Performance improvement in photovoltaic-grid system using genetic algorithm

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ABSTRACT

In recent, photovoltaic (PV) power generation has increased in importance. The growing significance of PV power production has generated the demand for enhancing energy efficiency via continuous operation at the maximum power point (MPP). To enable effective MPP tracking, the suggested system integrates a proportional-integral (PI) controller with the perturb and observe (P&O) technique. In order to improve performance in a PV grid system, this work provides a unique method using a proportional-integral-derivative (PID) controller optimized using a genetic algorithm (GA). The proposed controller architecture integrates the GA algorithm with a PID controller in the voltage source inverter (VSI) of the PV system. To enable effective grid integration, the GA is used to continually optimize the PID controller settings. The converter's design criteria and computations are discussed, and MATLAB simulations are used to assess the system's performance. Compared to traditional PID controllers, the observed findings show increased efficiency, cheaper cost, and enhanced controllability. The suggested GA-PID controller offers opportunities for more study and development in this area while showing potential for improving PV grid system performance.

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1. INTRODUCTION

Energy is highly significant in the evolution of human activity, and power is one of the most pressing concerns for every nation's future. There is a direct relationship between the growth of human behavior and also its energy usage [1]. Obtaining photovoltaic (PV) power consists of developing, choosing, and deciding specifications based on a range of parameters like geographical area, meteorological conditions, sun irradiation, and load consumption. PV power generation is a way of generating energy by transforming sunlight into direct current (DC) energy via PV semiconductors [2]. PV systems are classified into standalone, grid-connected and hybrid systems, in which solar systems are combined with other energy source systems [3]. The maximum power collected from the PV generator is, therefore, heavily dependent on three variables, irradiance, the temperature of the cell, and load impedance [4], [5]. A PV module's output V-I characteristic is affected by irradiance and temperature. Variations in irradiance impact PV output current, whereas temperature changes impact PV output voltage [6]. Mechanical mechanisms were designed to keep the PV panels receiving the most solar energy. An electric maximum power point tracking (MPPT) adjusts the active PV current or voltage to achieve maximum power. To sweep the PV power, this tracker often requires a switching converter [7]. Among several MPPT techniques, the perturb and observe (P&O) algorithm is highly used [8]–[10]. Because of its simple structure, it is the most often used approach for maximum power tracking. This approach performs by perturbing the PV panel terminal voltage and comparing the PV output power to the initial perturbation cycle [11]. To prevent undesirable impacts on the output PV power and draw its maximum capacity, a DC/DC converter may be installed here between the PV panel and the battery, which could regulate the MPP in addition to the standard controller functions [12].

A DC/DC converter is an electronic system that transforms a range of DC voltage from one level to another. It has great attention among researchers to enhance or increase the output voltage of renewable energy systems such as fuel cells, PV systems, and wind energy systems [13]. The boost converter circuit is implemented between the PV array and the load side of the system. It enhances the voltage level by increasing the input DC source and comprises an inductor, capacitor and switching device [14]. The proposed MPPT technique with proportional integral (PI) control [10] is used to adjust the output power and voltage of a boost converter. The components of PI control are integral gain and proportional gain [15]. The Ziegler-Nichols technique calculated the proportional gain Kp and the integral gain Ki. Although proportional gain, Kp, is useful for reducing step-up time, it is not a precise solution for eliminating steady-state error. Ki, the integral gain, effectively eliminates steady-state error [16]. This control technique is simple and gives high efficiency. These control signals are given to the gate of the converter switch.

Inverters are often used worldwide to transform DC-alternating current (AC) with variable amplitude and frequency. The inverter’s output voltage is regulated by the inverter’s internal control rather than by adjusting the incoming dc output or the outgoing ac output [17]. In this paper, the DC output of the boost converter is converted to a three-phase AC supply connected to the grid. Many pulse width modulation (PWM) techniques were used to control such a voltage source inverter (VSI) [18]. The conventional control method yields a series of algebraic numerical methods. Calculating the best switching angles is a difficult and time-consuming task. Non-traditional approaches using evolutionary algorithms, like genetic algorithm (GA), have recently been used to eliminate harmonics in three-level inverters [19]. The GA is a population genetics-based flexible heuristic search tool. John Holland invented the use of GAs in the 1970s [20]. The GA is a probabilistic searching method based on genetics and natural selection. An MPPT approach is used for a microgrid-linked solar PV system based on the concept of a P&O approach [21], [22]. It is an iterative algorithm that requires a starting point to trace the MPPT. There is a lot of information to be gained from the literature on PV energy production and control strategies. The goal is to improve the PV system’s efficiency, cost-effectiveness, and management by overcoming the drawbacks of conventional proportional-integral-derivative (PID) controllers. The most significant contribution is the incorporation of a GA algorithm and a PID controller in the PV system’s VSI. Through this connection, the PID controller’s settings may be optimized in real time, leading to better performance and more grid integration potential.

