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Development of Improved Maximum Power Point Tracking Algorithm Based on Balancing Particle Swarm Optimization for Renewable Energy Generation

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ABSTRACT

Maximum Power Point Tracking (MPPT) is the method of operating the photovoltaic system in a manner that allows the modules to effectively transfer all the power generated from the panel to the load.Maximum Power Point (MPP) tracking technique based on Balancing Particle Swarm Optimization (BPSO) were successfully developed in this paper to solve the problem of premature convergence and also latency in convergence/tracking. The performance of the developedBPSO was evaluated at solar irradiance of 1000W/m^2, 500W/m^2 and 600W/m^2 at constant temperatures of 25^{o}C simultaneously.From the BPSO simulation results, it was observed that, it took the developed model0.23secs to locate the Global maxima (GP) with a very high-power output. The developed model achieved this by balancing the panel conductance with the load conductance and also compare the output power with the global peak power, if the newly output power is greater than the global peak power the MPP tracker settles at the newly detected output power but if it is less than that it maintains its previous MPP position.The developed BPSO algorithm settled at GP of **255.063W** at **0.2292secs** and at this point, the source impedance balances with that of the load impedance which results to negligible change in conductance. From the validation result, the convergence time of the scanningparticle swarm optimization and BPSO technique at MPP was 0.40secs and 0.23secs which showed that BPSO has42.7%relative improvementin terms of premature convergence and tracking speed. The simulation was done using 2020B MATLAB SIMULINK.
Keywords: Balancing, Particle, Swarm, Optimization, Photovoltaic, Premature Convergence, Conductance, Scanning Particle Swarm Optimization,Global optima, maximum power point tracker

INTRODUCTION

Energy plays an important role in our everyday life and its insufficient supply leads to energy crisis and shortage for our daily activities due to increase in population, urbanization and industrialization. Despite the insufficiency in supply of energy for consumption by the conventional sources of energy such as fossil fuel, it also has the problem of environmental degradations and air pollution which was caused by the release ofhazardous CO_2 to the environment from the exhaust of the combustion Engines. This shortcomings of the conventional sources of energy have caused more harm to human health such as cancer. Hence, to overcome these major shortcomings of conventional sources of energy, renewable sources of energy such as solar, wind, hydro, biogas,tidal energy, geothermal etc were introduced as an alternative[1][2][3].Due to the shift in non-renewable energy such as fossil fuel to renewable, the trend of fossil fuel dependency declined from 86% in 1973 to 81% in 2016 (IEA, 2018). Among the trending renewable energy sources solar has taken the lead as the center stage for the emerging technology due to its natural abundance, low maintenance cost and its high utilization has no adverse effect on the environment. Another added factor that boosted the use of PVs as a source of electricityis its advancements in manufacturing technology, increasing system efficiency, and decreasing overall system cost.Solar energy can be converted into electrical energy through two major techniques know assolar thermal techniques and solar photovoltaic (PV) techniques. The process of generating electricity based on photovoltaic effect which is widely used to produce electricity from solar energy is known as Solar PV techniques. The PV systems are leading the global renewable installation with total

installed capacity of 402GWp atthe end of 2017 (IEA PVPS,2018)[4].
Despite the good and excellent qualities of renewable sources of energy, PV systems are still facing some challenges such as low conversion efficiency, premature convergence, inability to detect the real Maximum power point (MPP) and latency in convergence. The energy generation from the PV system is highly dependent on temperature and intensity of irradiance that was casted on the solar PV panel. The Standard Test Conditions (STCs) for some measurable PV parameters such as irradiance, temperature, the air mass, wind speed and the solar PV panel tilt angle when the panel faces southern hemisphere are 1kW/m^2, 25^{0}C, 1.5,2m/s and 30°respectively [5].The aforementioned drawbacks of PV system has led to more research in geographical, environmental and technological factors that affects maximum power of solar photovoltaic cells and the best technique to curtail it [6]. Furthermore, anEfficiency Enhancement (EE) system such as solar tracking system and Maximum Power Point Tracking (MPPT) system were introduced to increase tracking efficiency and for optimum operation. One of the problems facing solar PV tracking is the problem of partial shading which createsmultimodal points along the P-V curve. The created multimodal points along PV curves made non intelligent maximum power point tracker (MPPT) ineffective in detecting the global point/maximum power point.The multiple points created along the P-V characteristics curve is a s a result of partial shading. Partial Shading Condition (PSC) occurs when a shadow is casted on the PV panel as a result of obstructions caused mainly by clouds, birds, trees, buildings and towers. PSC has great effect on the performance ofPV systems such as devaluation of power from PV module as a result of PV cell arrangement, utilized bypass diodes and pattern of shading that was casted on the panel. PV panels that experience PSC without proper bypass diode installation most times got damaged due to hotspot and systemseeing the partially shaded panel as load.Many conventional MPPT techniques were mostly attracted to the local peak which in turn decreases the proficiency of the PV system. The conventional or non-intelligent MPPT techniques that could not locate the real MPP during rapid PSC as reviewed in literatures are Perturb & Observe (P&O)[7][8],Adaptive Perturb &Observe (AP&O)[9],Modified Perturb and Observe (MP&O)[10][3], Improved Perturb and Observe (IP&O)[11],Incremental conductance (INC)[12][13][14][15][16][17]. Modified Incremental Conductance (MINC)[18],[19],[20], Improved Incremental Conductance (IINC)[19], Advanced Incremental Conductance (AINC)[21] and optimized adaptive differential conductance (OADC)[22]techniques. Those mentioned and reviewed techniques were the most popular and frequently used MPPT for solar PV tracking. The three most popular non-intelligent MPPT techniqueat which other improvement/advancement emanuiated from are the pertub and obsserve, incremental conductance and differential conductance tecniques. The concept of P&O is based on observation of PV array output power and its perturbation by changing the voltage of PV array cells. The algorithm increments or decrements the reference voltage continuiously based on the previous value of power until it reaches the MPP [23]. The P&O, AP&O, MP&O, IP&Omethods have some limitations such as tracking failure, delay in covergence and low power conversionduring PSC. Some of the limitations were overcomed by Incremental Conductance technique. INC makes use of the concept of differentiating two quantities (power against voltage) and equating the resultant value to zero[24]. INC technique also lack accuracy and speed during tracking. This limitation leads to Optimized Adaptive Differential Conductance Technique (OADC)[22].OADC technique differentiated the voltage and current at its maximum power point and picks a value at the P-V curve intersection point. OADC obtains the MPP of the PV by subtracting the impedance of the panel with that of the load and equating it to zero. Hence, at rapid PSC, some of the non-inteligenttechniques finds it difficult to locate the global maximum power point (GMPP) and at thesame time maintain tracking speed. The rapid change in environmental conditions has rendered non-intelliegnt MPPT incapacitated and most times end up settling at the Local Maximum Power Point (LMPP) which causes reduction in harnessed and transferred power.
Due to the inability of the non-intelligent MPPT technique to detect the real MPP during partial shaded conditions accurately, the research has shifted to intelligent based technique which comprised of Artificial Neural Network

