



## ESTIMATION OF PV MODULE PARAMETERS USING GENERALIZED HOPFIELD NEURAL NETWORK

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### ABSTRACT

The estimation of solar photovoltaic (PV) system with help of electrical model parameters, such as photon generated current, the diode saturation current, series resistance, shunt resistance, and diode ideality factor, are desirable to predict the real performance characteristics of solar PV under varying environmental conditions. Finally, performance indices, such as PV characteristics curve are estimated for the various solar PV panels using GHNN optimization technique.

**Keywords:** Generalized Hopfield Neural Network (GHNN), Photovoltaic (PV).

### 1. INTRODUCTION

Solar panels harness the sun energy in the form of light and convert the energy into electricity. Although the average consumer might associate solar panels with residential rooftop assemblies, solar panels are available for a wide range of applications, including powering individual gadgets, electronic devices and vehicle batteries.

The reserves of fossil fuels are rapidly decreasing at present due to the increased use of thermal power plants and air pollution associated with the combustion of fossil fuels is increasing. Hence, in the present scenario, there is an urgent need to speed up the research and development of renewable energy technology, especially solar energy, to meet the world energy demand.

The goal of this dissertation is to develop and apply an integrated assessment framework, for one of the sustainable electricity options, solar photovoltaic (PV) technology. In this dissertation different types of photovoltaic modules are considered that are widely manufactured in the market at present, and the future implications of using PV technology in the electricity sector is evaluated.

PV electricity mitigates emissions from thermal power plants to the grid. Inclusion of such monetary benefits from mitigation into the evaluation of the economic performance, PV technology encourage economic sustainability.

## 2. ANALYSIS OF SINGLE DIODE PV MODULE

A single diode model of the solar PV module is have the unknown parameters from figure 2.1, namely  $I_{lg}$ ,  $I_{sat}$ ,  $A$ ,  $R_{se}$ , and  $R_{sh}$ . By taking the datasheet information provided by the manufacturer of the PV module at standard test conditions (STCs), the PV module's parameters are estimated.

### 2.1. Single Diode Solar PV Module

A single diode model of the PV module is shown in Figure 2.1. By using the PV module parameters obtained at STCs, the values of the five parameters and the MPP of the PV module can be estimated at any temperature and irradiance condition.

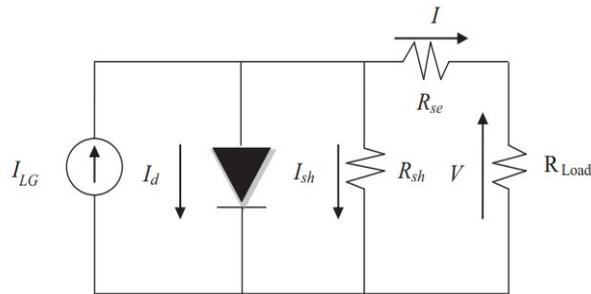


Fig 1. Equivalent circuit of PV module

$$I = I_{lg} - I_{sat} \left[ e^{\left( V + \frac{IR_{se}}{N_s V_t} \right)} - 1 \right] - \frac{V + IR_{se}}{R_{sh}} \quad (1)$$

Where,

$I_{lg}$  - Light generated current in amps

$N_s$  -Number of solar cells connected in series

$I_{sat}$ - Diode reverse saturation current in amps

$R_{se}$ -Series resistance of solar module in ohms

$R_{sh}$ -Shunt resistance of solar module in ohms

The thermal voltage of diode,  $V_t$ , is expressed as,

$$V_t = AkT_c/q \quad (2)$$

Where,

$A$ - Diode ideality factor

$k$  -Boltzmann constant ( $1.3806 * 10^{-23}$  J/K)

$T_c$  - PV module temperature (STC) in K

$q$  - Electronic charge ( $1.602 * 10^{-19}$  C)

The important parameters to be noted from the manufacturer's datasheet are short circuit current ( $I_{sc}$ ), open circuit voltage ( $V_{oc}$ ), and maximum power point are ( $V_{mpp}$  &  $I_{mpp}$ ). The values at STCs, for which the irradiance ( $G_{stc}$ ) is  $1000 \text{ W/m}^2$  and the cell temperature ( $T_{stc}$ ) is  $25^\circ \text{C}$ . The

data sheet also provides temperature coefficients for short circuit current (ki), open circuit voltage (kv), and maximum power (kp).

