PV power generated. This is because the performance of PV system is influenced by the cell temperature, fault level of PV array and voltage of the power output. Henceforth, power tracking methods are important because it minimizes the problem of low conversion efficiency of the PV system at various conditions.

Maximum Power Point Tracker (MPPT) is one of the methods that have been implemented in PV applications as it enhances its conversion efficiency which relies on the operating voltage of the array. Artificial Intelligence (AI) such as Artificial Neural Network (ANN) and Particle Swarm Optimisation (PSO) had been introduced into the MPPT controller by searching the maximum power point of the PV module. Although MPPT has advantage in control algorithm, that advantage becomes a disadvantage in terms of cost and capacity. In addition, the complexity of the overall system consumes more power. Therefore, another technique had been introduced to optimal power tracking using ANN to forecast solar insolation. This method is not complex and it is suitable for mounted stationary PV panel corresponding to this research.

Henceforth, this paper features an important criterion to optimise power for the PV generator based on solar insolation prediction and characteristics of PV panel. The priority of these criteria is determined using two methods. Artificial neural network (ANN) is used to forecast the solar insolation level due to its ability to solve multivariable problem with less knowledge of internal system parameter. The proposed PSO optimise the power generated at a specified voltage level under various operation circumstances. PSO would be a useful tool to optimise the PV generated power due to its well-known method for optimising nonlinear function based on swarming social interaction.

II. MATERIALS AND METHODS

2.1 PV System Architecture

The experiment takes place by logging the solar insolation fall horizontally on the PV panel as well as the charging voltage and current at no load. The solar data logger is tilted at the same angle as the solar panel while the power logger is tapped at 1 as shown in Fig 1.

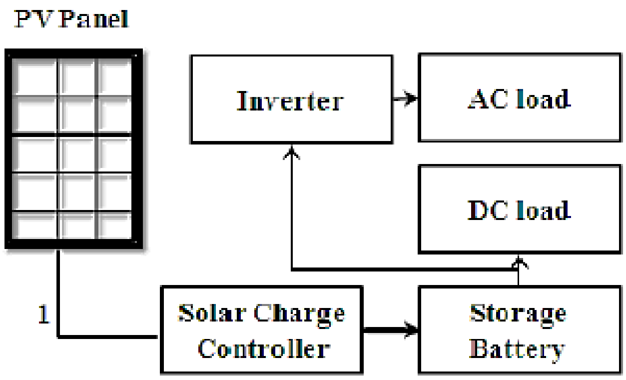

Figure 1 PV Panel Deployment Architecture

The actual solar insolation level is measured for a period of time followed by the ANN based solar insolation level forecast. The forecasted results are then applied into PSO in order to evaluate the best power optimisation at a specified voltage level.