(ANN)[1][25][26], DIRECT search algorithm[27], Fuzzy logic (FL)[28][2][29][30][1],Takagi-Sugeno (T-S)Fuzzy [31][32], Particle Swarm Optimization (PSO)[33][34][35], Adaptive Particle Swarm Optimization (APSO) [36][37][38][39], Improved Adaptive Particle Swarm Optimization (IAPSO) [40], New Adaptive Particle Swarm Optimization (NAPSO) [41]and also MPPT hybridization[42][43]. The shift to intelligent MPPT did not also solve the multidimensional and multimodal problems associated with PSC though it reduced it to reasonable extent.However, more research are channelled to swarm intelligence and evolutionary algorithmssuch as PSO due to its simplicity, excellent tracking, fast convergence and ease of implementation at low cost. Despite the excellent performance of PSO, it also has limitations of premature convergence, convergence speed and initial weight value. The main contribution ofthis study is the development of a newMPPT algorithmbased on Balancing particle swarm optimization tecnique to detect the real GMPP while improving tracking efficiency, convergence time and accuracy in a PV system. Resultant conductance algorithm and power comparison techniques were used to control the tracking speed and to detect when PSC occurs respectively. The developed resultant conductance algorithm achieved this by balancing the conductance of the panel with that of the load. It also proposed a good social and cognitive values for best tracking and fatest convergence. Furthermore, the resultant condutance (RC) values changes only when the power variation of the system exceeds a predetermined power value. Owning to thisexcellent strategy, small changes on the RC values leads to immediate retracking and locating of the new GMPP which is sufficient enough to guarantee that the system will not be trapped at LMPP and also avoids prolonged oscillations. The proposed method is evaluated in terms of convergence time, power oscillation in steady state, and accuracy in tracking the GMPP considering several operational scenarios under different PV module configurations. This study is futher organised as follows: Mathematical modelling of solar PV system forms section 2, Section 3 details particle swarm optimization. In Section 4 Proposed Methodology and its Derivations and Conclusion is presented in Section 5.

Mathematical Modeling of Solar PV Systems

A Photovoltaic array consists of several photovoltaic cells connected in series and parallel. The circuit resistance is connected in series (R_s) and parallel (R_p). Series connections are responsible for an increase in voltage of the module whereas the parallel connection is responsible for an increase in the current of the cell array. An ideal solar cell is modelled by a current source in parallel with a diode current and dark current [44][45][46]. Parallel resistanceis added to the circuit as shown in figure 1 to limits the cell performance and accounts for the dissipative phenomena at the cell internal losses. This implies that a very high value of R_p leads to a significant reduction in dark current. The resistance of the shunt takes care of the recombination losses, mainly due to thickness, surface effect and the non-ideality of the junction. A single diode equivalent electrical circuit consists of the photocurrent (I_{ph}) thediode current (I_D)and shunts current (I_p) as represented in Figure 1

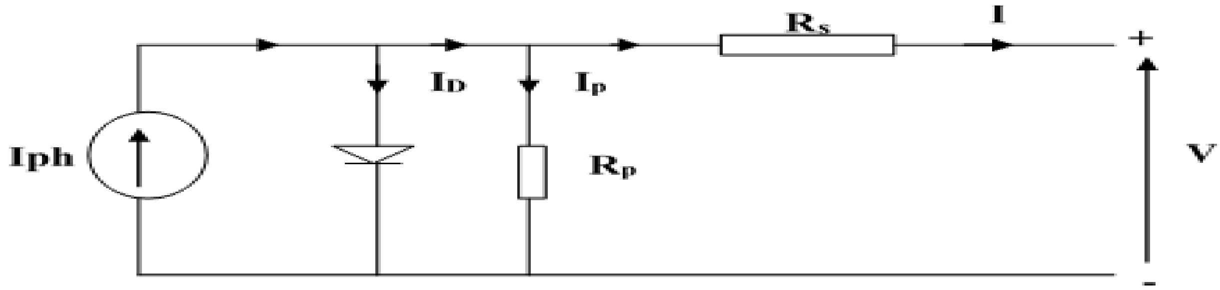

Figure 1: The Equivalent Circuit of a PV cell with a Single Diode [47].

Applying and analysing Kirchhoff's law to the nodes of the circuit of Fig 1 gives equation (2)

$$I = I_{ph} - I_D - I_p \quad (1)$$

Where: I = output current; I_{ph} =Photovoltaic current; I_D= Diode current and I_p= dark current.

When Kirchhoff's law is applied in nodes of figure 1 equations (1) - (7) were obtained.

$$I_{ph} = I_{sc}[1 + k_i(T - T_{ref})]\frac{G}{G_{ref}} \quad (2)$$

$$At\ STC; \quad I_{ph} = I_{sc} \quad (3)$$

$$I_D = I_o\left(\exp\left(\frac{q(V + IR_s)}{\alpha nkT}\right) - 1\right) \quad (4)$$

$$I_o = I_{rs}\left[\frac{T}{T_{ref}}\right]^3 \exp\left[\left(\frac{qE_{gap}}{\alpha k}\right)\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \quad (5)$$

$$\text{At STC}; \quad I_o = I_{rs} \quad (6)$$

$$I_p = \frac{V_D}{R_p} = \frac{V + IR_s}{R_p} \quad (7)$$

The PV characteristic equation was obtained by Substituting equation (2), (4) and (7) in equation (1) as shown in equation (8).

$$I = I_{ph} - I_o\left(\exp\left(\frac{q(V + IR_s)}{\alpha nkT}\right) - 1\right) - \frac{V + IR_s}{R_p} \quad (8)$$

Equation (8) is a general PV characteristic equation of a single diode model [48][44][49][50] and figure 2 is array of solar PV panel. One of the problems that solar PV panels use to encounter is the problem of shadow casting on top of the panel caused by birds, buildings and tress and that indirectly reduces the amount of irradiance casted on the panel. This in effect causes the operating point of a solar PV to shift from the current maximum operating point which led to multiple peaks in solar p-v characteristic curve and in return causes power loss. This partial shading on the cells of the PV panel as shown in figure 2 causes the other panels to see the shaded panel as load because it is no more transmitting the required energy whichcauses hotspot and sometimes results to panel damage. From research it was observed that partial shading issue can be curbed to a reasonable extent using intelligent method of maximum power point tracking technique. Furthermore, among the various intelligent tracking technique particle swarm optimization technique has proved to be the best in solving the problem of premature convergence and latency in tracking.