### 2.1.1. Extraction of PV Module Parameters

The five unknown parameters are to be estimate of the PV module from the nonlinear equation (1), five independent equations are required. The first three equations, (4), (7), and (9), are derived from Eq. (1) by applying short circuit, open circuit, and MPP conditions. The remaining two equations, (12) and (14), are derived by differentiating the values of power and current with respect to voltage.

### 2.2. SHORT CIRCUIT CONDITION (SCC)

Under the short circuit condition,

$$I_{sc} = I_{lg} I_{sat} \left[ e \left( \frac{I_{sc} R_{sh}}{N_s V_t} \right) - 1 \right] - \left( \frac{I_{sc} R_{se}}{R_{sh}} \right) \quad (3)$$

After some approximation, the light generated current ( $I_{lg}$ ) can be written as

$$I_{lg} = \frac{I_{sc}(R_{se} + R_{sh})}{R_{sh}} \quad (4)$$

### 2.3. OPEN CIRCUIT CONDITION (OCC)

Under the open circuit condition,

$$0 = I_{lg} - I_{sat} e \left( \frac{V_{oc}}{N_s V_t} \right) - \frac{V_{oc}}{R_{sh}} \quad (5)$$

This equation is rearranged and the reverse saturation current is expressed as

$$I_{sat} = \left( I_{lg} - \frac{V_{oc}}{R_{sh}} \right) e \left( -\frac{V_{oc}}{N_s V_t} \right) \quad (6)$$

Substituting  $I_{lg}$  from short circuit, the saturation current can be derived as,

$$I_{sat} = \left( \frac{I_{sc}(R_{se} + R_{sh})}{R_{sh}} - \frac{V_{oc}}{R_{sh}} \right) e \left( -\frac{V_{oc}}{N_s V_t} \right) \quad (7)$$

### 2.4. MAXIMUM POWER POINT (MPP) CONDITION

The maximum power point calculation are as follows:

$$I_{mpp} = I_{lg} - I_{sat} \left[ e \left( \frac{V_{mpp} + I_{mpp} R_{se}}{N_s V_t} \right) - 1 \right] - \frac{V_{mpp} + I_{mpp} R_{se}}{R_{sh}} \quad (8)$$

Inserting  $I_{lg}$  and  $I_{sat}$  into this equation, we get the equation as

$$I_{mpp} = \left( \frac{I_{sc}(R_{se} + R_{sh}) - (V_{mpp} + I_{mpp} R_{se})}{R_{sh}} \right) - \left( \frac{I_{sc}(R_{se} + R_{sh}) - V_{oc}}{R_{sh}} \right) e \left( \frac{V_{mpp} + I_{mpp} R_{se} - V_{oc}}{N_s V_t} \right) \quad (9)$$

## 2.5. CALCULATION OF INITIAL VALUES

To select the initial value for  $R_{se}$  and  $R_{sh}$ , the following equations are considered. Because of high sensitivity, the numerical methods may fail to converge due to improper selection of the initial value of the PV module parameters.

$$R_{se\ initial} = \left( \frac{V_{oc}}{I_{sc}} \right) - \left( \frac{V_{mpp}}{I_{mpp}} \right) \tag{10}$$

$$R_{sh\ initial} = V_{mpp} / (I_{sc} - I_{mpp}) \tag{11}$$

The  $V_t$ ,  $R_{se}$  and  $R_{sh}$  are given by the equations,

$$V_t = \frac{V_{mpp} + I_{mpp} R_{se} - V_{oc}}{(N_s \ln \left( \frac{I_{sc} (R_{se} + R_{sh}) - V_{oc}}{(I_{sc} - I_{mpp})(R_{se} + R_{sh}) - V_{mpp}} \right))} \tag{12}$$

$$R_{se} = \frac{V_{oc} - V_{mpp} + N_s V_t S}{I_{mpp}} \tag{13}$$

Where,

$$S = \ln \left( \frac{(N_s V_t (I_{mpp} (R_{se} + R_{sh}) - V_{mpp}))}{I_{sc} V_{mpp} (R_{se} R_{sh}) + I_{mpp} R_{se} (V_{oc} - I_{sc} R_{se} - I_{sc} R_{sh}) - V_{mpp} V_{oc}} \right)$$

$$R_{sh} = \frac{\left( (N_s V_t (R_{se} + R_{sh}) + R_{se} (I_{sc} (R_{se} + R_{sh}) - V_{oc})) \left( \frac{e^{(I_{sc} R_{se} - V_{oc})}}{N_s V_t} \right) \right)}{\left( (N_s V_t + (I_{sc} (R_{se} + R_{sh}) - V_{oc})) e^{\left( \frac{I_{sc} R_{se} - V_{oc}}{N_s V_t} \right)} \right)} \tag{14}$$

