A novel MPPT scheme for solar powered boost inverter using evolutionary programming

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A Novel MPPT Scheme for Solar Powered Boost Inverter using Evolutionary Programming

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***Abstract*—Due to its ability to handle nonlinear functions regardless of the derivative information, Evolutionary Programming (EP) are envisaged to be very effective for Maximum Power Point Tracking (MPPT) of Photovoltaic cell (PV). This paper proposes a critical evaluation of MPPT algorithm of PV model using EP. The proposed model is then compared with the conventional Newton raphson algorithm. The simulation results obtained from the EP were found to be more accurate with the real maximum power point. The algorithm has better accuracy especially at low irradiance level that allows for a more accurate prediction of PV system performance. The EP based MPPT algorithm was tested with single stage boost inverter.**

Index Terms—Photovoltaic cell (PV), MPPT algorithm, Evolutionary Algorithm, Newton raphson method, solar powered single stage boost inverter.

I. INTRODUCTION

Large and small scale PV power systems have been commercialized due to its potential long term benefits. Their growth rates have been accelerated by the generous fed in tariff schemes and other initiatives provided by various governments to promote sustainable green energy. In large PV power generation, systems are dominated by grid connected: examples can be seen in [1]-[3]. To ensure optimal use of the available solar energy, maximum power point tracking scheme is applied to the power converters [4]-[5]. However, for a proper design of MPPT, an accurate simulation model of the module is required. This is especially the case when the peak power point changes continuously due to environmental variations. In particular, one important situation to be considered is the substantial drop of power yield during partial shading conditions of PV modules.

Several different MPPT techniques have been proposed in the literature. The techniques summarized in [6] can be classified as: (1) Look-up table methods, (2) Perturbation and observation methods, and (3) Model-based computational methods. Two major techniques in the "Model-based computational methods [6]" category are voltage-based MPPT (VMPPT) and current-based MPPT (CMPPT) techniques. Both the CMPPT and VMPPT methods have been investigated in [6] for matching resistive loads and DC motor loads. But all these methods works better only when the complete module is radiated with the same irradiance (i.e. without shading effect). So they fail during partial shading conditions. Literature also proposes many artificial intelligence techniques to find out the MPPT during partial shaded conditions [7]. But those techniques requires lot of computation which are quite complex. This paper proposes a novel technique to find the MPPT point of a PV cell using simple evolutionary algorithm.

II. PV MODULE MODELLING

The possibility of predicting a photovoltaic plant's behavior in variance irradiance and temperature is very important for sizing the PV plant and converter. There are numerous methods presented in the literature, for extracting the panel parameters. In this paper a photovoltaic panel model based on the manufacturer's data sheet is presented. The equivalent circuit of the single-diode model for the PV cells is shown in fig 1 [8]. Series resistance (R_S) is the parasitic resistances.

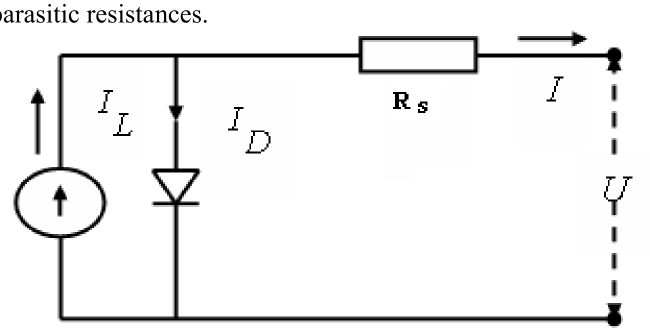

Fig 1 Equivalent Circuit of PV Cell

In this model the effect of R_{SH} is neglected to simplify the model. The output current of the PV cell is given by:

$$I = I_L - I_D \text{ Where}$$

$$I_D = I_o\left[\exp\left(\frac{U + IR_s}{\alpha}\right) - 1\right]$$

$$I = I_L - I_o\left[\exp\left(\frac{U + IR_S}{\alpha}\right) - 1\right] ------(1)$$

Where I_L is the light current or Photo Generated Current in Amps, I is the output current in Amps, I_D is the diode Current in Amps, I_0 is the reverse saturation Current of diode in Amps, $\alpha = nkT/q$ is the thermal voltage timing completion factor, n is the diode ideality Factor, K is the Boltzmann's constant, T is the absolute temperature and q is the elementary charge. The four parameters I_L, I_0, R_s and α need to be determined to study the I-U Characteristics of PV cells.