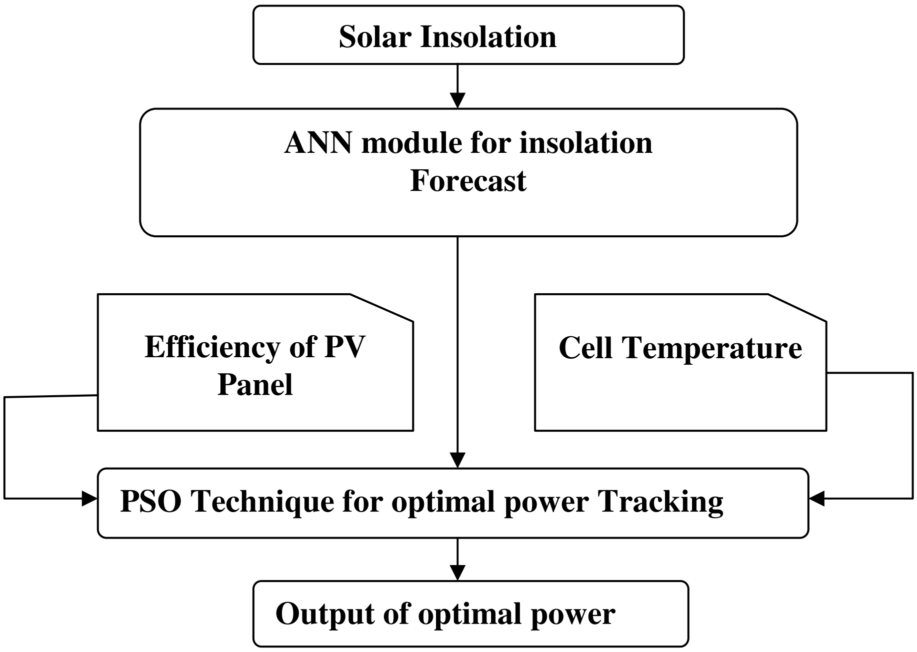

Figure 2 Block Diagram for Optimal Power Tracking

Essential data such as solar insolation, charging current and PV generated voltage have been measured for 60 days, from Aug 9th 2011 to oct 9th 2011. The data are only been collected for 12 hours per day from 7am to 7pm under tropical climate conditions where this is the period for the sun radiates the most. Fig. 3 shows the daily average solar insolation level along the period of 60 days. Fig 4 shows the experimental mean values of 12 hourly solar insolation level.

