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Implementation of Genetic Algorithm to generate Backstepping Controller's Gains for MPPT of Partially Shaded Photovoltaic Panels

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Abstract- The ability for the solar panel to operate at its maximum power point makes tracking the maximum power point of the photovoltaic model more important nowadays. The MPP tracking becomes more difficult and challenging during changes in weather conditions, which have a significant impact on PV power. In this paper a new method has been used to track the (GMPP) that combines (GA) with (BSC). The GA is used to generate the reference voltage that harmonize to the GMPP and the optimum BSC gains (K_1 and K_2). While the BSC operates the SEPIC duty cycle in order to follow the reference voltage found by the GA.

The proposed method is compared to other methods INC-BSC, P&O-BSC, GA-BSC and PSO-BSC using different BSC gains. According to the results, the suggested method succeeded in tracking the GMPP, while in some instances, the other MPPT methods tend to focus on the LMPP, which causes power losses. Additionally, using GA to generate the optimal BSC gains help to reduce oscillations around the GMPP. It helps minimize the voltage error by four times than the standard GA-BSC method and lead to fast tracking, two times faster than the standard GA-BSC method, and four times faster than PSO-BSC method. Furthermore, the findings showed that under the partial shadow condition, the performance criteria of the recommended technique outperform those of the PSO-BSC technique tracking.

Keywords- Maximum power point tracking; Backstepping controller; Genetic algorithm; Partial shading effects; Photovoltaic array.

Nomenclature

PV: Photovoltaic
GMPP: Global Maximum Power Point
LMPP: Local Maximum Power Point
MPPT: Maximum Power Point Tracking
MPP: Maximum Power Point
GA: Genetic Algorithm
PSO: Particle Swarm Optimization
BSC: Backstepping Controller
SMC: Sliding Mode Controller
SEPIC: Single-ended primary-inductor converter
INC: Incremental conductance
P&O: Perturb and Observe
GHG: Greenhouse Gases
PID: Proportional Integral Derivative
DC: Direct Current
STC: Standard Conditions
E_g : Band-gap energy

1. Introduction

The worldwide demand for energy is rapidly changing, natural energy resources such as gas and oil are depleting, and energy costs are rising as a result of the rapid dissemination, growth of industry and urban planning in recent years. The environmental issue is added to this energy concern [1]. We can see that the excessive buildup of greenhouse gases (GHG) in the atmosphere has disrupted the climate on the surface of our planet [2]. This causes global warming to occur at the earth's surface. The rise in energy costs, combined with environmental constraints, are driving the researchers to develop technology solutions that improve resource management and the use of renewable energies.

There are several types of renewable energies all produced from one source: The sun is our lucky star! It is our great, and almost unique, energy provider on earth. The sun not only warms and illuminates us, but it also moves air masses (wind energy). It is the engine of the water cycle, which drives the turbines of our hydroelectric dams. Solar energy enters all the food chains, without it, there is no life on earth. It is therefore quite naturally that men were interested in this source of energy [3].

In addition, solar energy is the most widespread and distributed energy source on the planet. In a single year, humanity consumes 10 billion tons of oil [4]. This is less than 3% of what the sun offers us for free each day. This energy is renewable for the next 4.5 billion years as long as the sun shines. Another advantage is that its use does not emit greenhouse gases.

The cost of maintaining and manufacturing solar panels has fallen dramatically in the past decade, making solar energy more affordable and often cheaper. That's why solar photovoltaic is the most widely used renewable energy. In 2019, solar panel installations around the world reached almost 115 GW. This represents a 12% increase over 2018. 627 GW of solar photovoltaics were installed worldwide in 2019 [5].

A PV generator or module is composed of a group of fundamental photovoltaic cells mounted in parallel or in series to achieve the appropriate electrical properties. The cells in a series grouping are traversed by the same current, and the series grouping's characteristic is obtained by adding the voltages at a specific current. However, when cells are linked in parallel, they all experience the same voltage, and the characteristic of the group is determined by adding the currents at a specific voltage.

Irradiance and temperature have a direct impact on the properties of a PV cell or a PV generator. In actuality, the operational power point position varies during the day due to the weather. For this reason, it is strongly advised to use the MPPT to ensure that the solar system is producing its maximum power [6-7].

According to a literature review, the MPPT methods used by researchers can be divided into online, offline, and hybrid methods. The offline approaches, rely on preexisting knowledge of the properties of photovoltaic panels and measures of solar irradiation, such as the open circuit voltage (V_{oc}) and the short circuit current (I_{sc}) [8-9]. Their drawback is that they avoid measuring the PV panel's actual extracted power, which causes a lack of accuracy notably amid quick changes in atmospheric conditions. Online methods which include (P&O) [10-11] and (INC) [12-13] are the most used algorithms by researchers because of their simplicity and ease of implementation.

For the P&O algorithm a tiny disturbance in the photovoltaic voltage is provided to cause the PV module's power to vary. After each disturbance, the power output from the solar cell is measured. If the measured power is greater than the measured power of the previous period, the controller maintains this search direction and performs the next power jump. If the measured power is lower than the last measurement period, the controller changes the search direction and now performs load jumps in the opposite direction. In this way, the maximum power is constantly sought. The disadvantage of this method is that it requires oscillating output power around the maximum power point, even under constant illumination.

On the other hand, the INC approach is just an improved version of the P&O method, and it's based on the fact that the power-voltage derivative is zero at the MPP. It can calculate the MPP without oscillating around it. It is more accurate than the P&O method for tracking maximum power points under rapidly changing irradiation conditions.

P&O and INC methods operate using an iterative approach that continually runs a microprocessor in the MPP tracker, so that even when irradiation conditions change, the MPP is always operational. However, these methods are susceptible to failure, particularly under conditions of rapid convergence and large irradiance fluctuations.

When the PV modules of the PV array are partially shaded, they receive non-uniform insolation. This results in multiple peaks on the power-voltage (P-V) curve, corresponding to local and global maximum powers rather than a single maximum power in the case of uniform insolation. Due to their lack of nonlinear capacity, the P&O and INC approaches suffer from fluctuations in this situation. Furthermore, they cannot localize the GMPP, but can only remain at the LMPP, which might result in a loss of power.