The next several chapters of this article will go into great depth on the converter’s design requirements and computations. It shows the combination of the PID controller with the GA algorithm, and describes how MATLAB simulations are used to evaluate the system’s efficacy. The simulation results will show how the proposed GA-PID controller outperforms conventional PID controllers in terms of efficiency, cost-effectiveness, and controllability.

2. METHOD

2.1. Modelling and working of a PV cell

Using the PV effect, a PV cell transforms sunlight into electricity. Photons are solar energetic particles that make up sunlight. Photons have varying levels of energy that correspond to various wavelengths of the solar spectrum. Photons that reach a PV cell might be reflected, absorbed, or pass through. However, only photons that are absorbed create electricity. The photon’s energy is then converted to an electron in a semiconductor atom of the cell. With this energy, the electron can escape from its usual location and join the flow in an electrical system [23]. The voltage required to push the current through the load is provided by a built-in electrical field. The electric field inside a PV cell is created by sandwiching two semiconductors together. Due to holes or electrons, the p and n kinds of semiconductors correlate positively and negatively. The panel employed in modeling a PV operates via the photoelectric effect. Figure 1 presents the equivalent circuit of a PV cell and the modeling is accomplished by linking a current source in parallel with an inverted diode.

The PV system’s power voltage characteristics are determined by multiplying current and voltage. The following equations represent the mathematical model of a PV cell’s single diode; here, I_{ph} =photon current, T is the temperature, I_{sc} short circuit current, I_r and solar irradiation. When the temperature changes, the module’s saturation current I0 also varies in (2) and the calculation of the output current of the panel is in (4).

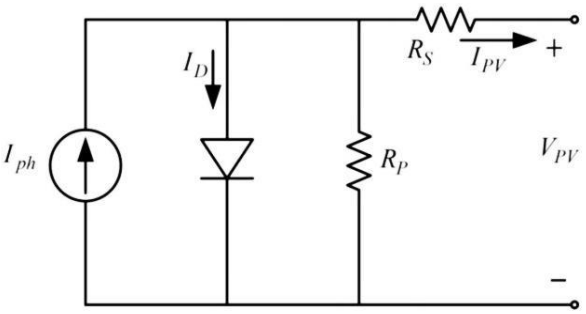

Figure 1. PV cell equivalent circuit

$$I_{ph} = [I_{sc} + Ki(T - 298)] \times \frac{I_r}{1000} \quad (1)$$

$$I_{rs} = [exp(V_{OC}q/TN_{skn}) - 1)]I_{sc} \quad (2)$$

$$I_O = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{xqE_{go}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad (3)$$

$$I = \left(N_pXl_{ph} - Xl_oN_p\right)x\left[exp\left(\frac{\frac{V}{N_S} + IX\frac{R_S}{N_p}}{nxV_t}\right) - 1\right] \quad (4)$$

$$I_{sh} = \frac{\frac{(V \times N_P)}{N_S} + (1 \times R_S)}{R_{sh}}, V_t = \frac{k \times T}{q} \quad (5)$$

2.2. P&O MPPT algorithm

Solar cells have very low efficiency. To improve efficiency, mechanisms for correctly matching source and load should be implemented. The MPPT is one such approach. The MPPT approach extracts the most feasible power from a charging source. The V-I characteristics of PV systems are nonlinear, making it challenging to power a specific load. This is accomplished by employing a boost converter and its duty cycle is changed via the MPPT algorithm. This algorithm is the basic MPPT strategy. The model was created by utilizing only one voltage sensor attached to the PV panel's output voltage to sense the panel voltage, making the model simple to apply in MATLAB/Simulink. Figure 2 shows the proposed system's block diagram consisting of a PV array, power electronic converters and the grid with the proposed controllers.