The PV module parameters  $I_{lg}$ ,  $I_{sc}$ ,  $A$ ,  $R_{se}$  and  $R_{sh}$  can be obtained by open and short circuit test. First, these three equations are solved by GHNN and the values of  $V_t$ ,  $R_{se}$ ,  $R_{sh}$  are obtained

The remaining parameters are obtained from short and open circuit test using the values of  $V_t$ ,  $R_{se}$ ,  $R_{sh}$ .

## 2.6. EFFECT OF VARYING IRRADIANCE AND TEMPERATURE

The light generated current and short circuit current are directly proportional to irradiance and depends on temperature.

$$I_{lg}(G) = I_{lg}(stc) \times \frac{G}{G_{stc}} \tag{15}$$

$$I_{sc}(G) = I_{sc}(stc) \times \frac{G}{G_{stc}} \tag{16}$$

Where,

$G_{stc}$  – Irradiance at STC ( $w/m^2$ )

G – Irradiance under given operating condition

The open circuit voltage equation can be described as the function of irradiance as given by and this equation is solved by Newton Raphson.

$$V_{oc(G)} = N_s V_t \ln \left( \frac{I_{lg(G)} R_{sh} - V_{oc(G)}}{I_{sat} R_{sh}} \right) \quad (17)$$

The short circuit current and open circuit voltage can be evaluated for the given operating temperature as given by

$$I_{sc(T)} = I_{sc(stc)} + k_i (T_c - T_{stc}) \quad (18)$$

$$V_{oc(T)} = V_{oc(stc)} + K_v (T_c - T_{stc}) \quad (19)$$

Where,

$T_{stc}$  – Cell temperature at STC, K.

The light generated current can be determined as a function of temperature and is given by,

$$I_{lg(T)} = I_{sc(T)} (R_{se} + R_{sh}) / (R_{sh}) \quad (20)$$

The short circuit current, open circuit voltage and light generated current can be estimated at any temperature and irradiance using the following three equations.

$$I_{lg(GT)} = \left( I_{lg(stc)} + k_i (T_c - T_{stc}) \right) \left( \frac{G}{G_{stc}} \right) \quad (21)$$

$$I_{sc(GT)} = \left( I_{sc(stc)} + k_i (T_c - T_{stc}) \right) \left( \frac{G}{G_{stc}} \right) \quad (22)$$

$$V_{oc(GT)} = V_{oc(G)} + K_v (T_c - T_{stc}) \quad (23)$$

The thermal voltage  $V_t$  is directly proportional to PV panel cell temperature and is given by,

$$V_t(T) = V_{t(stc)} \left( \frac{T}{T_{stc}} \right) \quad (24)$$

The diode reverse saturation current, which is a function of irradiance and temperature can be calculated from the equation,

$$I_{sat(GT)} = \frac{I_{sc(G)} (R_{se} + R_{sh}) - V_{oc(GT)}}{R_{sh}} e \left( - \frac{V_{oc(GT)}}{N_s V_t(T)} \right) \quad (25)$$

## 2.7. ESTIMATION OF MAXIMUM POWER POINT

The proper initial values of  $V_{mpp}$  and  $I_{mpp}$  should be chosen to estimate the accurate MPP by using the well-known values of  $V_{oc}$  and  $I_{sc}$  under given operating conditions. Under varying irradiance and temperature,  $V_{t(GT)}$ ,  $R_{se(GT)}$  and  $R_{sh(GT)}$  are obtained by using the estimated parameters of the PV module such as  $I_{lg}$ ,  $I_{sat}$ ,  $A$ ,  $R_{se}$  and  $R_{sh}$  at STC's.