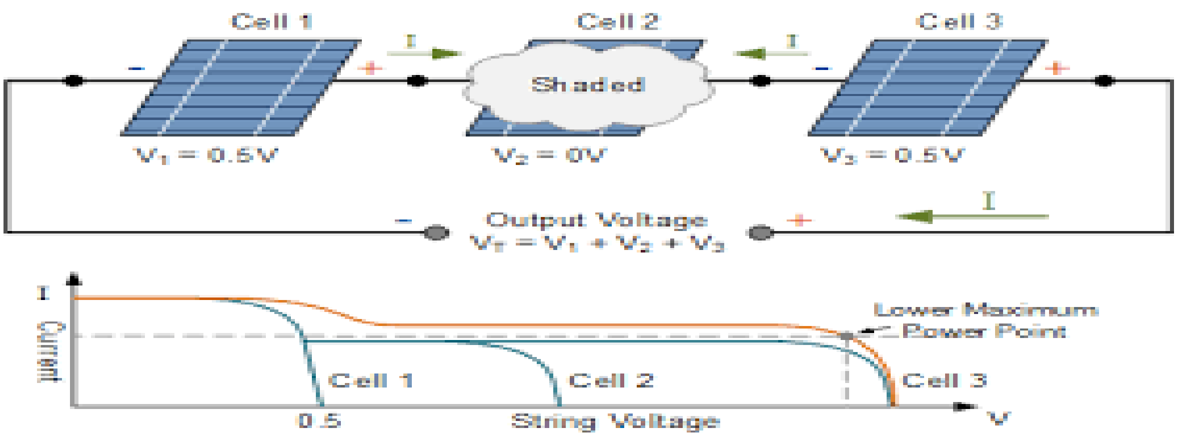

Figure 2:Partially Shaded SolarPV Panels

Particle Swarm Optimisation Techniques

This PSO approach was used in detecting the MPP of a photovoltaic solar system where the particles get random values of duty ratios and the corresponding output powers were collected and their results compared.Particle swarm optimization method was selected among other intelligent MPPT due to its ability to locate maximum power point effectively and efficiently during PSC. This research work will tackle premature convergence and latency in tracking by developing Balancing particle swarm Algorithm, adopting and selecting the best recommended tracking parameters. In this paper, the Conventional PSO technique was modified to Balancing Particle Swarm Optimization (BPSO) by using resultant conductance algorithm to obtain the duty cycles and balances the system differences. One of the major parameters modified in accordance with the best approach as reviewed in literature is the initial weight and duty cycle which are the major determinants to be adopted in order to avoid premature convergence and latency in convergence. Equation (9) and (10) were the generally accepted characteristic equation for PSO at which every other state-of-art equation were adopted and developed from. Balancing particle swarm optimization as every other state-of-art algorithm beckoned on the PSO principles but with different methodology.

$$v_i^{t+1} = wv_i^{t+1} + c_1 rad(1) * (P_{besti} - x_i^t) + c_2 rad(2) * ($$

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

Where

x_i = Particle position for i; v_i =Velocity of the particle at i,

t = Number of iterations; w = Inertia weight, Gbest=Global Peak/Swarm best position

r_1, r_2 = uniformly distributed random variables within [0, 1]; c_1= cognitive coefficient

Pbest=Local Peak/Individual best position; c_2 = social coefficient

Proposed Methodology and its Derivatives

The approach and method used to achieve the developed BPSO techniques were as shown in equation (11) - (13). Equation (11) is the linearly decreasing weight algorithm that is used to limit and maintain the MPPT within theMPP region. Resultant conductance algorithm in equation (12) is used for effective convergence whereas equation (12) is used for power comparison and for easy detection of change in conductance.

Assumptions and Modifications of some Parameters made in this paper

Case1: Linearly Decreasing Weight (LDW) with minimum and maximum values of 0.4 and 0.9 were used as reviewed in literature as the best value to be used in an LDW form. Equation (11) was obtained by modifying the LDW algorithm in scanning particle swarm optimization. This equation will help in limiting the search for MPP within a specified range in a descending order along the P-V curve region where the MPP is located. This algorithm enhances smooth and efficient tracking of the Global point.

$$w = -\left(\frac{i}{Itmax} * (wmax - wmin)\right) + wmax \qquad (11)$$

Wmax = maximum value of initial weight;Wmin = minimum value of initial weight

Itmax = maximum number of iterations; i = current iteration; Where i $\leq Itmax$.

Case 2:Initializing the PSO particles at the anticipated locations of peaks can be obtained in (12) This will drastically reduce the convergence time and avoid premature convergence by balancing the impedance of the load with that of the solar PV panel accurately.

$$\Upsilon = \frac{1}{Z_{Load}} - \frac{1}{Z_{Panel}} = 1 - \left(\frac{(z-k+1) * kv}{z}\right) * \frac{v_{oc}}{V_{DC}} \qquad (12)$$

Where;

Υ= Resultant conductance; VDC = DC-link voltage

z = total number of peaks; Voc = open circuit voltage; $kv = 0.82$,

Z_{Load} = impedance of the Load; Z_{Panel}= Impedance of the Panel

k = number of places where the impedance of panel and load are equal

Case 3: The change in output power as a result of partial shading condition is being determined and balanced using Equation (13). This algorithm achieved this by comparing the power generated by the panel to that needed by the load and update the system about the existing change and balances it for effective power conversion.

$$\left|\frac{GP_i - GP_{i-1}}{GP_{i-1}}\right| > \varepsilon \qquad (13) \qquad 0 < \varepsilon \leq 5\%$$

This algorithm uses balancing technique to achieve its awesome performance. It uses the technique of checking the differences between the previous power and the current power values and divide it by the current power value. The value obtained will be compared and be checked if it is greater than 5% of the initial value. If the obtained value violated the stated condition the operating point will be forced to settle at the newly found global point, otherwise the algorithm will maintain the old global best position which shows that at that point, there is no atmospheric change and the system is still operating at its optimal. Finally, the cognitive and social coefficients used in this paper as recommended by scanning particle swarm optimization technique and other techniques reviewed in literature for effective tracking and avoidance of premature convergence during PSC range lies from $1.2 \leq c1 \leq 1.6$ and $1.8 \leq c2 \leq 2$. In this research paper c1=1.6 and c2=1.8 which is within the specified and recommended range of values for optimum performance.