Light Current I_L is determined by

$$I_L = \frac{\phi}{\phi_{ref}}\left[I_{L,ref} + \mu_{I,SC}\left(T_c - T_{c,ref}\right)\right] ----(2)$$

Where ϕ is irradiance in W/m^2; ϕ_{ref} is the reference irradiance (1000 W/m^2 is used in this study); $I_{L,ref}$ is the Light Current at reference Condition (1000 W/m^2 and 25^{0}C is used in this study) ; T_C PV cell temperature, $T_{C,ref}$ reference temperature (25^{0}C is used in this study) and μ_{isc} is the temperature coefficient of the short circuit current in A/^{0}C.

Saturation Current I_0 is determined by

$$I_o = I_{o,ref}\left(\frac{T_{c,ref} + 273}{T_c + 273}\right)^3 \exp\left[\frac{e_{gap}N_s}{q\alpha_{ref}}\left(1 - \frac{T_{c,ref} + 273}{T_c + 273}\right)\right] -----(3)$$

Where $I_{0,ref}$ is the saturation current at reference condition; e_{gap} is the band gap of the material (1.17ev for Si materials); N_s is the number of cells in series in PV module; q is the charge of electron; α_{ref} is the value of α at reference condition.

Series resistance R_s is determined by

$$R_s = \frac{\alpha_{ref}\ln\left(1 - \frac{I_{mp,ref}}{I_{sc,ref}}\right) + U_{oc,ref} - U_{mp,ref}}{I_{mp,ref}} ----(4)$$

Where $U_{oc,ref}$ and $U_{mp,ref}$ are the open circuit and peak point voltages at reference conditions, $I_{sc,ref}$ and $I_{mp,ref}$ are the Short circuit and peak point currents at reference conditions.

Thermal Model equations of PV cell is given by

$$C_{pv}\frac{dT_c}{dt} = k_{in,pv}\phi - \frac{U \times \mathrm{I}}{\mathrm{A}} - K_{loss}\left(T_c - T_a\right) ---(5)$$

Where C_{PV} is the overall heat capacity per unit area of the PV cell/Module; $K_{in,PV}$ Transmittance absorption product of PV cells; K_{loss} overall heat loss coefficient; T_a is the ambient temperature; A Effective area of the PV Cell/ module;

III. THE SINGLE STAGE BOOST INVERTER

The boost inverter achieves DC – AC conversion as follows: the power stage consists of two current bi-directional boost converters and the load is connected differentially across them (Fig. 2). These converters produce a DC - biased sinusoidal waveform (Fig. 3), so that each converter produces a unipolar voltage. The modulation of each converter is 180 degrees out of phase with respect to the other, which maximizes the voltage excursion over the load [7]-[8].

A. *Steady state analysis*

The analysis of the boost inverter under steady state is done by considering one converter as a voltage source (Fig. 4). The gain of the converter vs. the duty cycle is obtained by [9].

$$V_o = 2V_a - 2V_{dc1} ----------------- (6)$$

$$\frac{\mathrm{V_o}}{\mathrm{V_{in}}} = \frac{2D - G_n(1 - D)}{(1 - D)} ------------- (7)$$

Where Gm is the maximum gain (V_{op}/ V_{in}), V_{op} is the peak output voltage, Va is the capacitor voltage V_{dc}, is the dc component of V_a. The inductor current depends on the demanded current and maximum gain; it is determined by [9],

$$I_L = \frac{2D - G_m(1 - D)V_{IN}}{(1 - D)^2 R} -------------- (9)$$

B. *System modeling*

The boost inverter is modeled as two dc-dc boost converters, but one of them is considered as an ideal sinusoidal voltage source plus a dc component. The system model is given by [9].

