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Power Maximization in Standalone Photovoltaic System: An Adaptive PSO Approach

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Abstract— A control strategy for power maximization which is an important mechanism to extract maximum power under changing environmental conditions using Adaptive Particle Swarm Optimization (APSO) is proposed in this paper. An Adaptive Inertia Weighting Factor (AIWF) is utilised in the velocity update equation of traditional PSO for the improvement in speed of convergence and precision in tracking Maximum Power Point (MPP) in standalone Photovoltaic system. Adaptation of weights based on the success rate of particles towards maximum power extraction is the most promising feature of AIWF. The inertia weight is kept constant in traditional PSO for the complete duration of optimization process. The MPPT in PV system poses a dynamic optimization problem and the proposed APSO approach paves way not only to track MPP under uniform irradiation conditions, but also to track MPP under non uniform irradiation conditions. Simulations are done in MATLAB/Simulink environment to verify the effectiveness of proposed technique in comparison with the existing PSO technique. With change in irradiation and temperature, the APSO technique is found to provide better results in terms of tracking speed and efficiency. Hardware utilizing dSPACE DS1104 controller board is developed in the laboratory to verify the effectiveness of APSO method in real time.

Index Terms—DC-DC power converter, Adaptive PSO, Maximum power point tracking, Photovoltaic System

I. INTRODUCTION

The energy requirement in the world is ever increasing. Traditional energy resources fail to suffice the growing energy deficit in the fast-growing world. Therefore, developments in the field of renewable energy systems are expected to increase. It becomes essential to explore available renewable energy resources which could provide energy in a workable manner. Because of the abundant, everlasting and non-polluting nature of solar energy, it is found to be the perspective solution for energy crisis. Apart from sunlight and solar heating, energy from the sun is available indirectly in the form of biomass, wind energy and hydroelectric energy, and is found to possess many advantages over the traditional energy resources. In spite of the aforementioned advantages, conversion of natural renewable energy forms into a manageable and beneficial energy form such as electrical energy while keeping the price low summons to contest the mankind [24].

Photo voltage is generated in a solar cell when light shines on it. The generated voltage drives the current in an external circuit delivering power. Photovoltaic panel consists of many numbers of solar cells coupled either in series or parallel. The nonlinear current Vs voltage (IV) characteristics of the photovoltaic curves indicate the change

in Peak Power Point (PPP) with changes in irradiation and temperature, thereby causing the efficiency of the photovoltaic panel to depend on environmental conditions. Therefore, tracking of MPP becomes indispensable to deliver maximum possible power leading to an improvement in the efficiency of the panel. MPPT techniques which can locate MPP using either a valid model or search methods has to be used [25]. The search methods vary with range of operation, sensor requirements, speed of convergence, complexity and cost. By and large, methods such as Hill Climbing, Perturb and Observe, and Incremental Conductance are used [1-12]. The main drawbacks with these methods are oscillations around MPP and its inability to trail MPP under quickly changing atmospheric conditions.

Numerous researchers have presented intelligent tracking methods for appropriate tracking and improvement in dynamic and steady state performances [13-16]. Fuzzy Logic and Neural Network methods are suitable for tracking under changing environmental conditions. Fuzzy Logic method requires knowledge or experience to choose right error computation and rule base table. Different photovoltaic modules have dissimilar characteristics and the Neural Network is to be trained for each module. Also, it demands periodical training to guarantee accurate tracking as the characteristics change with time. The improvement in dynamic performance and MPP tracking accuracy under rapidly changing environmental conditions can be addressed by the use of Evolutionary Algorithm (EA) techniques [21]. Because of the ability of EA techniques to handle non linear objective functions, it is envisioned to be effective in dealing with MPPT problem. Among the available EA techniques, PSO is effective due to its flexible and well-balanced nature to improve exploration capabilities locally as well as globally. Because PSO remain unaffected by the magnitude and nonlinearity of the real-world optimization problems, the problems are solved using PSO since its inception. For instance, MPP is tracked using PSO in [20]. As PSO is one of the search optimization techniques that uses reduced search space, location of MPP despite changing environmental conditions is possible [26-30].