From these assumptions stated above, Equation (14) is formulated using cases from (12) -(13) in accordance with the normal conventional PSO principles .

$$v_{i+1}^{k} = w\left(v_i^k + c_1 r1 * (P_{besti} - \Upsilon_i) + c_2 r2 * (G_{besti} - \Upsilon_i)\right) \qquad (14)$$

$$\Upsilon_i = 1 - \left(\frac{(z-k+1) * kv}{z}\right) * \frac{v_{oc}}{V_{DC}} \qquad (15)$$

Where;

Υ_i = resultant conductance at i position; V_i =Velocity of the particle at i,

k = Number of iterations; w = Inertia weight r_1, r_2 = uniformly distributed random variables within [0, 1]

c_1=cognitive coefficient; c_2 = social coefficient; Pbest= Best individual position Gbest =Best swarm or global optimum

Figures 3 and 4 are Simulink Diagrams of a solar PV module with BPSO based MPPT controller and Tata power solar Photovoltaic panel (TP250MBZ). The Simulink diagram was connected with many electrical parameters such as inductors, diodes, resistors and capacitors which formed the boast buck converter for effective and efficient power transfer. The difference between BPSO and SPSO is that the BPSO makes use of conductance as a measure of accuracy while SPSO makes use of duty circle which is adjustable and may be wrongly chosen. Secondly, the BPSO makes use of the summation of the panel's power and compare it with the output power (load) while SPSO makes use of panel measurement singly and check for the panel with highest power which is prone to error. Balancing Particle Swarm Optimization (BPSO) technique is developed in this paper for adaptive matching of the panel power with that of the output power (load) to maximize the power transfer from the PV panel to the load. The developed techniques also ensured that premature convergence was avoided and time taken for it to converge was drastically reduced.

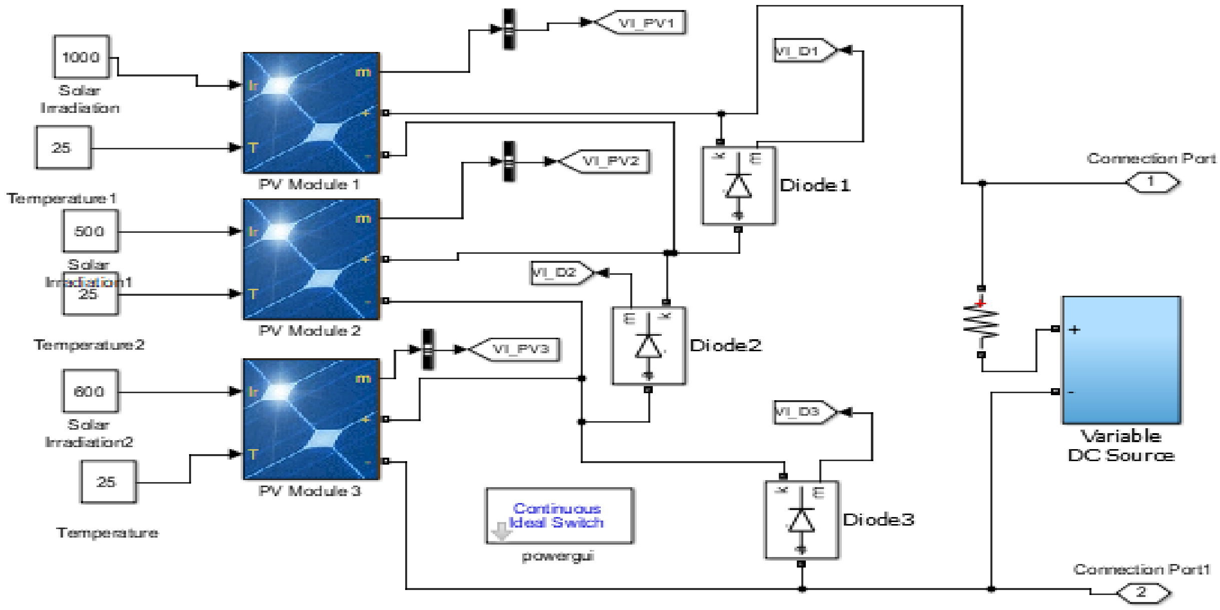

Figure 3: Configuration of Tata power solar Photovoltaic panel (TP250MBZ)

