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Robust Modified Flower Pollination Algorithm for Power Quality Enhancement in an Autonomous 31-Level Cascaded H-Bridge Photovoltaic Inverter with Partial Shading Conditions

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Abstract: The effect of global warming and the scarcity of fossil fuels has created an enormous problem in today's era. To overcome such a problem, renewable energy sources, particularly solar energy, play a crucial role in meeting the developing need for power. However, the design of the Solar Photovoltaic (PV) system is interrupted by various factors such as the effect of temperature, isolation, aging, partial shading conditions, etc. Among all the factors mentioned, partial shading results in the significant diminution of power. To address this shading effect and enhance the flexibility of the PV system in terms of better utilization and energy extraction, a 31-Level Cascaded H-Bridge Multilevel Inverter (CHB-MLI) has been implemented to the autonomous PV system comprising of Maximum Power Point Tracking (MPPT) controller, boost converter and variable loads in MATLAB/Simulink architecture. To track maximum power from PV during varying irradiance and temperature and to further improve the system performance in terms of better convergence speed, an MPPT system with a Modified Flower Pollination Algorithm (MFPA) based PID controller has been proposed in this paper. To justify the suggested approach, the is-landed PV system is led to variation in irradiance and load. A detailed comparison of the proposed MFPA technique with classical control techniques has been meticulously discussed. The results obtained indicate that the suggested MFPA tuned PID with MLI outperforms the conventional methods in better system stability, reduced harmonics, and enhanced capacity to track maximum power from the PV system. In addition to this, the Total Harmonic Distortion (THD) using Fast Fourier Transform (FFT) has been found to verify IEEE-1547 power quality constraints. The values are found to be well within limits, thus justifying its real-time applications.

Keywords: Maximum power point tracking (MPPT); cascaded h-bridge multilevel inverter (CHB-MLI); flower pollination algorithm (FPA); modified flower pollination algorithm (MFPA);; boost converter; partial shading.

I. Introduction

The generous economic development of India has a massive demand for its energy resources. The production of energy has enhanced in current years, and more progress is expected in upcoming years. The scarcity of conventional fuel materials and accumulation of petroleum crisis, which are meant for conservation, has led to strong awareness against the circulation of renewable power, indicating solar, wind turbine, geothermal, biomass, and hydro to achieve an adequate and efficient supply of energy [1]. Out of all renewable resources, generation of photovoltaic power based on solar energy has been verified to be a much energetic and promising potential due to several advantages such as [2]: 1) installation of low power generation is possible for giving small or medium level of voltages; 2) natural source of renewable energy; 3) pollution-free; 4) abundantly available; 5) hassles low maintenance, etc. Various topologies have been recognized to handle photovoltaic energy production, which relies on several factors such as the availability of PV panels, quality of signal output, enhancement of system efficiency, and management of complexity [3, 4].

1.1 Motivation and Incitement

The PV system sometimes fails to deliver power efficiently, thus degrading the system's accuracy due to several exceptional conditions such as variable temperature, inhomogeneous irradiance, and improper selection of converters. The problem gets even more complex when the array receives non-uniform irradiance [5]. The various factors for unequal irradiance on PV modules can be the variation of incline angles of modules in an array, partial shading by the close entity, scramble of birds, single or multiple leaves that oppose the cell/module, snow or dust particle on the same modules within the array [6, 7].

To surmount the faults occurring in the entire PV system, this research proposes a well-organized power electronics interface whose switching action is stipulated by the intellectual controller. Unlike a conventional two-level inverter, a Multilevel Inverter (MLI) is projected to operate as an interface whose function is demonstrated by the intelligent controller to alter the transmission of switches based on fault and normal circumstances [8]. For a grid of medium voltage, it is challenging to assemble individual power semiconductor switches directly. Therefore, an MLI is recognized as a substitute in high power and medium voltage conditions. Furthermore, as a cost-effective solution, MLI enhances power ratings and permits low power applications in renewable energy sources [9].

Furthermore, it has been identified that the MLIs can operate in an unbiased condition at less power when the fault occurs. Due to the high output voltage quality, the MLI is widely used in the power sector. It also suggests an enhanced option at the high-power end due to the maximum ratings of volt-amperes [10].

1.2 Literature Review

Enhancement in reliable power generation management under various environmental situations can be brought about by implementing MPPT control techniques [11]. Many authors have suggested multiple methods in the literature such as conventional PID controller [12], Fuzzy tuned PID controller [13], heuristic technique tuned PID controller [14], etc. The PID controller is generally used due to less cost and simplicity in design. Nevertheless, the linear PID controller cannot respond to variations in the operating situation and thus cannot exhibit optimal performance [15]. On the other hand, the fuzzy-based controller is nonlinear, but its gain values must be manually tuned and need human intervention. However, nature-inspired optimization techniques can automatically respond to system parameters changes without physically changing the control parameters. In the recent past, there are many evolutionary techniques available in the literature as suggested by many authors, such as Particle Swarm Optimization (PSO) [16], Weighted Superposition Attraction Algorithm (WSAA) [17], Bee Colony Optimization (BCO) [18], Brain Storming Optimization (BSO) [19], Spider Monkey Algorithm (SMA) [20], Crow Search (CS) [21], Flower Pollination Algorithm (FPA) [22], etc.

1.3 Problem Formulation

Among all, the FPA based evolutionary techniques have been proven to be more efficient than others in terms of better search performance and convergence speed. To further enhance the convergence speed, local and global search process, this paper suggests a Modified Flower Pollination Algorithm (MFPA) based evolutionary technique for optimal and dynamic tuning of the PID controller parameters. The proposed controller controls power and brings about inverter control for effective THD elimination [23]. Also, for addressing the shading effect and improving the supply of the PV system in terms of better utilization and energy extraction, a 31-Level Cascaded H-Bridge Multilevel Inverter (CHB-MLI) has been implemented to the autonomous PV system instead of a traditional two-level inverter.