In order to solve this matter and overcome the constraints of the traditional P&O and INC approaches, researchers have used hybrid methods that can accurately track the MPP. These methods uses algorithms with controllers such as P&O with (PI, PID) controllers [14-15] and INC with (PI, PID) controllers [16-17]. The simulations and test results showed that the use of (PI, PID) controllers enables a better tracking of the MPP and improves the perturbation characteristics of the P&O and INC methods.

In addition, we can find in the literature other controllers used with P&O and INC, such as fuzzy logic controllers [18]. These controllers are very efficient, dependable, and can successfully simulate human logical reasoning, which can improve power quality and reduce frequency fluctuations, resulting in better tracking when compared to PI, PID controllers.

In fact, PI and PID are linear controllers, while PV generator and time variant properties of the power electronic converters are known by their nonlinearity. That's why it is preferable to look for nonlinear approaches that can guarantee the reliability of the PV system under variable operating conditions and provide high tracking efficiency.

The nonlinear controllers most commonly used by researchers are the (SMC) and (BSC). However, the controller needs to be appropriately provided with an accurate reference, just like in every closed-loop control system design. In our case the reference is the maximum power voltage, and it can be generated using several methods. P&O and INC can also be used to find the reference: Using algorithms combined with nonlinear controllers such as P&O BSC [19] and INC BSC [20] showed a better tracking and fast convergence. However, their drawback is that oscillations persist at the maximum power point, and they still fail to track the GMPP and stick to the LMPP under partial shading conditions.

To face this challenge, researchers tried to develop methods that can track the GMPP. They used optimization algorithms with controllers such as (PSO) [21-23], Harmony search (HS) [24], Ant colony optimization (ACO) [25], Differential evolution (DE) [26], Genetic algorithm (GA) [27], Hierarchical genetic algorithms [28], and Random search optimization algorithm (RSA) [29], Crow search algorithm (CSA) [30]. Using these techniques, all power peaks can be identified, with the largest peak being designated as the GMPP. In addition, we can find in the literature improved versions of these optimization algorithms used to track the GMPP, such as the Enhanced Autonomous Group PSO (EAGPSO) algorithm [31]. This enhanced verion provides faster tracking and higher efficiency than the regular PSO.

We have just seen that tracking the voltage of the maximum power point has been successfully accomplished using nonlinear control techniques. However, unlike PIDs, there are no defined techniques for tuning control gains, which pushes researchers to calculate them manually or sometimes uses other BSC method gains, which can lead to nonoptimal results. Therefore, we suggest in this work a new method that can generate the BSC gains using GA, which provides more opportunities to acquire an ideal tuning to manage the system response.

In this paper a hybrid method is proposed that combines GA with BSC. The objective is to control the PV system and track the GMPP: The BSC goal is to track the reference voltage generated with the GA by altering the duty cycle of the (DC-DC) converter. GA is also used to generate the BSC gains K_1 and K_2 for an optimal result.

The structure of this paper is as follows. The modeling of the PV module and the SEPIC are both covered in the second section. The suggested approach is presented in the third section. While the fourth and final portion, respectively, give the simulation results and conclusion.

2. Proposed Photovoltaic System

The photovoltaic system proposed in this work is presented in Fig.1. It consists of three main parts, which are a solar panel made up of three 55W modules connected in series, a DC-DC converter (type: SEPIC), and a resistive load of 150Ω.

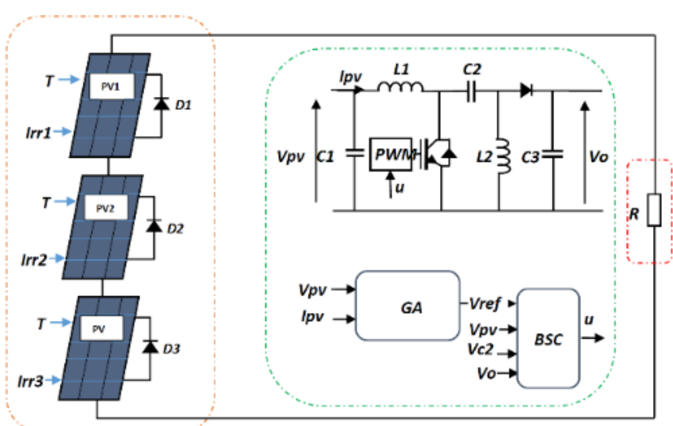


Figure 1. PV System Studied

2.1. Modelling of a Photovoltaic Module:

Due to its simplicity, the single diode model is frequently used to simulate solar modules. However, because the absolute errors of current and voltage are relatively high, the model's accuracy could degrade. Thus, the double diode model is taken into account in this work in order to have an appropriate modeling.

The following equation can be used to express the output current of a solar cell:

$$I = I_{ph} - I_{D1} - I_{D2} - \frac{V + R_s I}{R_p} \quad (1)$$

Where I and V represent the current and voltage of the PV module, I_{ph} represent the photocurrent, R_s , R_p are the series resistance, shunt resistance of the PV module and I_{D1} , I_{D2} are the currents in diodes 1 and 2 which are represented as follows:

$$I_{D1} = I_{01}\left(exp\left(\frac{V + R_s I}{a_1 V_t}\right) - 1\right) \quad (2)$$

$$I_{D2} = I_{02}\left(exp\left(\frac{V + R_s I}{a_2 V_t}\right) - 1\right) \quad (3)$$

After that, by replacing Eq.(2) and Eq.(3) in Eq.(1) we get:

$$I = I_{ph} - I_{01}\left(exp\left(\frac{V + R_s I}{a_1 V_t}\right) - 1\right) - I_{02}\left(exp\left(\frac{V + R_s I}{a_2 V_t}\right) - 1\right) - \frac{V + R_s I}{R_p} \quad (4)$$

Where (I_{01} , I_{02}) are the diode saturation currents, (a_1 ,a_2) are the ideality factors, "$V_t = \frac{kT}{q}$" is the thermal voltage, T is the temperature of the cell in Kelvin (K), q is the charge of electron (1.6×10^{-19}) and k is the Boltzmann constant.