Nonetheless, the traditional PSO method has two dynamic properties that diminishes the searching capability. The first problem is the premature convergence and the next is the inability of PSO method to maintain balance between the global and local searches. These limitations impose constraints on the wider application of PSO to real world problems [23]. Therefore, adaptive PSO whose inertia weight is adapted based on the success rate of particles is proposed for better tracking speed and efficiency. AIWF is

the key parameter in APSO which is presented in the velocity update equation of traditional PSO that changes the inertia weight according to the imminence of particle towards best solution. The effectiveness of APSO in MPP tracking is assessed by comparing the performances of both PSO and APSO. Introduction of adaptive inertia weight strategy in the existing traditional PSO for MPP tracking is the main contribution in this paper. The results obtained in both hardware and software pertaining to MPP tracking under dynamic environmental conditions are extensively discussed. The rest of the sections are organized as follows. Section II presents overview of the standalone photovoltaic system. Section III comprises of traditional PSO method for MPP tracking. Section IV details the APSO based MPP tracking. The simulation and hardware results are provided in Section V and Section VI respectively. Section VII completes the paper.

II. SYSTEM OVERVIEW

The Standalone Photovoltaic (SPV) system consists of a solar panel, power converter, MPPT controller and load. The configuration of standalone photovoltaic system employing MPPT control is shown in Figure 1.

Figure 1. Configuration of standalone photovoltaic system employing MPPT control

Solar cell is the elementary component of the photovoltaic panel and possesses the advantages of photovoltaic effect, thereby converting electromagnetic radiation into electric current. Numbers of solar cells are connected in series and parallel to comprise the panel. Equivalent circuit of the solar cell is shown in Figure 2. Resistance R_s and R_p are included in series and parallel to represent the ohmic losses in the cell. High value of shunt resistance in practical case causes the third term in Equation (1) to be of negligible value during analysis [24].

Figure 2. Equivalent circuit of solar cell

The IV equation of a single cell using the single diode model [4] is given by

$$I = I_L - \left[I_o \exp\left(\frac{q(V + IR_s)}{nkT}\right) - 1 \right] - \frac{V + IR_s}{R_p} \quad (1)$$

where I_L is light generated current, I_o is reverse saturation current, q is the electron charge ($1.6 \times 10^{-19} \text{C}$), n is diode

ideality factor, k is Boltzmann's constant (0.0017A/K) and T is temperature.

The module output current represented as I_{pv} is given by

$$I_{pv} = N_p \times I_{ph} - N_p \times I_o \left[\exp\left\{ \frac{q \times (V_{pv} + I_{pv} R_s)}{N_s k n T} \right\} - 1 \right] \quad (2)$$

where N_p and N_s are the number of parallel and series cells respectively.

Equation (2) is used in MATLAB/Simulink to model SOLKAR 37W module, to obtain IV characteristics and PV characteristics for various irradiation values at constant temperature of 25°C and varying temperatures at constant irradiation level of 1000W/m^2 . Table I shows the electrical characteristics of SOLKAR 37W panel at Standard Test Conditions (STC) obtained from the datasheet of the module provided by the manufacturer. It is understood that current and power varies proportional to irradiation, voltage across panel varies inversely proportional to irradiation and the power extracted by the panel lowers with increase in temperature.

TABLE I. ELECTRICAL CHARACTERISTICS OF SOLKAR 37W PV PANEL AT STC

Description	Rating
Rated power	37.11 W _p
Voltage at maximum power (V_{mp})	16.56 V
Current at maximum power (I_{mp})	2.25 A
Open circuit voltage (V_{oc})	21.24 V
Short circuit current (I_{sc})	2.55 A
Total number of cells in series (N_s)	36
Total number of cells in parallel (N_p)	1

Power output from the PV panel varies continuously with variations in irradiation and temperature. It becomes necessary to employ MPP tracking controllers to abstract maximum power and transfer it to load. DC-DC converters for which the PWM signal is generated based on the MPPT algorithms serve as MPPT controllers. It acts as an interface between the panel and load transferring maximum possible power from panel to load. To intensify the lower module voltages, standalone photovoltaic system utilizes a boost converter as the power processing unit in the present work. The circuit of the boost converter consists of input voltage source, MOSFET switch, diode D , filter capacitor C , boost inductor L and a load as indicated in Figure 1.