1.4 Contribution to Knowledge

The significant contributions of this research work are enumerated below:

- Design of a robust MFPA for optimal parameters selection of the MPPT and inverter control. As well as to ensure better convergence speed as compared to conventional FPA.
- Justify the use of a bypass diode in enhancing PV system characteristics during shading conditions.
- Comparative analysis of various system characteristics concerning the conventional PID, FPA, and proposed MFPA technique by subjecting the system to multiple uncertainties in irradiance and load.
- Implementation of a 31-Level CHB-MLI to address the shading effect and enhance the flexibility of the PV system in terms of better utilization and extraction of energy to the islanded PV system supplying power to variable loads compared to the traditional two-level inverter.
- Comparative study of conventional two-level inverter with 31-Level CHB-MLI by calculating the THDs through FFT analysis.
- Detailed study of the THD values, controller parameters, and power system parameters between the conventional and proposed MPPT methods.

1.5 Paper Organization

The remaining part of the paper is organized as follows. Section 2 discusses the modeling of the system undertaken for study and the partial shading effects. The conventional and the proposed MPPT control techniques and MLI are elaborated in Section 3. In Section 4, the results obtained from simulation under varying conditions of irradiance and load are illustrated and analyzed for real-time implementation and justification of the application of the suggested technique. Lastly, the entire research work is concluded in Section 5.

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II. System Modeling

Figure 1 illustrates the block diagram representation of the total system comprising of PV system with partial shading conditions, boost converter, MPPT controller, 31-Level CHB-MLI, and variable loads. In addition, the values of each system parameter have been introduced in the Appendix A.

2.1 Effect of Partial Shading

In an extensive photovoltaic system, partial shading often occurs because of the vast surface area and vigorous conditions of weather. It results in a massive power failure, thus threatening the solar generating system's protection, consistency, and power management.The characteristics curve of the PV system's Power-Voltage (P-V), Current-Voltage (I-V), and Power-Current (P-C) represent several peaks due to unequal shading[24]. These curves comprise one global maxima and numerous local minima points. For several irradiance conditions, the PV system curves are generally multimodal, mainly obtained by creating a by-pass diode. When a partial shading condition occurs, a single PV cell's shaded region decreases the module's total current, ensuring the voltage rises across the unshaded part. This increase in voltage usually results in the condition of reverse bias. This whole occurrence leads to hotspot heating and rigorous distraction of heat in shaded cells, thus causing the damage of cells. Here, a bypass diode is connected in shunt where it turns into forward bias, which leads to the flow of current. Therefore, short circuit current reduces, which naturally prevents hotspot heating [25].

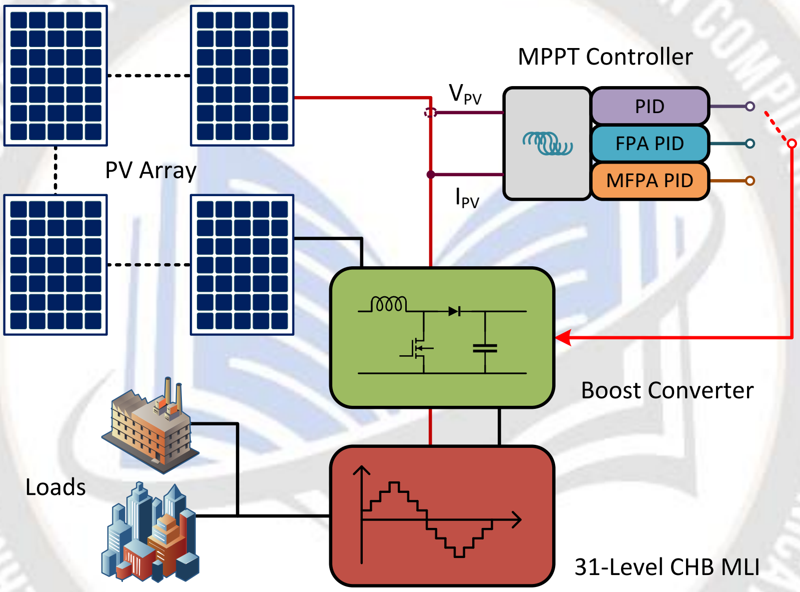

Figure 1: Block diagram representation of the total system

III. Comparative Study of MPPT Techniques and Multilevel Inverter

The power obtained from the PV generating system is affected by various atmospheric conditions such as temperature, insolation, partial shading, [26], etc. As a result, the characteristics shown by PV are highly nonlinear and dynamic. So, extracting maximum power becomes very difficult. As a solution to this issue, the concept of MPPT is developed to enhance the system's efficiency. Maximum Power Point (MPP) is the best operating point of the PV generating system at which maximum energy is productively delivered to the load. Many types of MPPT methods have been presented in the literature by many researchers to track maximum power from the PV system.

This paper proposes an MFPA optimization technique to dynamically tune the PID control parameters for efficient MPPT owing to its faster convergence speed and better searchability. Furthermore, the characteristics of the islanded PV system with the proposed technique obtained are contrasted with other classical methods such as FPA based PID and conventional PID controller.