For photovoltaic modeling, the factors a_1, a_2, I_{01}, I_{02}, I_{ph}, R_{s}, and R_{p} are crucial. The manufacturer datasheet does not provide them. In order to extract them, a hybrid method was used, combining analytical method with GA, as described in [32].Table 1 displays the SM55 module's datasheet parameters, while Table 2. presents the extracted parameters.

The meteorological conditions (Temperature "T" and Irradiance "G") have an impact on the extracted parameters:

$$I_{ph} = I_{ph,STC}\left(\frac{G}{G_{STC}}\right)\left(1 + k_i(T - T_{STC})\right) \quad (5)$$

$$I_{01} = I_{01,STC}\left(\frac{T}{T_{STC}}\right)^3 exp\left(\frac{q}{a_1 k}\left(\frac{E_{g,STC}}{T_{STC}} - \frac{E_g}{T}\right)\right) \quad (6)$$

$$I_{02} = I_{02,STC}\left(\frac{T}{T_{STC}}\right)^3 exp\left(\frac{q}{a_2 k}\left(\frac{E_{g,STC}}{T_{STC}} - \frac{E_g}{T}\right)\right) \quad (7)$$

$$R_s = R_{s,STC}\left(\frac{T}{T_{STC}}\right)^3\left(1 - 0.217 \times ln\left(\frac{G}{G_{STC}}\right)\right) \quad (8)$$

$$R_p = R_{p,STC}\left(\frac{G_{STC}}{G}\right) \quad (9)$$

$$E_g = E_{g,STC}(1 - 0.0002677 * (T - T_{stc})) \quad (10)$$

Table 1. Datasheet parameters for the SM55 PV module at standard test conditions (STC)

Module	SM55
V_m $[V]$	17.4
I_m $[A]$	3.15
I_{sc} $[A]$	3.45
V_{oc} $[V]$	21.7
N_s $[cells]$	*36*
K_i	1.2×10^{-3}
K_v	*-0.077*

Table 2. Parameters of the module SM55

Module	SM55
I_{ph} [A]	3.4500
I_{01}[A]	4.8140×10^{-10}
I_{02} [A]	1.3173×10^{-6}
R_S [Ω]	0.4333
R_p [Ω]	186.3065
a_1	1.0383
a_2	1.9638

2.2. DC-DC Converter

In order to match the impedance of the PV source and the load, every MPPT system needs a DC-DC converter. It helps avoiding disturbances in our application, by adapting the voltage level for controlling solar power under the effects of partial shade, enabling the photovoltaic power to follow the location of maximum global power. The converter used in this paper is a SEPIC and it's represented in Fig.1: It consists of coupling capacitor C_2, and output capacitor C_3, two inductors L_1 and L_2, diode D and load resistance.

This converter converts the input DC voltage to the required output voltage level by exchanging energy between the inductor L_1, capacitor C_1, and inductor L_2. Typically, the quantity of energy exchanged is managed by a power transistor switch (S1) such as MOSFET.

From [33] the following state equations can be used to describe the mathematical representation of the SEPIC:

$$\begin{cases} \dot{V}_{pv} = \frac{I_{pv}}{C_1} - \frac{I_{L1}}{C_1} \\ \dot{I_{l_1}} = \frac{(u-1)(V_{c2}+V_0)}{L_1} + \frac{V_{pv}}{L_1} \\ \dot{V_{c_2}} = \frac{(1-u)I_{l1}}{C_2} + \frac{dI_{l_1}}{C_2} \\ \dot{I_{l_2}} = \frac{-uV_{c2}}{L_2} + \frac{(1-u)V_0}{L_2} \\ \dot{V}_0 = \frac{(1-u)(I_{l2}+I_{l_1})}{C_3} - \frac{V_0}{RC_3} \end{cases} \quad (11)$$

3. Proposed GA-BSC Based GMPPT Technique

This study's goal is to control the chosen PV system and track the GMPP. The proposed technique used in this study combines GA with BSC. The nonlinear BSC is programmed to track the reference voltage. The controller, because of its nonlinear function, develops the nonlinear control rule that modulates a pulse width signal, which in turn drives the system via the SEPIC attached to the load. While The GA has two objectives, the first one is generating the reference voltage that corresponds to GMPP and second one is to find the optimal value for the parameters K_1 and K_2 of the BSC.

The GA is a search heuristic algorithm that is based on Darwin's theory of the evolution of species. In order to solve a problem, this algorithm mimics the process of natural selection by simulating "survival of the fittest" among individuals from successive generations. A GA considers the following five stages:

-Initial population: Each individual within a population is unique. These differences, more or less significant, will be decisive in the selection process.

-fitness function: It establishes an individual's level of fitness. Following the population's composition, the fitness function assigns a score to each individual.

-Selection: The individual chosen for reproduction will depend on their fitness rating. The most fit individuals are permitted to pass on their genes to the following generation.

-The crossover: The crossover begins with two parents exchanging their property for the benefit of their two children.

-The mutation: Entails changing an individual's characteristics with a slim chance of chance.

When the population has converged, the algorithm stops working. The Genetic Algorithm is then stated to have offered a number of solutions to our problem.

The first objective is to identify the PV module's optimal voltage, which is constrained to a range between $0V$ and V_{oc}, and seeks to determine the GMPP. The second objective serves to find the optimal BSC parameters K_1 and K_2.

3.1. *Genetic Algorithm MPPT*

The GA is used to generate the reference voltage and the K_1 and K_2 BSC parameters. For the reference voltage the initial population used is a vector composed if 6 individuals that cover the interval $[0V, V_{oc}]$. These individuals are delivered to the DC-DC converter one at a time in the form of reference voltages. The global maximum power is attained and stored once the ideal reference voltage has been established.