If the MOSFET switch is operated with a duty cycle k , the voltage gain of the converter is given by

$$\frac{V_o}{V_{in}} = \frac{1}{1 - k} \quad (3)$$

When input and output powers are equated, the average value of input current can be obtained as

$$I_L = I_{in} = \frac{V_o \times I_o}{V_{in}} = \frac{I_o}{1 - k} = \frac{V_{in}}{R_{in}} = \frac{V_{in}}{R(1 - k)^2} \quad (4)$$

It is observed from Equation (4) that the impedance of the converter at the input side is altered in addition to the regulation of output voltage when duty cycle of the converter is changed. To facilitate maximum power extraction, an optimum impedance across the PV module has to be presented which becomes possible by controlling the converter.

V_{mp} is the voltage and I_{mp} is the current at maximum power point state and therefore,

$$\frac{V_{mp}}{I_{mp}} = R_L (1 - k_{op})^2 \quad (5)$$

where k_{op} is the duty cycle to be utilised for the optimal tracking of MPP.

Critical value of the inductor is calculated by

$$L_{critical} = \frac{R \times k(1 - k)^2}{2f} \quad (6)$$

For continuous conduction mode operation, the inductor value must be greater than $L_{critical}$.

The filter capacitor is determined by the following expression

$$C = \frac{k}{R \times (\Delta V_o / V_o) \times f} \quad (7)$$

where ratio of the desired constant output voltage $\Delta V_o / V_o$ is the allowed ripple and f is the switching frequency. The values of the components selected for the converter in all the simulation works are given in Table II.

TABLE II. BOOST CONVERTER COMPONENT VALUES

Description	Rating
Inductor	120 μ H
Capacitor	330 μ F
Resistor	50 Ω , 1A
Switching frequency	10kHz

As the current research on photovoltaic system is oriented towards developing control algorithms that can maximize the efficiency, a rheostat is connected as load. The power gets dissipated in the load when current flows through it.

III. TRADITIONAL PSO METHOD FOR MPP TRACKING

Eberhart and Kennedy developed Particle Swarm Optimization in 1995, a stochastic, population-based algorithm which is stimulated by the social behavior of bird grouping. PSO is an optimization algorithm that deals with problems to provide an optimal solution [22]. The algorithm maintains a swarm of particles, also called as agents and each agent holds the ability of exchanging information with the other during the search process. Each particle has to follow two rules. First rule is to chase the particle that performs the finest and the second rule is to travel towards the finest conditions as arrived by the particle itself [23]. Therefore, the position of each particle is influenced by the best particle in the neighborhood, p_{best} (personal best), and the best solution found by all the particles in the population, g_{best} (global best). The direction and velocity of the movement of particles are continuously revised based on personal and global best values thereby converging to optimal value.

Following are the equations that define standard PSO method [21]:

Particle position is obtained by

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (8)$$

Velocity of the particle is calculated using

$$v_i(t+1) = w \times v_i(t) + c_1 \times rand_1(pbest_i - x_i(t)) + c_2 \times rand_2 \times (gbest - x_i(t)) \quad (9)$$

$i = 1, 2, 3, \dots, N$

where x_i denotes position of particle i , v_i is the velocity of the particle, t represents iteration number, w is the inertia weight, $rand_1, rand_2$ are uniformly distributed random

variables in the interval [0,1] and c_1, c_2 are the learning factors, where c_1 is cognitive coefficient and c_2 is social coefficient, the best position is represented as $pbest_i$ that the i^{th} particle has found and $gbest$ stores the finest position of all the particles. $v_i(t+1)$ in Equation (8) represents the step size.

The calculation process involved in tracking MPP utilizing PSO method is explained in the following steps.

- (1) Set the particles number, maximum number of epochs, inertia weight, cognitive and social coefficients.
- (2) Randomly assign the positions and velocities of each particle where position corresponds to duty cycle value and velocity to step size.
- (3) Fitness function in the current work is the panel power P_{pv} , $P_{pv} = V_{pv} \times I_{pv}$. V_{pv} and I_{pv} are panel voltage and panel currents respectively. Initial duty cycle values of all the particles are fed to the converter and related P_{pv} is measured.
- (4) Individual and global best values ($pbest_i$ and $gbest$) of power and duty cycle are brought up-to-date by linking the recently measured power against the previous value, and substituting $pbest_i$, $gbest$ and corresponding positions, if measured power is maximum.
- (5) The duty cycle and the step size values are updated using equations (8) and (9).
- (6) Because the power changes with environmental conditions, steps (4) and (5) are repeated continuously to enable continuous tracking of MPP.