3.1 MPPT Techniques

3.1.1 Proportional Integral and Derivative (PID) controller

PID controller is a linear controller consisting of the proportional, integral, and derivative control modes. It minimizes error using a feedback system. The proportional parameter Kp helps increase the rise time, the integral parameter Ki significantly minimizes the steady-state error, and the derivative parameterKd reducesthe settling time and peak overshoot. The main merit of this controller is that it can employ all three controllers together to achieve a robust control signal [12]. However, the major drawback is that the PID controller cannot respond due to the unpredictable

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nonlinear nature of the power system, variation in load demand, or any system parameters. So proper tuning is required in offline mode for accurate functioning, which makes it lose its effectiveness.Figure 2 shows the block diagram of the conventional PID controller**.** The transfer function of the PID controller is given as:

$$u(t) = Kp * e(t) + Ki * \int e(t)dt + Kd * d/dt\, e(t) \quad (1)$$

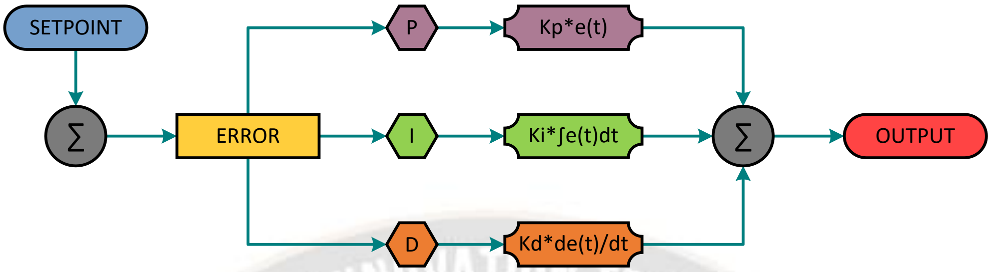

Figure 2: Block diagram of conventional PID controller

3.1.2 Flower Pollination Algorithm (FPA)

For a long time, researchers are being inspired by nature to answer tremendousdemanding issues with the help of various admirable metaheuristic techniques of optimization. However, our biotic system has a few mesmerizing features that inspire these techniques, which are proved effective in fixing these issues by finding an optimum solution [27]. Such a versatile and modern technique is FPA, basing on the act of pollination of flowing plants. Over 125 years, flowers are playing a crucial role in the evolution of these flowering species [28]. Flower's essential function is to spawn through the act of pollination. Pollination occurs when the male anther conveys its pollen grains to the female stigma of a flower of the alike or different plant [22]. Pollinators such as insects, birds are responsible for this transfer. Pollination is of two types based on the category of pollinators:

1. Abiotic Pollination: Pollination is raised due to non-living beings such as wind, water, rain, etc.
2. Biotic Pollination:Pollination is raised due to living beings such as honeybees, bats, squirrels, insects, birds, etc. Above 80% of the propagation is caused by this pollination in flowering plants [23].

Few pollinators have an attractive attribute of hitting only specific flower species, avoiding others known as pollinator constancy. Following are the advantages of these pollinator constancies: a) Increase the probability of transferring pollen grains to the same species of alike or different plants, which let the flowers spawn, and b) Pollinators are also too familiar with the nectar supply from these specific flowers, requiring less memory, and exploration cost. In addition, it confirms the inlet of nectar into stigma and the occurrence of pollination.

There are two ways for the occurrence of pollination:

1. Self Pollination: Pollination occurs by the same flower or another flower on the same plant. Usually abiotic since carried out by non-living beings.
2. Cross Pollination:Pollination occurred by another flower of the other plant of similar species [29]. Usually biotic since carried out by living beings.

Pollinators such as honeybees, birds, etc., usually manifest the behavior of Lévy flight to optimize their exploring ability for transferring pollen grains [30]. It signifies an arbitrary jump or flies that a pollinator takes, where the step's length has a probability division, usually with a wide variance. In addition, the attribute of the pollinator constancy helps them to distinguish between alike and different flowers. Rules that specify the characteristics of pollination, habitat of the pollinators, and the pollinator constancy are as follows:

- Rule 1: Pollinators show Lévy flight attributes
- Rule 2: Abiotic and Self-pollination are an intrinsic part of local pollination.
- Rule 3: Spawn probability is enhanced due to the pollinator constancy and is also proportional to the aspects of involved flowers.
- Rule 4: Switching probability $p_r \in [0, 1]$ usually controls the occurrence of global and local pollination.

Dissimilar to the real world, it is assumed that a lone flower is at each plant, and a lone pollen can be released by each flower [30]. Thus, it is not needed to distinguish a pollen, a flower, or the optimum solution to an issue. So, the lone pollen or flower can be referred to by the term 'y_i'.

3.1.2.1 Global Pollination Search Process

In search of diversity and optimal spawn, a long distance is covered by the biotic pollinators in global pollination. Mathematical representation of FPA's rules (1) and (3) can be expressed as follows:

$$y_i^{t+1} = y_i^t + L\,(g^* - y_i^t) \quad (2)$$

Where, $'y_i^t'$ is the solution or the lone pollen at the iteration $'t'$, $'g^*'$ is the ideal solution among other solutions of that iteration and $'L'$ is the step size used to direct the

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pollination potential and can be obtained from Lévy distribution using (3):

$$L \sim \frac{\lambda * \Gamma(\lambda) \sin\left(\frac{\pi\lambda}{2}\right)}{\pi} \frac{1}{s^{1+\lambda'}} \quad , (s "0) \tag{3}$$

Where, $\Gamma(\lambda)$ is the standard gamma function valued as 1.5. For step size $s > 0$, only this distribution is used.