After testing every individual of the generation, the selection is carried out by elitism. This action is based on the following equation:

$$v_i(n) = rand(1)v_i(n-1) + \big(1 - rand(1)\big)v_j(n-1) \quad (12)$$

Individual mutation is extremely unlikely to happen. The algorithm uses the following equation to change individuals randomly in this step:

$$v_i(n) = v_{min} + rand(1)(v_{max} - v_{min}) \quad (13)$$

Where v_{max} and v_{min} are respectively the maximum and minimum voltages in the search space. The Eq.(14) and Eq.(15) are used for stopping the search process to minimize the oscillations often brought on by the mutation and get the best answer among all the generations as an ideal reference voltage. Temperature or solar irradiation can vary, that's why the algorithm has been modified to restart the search procedure whenever they change. In fact, when the following circumstances exist, the (GA) is reset:

$$v(n+1) - v(n) < \Delta v \quad (14)$$

$$\frac{p_{pv}(n+1) - p_{pv}(n)}{p_{pv}(n)} > \Delta p_{pv} \quad (15)$$

3.2. *GA-Backstepping Controller*

This section synthesizes the nonlinear controller. Once the reference voltage is generated by the GA, the controller uses it to drive the PV system to its maximum power point. The (BSC), whose is based on Lyapunov theory, is the controller suggested in this paper.

First Step is defining the first tracking error, it's the difference between the actual PV voltage and the reference voltage generated by GA:

$$\epsilon_1 = y - y_{ref} = V_{pv} - V_{ref} \quad (16)$$

The time derivative of ϵ_1 is:

$$\dot{\epsilon_1} = \dot{V}_{pv} - \dot{V}_{ref} \quad (17)$$

Therefore, substituting $\dot{V}_{pv}$ by its expression in Eq.(11), Eq.(17) can be shown as:

$$\dot{\epsilon_1} = \frac{I_{pv} - I_{L1}}{C_{pv}} - \dot{V}_{ref} \quad (18)$$

Lyapunov functions are added to the controller to guarantee stability:

$$V_1(\epsilon_1) = \frac{1}{2}\epsilon_1{}^2 \quad (19)$$

With $V_1(\epsilon_1) > 0$

The time derivative of $V_1(\epsilon_1)$ gives:

$$\dot{V_1}(\epsilon_1) = \epsilon_1\dot{\epsilon_1} = \epsilon_1\left(\frac{I_{pv} - I_{L1}}{C_{pv}} - \dot{V}_{ref}\right) \quad (20)$$

The time derivative of the Lyapunov function $V_1(\epsilon_1)$ must be negative in order to maintain Lyapunov stability. In actuality, that is achievable if this circumstance holds true:

$$\frac{I_{pv} - \alpha_1}{C_{pv}} - \dot{V}_{ref} = -K_1\epsilon_1 < 0 \quad (21)$$

To meet the performance standards, K_1 is a positive parameter ($K_1 > 0$) that can be selected or calculated. Assuming the virtual control $\alpha_1 = (I_{L1})_d$ that enables the stabilization of ϵ_1. Where $(I_{L1})_d$ is the desired value of the first inductor's current. As a result, the virtual control α_1 can be stated as follows using Eq.(21):

$$\alpha_1 = -C_{pv}\dot{V}_{ref} + I_{pv} + C_{pv}K_1\epsilon_1 \quad (22)$$

Second Step is defining the second tracking error:

$$\epsilon_2 = I_{L1} - \alpha_1 \quad (23)$$

Rearrange Eq.(23) gives:

$$I_{L1} = \epsilon_2 + \alpha_1 \quad (24)$$

By inserting Eq.(24) into Eq.(18), we get:

$$\dot{\in}_1 = \frac{I_{pv} - (\epsilon_2 + \alpha_1)}{C_{pv}} - \dot{V}_{ref} \quad (25)$$

Replacing $\alpha_1$by its value gives:

$$\dot{\in}_1 = \frac{I_{pv}}{C_{pv}} - \frac{\epsilon_2 - C_{pv}\dot{V}_{ref} + I_{pv} + C_{pv}K_1\epsilon_1}{C_{pv}} - \dot{V}_{ref} \quad (26)$$

If we condense Eq.(26), we get:

$$\dot{\in}_1 = -\frac{\epsilon_2 + C_{pv}K_1\epsilon_1}{C_{pv}} \quad (27)$$

Replacing $\dot{\in}_1$in the Eq.(20):

$$\dot{V_1}(\epsilon_1) = -\frac{\epsilon_1\epsilon_2}{C_{pv}} - K_1\epsilon_1{}^2 \quad (28)$$

The time derivative of ϵ_2 can be represented as follows using Eq.(11) and Eq.(23):

$$\dot{\epsilon_2} = \frac{1}{L_1}V_{pv} - \frac{1}{L_1}(1-u)(V_{c2} + V_0) - \dot{\alpha_1} \quad (29)$$

Where:

$$\dot{\alpha_1} = -C_{pv}\ddot{V}_{ref} + \dot{I}_{pv} + C_{pv}K_1\dot{\epsilon_1} \quad (30)$$

The second Lyapunov function $V_2(\epsilon_1, \epsilon_2)$ is taken into consideration to guarantee the convergence of both errors to zero.

$$V_2(\epsilon_1, \epsilon_2) = V_1(\epsilon_1) + \frac{1}{2}\epsilon_2{}^2 \quad (31)$$

The time derivative of $V_2(\epsilon_1, \epsilon_2)$ gives:

$$\dot{V_2}(\epsilon_1, \epsilon_2) = \dot{V_1}(\epsilon_1) + \epsilon_2\dot{\epsilon_2} \quad (32)$$

Taking into account the new expression of $\dot{V_1}(\epsilon_1)$ from Eq.(28):

$$\dot{V_2}(\epsilon_1, \epsilon_2) = -K_1\epsilon_1{}^2 - \frac{\epsilon_1\epsilon_2}{C_{pv}} + \epsilon_2\dot{\epsilon_2} \quad (33)$$

The following condition must be met in order to achieve Lyapunov stability, $\dot{V_2}(\epsilon_1, \epsilon_2)$ must be negative, which implies the following condition has to be satisfied:

$$-\frac{\epsilon_1}{C_{pv}} + \dot{\epsilon_2} = -K_2\epsilon_2 < 0 \quad (34)$$

With K_2 is a positive constant $K_2 > 0$ that presents a regulation parameter.