$$\begin{bmatrix}\dot{X}1 \\ \dot{X}2\end{bmatrix} = \begin{bmatrix}0 & \frac{-W_o}{2} \\ \frac{W_o}{2} & -W_1\end{bmatrix}\begin{bmatrix}X_1 \\ X_2\end{bmatrix} + \begin{bmatrix}0 & \frac{W_o}{2} \\ \frac{-W_o}{2} & 0\end{bmatrix}\begin{bmatrix}X_1 \\ X_2\end{bmatrix}u + \begin{bmatrix}b \\ c\end{bmatrix} ---------------(10)$$

Where $\mathrm{X}_1 = I_L\sqrt{L}, X_2 = V_c\sqrt{C}, W_o = 1/\sqrt{LC}, W_1 = 1/RC, b = V_{in}/\sqrt{L}$

$C = V_b/R, u = \begin{cases}1 \\ 1\end{cases}$

C. *Design of boost inverter*

The inductor and capacitor values are calculated based on the inductor current and capacitor voltage ripple. The switching frequency should be greater than the output voltage frequency.

The DC component of the capacitor voltage V_{dc} must be calculated as:

$$V_{dc} \geq \frac{V_{op}}{2} + V_{in} ------------- (11)$$

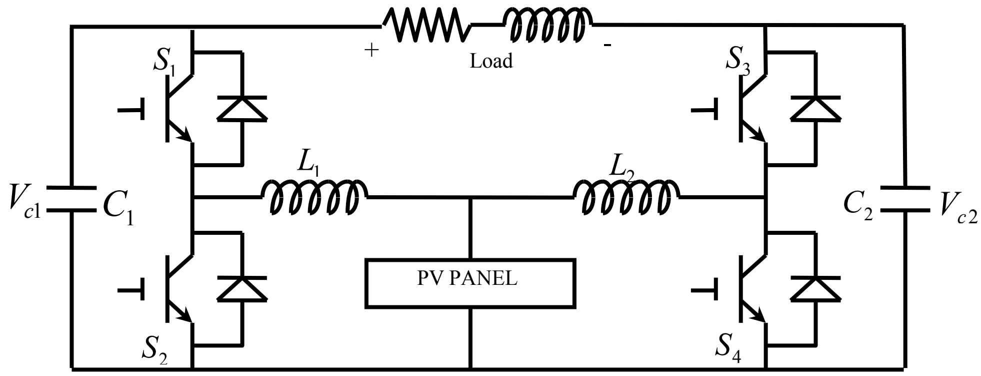

Fig 2 Single Stage Boost Inverter

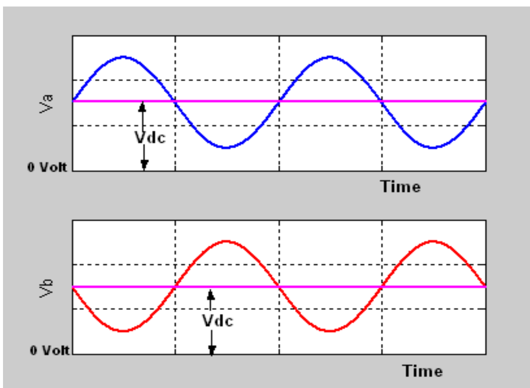

Fig. 3. Output voltage for each DC-DC converter

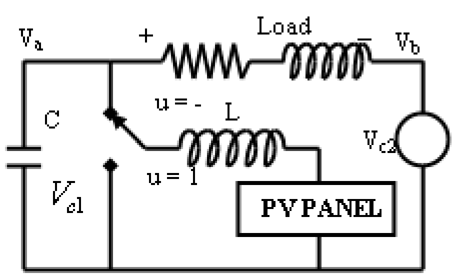

Fig. 4. Simplified circuit of boost inverter

The maximum capacitor voltage and inductor current is determined by:

$$V_{c\max} = V_{dc} + \frac{V_{op}}{2} \text{ -------------------- (12)}$$

$$I_{L\max} = \frac{2D_{\max} - G_n(1 - D_{\max})V_{in}}{(1 - D_{\max})^2 R} \text{ ------------- (13)}$$

$$Where\ \mathrm{D}_{\max} = 1 - \frac{V_{in}}{V_{dc} + \frac{V_{op}}{2}},\ G_m{}' = \frac{2(V_{dc} - V_{in})}{V_{in}}$$