3.1.2.2 Local Pollination Search Process

There is the involvement of abiotic pollinators in local pollination. Mathematical representation of FPA's rule (2) and (3) that describes the local pollination and pollinator constancy severally are expressed in (4):

$$y_i^{t+1} = y_i^t + € (y_j^t - y_k^t) \tag{4}$$

Where, $'y_j^{t}'$ and $'y_k^{t}'$ are the pollens of the flowers of similar species from different plants, $'€'$ is an arbitrary vector. Attributes of pollinator constancy emulate this equation. If $'y_j^{t}'$ and $'y_k^{t}'$ are the pollens of a similar species belong to the same community, and then the equation will be enhanced with a random local walk if found $'€'$ from a random distribution whose interval is [0, 1].

3.1.2.3 Switch Probability

The percentage and frequency of each type of pollination must be considered necessary. A switch probability p_r followed in rule (4) is used to emulate the crucial attributes, where p_r value decides whether the global or local pollination is to be followed to modify the solution. To get other productive results, most of the applications are considered.

3.1.3 Proposed Modified Flower Pollination Algorithm (MFPA)

The FPA present in the literature [27-29] has been improvised in this research article, making use of the clonal feature being inspired from the Clonal Selection Algorithm (CSA) [29, 30] and is termed as Modified Flower pollination Algorithm (MFPA).

In MFPA, the convergence for local pollination is accelerated by replacing the Lévy flight with random walks, which can be achieved using non-uniform regular distribution within the range [0, 1]. Further, the local pollination search process has been modified by adding a scaling factor, C_2. For global pollination, the insects that can travel for longer distances are assumed to be the fittest among all other species. Let F be the fittest function so the fastness of the flower can be mathematically expressed as:

$$a_i^{\,t+1} = a_i^{\,t} + C_1 L(F^* - a_i^{\,t}) \tag{5}$$

Where, C_1 represents the step size scaling factor.

The modified local pollination and the improved flower constancy can be mathematically given as:

$$a_i^{\,t} = a_i^{\,t+1} + C_2 L€(a_i^{\,t} + a_k^{\,t}) \tag{6}$$

Here, the fitness function is taken as the cost function F as given in (5), and the solution vector $a_i^{\,t}$ designates the values of the PID controller (Kp and Ki).

Figure 3 represents the block diagram of the MFPA controller. The proposed technique tunes the PID controller parameters for minimization of the Integral Time Absolute Error (ITAE), which can be mathematically evaluated as:

$$F = t \int_0^t e(t)dt \tag{7}$$

The parameter $e(t)$ in Eq. (7) is the small change in PV array power at time instant 't' and '$(t-1)$' respectively. This error $e(t)$ has been used to stimulate the PID controller. The output of the PID controller drives the gate signal of the MLI. Further, the classical PID controller has been tuned by the proposed MFPA technique at variable uncertainty conditions of irradiance and load. The objective function F is the function of the three parameters (Kp, Ki, and Kd) of the PID controller. Figure 4 illustrates the flowchart of the MFPA.

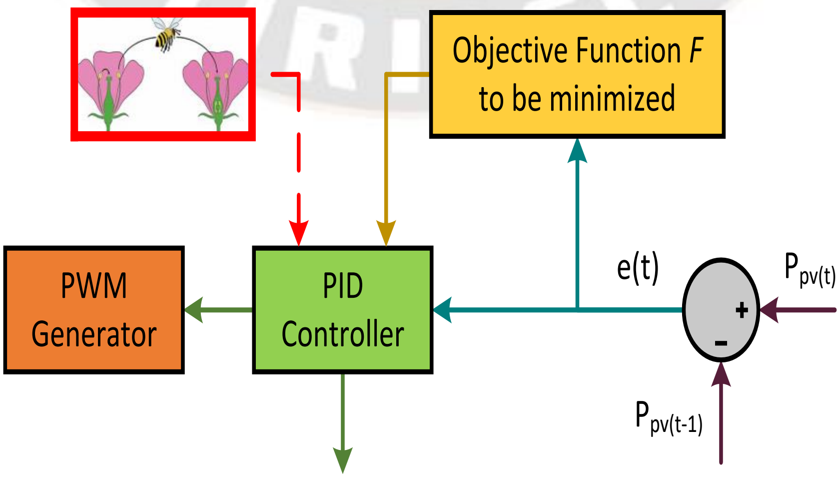

Figure 3: Suggested controller diagram

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3.2 Multilevel Inverter

The MLI finds its application in the power sector because of the quality of eminence of output voltage. It is essentially implemented in high power and medium voltage conditions. Higher voltages are generated using the devices of lower rating [31]. In MLI, reduced THD can be achieved by increasing the number of the voltage waveform. Further, the switching frequency can be reduced for the Pulse Width Modulation (PWM) operation. The MLI comprises many switches. Depending upon the arrangement of switches and phase angles between them, the MLIs are broadly classified into three types [32, 33]: 1) Cascaded H-Bridge MLI; 2) Diode Clamped MLI, and 3) Flying Capacitor MLI. Out of the above three varieties of MLI, the CHB-MLI outperforms the other two MLIs due to the following advantages: 1) it does not need any capacitor or diode for clamping; 2) it can achieve the same quantity of voltage levels requiring significantly less number of switching; 3) reduced switching losses and stress of device; and 4) it uses fewer power electronics components such as a diode, capacitor, etc. so losses and thus THD is comparatively low. So, considering the relatively better performance of Cascaded MLI, a 31-Level CHB-MLI is designed and implemented for enhancing the power system stability of the standalone PV system with variable loads.