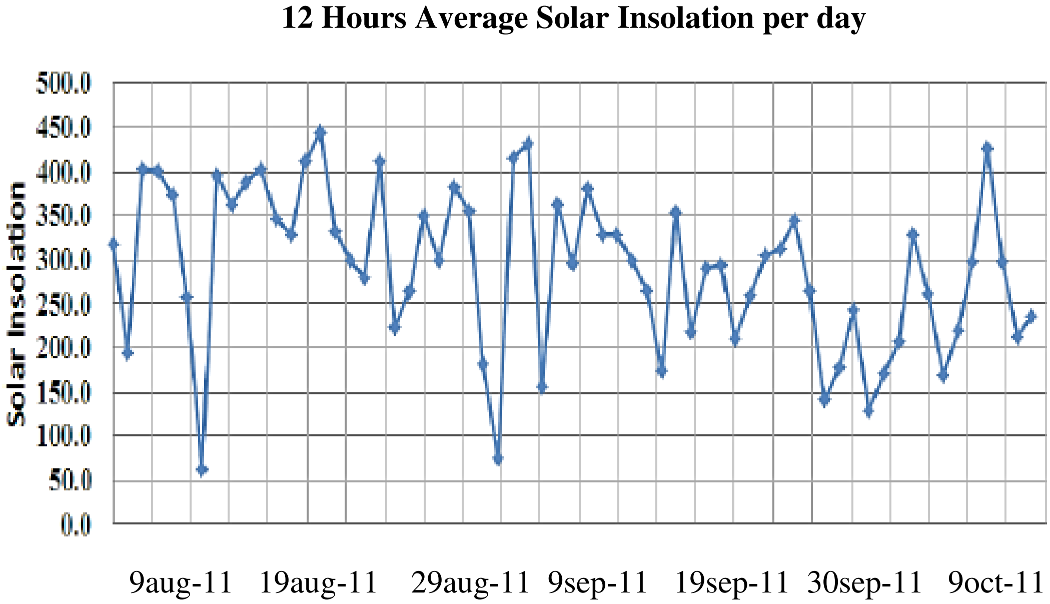

Figure 3 Daily average insolation level

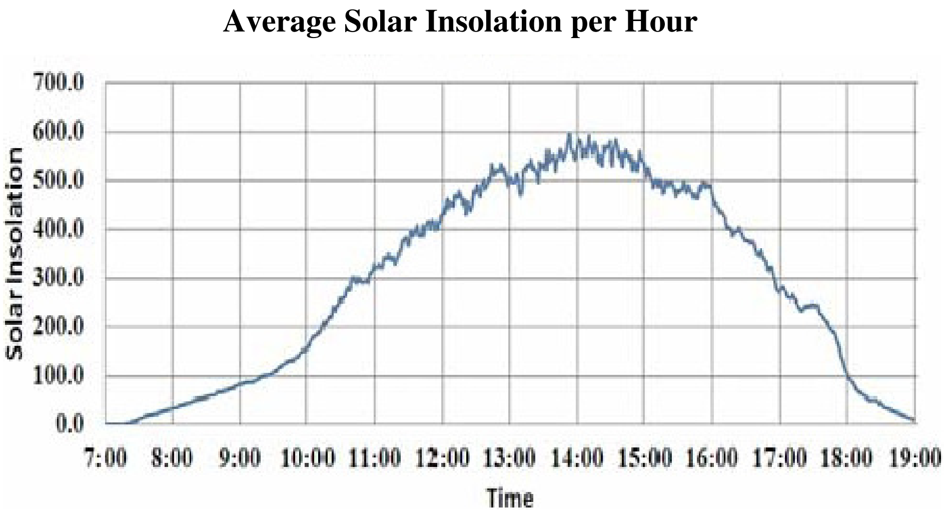

Figure 4 Average 12 hourly solar insolation level

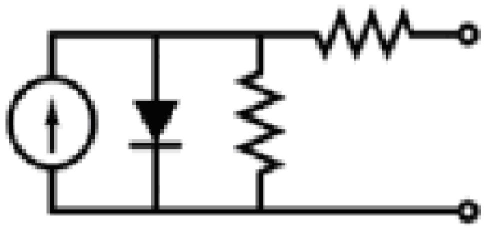

Figure 5: Equivalent Circuit of Solar Cell

2.2 Solar Insolation Level Forecasting using ANN

ANN has been widely used in many applications especially and forecasting due to its well known fees-forward structure. The MLP structure presented in this research comprises of an input, output and a hidden layers. This structure imitates the basic function of the human brain as it receives inputs, combine them and produce final output result. The input data are divided into training, validation and test sets. The input and output data are normalised in the range between -1 and 1

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MLP network has various connection styles and learning algorithms as it is adapted to its structure and convergence time. Back-propagation is a popular supervised learning algorithm and it is used in this research due to its ability to adjust the weights for the network in producing a desired output. Without supervised learning algorithm, the weights are not adjusted to the target data as the desired output is unachievable.

The best MLP structure depends on the best activation function and number of neurons in the hidden layer. Trial and error method determine the results of a suitable number of neuron in each model.

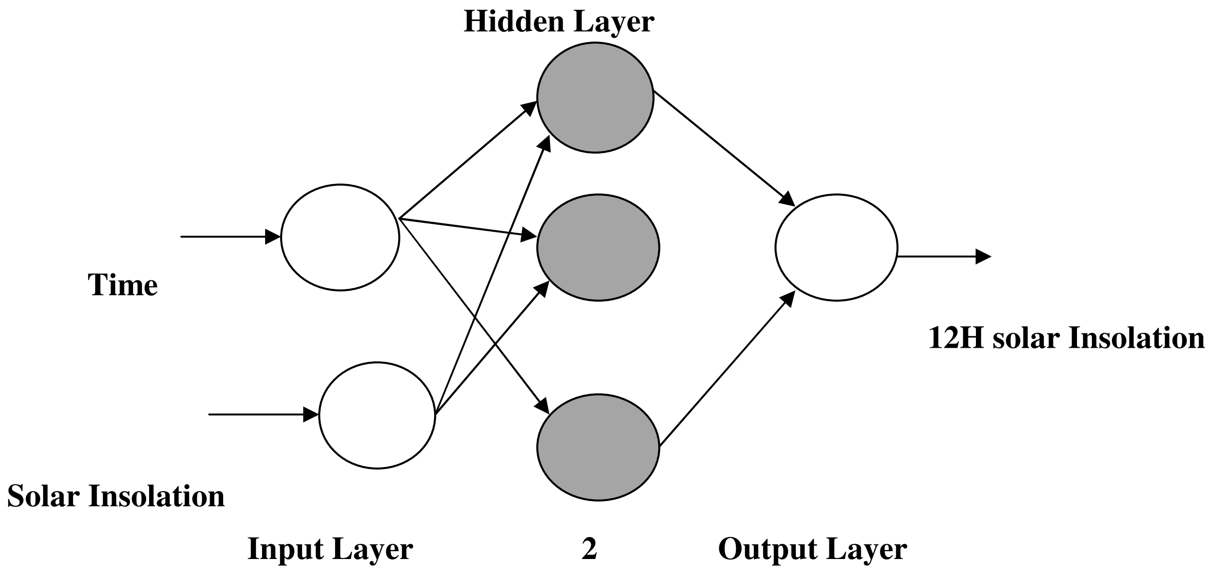

Figure 6 MLP Network for 12-Hour Forecast

2.3 The Proposed PSO Algorithm for Optimal Power Tracking

PSO is proposed in this research to optimise the power generation for the PV system under various operating conditions such as different insolation levels and cell temperatures. Various PV panel efficiencies are tested in order to determine the effectiveness of the power generation optimisation using PSO technique. The procedure of the developed PSO algorithm is presented in the flowchart given, where the algorithm is divided into six key steps as follows:

1. Initialization of swarm position with random guess for the searched solution *PPV optimal*.
2. Evaluation of the objective function of the corresponding initialised *PPV optimal*. The objective function is chosen to be the *m* order polynomial curve fitting of the power and voltage characteristics of the PV panel.
3. Updating swarm position and velocity according to Eqns. (1) and (2) [16].
4. Evaluation of the updated population.
5. Check if all iterations are carried out.
6. Output the global best result of *PPV optimal* that satisfied the objective function.