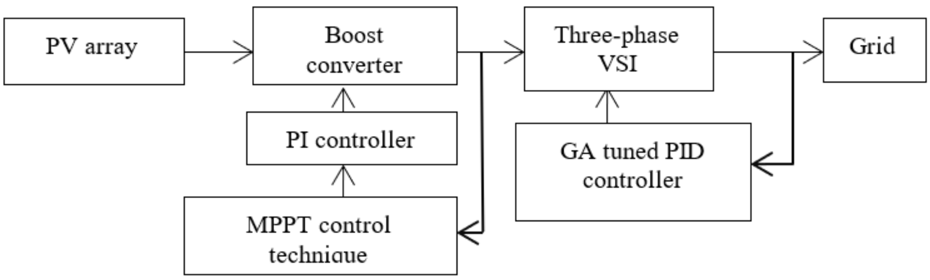

Figure 2. Block diagram of the proposed system

Figure 3 presents the MPPT P&O algorithm flowchart, which measures the current and voltage to acquire the MPP using the given algorithm flow. This approach takes less time to reach the MPP. The P&O MPPT method requires that if the operating PV panel unit's voltage source is perturbed by a minor increase if the next revolution in a power change ΔP is the positive charge (ΔP>0), it transforms to move in the MPP tracking and continues to disturb the system. Suppose ΔP contains a negative charge (ΔP<0); it is missing from the MPP's direction; therefore, the signal of great disturbance must be twisted.