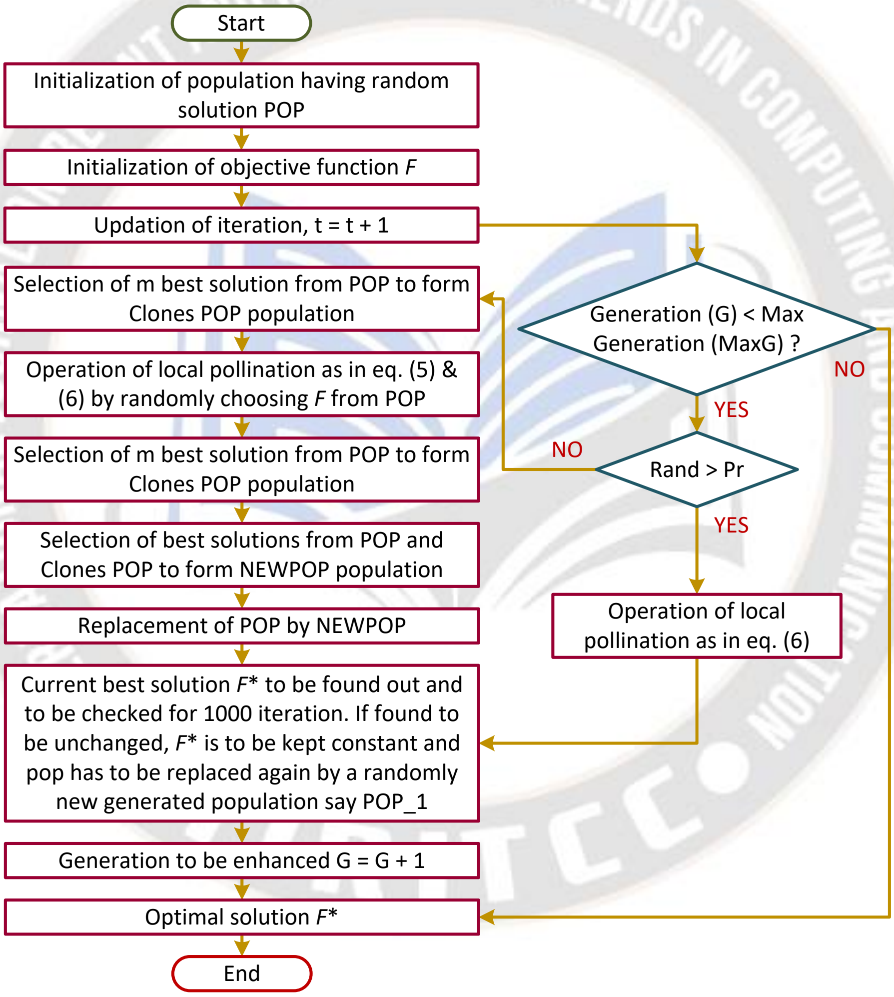

Figure 4: Flowchart of modified flower pollination algorithm

IV. System Model in Simulink Architecture and Result Dicussion

In this paper, a standalone PV-based generating system with CHB-MLI subjected to partial shading conditions and variable load has been designed in the MATLAB/Simulink environment. The values of all system components are given in Appendix A. Figure 5 shows the series connection of modules to form a PV array under the nominal condition of temperature (25°C) and irradiance (1000W/m^2) but with the partial shading condition.

Here two conditions of partially shaded PV array have been recognized:

1. Single module functioning at the uniform temperature as well as irradiation.

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2. Single module functioning at the various patterns of irradiance with a constant temperature.

Further, a complete contrast between the proposed MFPA method and conventional techniques is carried out by considering various voltage (V), current (I), and power (P) characteristics of the islanded PV system.

Figure 6 shows the system model designedin Simulink environment of the islanded partially shaded PV system with variable irradiance and load. The PV system is first connected to a boost converter, then to a 31-Level CHB-MLI, and finally supplies a variable load. The proposed technique is applied to track MPP and control the gate pulses of MLI, and the results obtained are compared with classical approaches to verify its robustness.

Case-I: Variable conditions of irradiation and load

Figure 7(a), 7(b), and 7(c) demonstrate the characteristics of voltage, current, and power with respect to time, respectively, of the standalone PV system, including several methods of MPPT. Figure 7(a) explains the comparison of voltage at various load and irradiance conditions. In FPA MPPT, the PV voltage is increased by 120.02%, while in the proposed MFPA MPPT, the voltage is increased by 128.52%, thus ensuing an enhancement of 8.5% with respect to MFA MPPT. In Figure 7(b), the current of the PV system as estimated by FPA MPPT is 18.18%, whereas is it almost increased by 4 percent, i.e., 74.38% by MFPA MPPT. Finally, in Figure 7(c), enhanced performance of the proposed MFPA MPPT can be obtained from the power curve.

Case-II: Standard temperature and varying irradiance pattern

The four patterns of irradiance as mentioned below have been taken into consideration for studying the condition of partial shading at constant temperature and changeable insolation:

Pattern 1: 1000W/m², 800 W/m², 600W/m² and 400W/m²

Pattern 2: 900W/m², 700W/m², 500W/m², and 300W/m²

Pattern 3: 850W/m², 650W/m², 450W/m², and 250W/m²

Pattern 4: 800W/m², 600W/m², 400W/m², and 200W/m²

Here, Figure 8(a), 8(b), and 8(c) gives the I-V, P-I, and P-V curves of standalone PV generating unit at nominal temperature (25°C) and various patterns of insolation as considered. The simulation results indicate that the current flowing in the PV system entirely relies on the insolation pattern variation. With an increase in irradiance, the output current of the PV system also increases. Thus, global MPP and local MPPs have been formed because the modules acquire maximum and variable irradiance.

Case-III: Study of power, current and voltage curves of the standalone PV system for nominal and partial shaded conditions with and without the effect of a bypass diode.