In general, the PV module parameters change considerably due to various environmental conditions.

$$R_{se}(GT) = R_{se(stc)} \left( \frac{I_{lg}(GT)}{I_{lg}(stc)} \right) \tag{27}$$

The value of shunt resistance is considered a constant in [10] but the value of shunt resistance of the PV module is indirectly proportional to the short circuit current under varying operating conditions in this paper, anew equation is introduced for the shunt resistance variation with respect to temperature and irradiance and is expressed as

$$R_{sh}(GT) = R_{sh(stc)} \left( \frac{I_{sc}(stc)}{I_{sc}(GT)} \right) \tag{28}$$

In order to find MPP, The maximum voltage is found as a function of temperature and irradiance and is given by,

$$V_{mpp} = V_{oc}(GT) - I_{mpp} R_{se}(GT) + N_s V_t(GT) U \tag{29}$$

Where,

$$U = \ln \left( \frac{[ (I_{sc}(GT) - I_{mpp}) (R_{se}(GT) + R_{sh}(GT)) - V_{mpp} ]}{I_{sc}(GT) (R_{se}(GT) + R_{sh}(GT) - V_{oc}(GT))} \right)$$

The maximum current serves as a function of temperature and irradiance and is given by,

$$I_{mpp} = \frac{\frac{V_{mpp} Q}{N_s V_t(GT) R_{sh}(GT)} + \left( \frac{V_{mpp}}{R_{sh}(GT)} \right)}{1 + \left( \frac{Q R_{se}(GT)}{N_s V_t(GT) R_{sh}(GT)} \right) + \left( \frac{R_{se}(GT)}{R_{sh}(GT)} \right)} \tag{30}$$

Where,

$$Q = (I_{sc}(GT) (R_{sc}(GT) + R_{sh}(GT)) - V_{oc}(GT)) e^{\left( \frac{V_{mpp} + I_{mpp} R_{se}(GT) - V_{oc}(GT)}{N_s V_t(GT)} \right)}$$

These three equations can be solved using the Newton Raphson method and Generalised Hopfield Neural Network method. In these two method the error value is taken as the 1×10e-10. These are all the mathematical modelling of the 80W PV module that can be used for extracting the five parameters and finding the maximum power point of the prescribed PV module.

### 3. Generalized Hopfield Neural Network

The continuous time single layer feedback networks are called “gradient type networks” in which time is assumed a continuous variable. Gradient type neural networks are the Generalized Hopfield Neural Networks (GHNN) in which the computational energy decreases continuously with time. The evolution of the system is in the general direction of the negative gradient of the energy function. The generalized electrical architecture of the GHNN is shown as in Figure.3.1.

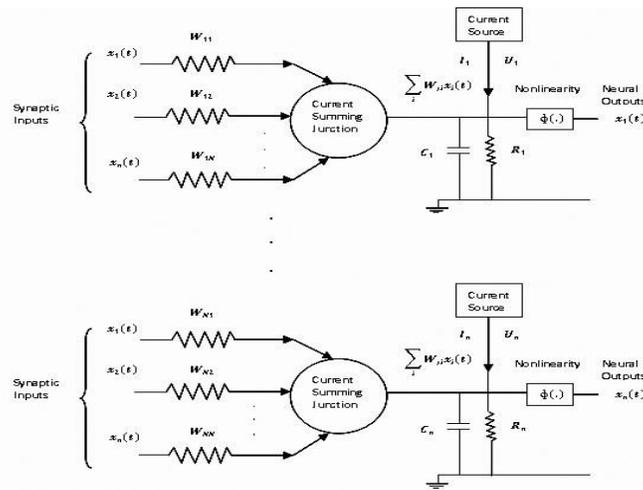


Figure.3.1 Generalized Architecture of GHNN

It consisting of an interconnection of  $n$  neurons, each one of which is assumed to have the same mathematical model described in equations (1) and (2). Where  $R_j$  represents leakage resistance,  $C_j$  represents leakage capacitance and  $\phi(\cdot)$  represents activation function. In physical terms, the synaptic weights  $W_{j1}, W_{j2}, \dots, W_{jn}$  represent conductance's, and the respective inputs  $x_1(t), x_2(t), \dots, x_n(t)$  represent potentials;  $n$  is the number of inputs. These inputs are applied to a current summing junction characterized by low input resistance, unity current gain and high output resistance. It thus acts as a summing node for the input currents. In the generalized Hopfield neural network the inputs to each neuron of the network not only come from the outputs of other neurons but also from the product of several outputs. The total current flowing toward the input node of the nonlinear element(activation function) in Figure.2 is therefore where the first term is due to the stimuli  $x_1(t), x_2(t), \dots, x_n(t)$  acting on the synaptic weights (conductance)  $W_{j1}, W_{j2}, \dots, W_{jn}$  respectively, and the second term is due to the current source  $I_j$  representing an externally applied bias.