The inductance and capacitance are calculated with a 20% ad 1.5% of ripple respectively.

$$L = \frac{t_{on}}{0.2 I_{L\max}} V_{in} \text{ and } C = \frac{t_{on}}{0.015 V_{c\max}} I_{op} \text{ ----- (14)}$$

Where I_{op} = Peak output current and $t_{on} = \frac{D_{\max}}{f_{\max}}$

IV. EVOLUTIONARY PROGRAMMING BASED MPPT ALGORITHM.

Few techniques based on different principles are fuzzy logic control, neural network [10], fractional open circuit voltage or short circuit current, current sweep, etc. Most of these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, not the exact one. In normal conditions the V-P curve has only one maximum, so it is not a problem. However, if the PV array is partially shaded, there are multiple maxima in these curves. In order to relieve this problem, some algorithms have been implemented as in [11]. But the algorithm implemented in [11] is difficult to implement in digital platform. So this paper suggests an easy method of implementing MPPT using Evolutionary Programming.

EP is an artificial intelligence method based on the mechanics of natural selections - mutation, competition and evolution. The general process of EP is briefed as follows:

A. *Initialization:*

The initial control variable population P_i is selected randomly from the sets of uniform distribution ranging over its minimum and maximum values.

B. *Statistics:*

The values of maximum fitness, minimum fitness, sum of fitness and average fitness of this generation are calculated.

C. *Mutation:*

Each P_i is muted and assigned to P_{i+m} in accordance with the following equation:

$$P_{i+m,j} = P_{i,j} + N(0, \beta(x_{j\max} - x_{j\min})\frac{f_i}{f_{\max}}), \quad \text{j} = 1,2,\ldots\ldots.\text{n}$$

Where, $P_{i,j}$ denotes j^{th} element of the i^{th} individual.

$N(\mu, \sigma^2)$ represents a Gaussian random variable with mean μ and variance σ^2; f_{max} is the maximum fitness of the old generation. $x_{j\,max}$ and $x_{j\,min}$ are the maximum and minimum limits of the j^{th} element. β is the mutation scale which is given as $0 < \beta \le 1$. If any $P_{i+m,j}$, $j=1, 2 \ldots\ldots n,$ where n is the number of control variables, exceeds its limit, $P_{i+m,j}$ will be given the limit value. A combined population is formed with the old generation and the mutated old generation.

D. Competition:

Each individual, P_i in the combined population has to compete with some other individuals to get its chance to be transcribed to the next generation.

The fitness function used here in the program is to minimize the value of I_{max} and it is the function of irradiance and cell temperature.

$$I_{\max} = \frac{\partial P}{\partial I}\left[f\left(\phi, T_c, P, V, I\right)\right] - - - - - - - (15)$$

The main objective of the EP is to minimize the above fitness function.

V. Sliding Mode Controller

For the purpose of optimizing the boost inverter dynamics, while ensuring correct operation in any working condition, a sliding mode controller is a more feasible approach. The main advantage over the classical control schemes is its insusceptibility to plant parameter variations that leads to invariant dynamics and steady-state response in the ideal case. But compared PI controller the control theory involved is rather complex. The sliding surface is a linear combination of the state variables. SMC forces the system to be held in the surface and system is driven to the equilibrium point.

$$\sigma = SX - SX_r = S_e X - - - - - - - - - - - - (16)$$

Where $S = [S_1 \quad S_2]$, X is the state variable, X_r is the reference variables and $eX = [eX_1 \quad eX_2]^T$. The condition for the existence of sliding mode is

$$\dot{\sigma}\sigma < 0 \text{ and } S_1 X_2 - S_2 X_1 > 0 - - - - - - - - (17)$$

Since X_2 is always positive, X_1 must be positive.