As a result, the real control is deduced based on Eq.(34) and Eq.(29):

$$u = \left[L_1\left(-K_2 \in_2 + \frac{\in_1}{C_{pv}} + \dot{\alpha_1}\right) - V_{pv}\right]\frac{1}{V_{c2} + V_{out}} + 1 \quad (35)$$

Thus:

$$\dot{V_2}(\epsilon_1, \epsilon_2) = -K_1\epsilon_1{}^2 - K_2\epsilon_2{}^2 < 0 \quad (36)$$

Which ensures converging ($\in = \epsilon_2, \epsilon_2$) asymptotically to 0. Thus, convergence of y to y_{ref}.

-The parameters K_1 and K_2:

The controller's gains have a significant impact on how it responds. There are tuning techniques for PID-type controllers that enable achieving the values of their gains to get the best response. However, there is no defined technique for tweaking a backstepping controller's gains.

The suggested approach uses GA with the objective function of the voltage error $\in_1$to obtain the optimum BSC gains K_1 and K_2 values.

$$f_{obj} = \in_1 = V_{pv} - V_{ref} \quad (37)$$

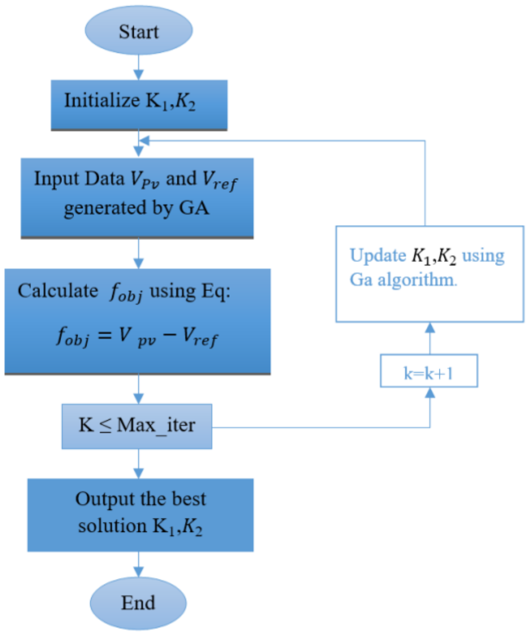


Figure 2. Flowchart of proposed Genetic Algorithm for BSC gains

Table 3. The SEPIC Components

Parameters	Values
L_1(mH)	0.35
L_2(mH)	0.35
C_1(μF)	440
C_2(μF)	440
C_3(μF)	740

Table 4. Backstepping controller parameters

BSC Gains	Proposed method P&O-BSC INC-BSC	GA-BSC PSO-BSC
K_1	1954.7	435
K_2	687.5369	500

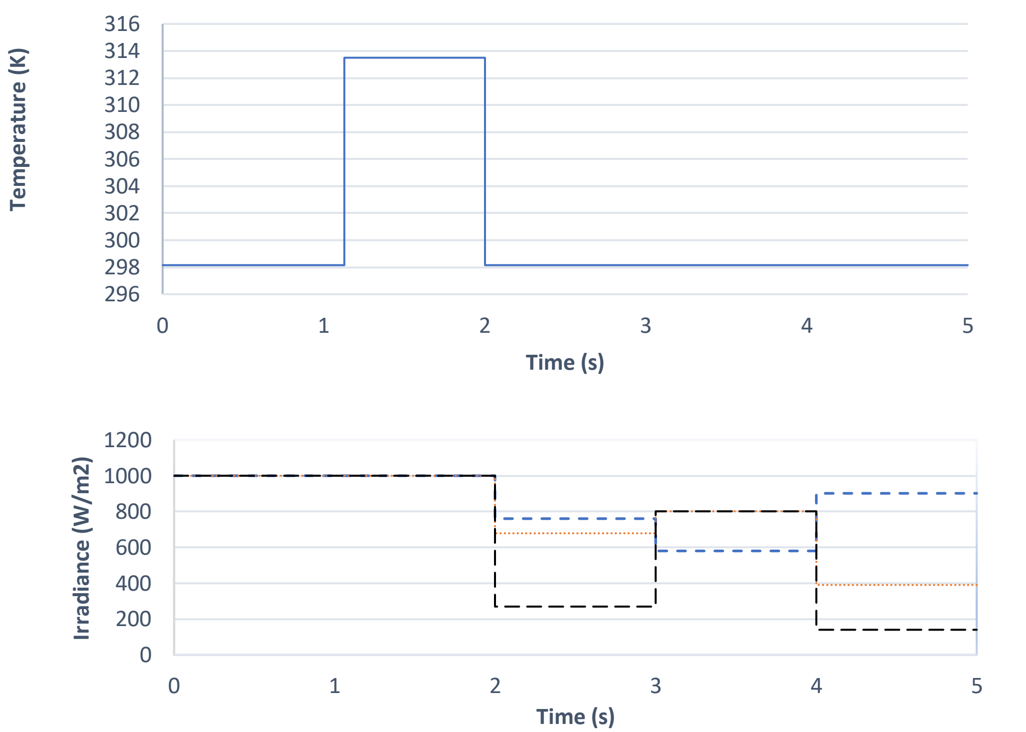


Figure 3. Meteorological conditions

4. Results and Simulation

The performance of the suggested hybrid GA-BSC is validated by a number of experiments utilizing numerical simulations built in the MATLAB/Simulink environment. The PV array used in this work consists of three PV modules of SM 55 W connected in series. This PV system is intended to be pushed to the maximum power point.

Due to the failure of the majority of MPPT algorithms in tracking the GMPP under rapidly changing operating settings, we explore the robustness of our systems under both uniform and irregular climatic situations, as shown in Fig.3: During the interval [0s,2s] the irradiation was fixed to 1000 W/m2 for the three PV modules. In the second interval [2s,5s] the irradiance was dropped and raised for the three PV modules to simulate the partial shading conditions.