$$\sum_{i=1}^N W_{ji} x_i(t) + I_j \tag{3.1}$$

Let  $u_{j(t)}$  denote the induced local field at the input of the nonlinear activation function. We may then express the total current flowing away from the input node of the nonlinear element as follows:

$$\frac{u_{j(t)}}{R_j} + C_j \frac{du_{j(t)}}{dt} \tag{3.2}$$

Where the first term is due to the leakage resistance  $R_j$  and the second term is due to leakage capacitance  $C_j$ . From Kirchoff's current law, we know that the total current flowing toward any node of an electrical circuit is zero. By applying Kirchoff's current law to the input node of the nonlinearity. We may define the dynamics of the network by the following system of coupled first-order differential equations by ignoring interneuron propagation time delays.

$$C_j \frac{du_{j(t)}}{dt} = -\frac{u_{j(t)}}{R_j} + \sum_{i=1}^N W_{ji} x_i(t) + I_j \tag{3.3}$$

An assumption is made that the activation function relating the output  $x_{j(t)}$  of neuron  $,j'$  to its induced local field  $u_{j(t)}$  is a continuous function and therefore differentiable. A commonly used activation function is the logistic function.

$$\varphi(u_j) = \frac{1}{1 + \exp(-u_j)} \quad j=1,2,\dots,n \quad (3.4)$$

The energy function for the proposed model is given by

$$E = (\sum_i \int_0^{x_i} \frac{\varphi^{-1}(s)}{R_i} ds \sum_i \sum_j W_{ij} f_{ij}(x_1, x_2, \dots, x_n) x_i + \sum I_i x_i) \quad (3.5)$$

By using conventional methodology one can see that the derivative for the proposed energy function is always less than or equal to zero, i.e.  $dE/dt < 0$  and energy of the system is thus bounded.

### 3.1. Application of GHNN to the solution of nonlinear equations

Let us consider a set of nonlinear algebraic equations given below:

$$\begin{aligned} f_1(x_1, x_2, \dots, x_j, \dots, x_n) &= P_1 \\ f_2(x_1, x_2, \dots, x_j, \dots, x_n) &= P_2 \\ \dots \\ f_j(x_1, x_2, \dots, x_j, \dots, x_n) &= P_j \\ \dots \\ f_n(x_1, x_2, \dots, x_j, \dots, x_n) &= P_n \end{aligned} \quad (3.6)$$

In the above equations  $f(\cdot)$  is a function of variables  $x_1, x_2, \dots, x_j, \dots, x_n \in \mathfrak{R}$  and  $\epsilon \mathfrak{R}$  is a real constant. Our objective is to find the values for variables  $x_1, x_2, \dots, x_j, \dots, x_n$  such that it satisfies the equation (3.6). To obtain the solution using proposed approach an energy function has to be formulated. The energy function for the above set of equations is derived as follows:

$$E = \sum_j^n ((g_j(\cdot))^2) \quad (3.7)$$

Where,

$$g_j(\cdot) = (f_j(x_1, x_2, \dots, x_j, \dots, x_n) - P_j) \quad (3.8)$$

Equations (3.7) and (3.8) have been used for designing the proposed network. The number of neurons in network is equal to the number of variables whose value is to be determined. In the given problem we have ‘n’ number of variables and hence the network should have ‘n’ number of neurons. The network dynamics are governed by the following differential equations:

$$\frac{du_j}{dt} = - \frac{dE}{dx_j} \quad (3.9)$$

$$x_j = \varphi u, \quad j = 1 \dots n \quad (3.10)$$

Where,  $u_j$  is the net input to the  $j^{\text{th}}$  neuron in the network and is its output. In this application the function  $\varphi(\cdot)$  linear input, output transfer function for the  $j^{\text{th}}$  neuron. Calculating the partial derivatives of equation (3.8) with respect to unknown variables  $x_1, x_2, \dots, x_j, \dots, x_n$  and collecting the terms of identical order will result in Hopfield equations like form. The coefficients and constants in the available expression give the weights and bias values for the network respectively.

### 3.2. APPLICATION OF GHNN TO ESTIMATION PV MODULE PARAMETRES STC AND VARYING IRRADIENCE AND TEMPERATURE

Single diode PV module equivalent circuit shown in fig 2.1. The Non Linear equation are derived from the equivalent circuit. From help of these Non-linear equations estimate the unknown parameters of the PV module using single diode equivalent circuit of Diode ideality factor (A), Shunt Resistor ( $R_{sh}$ ), Series Resistor ( $R_{se}$ ), Light generated current ( $I_{LG}$ ) and Saturation current ( $I_{sat}$ ).