The sliding mode uses two state variables to control the boost inverter, capacitor voltage and the inductor current. For capacitor voltage the reference is a sinusoidal voltage plus a dc component. This reference is independent of voltage. The other state variable is inductor current. The level of this current depends on the load. To avoid the dependence of the current with load, the measured current is filtered using a high pass band filter to obtain the ripple at switching frequency that simulates the error. In the boost inverter, since the current is varying in nature. The cut off frequency of the high pass band filter must be chosen carefully. It must be high enough to eliminate the 50Hz frequency of the current, but not too high that distort the current ripple that simulate the error. (At least 25% higher than 50Hz). Sliding mode controller scheme is shown in fig. 5. The controller parameters are calculated based on the boundary condition.

$$S_1 = \frac{S_2 X_{1p}}{X_{2p}} - (18)$$

Where $X_{1p} = I_{L\max}\sqrt{L}$ and $X_{2p} = V_{c\max}\sqrt{C}$

The reference current to the sliding mode controller is taken from the EP algorithm for varying irradiance and cell temperature.

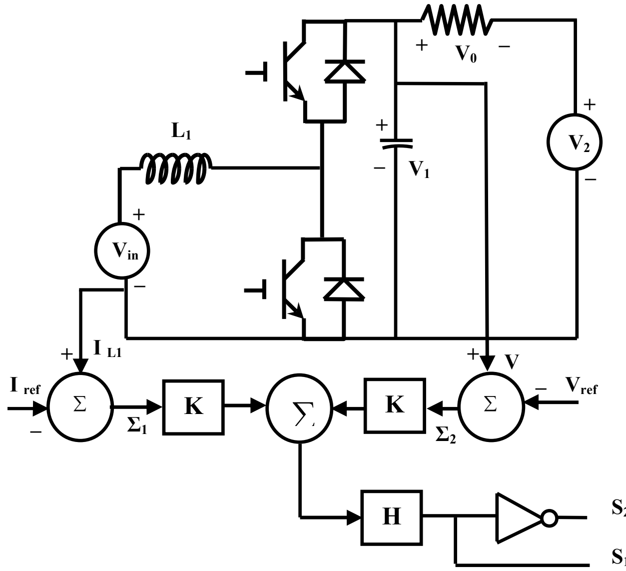

Fig 5 Block Diagram of Sliding Mode Controller.

VI. Simulation Results

A. PV Module Simulation Results

The photovoltaic module was simulated using MATLAB/SIMULINK. The parameters of the photovoltaic cell used for the simulation is given in the table I.

Table I PV Module Parameters

$I_{sc, ref}$	2.664 A	$I_{mpp, ref}$	2.448 A
R_s	1.324 Ω	$V_{mpp, ref}$	70.731 V
$V_{oc, ref}$	87.72 V	T_c	25^0C
S_x	1000 W/m^2		

The simulation is carried out for the above mentioned parameters for constant irradiance and constant cell temperature. Figure 6 shows the PV characteristics of the photovoltaic cell for constant irradiance and Figure 7 shows the VI Characteristics of photovoltaic cell at constant irradiance. It can be observed from the figure 6 and 7 that the maximum power point of the photovoltaic cell varies for all different conditions. The temperature and the irradiation depend on the atmospheric conditions, which are not constant during the year and not even during a single day; they can vary rapidly due to fast changing conditions such as clouds. This causes the MPP to move constantly, depending on the irradiation and temperature conditions.

If the operating point is not close to the MPP, great power losses occur. Hence it is essential to track the MPP in any conditions to assure that the maximum available power is obtained from the PV panel. In a modern solar power converter, this task is entrusted to the MPPT algorithms.