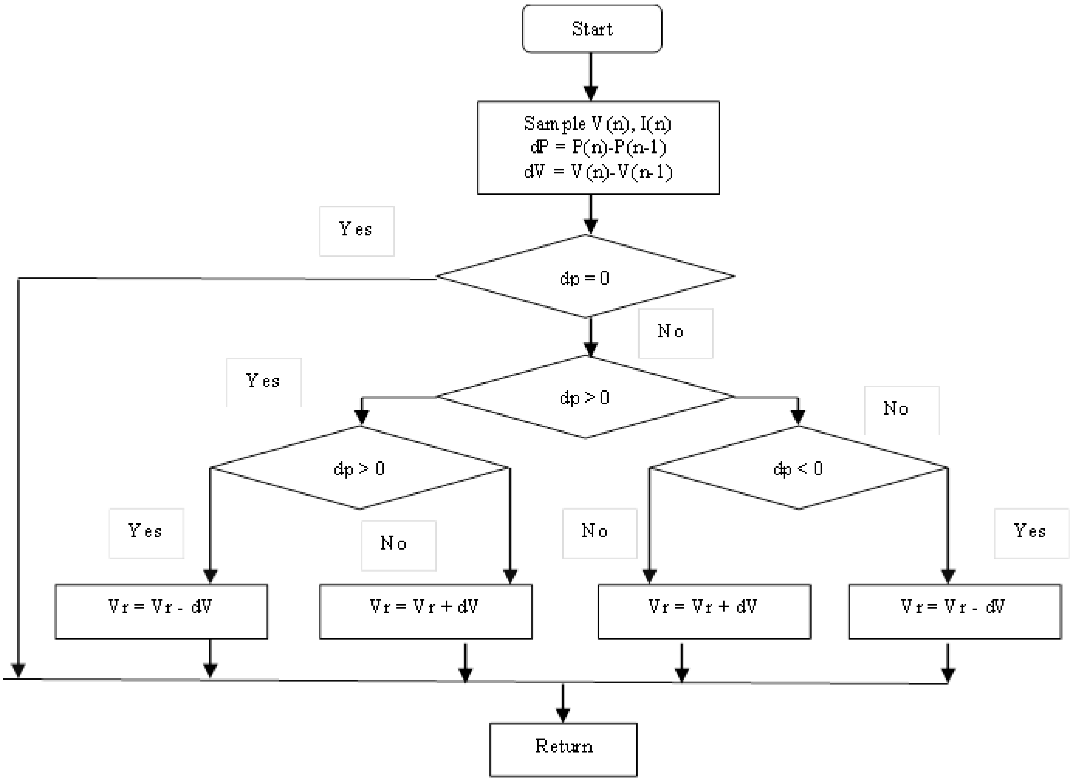

Figure 3. Flow chart of MPPT P&O algorithm

2.3. PI-based MPPT controller

The P&O algorithm may modify the duty cycle by observing the difference between the PV array voltage and the voltage of the power converter. PV array power is estimated using observed voltage and current measurements. To calculate the duty ratio, the most recent observation of the acquired power is matched to the preceding observation. Following that, the guaranteed difference is utilized to set the next PWM duty cycle. The developed PO algorithm searches for an increase in power perturbation and seeks to maintain the duty cycle constant in order to attain the MPP of the PV array; moreover, PI control is enabled to decrease output voltage oscillation. When there is a decrease in power observation, the method can reverse the perturbation. The algorithm continues this procedure until the PV array reaches the MPP; if the system hits the MPP, the method provides a stable duty cycle value. To improve stability, the oscillations at the MPP of the PV array must be decreased. Figure 4 presents the closed-loop PI control by producing the error signals and the output is processed using the proportional and integral gains. The error calculation of the PI based MPPT controller as shown in Algorithm 1.

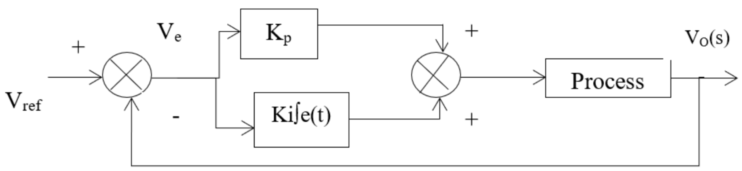

Figure 4. Closed loop PI control of the system

Algorithm 1. The error calculation of the PI based MPPT controller

```
Void_PI ()
{
Error=Vref-VO
Error_in=Error*dt+Error_in
Duty=Error_in*Ki+Error*KP
}
```

This controller merges both proportional and integral controllers. The control signal in this closed-loop system is proportional to both the error function's integral and the error signal. Controller tuning is setting controller parameters to match a particular performance standard. When only a proportional control measure is utilized, Ziegler and Nichols developed guidelines for PI controller tuning based on the observed step response or the value of Kp that results in marginal stability.

2.4. Boost converter

Boost converters are also known as step-up converters. It transforms a low input voltage into a high output voltage. It works similarly to an inverted buck converter. The boost converter circuit [24] is made up of an inductor, a diode, a switch, and a capacitor. The boost converter operates by switching on and off at regular intervals. When the switch is turned on, the inductor absorbs the energy, and when the switch is turned off, the total of the inductor energy and the supply emerges at the output. The power Mosfet serves as a switch in the boost converter. Figure 5 represents the equivalent circuit of a boost converter comprising the inductor, switch, capacitor and diode connected to the load.

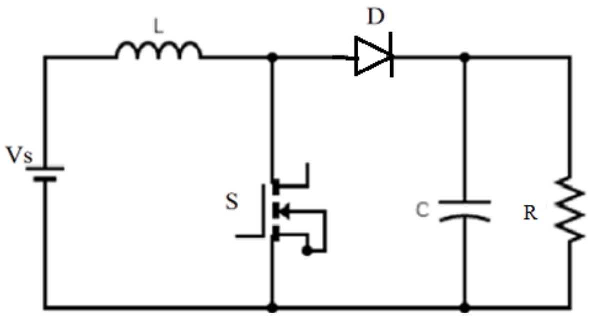

Figure 5. Boost converter circuit diagram

There are two modes of functioning for the circuit. When the Mosfet switch is turned ON at t=0, mode-1 begins. The rising input current goes via inductor L and the Mosfet switch. When the Mosfet switch is turned off at t=t1, mode-2 commences. The boost level of the output voltage is determined by the duty cycle of the switch and the provided source voltage, which is described as (6).

$$V_o = (1 - G)V_i \tag{6}$$

Vi is the input voltage, Vo is the output voltage and G is the duty ratio. The current that was previously going through the Mosfet will now be directed through L, C, the load, and diode D. The inductor current decreases until the Mosfet switch is switched back on in the following cycle. The load receives the stored energy in inductor L.