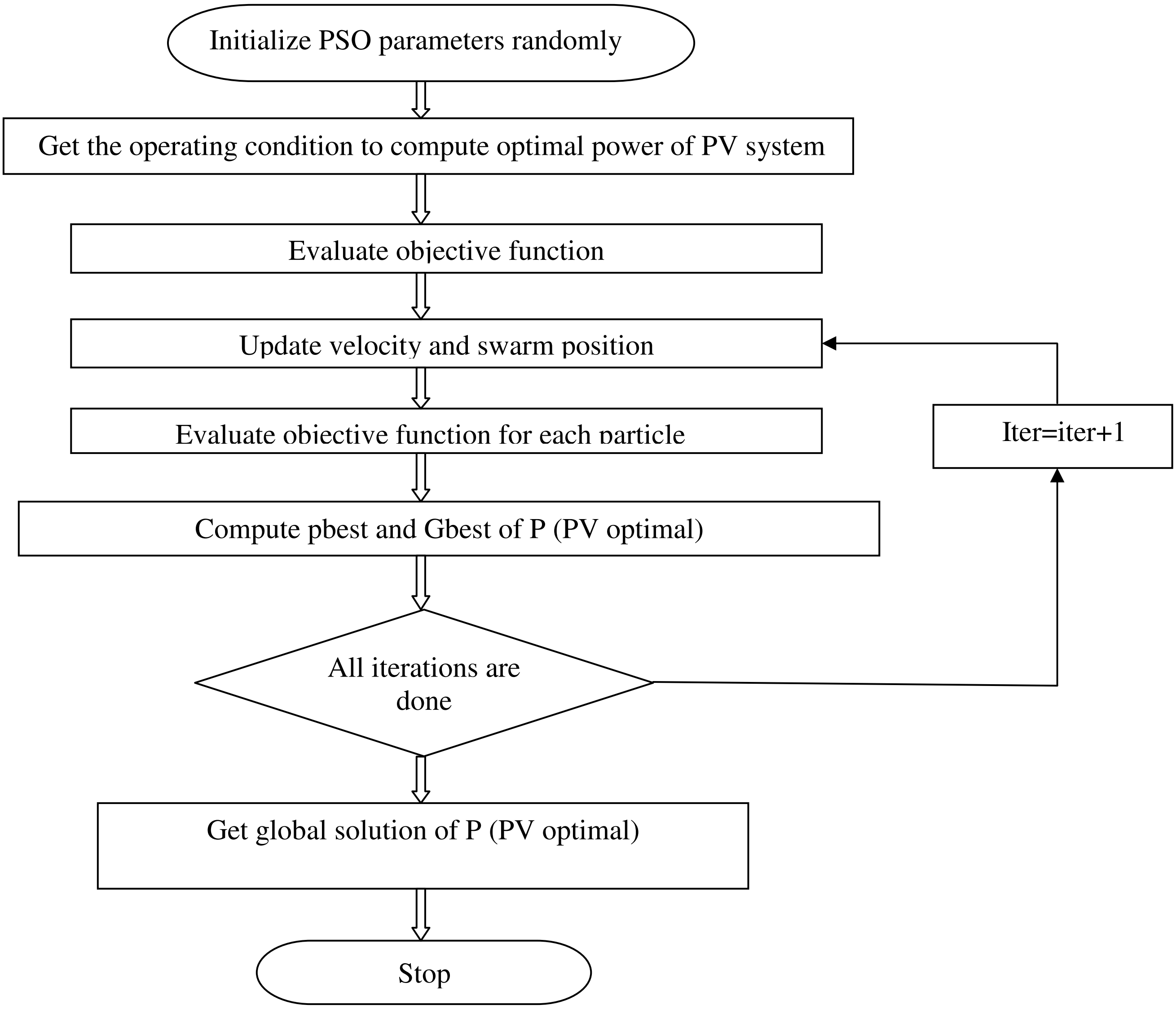

Figure.7 PSO FLOW CHART

$$Vi^{k+1} = \omega Vi^{k} + c_1\, r_1\, (Pbest_i^{k} - X_i^{k}) + c_2\, r_2 (\, Gbesti^{k} - X_i^{k}) \quad (1)$$

$$X_i^{k+1} = X_i^{k} + V_i^{k+1} \quad (2)$$

Where,

Vi^k velocity of individual, *I* at iteration *k,*
ω inertia weight parameter,
*c*1, *c*2 acceleration coefficients,
*r*1, *r*2 random numbers between 0 and 1 ,
$X\, i^k$ position of individual, *I* at iteration *k* ,
$Pbest\ i^k$ best position of individual, *I* at iteration *k* ,
$Gbest\ i^k$ best position of the group until iteration *k* ,

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{Iter_{max}} \times Iter \quad (3)$$

2.4 PSO Input Parameter

The selected input parameter of PSO comprises operating conditions such as insolation level, efficiency of the PV arrays and cell temperature. The details are explained as follows.