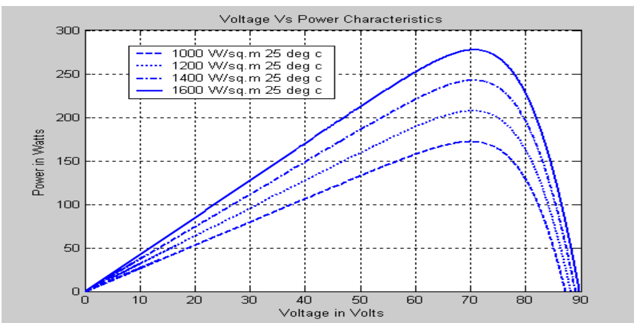

Fig 6 PV Characteristics of PV cell for constant temperature of 25^0C

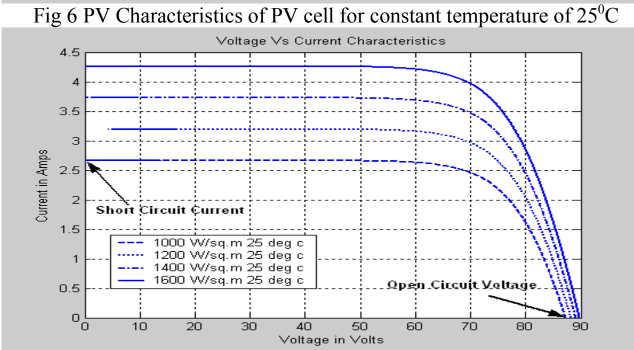

Fig 7 VI Characteristics of PV cell for constant temperature of 25^0C

B. *EP Simulation Results*

Fig 8 and Fig 9 Shows the VI and PV characteristics simulation results for MPPT algorithm of Newton raphson, Evolutionary programming and the real maximum power point (MPP) for the various irradiance and temperature levels. It is very clear from the simulation results that the maximum power point of evolutionary programming and the real MPP are one and the same. The result summary of the three algorithms is given in the table II in detail.

Fig 10 shows the convergence of the objective function w.r.to the number of iterations for the condition of 1400 W/m^2 of irradiance and 50^0 c of cell temperature.

C. *PV fed boost inverter with sliding mode controller*

The simulation of the boost inverter is done with circuit parameters with Input voltage V_{in}= 42 V, Output voltage V_o=100 Sin(ωt), Output frequency f_0= 50Hz, Switching frequency f_s=30KHz, Load resistance R= 50Ω Inductance L1 and L2=500µH, Capacitance C1 and C2=20µF. The panel voltage is considered to be varying due to the variation in the irradiance. The simulation results of a PV fed single stage boost inverter are shown in figure 11.