Only three parameters are need to calculate by using GHNN and remaining two parameters are related to each other. Form the Energy Function for taking the equations (12),(13) & (14) and separated into variable and constants. Here variables are  $V_t$ ,  $R_{sh}$  &  $R_{se}$  as follows  $x_1$ ,  $x_2$  &  $x_3$  constants are Data sheet values of the solar panel that is  $V_{oc}$ ,  $I_{sc}$ ,  $V_{mpp}$ ,  $I_{mpp}$  and  $N_s$ .

$$E = -0.5(x_1^2 + x_2^2 + x_3^3)$$

Where,  $x_1=R_{se}$ ;  $x_2=R_{sh}$ ;  $x_3=V_t$

The differential equation governing the performance of PV module is calculated using energy function and is given as follows:

$$\frac{dx_1}{dt} = -\frac{\partial E}{\partial x_1}$$

$$\frac{dx_2}{dt} = -\frac{\partial E}{\partial x_2}$$

$$\frac{dx_3}{dt} = -\frac{\partial E}{\partial x_3}$$

After this getting three differential equations with respect to corresponding variables of the Energy function. By using ODE solver for solving these three equations we get the value of the variables are  $V_t$ ,  $R_{sh}$  &  $R_{se}$ . Using these three values will help to find the A,  $I_{LG}$  &  $I_{sat}$ .

The parameters of PV module are namely  $I_{lg}$ ,  $I_{sat}$ , A,  $R_{se}$ , and  $R_{sh}$ . By taking the datasheet information Table 1, provided by the manufacturer of the PV module at standard test conditions (STCs), the PV module's parameters are estimated. By using the PV module parameters obtained at STCs, the values of the five parameters and the MPP of the PV module can be estimated at any temperature and irradiance condition.

#### ALGORITHM

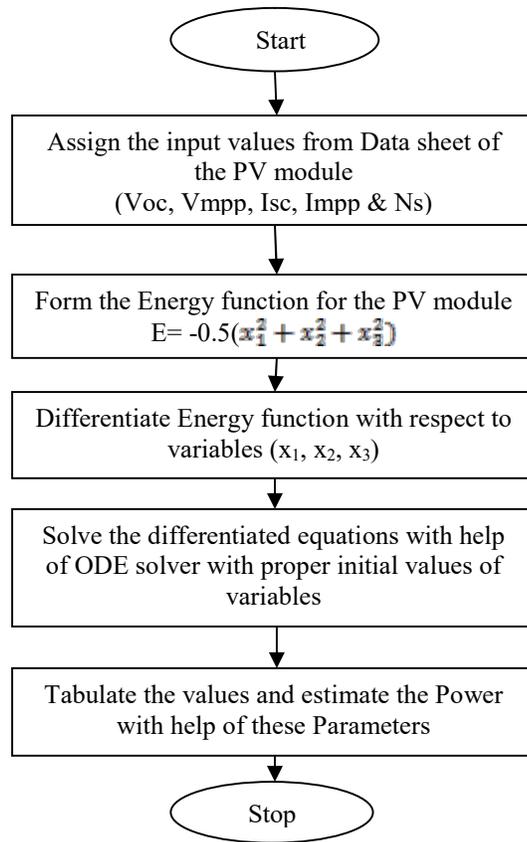
**Step 1:** Assign the input values for  $I_{sc}$ ,  $V_{oc}$ ,  $V_{mpp}$ ,  $I_{mpp}$  &  $N_s$ .

**Step 2:** Form the Energy function for PV module.

**Step 3:** Differentiate the Energy function with respect to variables.

**Step 4:** Solve the differentiated equations with help of ODE solver with proper initial values of the variables.

**Flow chart**



*Figure. 3.2 Flowchart for the GHNN method*

These values are given at STCs, for which the irradiance (Gstc) is 1000 W/ m<sup>2</sup> and the cell temperature (Tstc) is 25 ° C as followed by flow chart figure 3.2.