Figure 9(a), 9(b), and 9(c) demonstrate the comparison of P-I, P-V, and I-V curves of the standalone photovoltaic PV unit, respectively, where P for power, V for voltage, and I for current at nominal form (i.e., the irradiance of 1000W/m² along with the temperature of 25°C). Again, the curve generates the single MPP while the bypass diode provides numerous local MPPs with a single global MPP.

Case-IV: Comparative study of THD of voltage and current across load among MLI and conventional two-level inverter for the proposed control technique.

Figure 10(a) and 10(b) show the THD values for load voltage and load current, respectively, for the proposed MFPA techniques with MLI. THD found for voltage and current across the load, respectively, for the proposed MFPA techniques with conventional inverter are shown in Figure 11(a) and 11(b). It is found that the proposed MFPA technique with MLI for load voltage is 1.40%, whereas it is 5.95% for the proposed MFPA method with the conventional two-level inverter. Similarly, for load current, the THD is more, i.e., 6.32% for the proposed MFPA approach with traditional two-level inverter but, the THD is reduced to 1.60% with the implementation of MLI.

In this work, a 31-Level CHB-MLI has been implemented for a standalone PV system. Its effects on reducing the THD efficiently compared to the conventional inverter have been discussed, and the THD values obtained have been summed up in Table 1. The THD values for the proposed control technique with the MLI are minimal, thus ensuring better power quality. In Table 2 and Table 3, various control parameters (Kp, Ki, and Kd) and power system parameters (V, I, and P) comparisons have been made for PID, FPA optimized PID and proposed MFPA optimized PID.

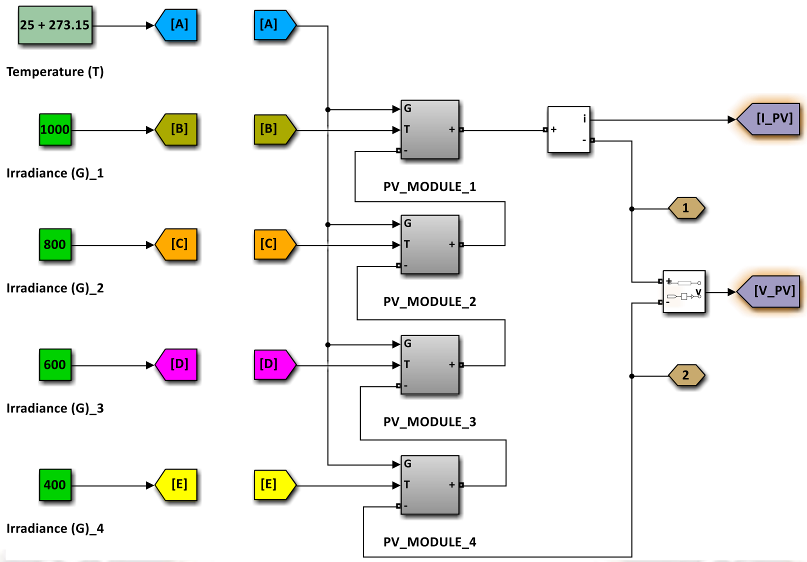


Figure 5: Formation of PV array from 4 PV modules connected in series under partial shading conditions

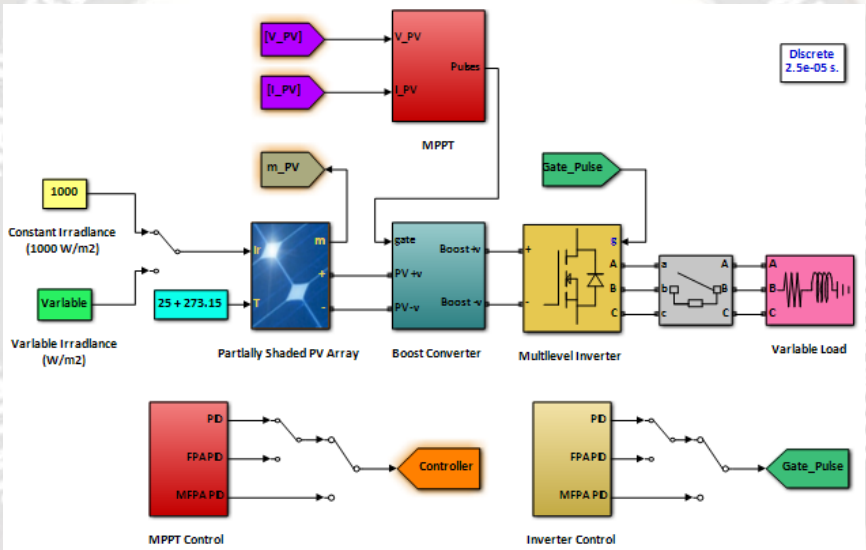
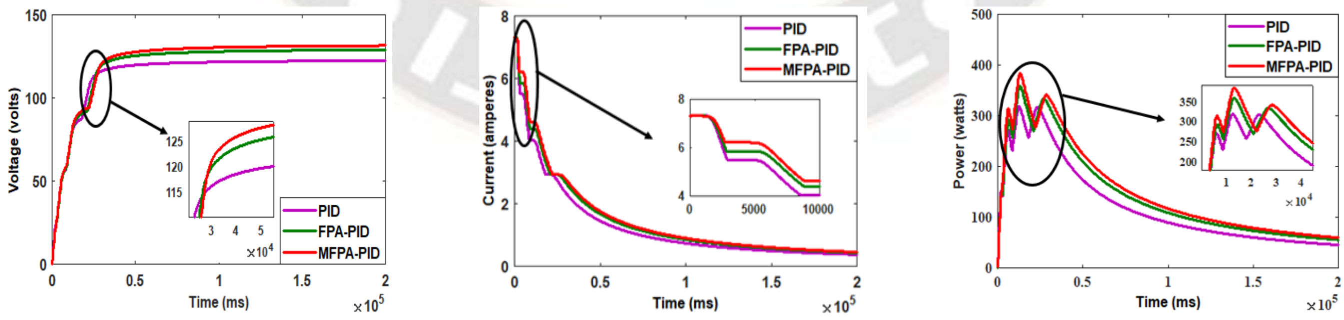