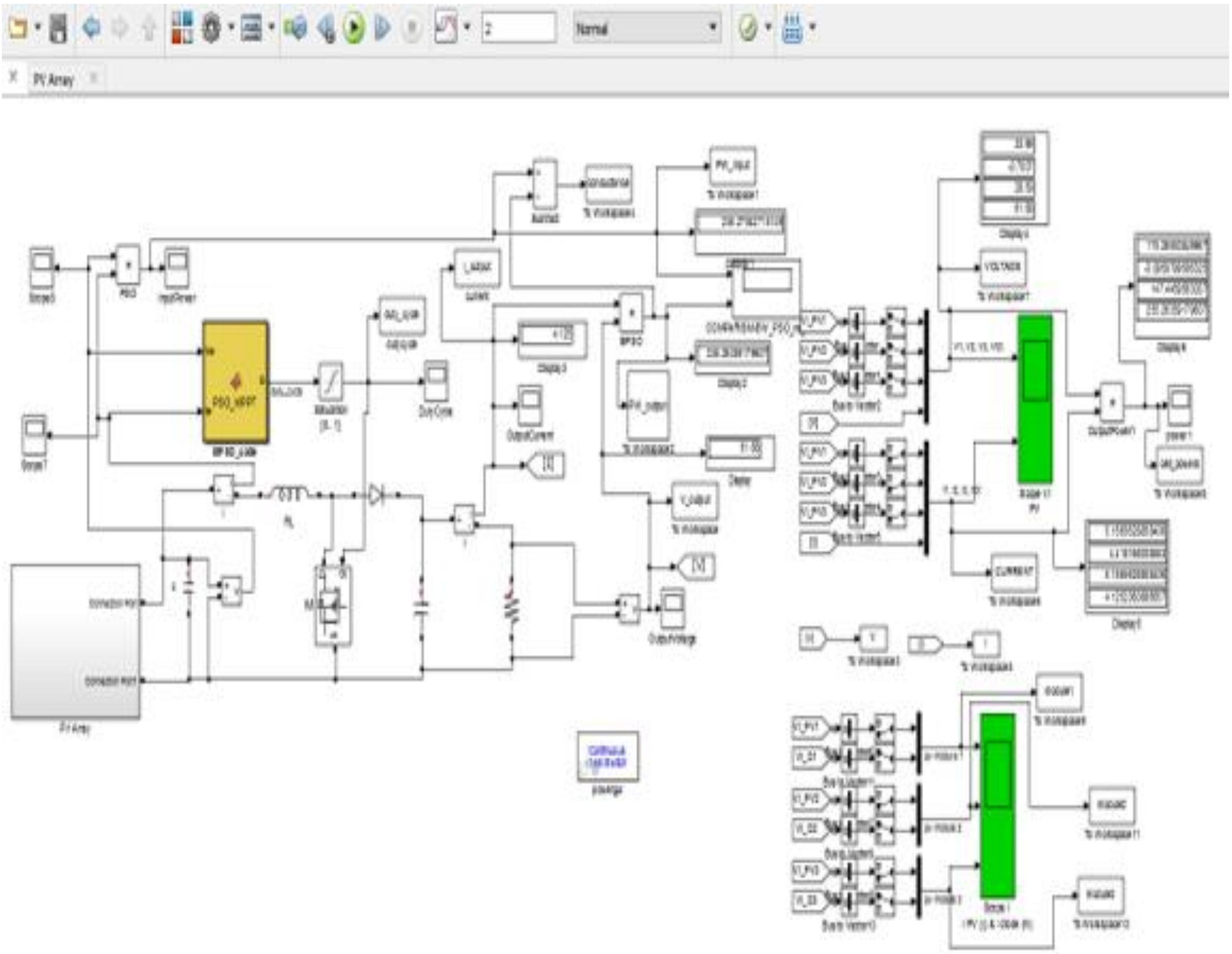

Figure 4: Simulink Diagram of PV module with BPSO based MPPT controller

Performance Metrics:Performance metrics are standard measurements that are used to evaluate and validate the effective performance of techniques. Ideal Maximum Power Point Tracking Accuracy (IMPPTA) will be used to validate the effectiveness and robustness of the proposed model. This is obtained by taking the absolute difference of the average mean of the new and old models, dividing it by the old model and expressing it in percentage as shown in Equation (16).

$$\text{IMPPTA} = \frac{\left|\frac{1}{N}\sum P_{old}\right| - \left|\frac{1}{N}\sum P_{new}\right|}{\left|\frac{1}{N}\sum P_{old}\right|} \times 100 \qquad (16)$$

Where; N = number of plotted data points;
$\sum P_{old}$ =Summation of the old model data
$\sum P_{New}$ = Summation of the new model data

The performance of the proposed model was validated using scanning Particle swarm optimization technique [52]. The scanning Particle swarm optimization was selected because it has good performance, low cost, easy to implement and also one of the most recent published MPPT technique with higher degree of accuracy [53].

The electrical specifications and characteristics of Tata TP250MBZ solar panel is as shown in table 1

Table 1: Tata Power Solar Systems TP250MBZ electrical specifications (3 Panels were used)

Names of parameter	Symbol	Value	Names of parameter	Symbol	Value
Diode ideality factors	A	2.0Ω	Temperature coefficients of V_{oc}	Kv	-0.3300 %/°C
Diode saturation current,	I_0	1.01×10^{-10}A	Temperature coefficients of Isc	Ki	0.063805%/°C
Light generated current	IL	8.8382A	Voltage Maximum Power Point	Vmpp	30.0V
Short circuit currt	Isc	8.8300A	Current Maximum Power Point	Impp	8.30A
No of PV cell / module	N	60.0	Reference Irradiance	G_{ref}	1000W/m^2
Series resistance	R_s	0.2914Ω	Reference Temperature	T_{ref}	25°C
Shunt resistance	R_{sh}	0.2914Ω	Maximum power	Mp	249.0W
Open Circuit Voltage	V_{oc}	36.80V	Working Irradiance	G	1000W/m^2, 500W/m^2 600W/m^2'
Working Temperature	T	25°C 25°C, 25°C			

RESULTS AND DISCUSSION

The results obtained from the MATLAB SIMULINK simulation of Equation (17) yielded the tables and graphs to be discussed below: Table 2 is a table showing the comprehensive variables generated from the developed BPSO algorithm. This table summarized the corresponding values of each variable with respect to iteration number and time taken for it to be completed. The developed model attained its first local maxima of 255.0021 at iteration 1551 with a very good tracking speed of 0.1291secs and finally balanced at iteration 2650. The developed model finally settled at the global maxima of 255.063W, 0.2292secsand at this point, the source impedance balances with that of the load impedance and the change in conductance became very negligible.

Table 2: A comprehensive Variables for BPSO

Itr	Panel Power (W)	Output Power (W)	BPSO Conductance	Time (Sec)
1	0.00000000	0.000000000	0.000000000	0.000000000
2	0.00000000	0.000000000	0.000000000	3.155443621e-30
3	3.087623137384e-56	2.553406117e-67	3.08762314e-56	6.310887242e-30
4	1.237930719190e-12	5.539954607e-26	1.23793072e-12	1.536618239e-09
5	1.237930719190e-12	5.539954607e-26	1.23793072e-12	1.536618239e-09
6	9.882385417439e-12	5.456913353e-26	9.88238542e-12	3.073236479-09
7	4.234227512740e-10	1.950647354e-26	4.23422751e-10	1.075632768e-08
8	4.044473025545e-08	8.410775437e-23	4.04447303e-08	4.917178366e-08
9	4.774128565375e-06	1.248365518e-18	4.77412857e-06	2.412490636e-07
10	0.000588607802	1.909203431e-14	0.00058861	1.201635463e-06
. .	. .	. .	. .	. .
1550	255.2940342135	254.9940602314	0.29997398	0.129000000
1551	255.2937325938	255.0021054777	0.29162712	0.1291000000
. .	. .	. .	. .	. .
2012	255.2826398436	255.2656218725	0.01701797	0.175000000
2013	332.2626015474	253.3604790590	78.9021225	0.175026264
. .	. .	. .	. .	. .
2649	255.2938779525	254.9984233120	0.29545464	0.229100000
2650	**255.2935805018**	**255.0063400093**	**0.28724049**	**0.229200000**
2651	255.2932896549	255.0140231624	0.279266493	0.229300000
. .	. .	. .	. .	. .
20688	255.2783447620	255.2637231337	0.014621628	1.999800000
20689	255.2783995013	255.2636555027	0.014743999	1.999900000
20690	255.2784271515	255.2635917961	0.014835355	2.000000000