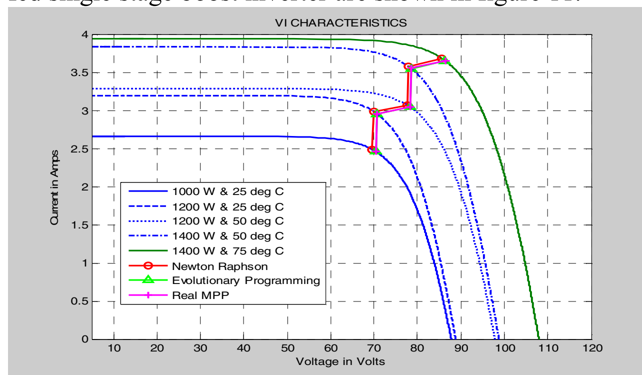

Fig 8 VI characteristics of PV cell with MPP

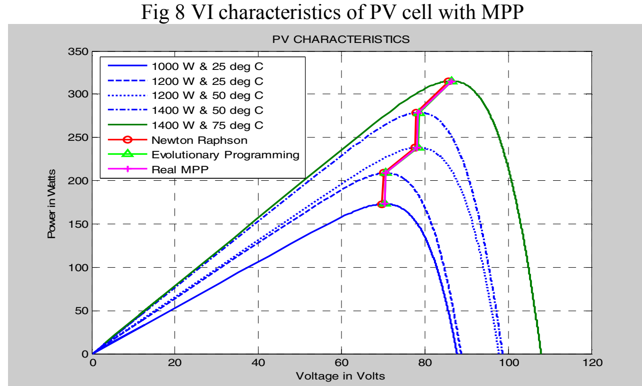

Fig 9 PV characteristics of PV cell with MPP

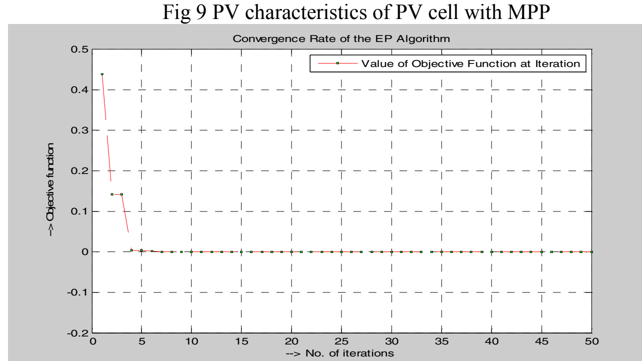

Fig 10 Convergence Rate of Objective Function

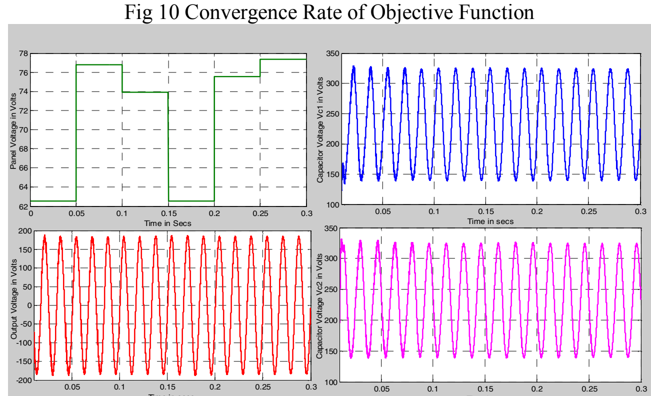

Fig.11. Simulation results for sliding mode controlled PV fed boost inverter

Table II Summary of Simulation results of different algorithms

Weather Conditions		**Newton Rapson (NR)**			**Evolutionary Programming (EP)**			**Real Maximum Power Point**			**% Error of P_{mp}**	
Irradiance in W/Sq.m	***Temp in deg C***	V_{mp} (Volts)	I_{mp} (Amps)	P_{mp} (Watts)	V_{mp} (Volts)	I_{mp} (Amps)	P_{mp} (Watts)	V_{mp} (Volts)	I_{mp} (Amps)	P_{mp} (Watts)	***EP***	***NR***
1000	25	69.60	2.48	173.07	70.31	2.46	173.19	70.41	2.45	173.19	0	6.62e-4
1200	25	70.02	2.98	208.73	70.68	2.95	208.85	70.61	2.95	208.85	0	5.65e-4
1200	50	77.58	3.06	238.14	78.28	3.04	238.26	78.20	3.04	238.26	0	5.25e-4
1400	50	77.90	3.57	278.71	78.55	3.54	278.84	78.49	3.55	278.84	0	4.54e-4
1400	70	85.64	3.68	315.22	86.32	3.65	315.35	86.35	3.65	315.35	0	4.27e-4

VII. CONCLUSIONS

A novel MPPT algorithm using EP technique was proposed to control PV arrays. As the proposed scheme is a multidimensional search-based technique, it is able to find the global MPP even under sudden changes in the environmental conditions. The developed algorithm is simple and also reduces the cost of the data acquisition system. The proposed algorithm was simulated along with the PV fed single stage boost inverter. To improve the dynamic stability and robustness sliding mode controller has been proposed and simulated. It has been observed that the system is robust and insensitive to parameter variation when it is controlled by sliding mode controller. A PV fed boost inverter is useful for applications in which the instantaneous output ac voltage should be larger than the input dc voltage. Reference points to the controllers are fed from EP algorithm.

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