Insolation Level: In general, the insolation level rating fora PV panel is ranges from 0-1.0 kW/m2 in terms of per unit value.

Temperature: The PV module panel rating is specified at a cell temperature either degrees or in Kelvin.

PV efficiency: The range of the rated value starts from 0.1 to 1.0 as each value defines the efficiency percentage for PV panel.

Order of polynomial: The order specifies for the polynomial curve fitting of the power and voltage characteristics of the PV panel.

III. RESULTS AND DISCUSSION

The forecasting results in two different weather conditions are shown in Table 1. In order to evaluate the obtained results, different parameters are calculated for each prediction. Correlation coefficient, *r* indicates the adjacent predicted and measured data. MSE provides information on long-term model performance which specifies the average deviation between the predicted values to the corresponding measure values. As the coefficient of determination, *R2* approaches 1 and MSE approaches zero this signifies the solution of the problem provides the most accurate solution.
Table shows the prediction results with minimal error as highlighted. The forecasted results for sunny and rainy weather on August 11th (2011) and August 15th (2011) are 0.2% and 0.09%, respectively as shown in Figs. 8 and 9.

Table 1 Number of Nodes corresponding to the MLP network performance on August 11th (Sunny) and August 15th 2011(Rainy).

No of Nodes	Sunny			Rainy		
	R2	MSE	r	R2	MSE	r
1	0.994	0.003	0.997	0.921	0.0075	0.974
2	0.978	0.01	0.991	0.905	0.0092	0.953
3	0.986	0.006	0.993	0.956	0.0044	0.981
4	0.988	0.006	0.994	0.942	0.0064	0.977
5	0.982	0.013	0.984	0.921	0.0076	0.967
6	0.977	0.01	0.997	0.968	0.0031	0.988
7	0.978	0.009	0.998	0.963	0.0038	0.991
8	0.976	0.01	0.993	0.948	0.0049	0.984
9	0.997	0.002	0.999	0.959	0.0042	0.989
10	0.984	0.006	0.996	0.92	0.008	0.963
15	0.977	0.01	0.996	0.993	0.0009	0.997
20	0.978	0.01	0.995	0.98	0.0023	0.992
25	0.982	0.008	0.993	0.945	0.006	0.987
30	0.985	0.007	0.997	0.942	0.0067	0.983

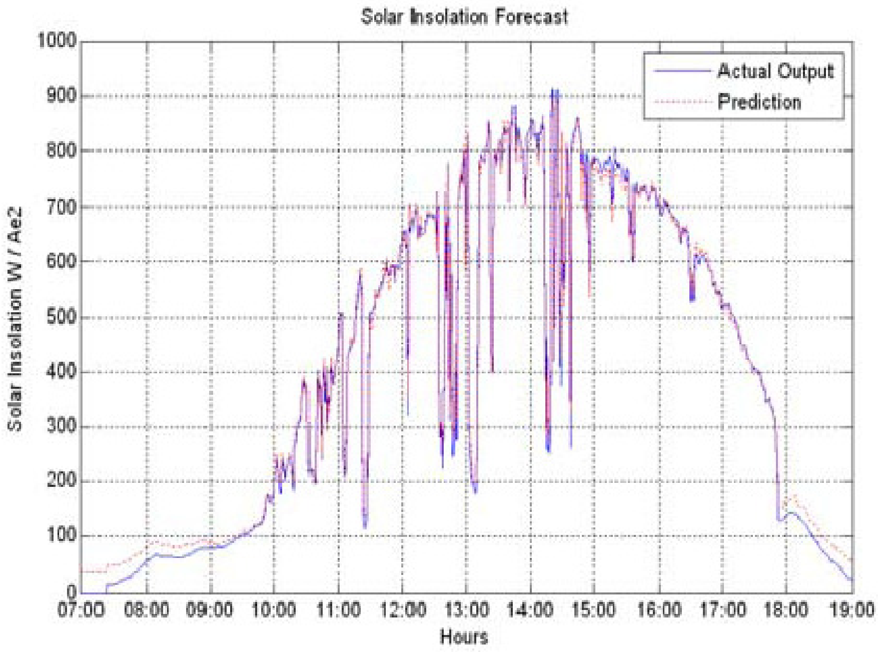

Figure 8 Solar Insolation measured and prediction on August 11th 2011(Sunny)