Figure 6: Simulink model of autonomous partially shaded PV system with variable irradiance and load



(a) (b) (c)

Figure 7: (a) Voltage at inhomogeneous insolation and load; (b) Current at inhomogeneous insolation and load; (c) Power at inhomogeneous insolation and load

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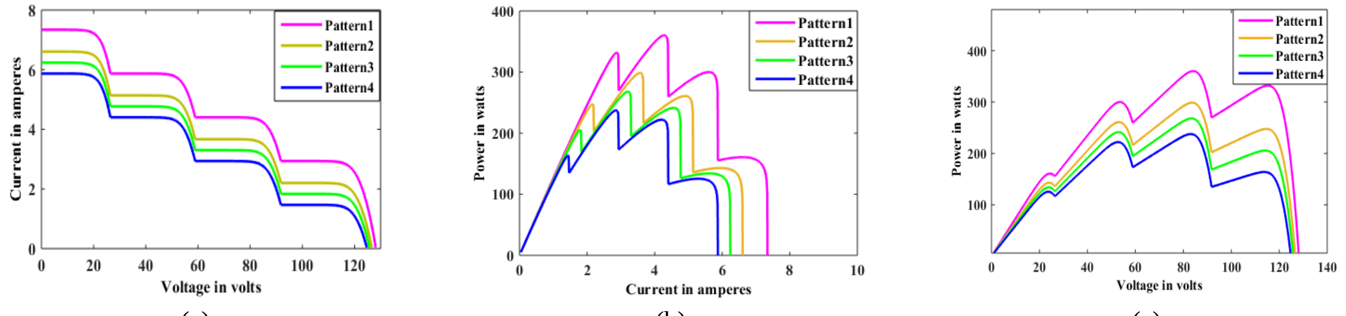
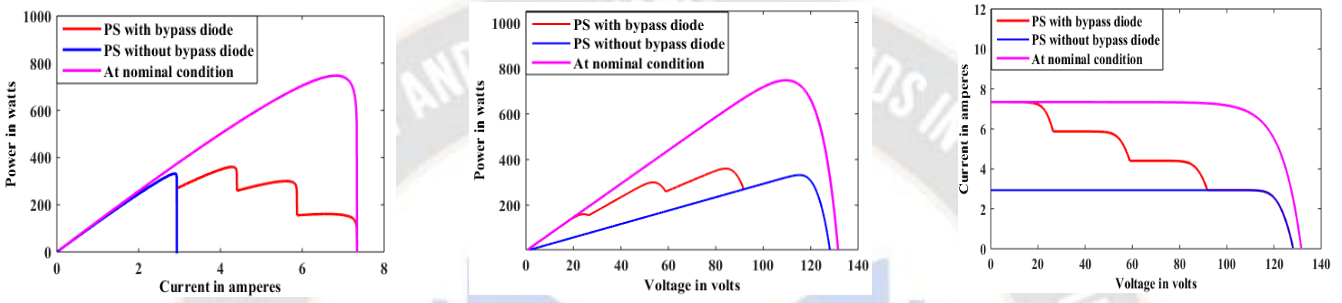


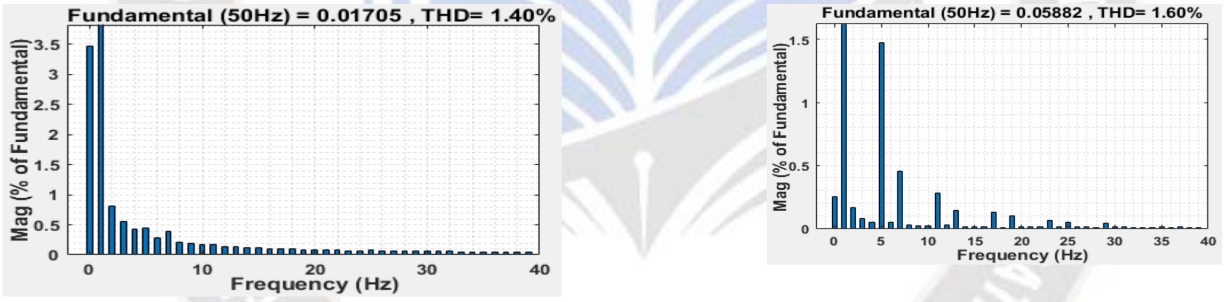
(a) (b) (c)