From table 2 it was observed that the developed model kept on tracking for a significant change within the operating point to check for discrepancy between the current operating point of the panel and the load. However, it was obviously observed from Table 2 that immediately the MPP was detected the difference between the impedance of the source with that of the load was so infinidesimal and that showed the effectiveness of the developed model. This developed algorithm with its fast tracking speed and accuracy in detecting MPPT has solved the problem of premature convergence and tracking latency by balancing the panel and the load impedance at iteration 2650, 0.2292secs and at this mentioned point the output power did not deviate from the maximum power point value of 255W till the end of the simulation. Furthermore, from Table 2, it is clearly observed that the source (panel) power was balanced with load at maximum power point of 255 and the algorithm kept searching for more deviation from the MPP and the discrepancy was so negligible that the MPP operating point was maintained at that level.

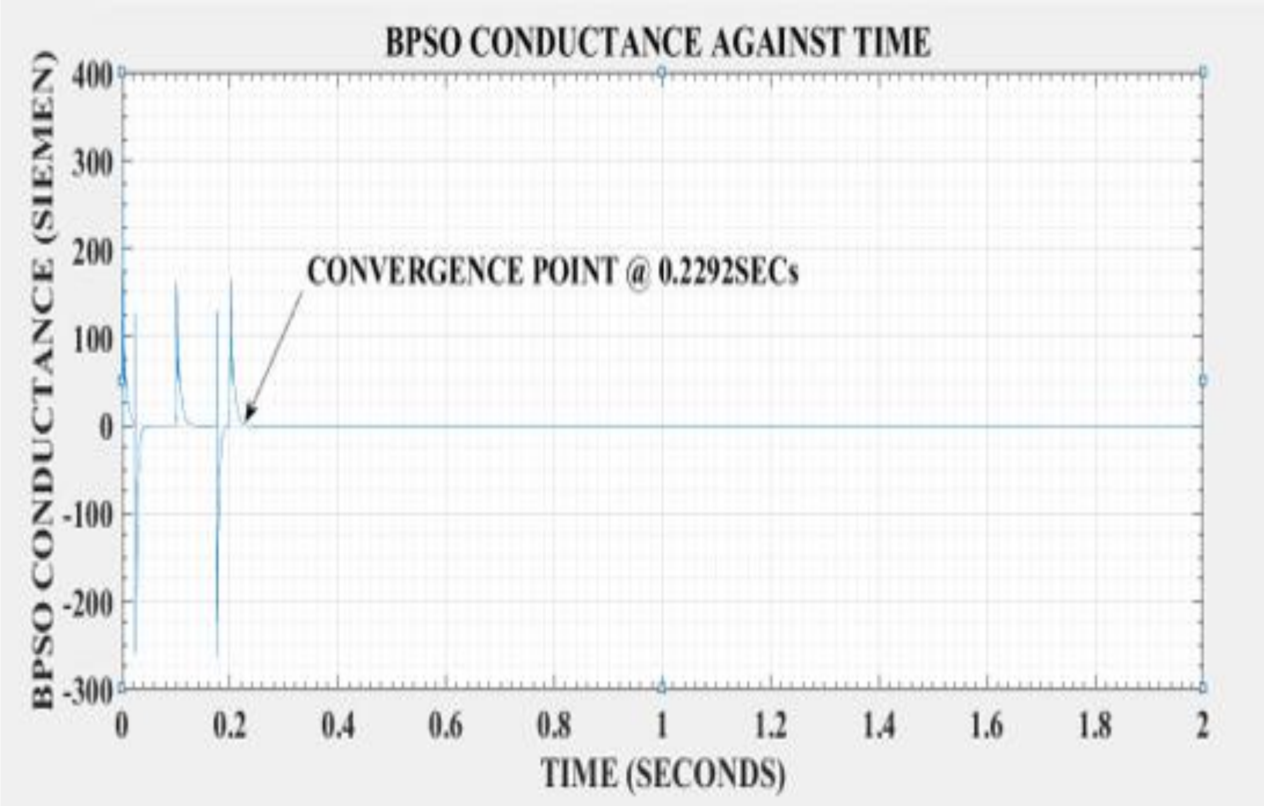

Figure 5: Graph of BPSO Conductance against Time

Figure 5, showed the relationship between BPSO conductance and time as illustrated in table 2. It was obviously observed from figure5, that, the conductance oscillates within 0secs to 0.2291secs which is a region within the BPSO conductance-time graph were the impedance of the panel is not the same as the impedance of the load as a result of instability/imbalance between the panel and the load. At this specified region the energy generated by the panel is not yet the same as the power delivered to the load but from 0.2292secs to 2.00secs the power dissipated from the panel is almost equal to the power transferred to the load and at that point the system is delivering at it its peak. This is so because at 0.2292secs and above the BPSO conductance is approximately zero which shows that the power is transferred at its maximum. This graph simply implies that the power generated from the panel is transferred to the load at very high speed of 0.2292secs which is the maximum time taken for the global optima to be located. It is also observed that the developed algorithm balanced the impedance of the source with the impedance of the load at 0.2292secs which implies that MPP has been detected and the system converged. It avoided premature convergence by not converging at the first time of obtaining/encountering local maxima but continue until it finally gets to the global maxima of 255.063secs where the maximum power point of the BPSO is located. When PSC was detected Equation 13 was adopted to re-track and locate the global maxima again. The efficiency and effectiveness of the developed algorithm in terms of data generation was obtained from the Simulink simulation of Figure 5.