For the temperature, it was 298.15 K between 0 to 1.13 seconds, 2 to 5 seconds, and it increased to 313.5 K between 1.13 to 2 seconds.

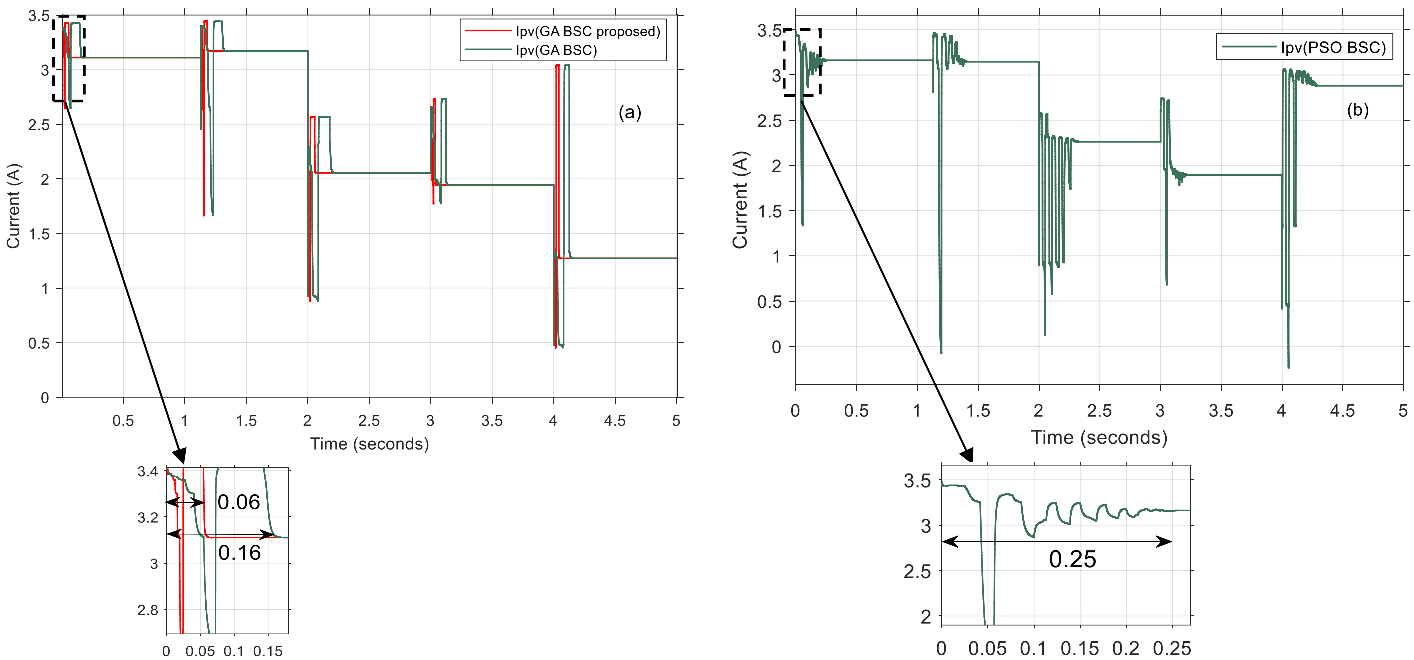
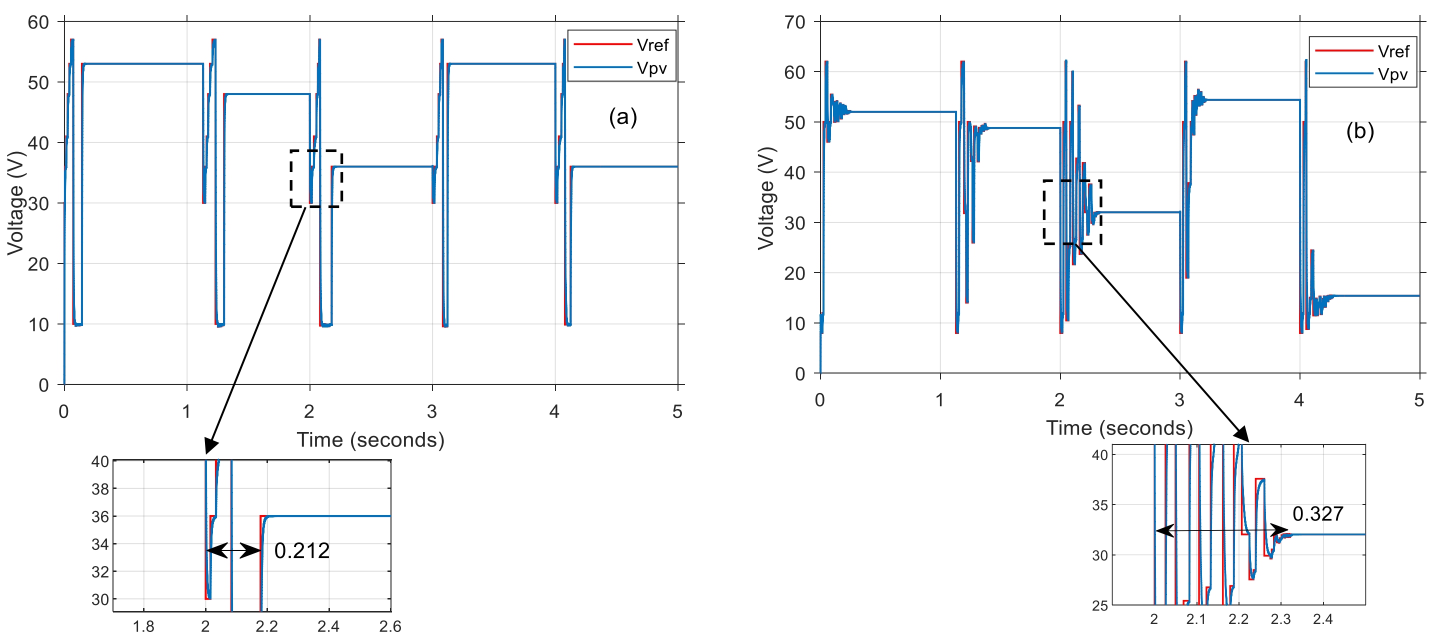