2.5. GA-tuned PID controller

The GA is an established and efficient search strategy that generates a population of potential people to discover the optimal solution for a variety of engineering challenges. In this application, the basic technique of the GA optimization approach involves the phases. However, manually changing the configurations of standard PID controllers may be time-consuming and difficult, particularly in dynamic and nonlinear systems such as PV systems. An optimization method called a GA was developed using the ideas of natural evolution. Compared with the traditional PID controller, the GA-PID controller [25] may investigate a wider parameter space, resulting in higher control performance and better system adaptability. The goal function is defined in fitness computation according to the system design criteria like settling and rising time, maximum overshoot and so on. The production stage of a new population includes three significant operations: reproduction, crossover, and mutation. In reproduction, the new population is identified to begin the procedure, which assesses all fitness by evaluating relative performance and then selects the best-qualified fitness. Then in the crossover section, a new offspring is created by combining diverse parental fitness, ensuring that the best fitness is identified. In mutation, it helps to retain the variability in the fitness discovered by the GA and can ensure that the best fitness is selected. The PID gain values Kp, Ki and Kd are obtained using the GA method and then applied to the PID controller. Figure 6 shows the general flowchart of GA in which selection, crossover and mutation are the steps involved to get optimum results by creating the population.

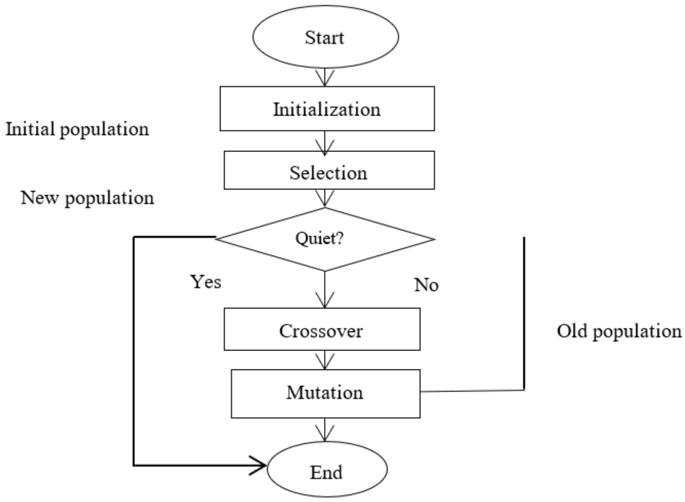

Figure 6. GA flowchart

3. SIMULATION AND RESULTS

The PV array generates the DC voltage and is connected to a DC-DC boost converter. The proposed controller controls the converter. Figure 7 displays the proposed simulation model in MATLAB tool and scope blocks are connected to display the results of the system.