Figure 8: (a) I-V curve; (b) P-I curve; (c) P-V curve



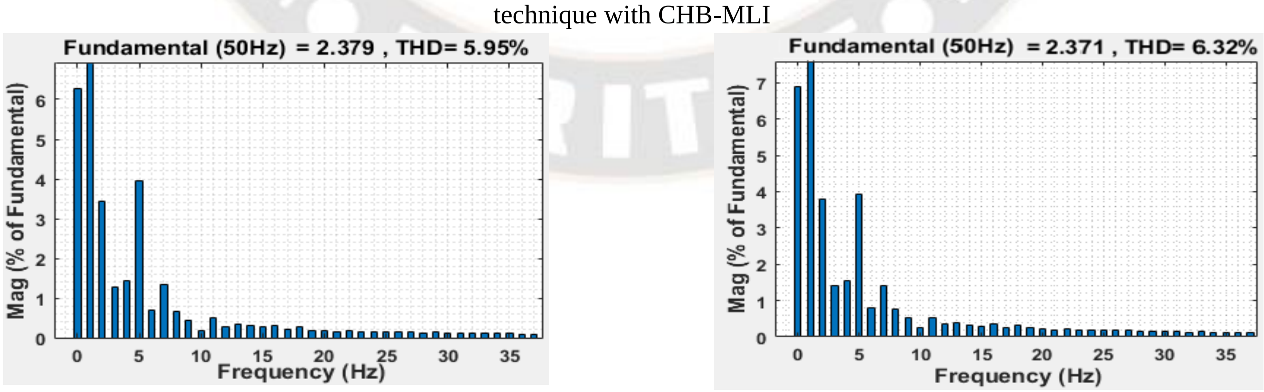
(a) (b) (c)

Figure 9: (a) Power Vs Current curve at nominal condition; (b) Power Vs Voltage curve at nominal condition; (c) Current Vs Voltage curveat nominal condition



(a) (b)

Figure 10: (a) THD of load voltage for proposed MFPA technique with CHB-MLI; (b) THD of load current for proposed MFPA technique with CHB-MLI



(a) (b)

Figure 11: (a) THD of load voltage for proposed MFPA technique with conventional inverter; (b) THD of load current for proposed MFPA technique with conventional inverter

Table 1:THD comparison for various MPPT control techniques with 31-level CHB-MLI and conventional inverter

	CHB-MLI (31-level)		Conventional Inverter	
Type of Controllers	Load VoltageTHD (in %)	Load CurrentTHD(in %)	Load VoltageTHD(in %)	Load CurrentTHD(in %)
MFPA-PID	1.40	1.60	5.95	6.32
FPA-PID	1.94	2.13	6.71	7.67
PID	2.07	3.34	8.61	9.55

Table 2:Controller parameters comparison for PID, FPA optimized PID and proposed MFPA optimized PID

	MFPA-PID			FPA-PID			PSO-PID		
Parameters	Kp	Ki	Kd	Kp	Ki	Kd	Kp	Ki	Kd
V	1.56	2.233	0.99	2.24	3.76	1.90	3.3	3.9	2.6
I	1.89.9	1.98	0.9345	2.58	3.87	1.97	3.789	4.7	3.128
P	1.23	2.334	0.8	1.96	3.45	1.5	2.9	4.5	2.175

Table 3:Power system parameters comparison for PID, FPA optimized PID and proposed MFPA optimized PID

	MFPA-PID			FPA-PID			PID		
Parameters	Settling time	Peak time	Percentage Overshoot	Settling time	Peak time	Percentage Overshoot	Settling time	Peak time	Percentage Overshoot
V	1.36	0.98	98.2	2.12	3.3	104.6	3.73	4.67	110.8
I	1.78	1.02	97.2	2.33	3.56	109.5	3.87	4.71	112.5
P	1.23	0.91	86.75	1.9	2.9	94.7	2.3	4.1	104.5

V. Conclusion

This paper puts forward a standalone PV generating unit with partial shading conditions comprising an MPPT controller, boost converter, multilevel inverter, and load. For effective MPP tracking and better convergence speed, a robust Modified FPA based MPPT technique is proposed in this research article. To further enhance the output voltage waveform by reducing the harmonics, a 31-Level CHB type MLI has been employed. For validation of the effectiveness and feasibility of the suggested technique, the system is subjected to uncertainties such as variation in irradiance and load. The characteristics of the suggested scheme is equated with conventional FPA and PID control methods. The results obtained indicate that the proposed technique surpasses the other classical methods in terms of faster MPP tracking time, better system stability with reduced harmonics, enhanced capability to meet load requirements even under uncertainty in load and irradiance.

Further, the THD values calculated through FFT analysis of load voltage and current are found to be well within IEEE-1547 constraints and hence validate the superiority of the MLI to reduce distortion better than the conventional two-level inverter. The characteristics and results obtained from the overall system under study with the proposed method and MLI thus justify its implementation for real-time applications. The possible directions for future work can be (i) the real-time employment of the proposed MFPA technique; (ii) design of more robust optimization techniques with enhanced dynamic global MPP tracking operation; (iii) study of the proposed method in the grid-connected mode of operation; and (iv) analysis of the PV system characteristics along with energy storage devices and FACTS controllers with the proposed MFPA technique and MLI.

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Appendix A

	Parameters	Values	Details
PV	K	$1.3806\,e^{-23}$	Boltzmann Constant
	N_s	54	Number of cells in series
	V_{oc}	32.91V	Open circuit voltage
	R_s	0.221Ω	Resistance in series
	I_{sc}	8.214A	Short circuit current
	K_v	-0.123	Temperature voltage constant
	T_n	25+273	Nominal temperature
	G	1000	Actual Irradiance
	E_g	1.12	Bandgap of silicon
	α	1.3	Diode ideality constant
	K_i	0.0032	Temperature current constant
Boost Converter	L	5mH	Inductance
	L_r	0.005Ω	Inductor Resistance
	C	100 μF	Capacitance
	f_s	50 Hz	Switching Frequency
	D	0.5	Initial Duty Ratio
	V_o	125V	Output Voltage
Multilevel Inverter	f_s	50Hz	Frequency
	p	99.999%	Pulse width
	d	0.0005 secs	Phase Delay
	N	(m-1)/2	Number of H-Bridges
	T	0.02 secs	Time Period
Flower Pollination Algorithm	p_r	0.8	Switching probability