Figure 4. Photovoltaic current for GA-BSC, GA-BSC proposed (a), and PSO-BSC (b)



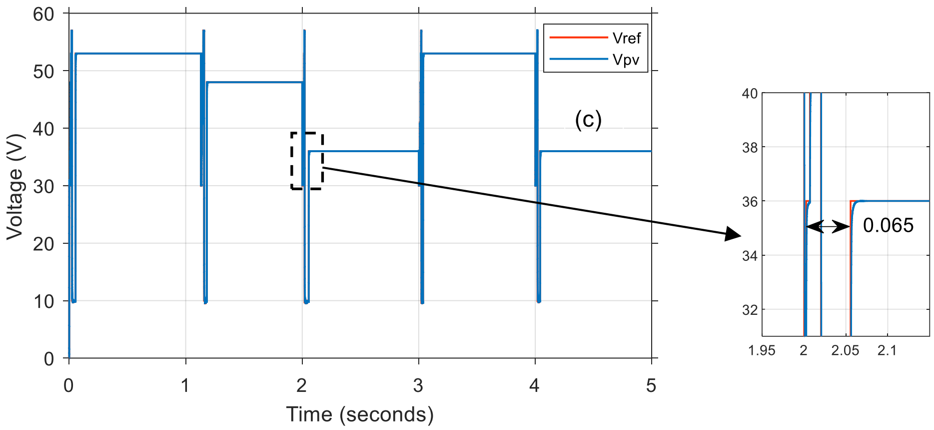


Figure 5. Photovoltaic voltage for GA-BSC (a), PSO-BSC (b) and GA-BSC proposed (c)

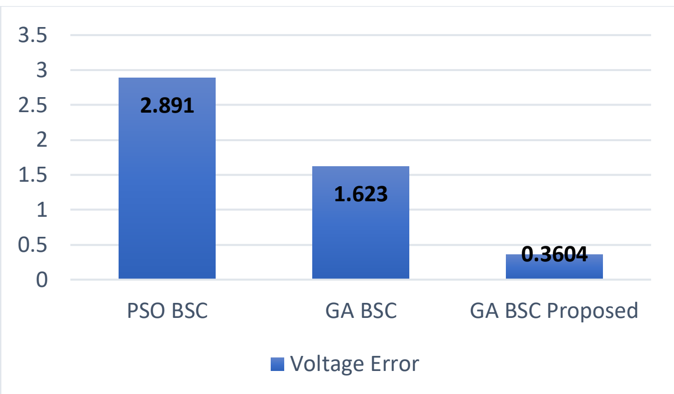


Figure 6. The Voltage Error

The proposed method uses GA to generate the reference voltage and the optimal BSC gains K_1 and K_2. The reference voltage is then exploited by the nonlinear BSC to drive the PV System to work at its maximum power point. The system consists of a SEPIC, its characteristics are shown in Table 3.

The suggested hybrid method is initially examined at standard test conditions (STC), in the interval [0s,1.13s] which corresponds to an irradiance of 1000 W/m2 and a temperature of 25°C.

Figure 4 and Fig.5 shows the photovoltaic current and voltage of three methods, PSO-BSC, GA-BSC, and the proposed GA BSC method with the calculated gains. The BSC gains for these methods are shown in Table 4: The BSC gains for the PSO-BSC method [20] are (K_1= 435 K_2=500). The GA-BSC method was tested with the same BSC gains as the PSO-BSC method to be able to see how much we can improve with optimal gains. The proposed method uses GA with BSC but the controller gains K_1 and K_2 were calculated using GA (K_1= 1954.7 K_2=687.5369).

As can be seen from these figures, thanks to the GA-BSC technique proposed, where we have calculated the optimal BSC K_1 and K_2 parameters with GA, the photovoltaic voltage tracks the reference voltage fast and accurately, with less oscillations and it stabilize faster than the other method. The GA BSC proposed method took 0,065 seconds to stabilize, while the GA BSC standard method with nonoptimal gains took more than triple the time of the proposed method 0,212 seconds, and PSO-BSC method took 0.327 seconds eight times slower than the proposed method.

The same thing goes for the photovoltaic current: The GA BSC suggested technique took 0,06 seconds to stabilize, whereas the GA-BSC standard method took 0,16 seconds, which is more than twice the amount of time as the proposed method. The PSO-BSC method took 0.25 seconds, which is four times the duration of the proposed method.

The voltage error which is the difference between the photovoltaic voltage and the reference voltage, can be used as a criterion to evaluate our method. Smaller error values mean that the photovoltaic voltage will tend to be close to the reference voltage, which means that the method tested has better tracking.

Figure 6 displays the voltage error of the three methods (PSO-BSC, GA-BSC, GA-BSC Proposed). The GA-BSC method has a smaller error than the PSO-BSC method, which confirm that GA algorithm is better than PSO algorithm at tracking the MPP.

In addition, we can clearly see the advantage of the proposed method with the calculated gains using GA. It has a voltage error that is four times less than the same method but with nonoptimal gains: This shows how important is to have the optimal gains for the controllers in every method.

-Evaluation of the Proposed Hybrid System at STC.