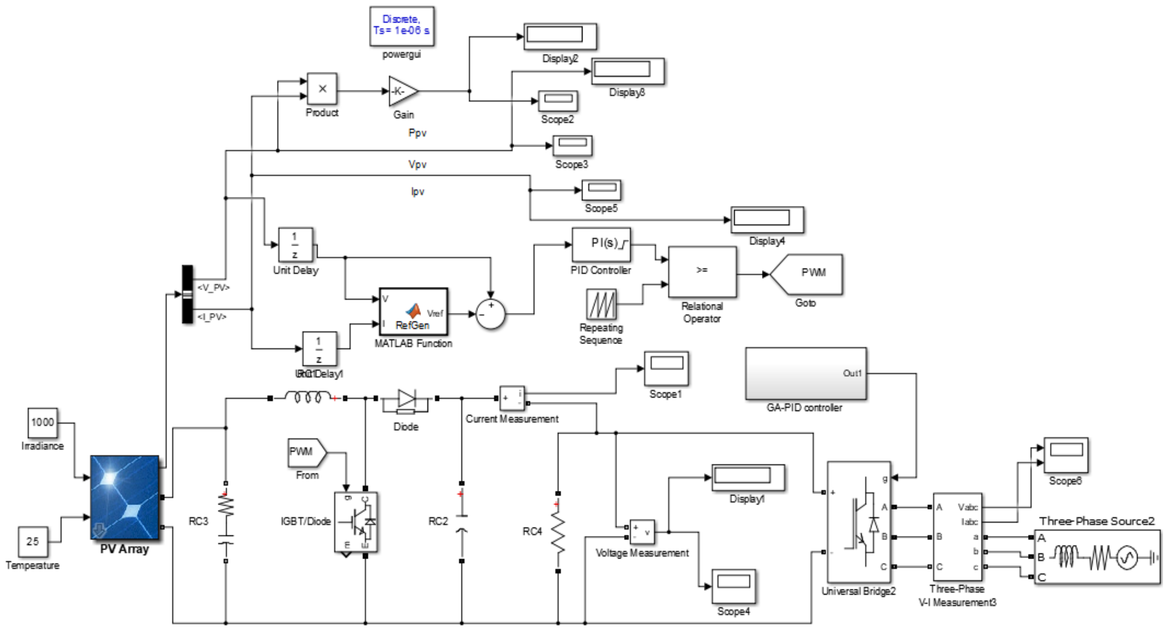

Figure 7. Simulation of the proposed PV system

The MPPT controller with PI control technique is used and a PWM generator is utilized, which sends the pulse signals to the gate of the switch. The MPPT algorithm is implemented in this model using a MATLAB function block [26]. The module type used in the PV array is Sanyo HIP-225HDE1. The number of parallel strings is 49 and 11 modules are connected in series. The irradiance and temperature given to the system are 1,000 w/m2 and 25, respectively. The result of the generated PV voltage and current are shown. Figure 8 displays the PV array voltage of 362 V and its DC output with some ripples. Figure 9 displays the PV current of 331 A, which represents the nonlinear characteristics of the PV array.

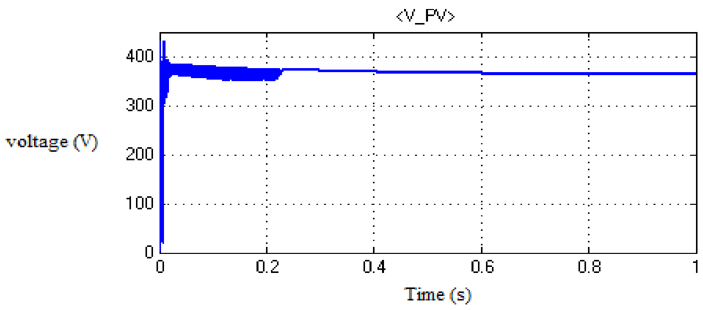

Figure 8. PV voltage of the system

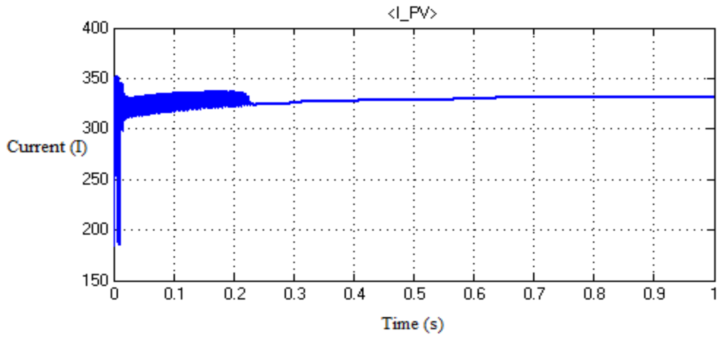

Figure 9. PV current of the system

The total PV power produced is the product of the PV voltage and current. The generated PV power is 120 KW. The boost converter is connected to the PV panel. This model features a standard boost converter with a gain of about 1.35. This means that the boost converter has been designed to convert and boost the nonlinear PV voltage to a fixed DC output voltage of 490 V. The boost converter's inductive and capacitive components are produced using theoretical calculations and design factors [27]. Based on the needed energy storage and the converter's switching frequency, the inductance value (L) is selected. The inductance value in the present case is 2.5e-3 H. The output ripple voltage and efficiency of the system, as well as its overall performance, are all impacted by the inductor choice. Depending on the PV current value, the inductor's ripple current is calculated. The ripple current is calculated to be about 33.1 A and it will be 10% of the PV current, which is around 331 A. The intended voltage ripple and the maximum permitted output voltage ripple are used to calculate the capacitance value (C). A capacitance value of 4300e-6 F has been used in the present case. The voltage ripple is calculated to be about 9.8 V using a voltage ripple of 2% of the output voltage (490 V). The designs of the inductive and capacitive components are affected by several factors, including the intended voltage output, power efficiency, component ratings, and system requirements [28]. These design choices are essential for ensuring the steady functioning of the boost converter and achieving the best possible performance of the PV-interfaced grid system. Figure 10 shows the power generated from the PV panel, which is 120 KW and is suitable for supplying high-power applications. Figure 11 displays the boost converter output voltage, which converts and enhances the nonlinear PV voltage to a constant DC output voltage of 490 V.