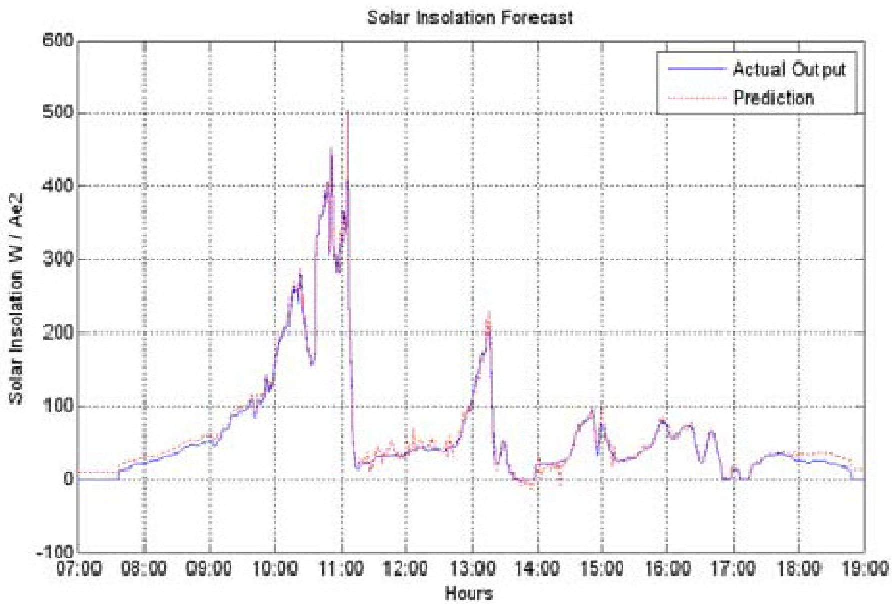

Figure 9 Solar Insolation measured and prediction on August 15th 2011 (Rainy)

Problems Formulations

Each computed value is used in PSO is to determine the best result of *PPV optimal*. Each calculation is explained in the following.

1. Objective function: Power generated by PV system

This paper proposes polynomial curve fitting technique in obtaining the optimal generated power of the PV system. This technique has been applied in many applications due to its best approximation corresponding. to the actual result. By using the curve fitting method under the power and voltage characteristics of the PV panel, the coefficient of the *m* order polynomial is obtained. Subsequently, the power generated of the PV system can be approximated by an *m* order polynomial as a function of the panel voltage. the optimal power tracking PV system can be expressed as follows:

$P_i(V_i) = \sum_{i=1}^{m} a_i v_i$

Subject to $0 \leq v_i \leq v_{i,0}$

Where
ai : Polynomial coefficient which is obtained through curve fitting model
m : Order of the polynomial chosen
vi,0 : Open circuit voltage of the *i* solar panel
P : Power generated of the system

Table 2. Approximation power with the increasing number of polynomial

Number of Polynomial,n	Power (W)
1	-4.737
2	28.48
3	55.93
4	55.39
5	54.98
6	56.26
7	55.59
8	55.58
9	55.63
10	55.44

The total generated power by the PV system can be calculated according to the following equation
$P_{PV}(V_i) = \sum_{i=1}^{N} P_i(V_i)$

IV. CONCLUSION

An integrated scheme for optimal power tracking has been proposed in this paper. With the aid of this method, the PV system is able to perform and to enhance the production of the electrical energy at an optimal solution under various operating conditions. As a result, a precise estimation of the PV power generation is known through the optimisation technique as it is to curb the conversion efficiency of the PV system. Likewise, it gives opportunity for any designer to deploy a stationary mounted rooftop PV system to fully harvest the solar energy at any potential location. Due to the offline optimisation technique, this method has its limitation. In contrast to the online optimisation technique, this method requires to store the collected data in a database which is normally done manually. Although this method has its setback, yet it can be modified in the future for online application purposes. The proposed method can become a useful tool in any possible applications regarding to economic power dispatch. The integrated scheme of optimal power tracking can be included into a control system as it can optimally dispatch power to the random loads based on the estimated power generated. Thus, this improves the power dispatch of the PV generator in order to avoid any electrical breakdown as the load fluctuates.

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