The success rate and search efficiency of PSO are determined by the values assigned for inertia weight and learning factors [21]. The particle lack accuracy, if inertia weight is chosen to be of higher value because of the larger step size. On the other hand, particle lacks movement if chosen inertia weight is smaller. Traditional PSO tracks MPP at faster rate under uniform irradiation and temperature conditions. However, when the conditions change, inertia weight has to be readjusted for enabling faster tracking of MPP. The traditional PSO method has to be modified for efficient operation of PV panel under changing environmental conditions.

IV. APSO BASED MPP TRACKING

Several variants of PSO are stated in the literature to enhance the performance of traditional PSO [17-19]. Modifications are incorporated mainly to enhance the ability of either exploration or exploitation or even both. One of the modifications introduced is the usage of adaptive inertia weight factor in velocity update equation. Velocity of the current particle is dependent on the previous velocity to provide necessary drive for the particles to move all over the search space. The inertia weight factor depends on the previous velocity so as to provide a balance between global exploration and local exploitation. Smaller inertia weight allows finest tuning in the recent search space, whereas high inertia weight aims at global exploration. Therefore, it becomes essential to control inertia weight for obtaining optimal solution. An extensive survey on various inertia weight structures of PSO algorithm is given in [23], and a modified structure which is dependent on the victory rate of

the particles is provided. The adaptive inertia weight structure is extended for tracking MPP in standalone photovoltaic systems in the current work.

Implementing adaptive control strategy requires evaluation of position of the group in each epoch. Hence, the percentage of victory (PS) is utilised to meet the requirements. Higher the percentage of victory higher the convergence to a point which is far away from the optimal point and therefore, the group progresses in a slower manner towards the optimal solution. Likewise, lower percentage of victory implies that all the particles are prone to oscillations around the optimal point lacking any further enhancement. The percentage of success value is therefore determined using Success Count (SC) of the particles. The chosen application deals with maximization problem and therefore, if the fitness in the present iteration is higher when compared to the value obtained in the earlier iteration, SC is set to 1. SC of particle i at iteration t is considered as

$$SC = \begin{cases} 1 & f > f_{pbest_i} \\ 0 & f \leq f_{pbest_i} \end{cases} \quad (10)$$

Figure 3. Flowchart of APSO algorithm
PS is computed from SC as follows

$$PS = \frac{\sum_{i=1}^n SC_i}{n} \quad (11)$$

where, n is the number of particles and PS lies between 0 and 1 which indicates the percentage of particles that has an improvement in their fitness in the previous iteration. The adaptive inertia weight based on percentage of success for updation is given by,

$$w(t) = (w_{max} - w_{min})PS + w_{min} \quad (12)$$

w_{max} and w_{min} are the maximum and minimum values of inertia weights selected to be in the range between 0 and 1. Although PS is in the range [0,1], w can be in any acceptable range. The problem under consideration is single objective optimization problem. The fitness value often changes with environment to enable continuous tracking of MPP for maximum power extraction in PV systems and therefore, no stopping criteria is imposed in the current work. The APSO algorithm will continuously search the duty cycle until the simulation is stopped. The flow chart pertaining to the steps involved in APSO method is shown in Figure 3.

The steps involved in tracking MPP utilising APSO algorithm is elaborated:

1. Selection of Parameters

In the current work, the position of the particle is designated as the duty cycle of boost converter and fitness value chosen is the module power. Though larger number of particles if chosen leads to accurate tracking of MPP even under changing environmental conditions, it requires more time to process. Hence, a balance is required to ensure accuracy and good tracking speed.

2. APSO initialization

Numbers of particles, maximum number of iterations, inertia weight, cognitive and social coefficients are set. The particles are placed randomly in the search space. The search space of the particles will lie in the interval [0, 1] as the duty cycle holds a value between 0 and 1. The position and velocity are initialized such that they correspond to duty cycle and step size respectively.

3. Fitness Evaluation

The objective function ' f ' in the current work is the total power output of photovoltaic module and is expressed as

$$f = P_{pv} = V_{pv} * I_{pv} \quad (13)$$

The fitness function is same as that of objective function and characterizes the convergence of the algorithm in obtaining the optimal solution. Here, the problem of optimization is to find the duty cycle k such that fitness function P_{pv} is maximized. The position of the particle i is fed to the switch of the converter and the module voltage V_{pv} and module current I_{pv} are measured to calculate the fitness value of particle i .