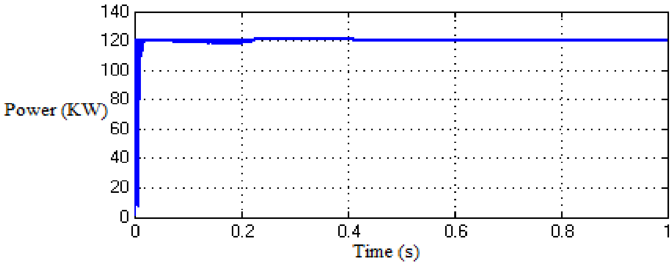

Figure 10. PV power of the system

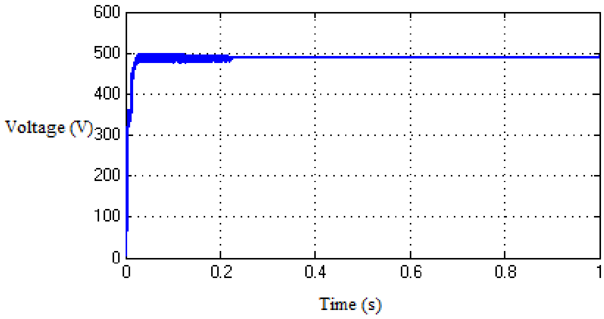

Figure 11. Boost converter voltage

Figure 11 boost converter voltage the ripple-free and constant DC bus voltage is achieved using the MPPT control technique. The results showed that the P&O algorithm successfully monitored the MPP, maximizing the PV array's generated electricity. It was shown that fluctuations in panel voltage, caused by elements like irradiance and temperature, directly affected the system's total output. The system constantly functioned closer to its MPP as the P&O algorithm modified the boost converter's duty cycle depending on the panel voltage, leading to higher power efficiency and improved overall performance. The DC bus voltage is converted into an AC by a VSI and is controlled using GA tuned PID controller to generate a distortion-free AC output voltage, which is connected to the grid. Figure 12 represents the inverter's output current and voltage are 12 A and 6 KW, respectively. Hence it can be applied for both domestic and industrial applications.

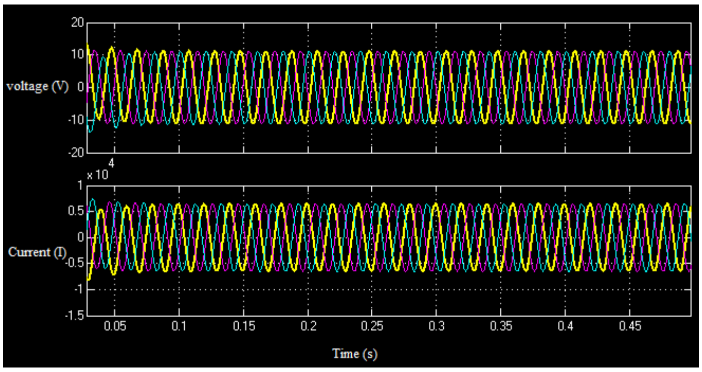

Figure 12. Inverter output current and voltage

The developed PV grid system using appropriate controllers is very efficient and provides optimum results. The power generation and voltage stability are analyzed from the MATLAB results. Compared to other MPPT techniques, the PI-based MPPT P&O method acquires the maximum output by the DC-DC converter. The GA-tuned PID controller in VSI shows less settling time and overshoot voltage when compared to traditional PID controllers.

4. CONCLUSION

This paper implements a PV system in MATLAB tool and improves the performance using various control techniques. The maximum PV output voltage from the boost converter is obtained using the PI-based MPPT control method. Compared to the conventional MPPT technique, the MPP was easily reached with this approach, and oscillation was equal to zero. To control the grid side inverter, the GA optimization technique is applied in a PID controller. The controller gain values are tuned using GA to get optimum results. The results of the generated PV power, voltage and boost converter's output are verified and evaluated. The panel produces 120 KW power and a voltage of 362 V. The designed boost converter increases the PV voltage to 490 V. The inverter voltage shows less harmonic distortion by the suggested control technique. The proposed system shows satisfactory results and the generated power is suitable for both DC and AC applications. For future research, we can integrate other renewable energy sources like wind and fuel cells into the system to obtain higher output.

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