*Table 1. Datasheet of PV modules*

PV Module	Datasheet values				
	I <sub>sc</sub> (A)	I <sub>mpp</sub> (A)	V <sub>oc</sub> (V)	V <sub>mpp</sub> (V)	N <sub>s</sub>
<b>KD245GX</b>	8.91	8.23	36.9	29.80	60
<b>U5-80</b>	5.21	4.58	21.34	17.46	36
<b>Shell SP70</b>	4.7	4.25	21.4	16.5	36

*Table 2. Estimated parameters for various PV modules at STCs*

PV Module	Estimated parameters				
	A	R <sub>se</sub> (Ω)	R <sub>sh</sub> (Ω)	I <sub>lg</sub> (A)	I <sub>sat</sub> (A)
<b>KD245GX</b>	1.429	0.1574	23.235	8.9123	4.67E-07
<b>U5-80</b>	1.6043	0.0092	66.63	5.2107	2.76E-06
<b>Shell SP70</b>	1.5536	0.3235	321.2234	4.7047	1.57E-06

The parameters are estimated using GHNN optimization technique in standard test conditions (STCs) and tabulated different PV modules of 250W solar panel KD245GX and 80W solar panels of U5-80, Shell SP70.

The GHNN method for estimated five parameters of PV modules with help of equations (12), (13) & (13) in STCs are shown in Table 2.

Table 3. Estimated parameters for various PV modules at varying irradiance and temperature

PV Module Parameters	G (W/m <sup>2</sup> )	Tc (°C)	A	Rse (Ω)	Rsh (Ω)	ILG (A)	Isat (A)	Vmpp (V)	Impp (A)	Pmpp (W)
KD245GX	600	25	1.4797	0.0944	1.04E+03	5.3465	8.56E-07	29.2352	4.9292	144.1015
	800	25	1.4524	0.1259	779.0438	7.1292	6.41E-07	28.9245	6.5614	194.1068
	1000	30	1.4093	0.1574	623.2331	8.9123	5.15E-07	29.6772	8.2255	244.1471
	1000	50	1.322	0.1574	623.2256	8.9124	5.15E-07	29.6745	8.2255	244.1286
	1000	70	1.2449	0.1574	623.2182	8.9125	5.16E-07	29.6717	8.2255	244.1093
	1100	25	1.4329	0.1731	566.5773	9.804	5.66E-07	29.4451	9.0371	266.1273
Shell SP70	200	25	1.7483	0.0647	1.61E+03	0.94	7.17E-06	15.1603	0.8428	12.7765
	400	25	1.7483	0.1294	803.0585	1.8803	1.43E-05	15.0481	1.6802	25.2812
	600	25	1.7483	0.1941	535.3723	2.8238	2.15E-05	14.8269	2.5123	37.2838
	800	25	1.7483	0.2588	401.5293	3.7624	2.87E-05	14.5227	3.3335	48.4109
	1000	25	1.7483	0.3235	321.2234	4.7047	3.59E-05	14.1407	4.1391	58.5244
U5-80	351	35.7	1.684	0.0032	189.3624	1.8332	9.03E-06	15.7181	1.5952	25.0768
	426	42	1.6503	0.0039	155.7984	2.2283	1.10E-05	15.7143	1.9384	30.4676
	568	44	1.6399	0.0052	116.7952	2.9723	1.47E-05	15.7079	2.5856	40.6229

The light generated current and short circuit current are directly proportional to irradiance and also depend on temperature. The unknown parameters of PV module namely  $I_{lg}$ ,  $I_{sat}$ ,  $A$ ,  $R_{se}$ , and  $R_{sh}$ , can be estimated at any temperature and irradiance condition.

PV modules of 250W solar panel KD245GX and 80W solar panels of U5-80, Shell SP70 are taken estimated PV panel equivalent circuit parameters at any temperature and irradiance conditions using GHNN optimization technique are shown in Table 3.

#### 4. CONCLUSION

In this work, the following PV modules are taken for estimate the five unknown parameters of KD245GX, U5-80 and Shell SP70. The GHNN optimization technique is used to estimate the five unknown parameters of the PV modules at STCs. Here, good convergence is achieved in the GHNN method during MATLAB coding, due to the selection of appropriate initial values from the series and shunt resistance equations. The Energy function is used to extract the MPP at different environmental conditions by considering the varying nature of shunt resistance, series resistance, and ideality factor. In particular, through the proposed equations of shunt resistance and ideality factor of the PV model, accurate MPP value is obtained. For a wide range of operating conditions, the MPP and the five unknown parameters of various PV modules are estimated.

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#### **Conflict of Interest**

None of the authors have any conflicts of interest to declare.

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