Under these circumstances, a maximum power of 165W and a maximum voltage of 52.2V are anticipated based on the specifications of the PV module studied (Table 1). Simulation results are illustrated in the following figures:

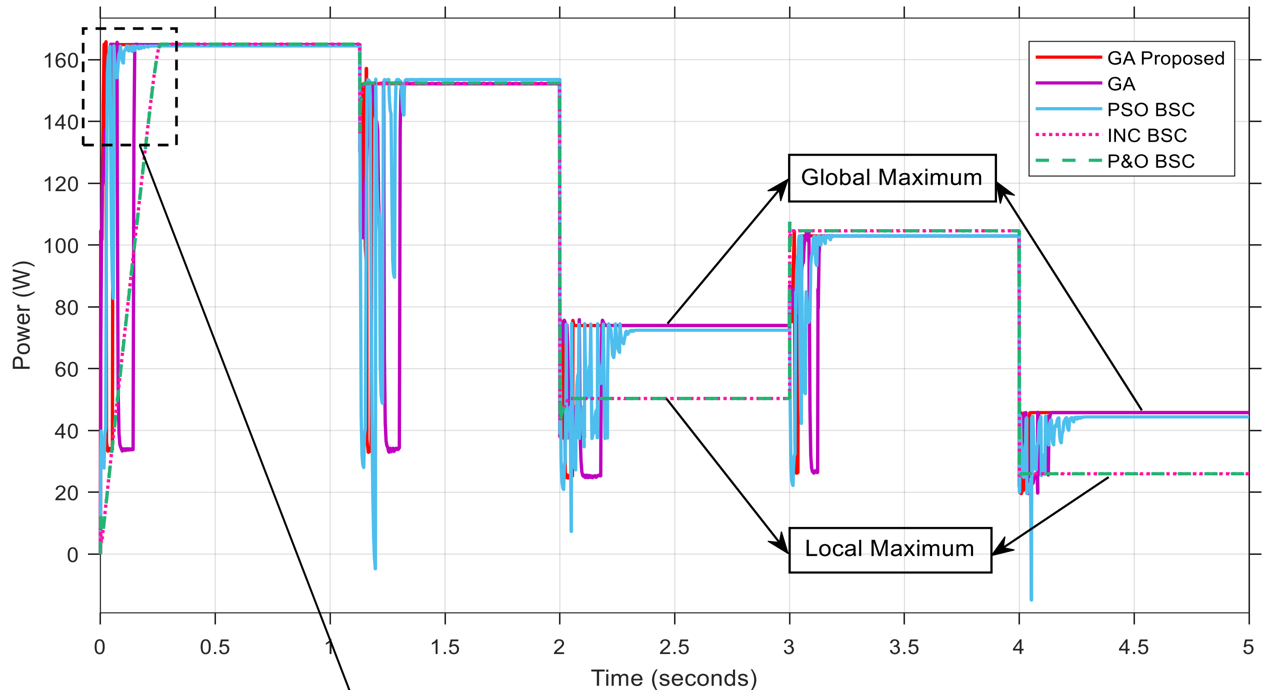


Figure 7. Comparison of MPPT and GMPPT techniques under various meteorological conditions

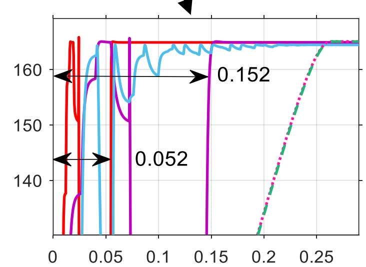


Figure 8. Comparison of MPPT and GMPPT techniques under STC

Figure 7 shows the tracking of the MPP power when the systems are put through the aforementioned situations. The power figure demonstrates the suggested hybrid system's strong MPP tracking capability. The suggested hybrid approach with the calculated BSC parameters K_1 and K_2 follows and stabilize at the MPP at 0.052s. In comparison to GA-BSC and PSO-BSC with a non-optimal K_1 and K_2 (Table 4), they can follow the MPP at 0.152s, 0.223s respectively, which is more than triple the time of the proposed method. The P&O-BSC, INC-BSC that take 0.252s, which is 5 times the time of the proposed method.

-Evaluation of the Proposed Hybrid System at various meteorological conditions.

The hybrid proposed method system is now functioning under the worst possible circumstances. The goal of this test is to assess the viability of the suggested MPPT system and its improved resilience against challenging operating circumstances.

Figure 8 presents a comparison of MPPT and GMPPT techniques (INC-BSC, PSO-BSC, P&O-BSC, GA-BSC) at various meteorological conditions. In this figure we can see the advantages of the suggested technique based on GMPPT in diverse meteorological scenarios as well as the drawbacks of the other MPPT approaches in non-uniform meteorological environments. Same as the STC, the proposed method tracks and stabilizes at the MPP faster than the other methods, and it succeeds in tracking the GMPP under uniform and particle shading conditions. On the other hand the MPPT approaches (P&O-BSC, INC-BSC) show significant oscillations in every temperature and irradiance changes. Under partial shading these methods fail to track the GMPP and stack to LMPP, causing a considerable power loss, (33% power loss compared to the proposed method).

The GA method, on the other hand, is more efficient and can be used in place of the PSO algorithm because it is faster than the PSO algorithm. In actuality, the parameters K_1 and K_2 of the BSC were calculated By GA in the proposed GA BSC method making the proposed method faster and more accurate than the GA BSC with nonoptimal gains and PSO-BSC method.

5. Conclusion

The main objective of this paper was to create a reliable MPPT Method that can locate and track the global maximum power point at any condition. The proposed method consists of Genetic Algorithm combined with Backstepping controller.

The Genetic Algorithm was used for two main objectives, the first one is to quickly and reliably provide a reference voltage, the second objective is to find the optimum K_1 and K_2 parameters for the backstepping controller. In the other hand the Backstepping controller was used to track the reference voltage found, by modifying the SEPIC duty cycle. The proposed method was compared to other methods (GA-BSC, PSO-BSC, P&O BSC, INC BSC) to be validated. The simulation results produced by the MATLAB-Simulink software has shown that P&O_BSC and INC_BSC methods can track the maximum power point in uniform climatic conditions. When partial shadowing occurs, these MPPT approaches have a significant flaw as they were not able to track the GMPP and just stick to LMPP, resulting power losses, unlike the proposed method that can detect the partial shading effect by following the GMPP which minimize the power losses. In addition, we saw that the proposed approach (GA-BSC) with the optimal K_1 and K_2 parameters for the backstepping controller generated using GA follows and stabilize at the GMPP 3 times faster than the GA-BSC with non-optimal K_1 and K_2 parameters, and 5 times faster than (P&O-BSC, INC-BSC). This showed how important it is to get the optimum values for the controller gains. Furthermore, the GA-BSC method was compared to the PSO-BSC method, which showed a significant advantage to the GA method that can be faster with minus oscillations and more reliable.

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