4. Individual and global best data updation

If the fitness value of the particle i in the current iteration is larger than that of the fitness value in the past, current value is considered to be the new $pbest_i$. Then the particle with finest value among the set is chosen as $gbest$ i.e., position of the particle that can provide maximum power is designated as $gbest$

5. Inertia weight updation

Inertia weight w in velocity update equation in standard PSO is present to keep the particle travel in the similar direction where it was originally heading. For the faster

convergence, the inertia weight is supposed to be reasonably chosen to achieve balance between exploration and exploitation. A linear function given in equation (12) which correlates the values of Percentage of success to the possible range of inertia weights is used to update the inertia weight adaptively.

6. Updation of Position and Velocity of each particle

The velocity and position of each particle are updated based on AIWF using equations (8) and (9). The equations of traditional PSO method are utilized except that inertia weight is of varying nature.

7. Output optimum duty cycle

If the set number of iterations are over, the optimum duty cycle corresponding to the value stored in *gbest* is provided to the power converter for the operation of photovoltaic panel at maximum power point.

8. Repetition

Generally, PSO methods are employed to solve problems in which optimum solution is time invariant. In this application, fitness value changes with environmental conditions and therefore the steps from 3 to 7 are repeated as long as simulation is in process.

V. SIMULATION RESULTS AND DISCUSSION

Standalone photovoltaic system employing boost converter is modeled in MATLAB/Simulink environment and embedded MATLAB function block is utilized to employ MPPT control based on APSO and traditional PSO techniques. The simulations offer an opportunity to verify the viability and the performance of the proposed APSO algorithm in MPP tracking. Simulation studies are carried out to validate the efficacy of APSO based MPPT method in tracking peak power point under constant and changing environmental conditions. The parameters of PSO and APSO MPPT techniques are shown in Table III.

TABLE III. PSO AND APSO PARAMETERS

Parameters	PSO	APSO
Size of the Population (N)	10	10
No. of epochs (i)	30	30
C_1	2	2
C_2	1.4	1.4
Inertia weight (w)	0.99	AIWF

Figure 4. Panel power plot for constant irradiation of 1000W/m² at 25°C

Three situations are considered in the simulation work for the purpose of comparison between APSO and

traditional PSO MPPT techniques. To compare the performance, the configuration parameters are set the same. In the first situation, irradiation and temperature are kept constant at 1000W/m² and 25°C respectively. The associated panel power and load power plots are shown in Figure 4 and Figure 5. It is observed that power flow is optimized using both PSO and APSO techniques exhibiting an efficiency of 99.83% and 99.56% respectively. Also, the magnitude of oscillations is less while APSO based tracking technique is adapted which can be well observed from the associated zoom plots.

Figure 5. Load power plot for constant irradiation of 1000W/m² at 25°C

Figure 6. Panel power plot for irradiation change from 1000W/m² to 900W/m² at 25°C

Figure 7. Panel power plot for irradiation change from 1000W/m² to 900W/m² at 35°C

Figure 8. Convergence characteristic of APSO

In the second situation, irradiation is varied from 1000W/m^2 to 900W/m^2 keeping temperature constant at 25°C . The change from one irradiation level to the other occurs at $t=0.5\text{s}$. For the same change in irradiation, temperature is changed from 25°C to 35°C in the next. The corresponding panel power plots for the former and latter situations are shown in Figure 6 and Figure 7. In both cases, APSO method is more capable in detecting the change in solar irradiation and performs variation in duty cycle, thereby tracking new values of maximum power. The convergence characteristic for APSO is included in Figure 8 for better understanding. Tracking accuracy of APSO method has improved than the traditional PSO method and simultaneous improvement of dynamic and steady state performances is possible. Also, steady state oscillations are small enough allowing it to be a better candidate for tracking MPP. Settling time and Efficiency of PSO and APSO methods obtained through simulation is consolidated and listed in Table IV. The dynamic response of the APSO method is certainly better than the traditional PSO method.