Table 3: Table showing the Output Power, BPSO Conductance and Time

Itr	Output Power (W)	BPSO Conductance	Time (Sec)
1	0.000000000	0.000000000	0.000000000
2	0.000000000	0.000000000	3.155443621e-30
3	2.553406117e-67	3.08762314e-56	6.310887242e-30
4	5.539954607e-26	1.23793072e-12	1.536618239e-09
5	5.539954607e-26	1.23793072e-12	1.536618239e-09
6	5.456913353e-26	9.88238542e-12	3.073236479-09
7	1.950647354e-26	4.23422751e-10	1.075632768e-08
8	8.410775437e-23	4.04447303e-08	4.917178366e-08
9	1.248365518e-18	4.77412857e-06	2.412490636e-07
10	1.909203431e-14	0.00058861	1.201635463e-06
. .	. .	. .	. .
346	248.9991787496	5.98618597	0.018600000
347	249.1687437637	5.83749384	0.018700000
348	249.3340902708	5.69239358	0.018800000
. .	. .	. .	. .
401	253.9727441255	1.34209090	0.024100000
402	254.0104119105	1.30422326	0.024200000
. .	. .	. .	. .
1550	254.9940602314	0.29997398	0.129000000
1551	**255.0021054777**	**0.29162712**	**0.1291000000**
1552	255.0099134091	0.28353470	0.129200000
. .	. .	. .	. .
2012	255.2656218725	0.01701797	0.175000000
2013	253.3604790590	78.9021225	0.175026264
. .	. .	. .	. .
2649	254.9984233120	0.29545464	0.229100000
2650	**255.0063400093**	**0.28724049**	**0.229200000**
2651	255.0140231624	0.279266493	0.229300000
2652	255.0214796035	0.271525650	0.229400000
. .	. .	. .	. .
20688	255.2637231337	0.014621628	1.999800000
20689	255.2636555027	0.014743999	1.999900000
20690	255.2635917961	0.014835355	2.000000000

From Table 3, it was observed that PSC was curtailed from iteration 2650 where the output global power was attained. At this point, tracking for maximum power point with reference to the BPSO conductance was initiated for future power comparison and re-use. It was observed that from iteration 1551, a local peak was found but the BPSO conductance is not yet balanced, indicating that local maxima has been found but was not the target point. The algorithm continued searching for the global maxima until it was found at iteration 2650 where the impedance of the load is approximately equal to the impedance of the panel. This searching and power comparison continued as the previous global maximum power was maintained due to negligible BPSO conductance value which has no effect on the output power of the PV. From Table 3, it is clear that the global maxima (MPP) remain constant at **255.00634W,0.2292secs** which is a point where the output power balances with the input power (convergence point). This showed the effectiveness of the developed algorithm in curbing premature convergence and latency in tracking.

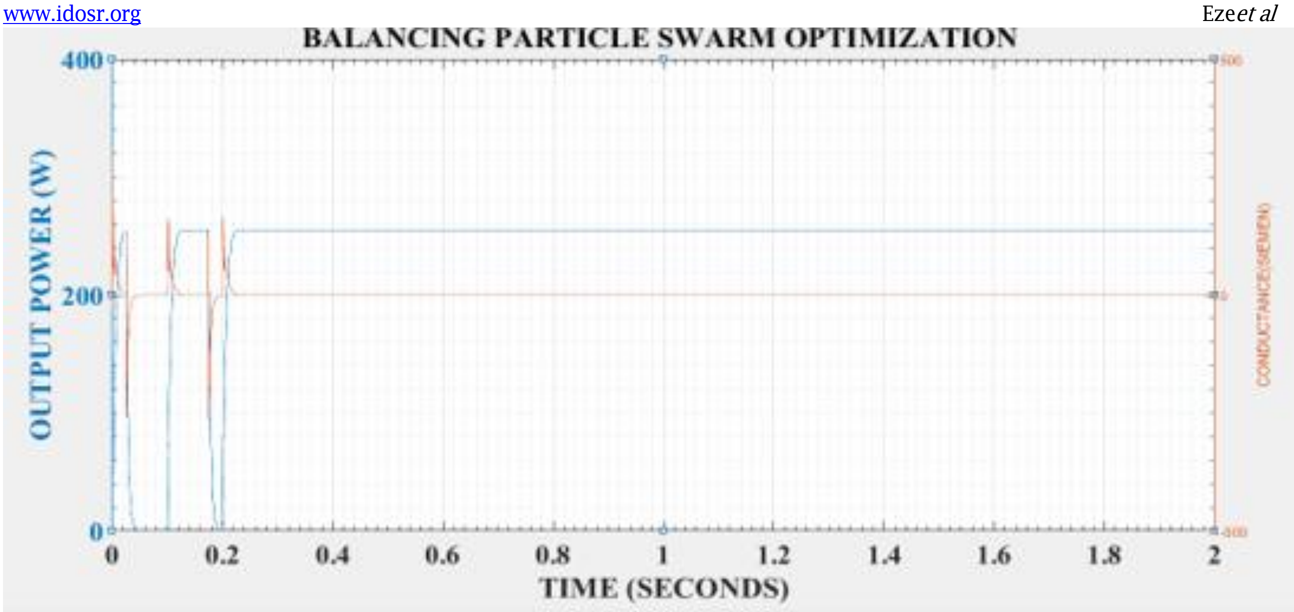

Fig. 4: Graph showing Output Power and BPSO Conductance against Time

From Figure 4, it is observed that the conductance fluctuates from 0secs to 0.2291secs and from 0.2292secs – 2secs the power generated by the PV panel is almost equal (balanced) with the power transferred to the load. It is clear from the graph that within fluctuation zone, whenever conductance is zero the output power is at maximum and vice versa. This showed how efficient and effective the developed algorithm was in terms of power transfer, speed of tracking and accuracy. The problem of premature convergence has been solved because there is less delay and many local points detected but never converged until it gets to the global maxima where the power is at peak and conductance nearly zero/constant. The algorithm first found the local maxima for good two times within 0secs- 0.2291secs as it makes use of peak-compare and balance technique before it finally detects the global maxima at very high speed. The search to detect the global maxima and converge took only 0.2292secs which is a very minimal time for an accurate target.

Table 4: Validation Table Showing the Output Power and Time of BPSO and SPSO Techniques

Balancing Particle Swarm Optimization (BPSO)		Scanning Particle Swarm Optimization (SPSO)	
Output power (W)	**Time (secs)**	**Output power (W)**	**Time (secs)**
255.0021	0.1291	75.0000	-
255.0063	**0.2292**	**93.0000**	**0.4000**

It is observed from Table 4 that the time taken for the two algorithms to find the local and global maxima were so different and incomparable. From table 4, it is clear that BPSO converged at global maxima of 255.0063W, 0.2292secs while SPSO converged at 93.0W, 0.400 secs. The difference in the time taken for the two models to converge was so clear and gives BPSO a better tracking performance and speed. This shows how efficient the BPSO algorithm was compared to the existing PSO techniques. The major thing compared in this validation is the convergence time as the setting conditions were not the same with respect to power transferred because the SPSO was done both practically and theatrical but BPSO was simulated theoretically. From the practical and theoretical result obtained in SPSO the convergence time were 0.4000secs and 10secs respectively[52], whereas the BPSO model has 0.2292secs theoritically.

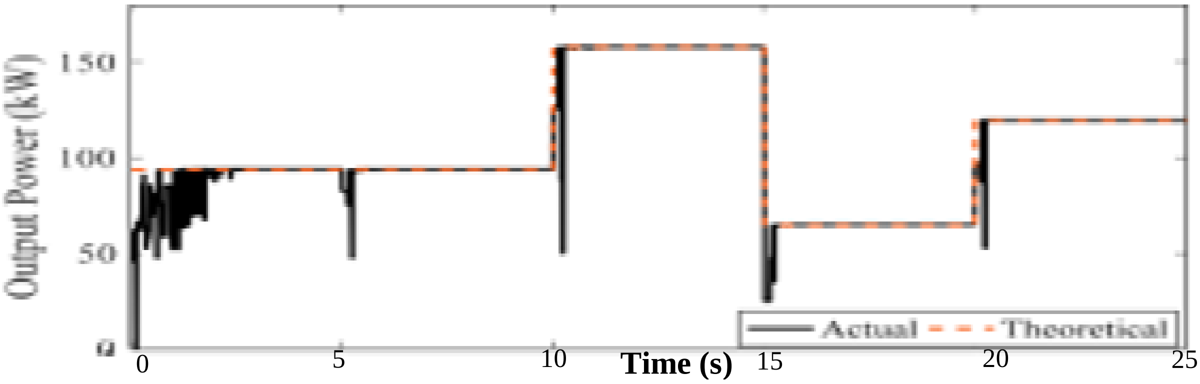

Figure6: Plot of SPSO Output Power against Time[52]

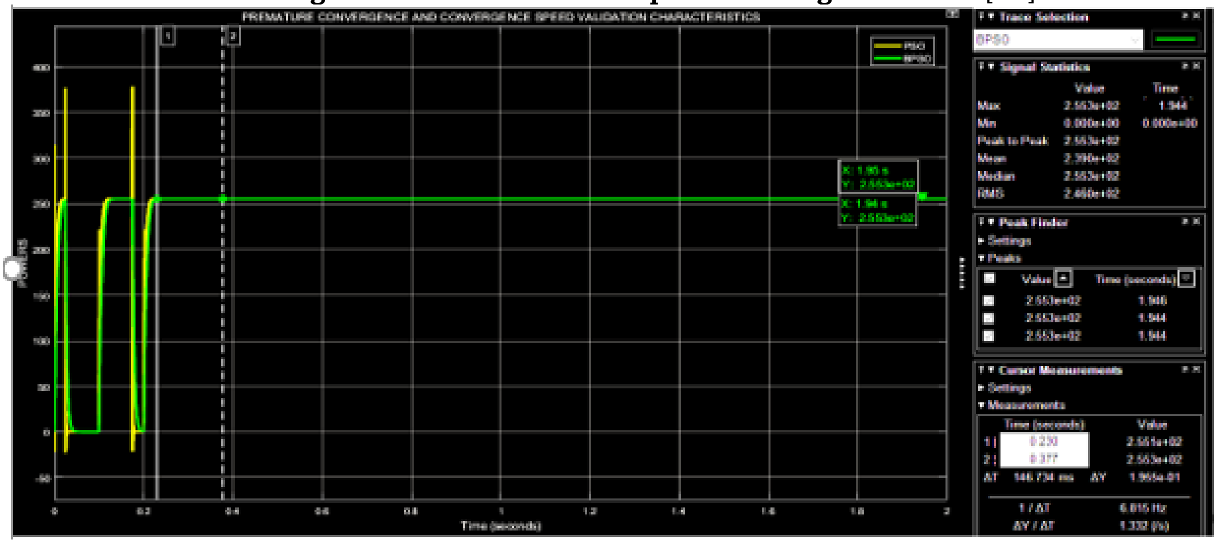

Figure7: Plot of BPSO Source Power and Load Power against Time

Figure 6 and 7 shows the comparison of the output power of SPSO and BPSO against time using maximum power point tracking technique. From figure6, it was observed and clearly stated in [54]that maximum power was obtained at 93W/m^2 and smooth tracking was initiated at 0.4 secs. From Figure8, it was observed that the global maxima of 255.0063W was obtained at 0.2292secs and constantly maintained. From Figure6and 8, the algorithms avoided premature convergence because they all attained several local maxima and never settled at it but got it at different speed level. It was also observed that there is a lot of damping/oscillation in Figure6 which reduced the quantity of power transferred to the load. This simply implies that BPSO has minimized the problem of premature convergence and tracking latency by avoiding settling at local maxima even though local maxima were obtained twice in few seconds but never converged until maximum power/global optima was located at 0.2292secs. On the other hand, after the global optima were found the tracking stopped and kept on accelerating within the region to check if there is atmospheric change that will lead to change in operating point and BPSO conductance of the PV system. Finally, the algorithms avoided premature convergence perfectly, but the BPSO has better tracking speed than SPSO because it converged at 0.2292secs which is faster than 0.4000secs. It was observed that,both tecniques have good convergence performance as they all avioded premature convergence but BPSO outperfomed in terms of tracking speed/convergence time. Therefore, convergence time (tracking speed) calculated using Equation (16) showed that the developed BPSO outperformed SPSO by 42.7%

CONCLUSION

The balancing particle swarm optimization was successfully developed, simulated and analyzed using MATLAB SIMULINK. From the analysis it was observed that the developed model was effective, efficient, accurate and robust. The choice of initial weight and BPSO conductance $\gamma^{(k)}$, effectively showed how latency in convergence and premature convergence were curtailed by applying the specified values on $\gamma^{(k)}$ developed model for better performance. The model handled the convergence speed by applying balancing power comparison concept. The results of this research work showed that it is not limited only to enhancement of power transferred to the load but also the choice of initial weight values to be used when applying PSO as means of MPPT in a solar PV system under PSC. The significance of the developed model is that it will lead to implementation of better intelligent based MPPT charge controller for PV applications. Integrating the developed model in charge controller will maximize the transfer of power from the solar photovoltaic panel under PSC to the load with minimal power loss which will be of an utmost use in the Electric Vehicle (EV) charging stations as it requires fast charging mechanism for easy recharging of the EV cars.

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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