TABLE IV. EFFICIENCY COMPARISON FOR PSO AND APSO METHODS

S.No	Method	Irradiation W/m^2	Temperature $^\circ\text{C}$	Settling time (s)	Efficiency (%)
1	APSO	1000	25	0.06	96.54
		900	35	0.053	96.63
		598	30.4	0.058	96.18
2	PSO	1000	25	0.063	96.29
		900	35	0.059	96.27
		598	30.4	0.061	96.02

VI. EXPERIMENTAL RESULTS

To understand the efficacy of the proposed APSO method for standalone photovoltaic system, a laboratory prototype utilizing dSPACE DS1104 controller board has been constructed as shown in Figure. 9. APSO based MPPT method is found to perform better than the traditional PSO method as per the simulation results obtained and therefore, it is implemented in real time for validation of the obtained results. The DS1104 controller board is the platform on which simulations are run as like that of MATLAB. The output from the hardware is controlled and monitored using control desk software. The controller board has the capability of handling voltage levels between -10V and $+10\text{V}$. Hence, a voltage divider circuit is employed to handle the panel voltage greater than 10V . Irradiation, temperature and current levels are measured using irradiation, temperature and current sensors respectively.

The sensors are calibrated appropriately based on the available data sheet. The irradiation sensor here is the analog pyranometer attached with a digital indicator that indicates the irradiation value. The APSO algorithm utilized will search for the optimal operating point and generate appropriate duty cycle which will lead to maximum power extraction from the photovoltaic panel.

Figure 9. Laboratory prototype

The laboratory prototype fabricated was utilized on a sunny day at various time intervals. The irradiation and temperature are respectively 598W/m^2 and 30.4°C . Control desk software is utilized to measure voltage, current and power of the PV panel and the values obtained are utilized to plot the graphs in MATLAB. The graphs corresponding to output voltage, output current and output power obtained while carrying out experiments in real time are shown in Figures 10, 11 and 12 respectively.

Figure 10. Output voltage at 598W/m^2 and 30.4°C

Figure 11. Output current at 598W/m^2 and 30.4°C

Figure 12. Output power at 598W/m^2 and 30.4°C

The output power obtained is 19.33W which is nearer to the expected output of 20.15W . Efficiency of the standalone PV system is given by the ratio of extracted output power to the expected output power which is found to be 95.93% for

the current experimental study. The corresponding voltage and current values are indicated with associated zoomed plots placed inside the main plots. Each of the associated plots indicate that APSO method works in an effective manner to extract maximum possible power with lesser magnitude of oscillations. The dynamic response during tracking of maximum power point is a crucial one and therefore obtained at various intervals. The values corresponding to the tests are listed in Table V. The steady state efficiency values are found to be consistent over a wide range and therefore APSO based tracking for the standalone photovoltaic system is considered to be a suitable candidate to employ for maximum power tracking in solar PV systems. Oscillations are very less, which implies that the system is a stable one.

TABLE V. EXPERIMENTAL RESULTS

S.No	Irradiation (W/m ²)	Temperature (°C)	Expected Power (W)	Obtained Power (W)	Steady State Efficiency (%)
1	598	30.4	20.15	19.33	95.93
2	554	32.6	18.27	17.52	95.89
3	437	24.8	15.22	14.5	95.27
4	520	28.9	17.58	16.84	95.79
5	474	31.3	15.61	14.91	95.51

VII. CONCLUSION

In this paper, power maximization in standalone photovoltaic system under constant and changing environmental conditions achieved using Adaptive Particle Swarm Optimization algorithm is presented. Instead of arbitrarily choosing weights, an adaptive PSO which is dependent on AIWF to increase the tracking speed and efficiency has been employed. Inertia weights are updated to speed up the search process. To assess the performance of APSO based MPPT technique, MPP tracking using traditional PSO is considered. The correctness of the control scheme based on APSO is validated through simulation by considering three different environmental conditions. As APSO method is found to provide superior results than traditional PSO method, the same is implemented in hardware to understand its veracity. Both the simulation and hardware results indicate that, APSO method pave way to effectively track MPP in standalone photovoltaic system. Also, the efficiency obtained after utilizing the APSO algorithm highlights the fact that it can meaningfully improve the settling time and precision of the traditional PSO. The proposed MPPT method based on APSO can be utilized directly without any modification in water pumping, street lighting and electric vehicle applications.

ETHICAL DECLARATIONS

Conflict of interest: All author states that there is no conflict of interest.

Ethical approval: Humans/Animals are not involved in this work.

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