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Effect of GA based PID controller in bidirectional converter

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ABSTRACT

The bi-directional direct current to direct current (DC-DC) converter plays a crucial role in applications involving photovoltaic (PV)-based micro grids. These PV-based hybrid systems have become imperative to ensure uninterrupted power supply and meet local power demands. Selecting the right controller for this converter presents a significant challenge. Traditional proportional integral derivative (PID) controllers yield suboptimal efficiency due to their high delay and settling times. This issue can be overcome by implementing a PID controller based on genetic algorithms (GA). An interconnected grid system is employed to regulate the DC connection voltage across various load conditions, with PV serving as the means to sustain electricity generation. Numerous operational modes tailored to demand are explored, and control techniques are used to maintain the desired DC link voltage level, ultimately enhancing the efficiency of both the PV system and the bidirectional converter in on-grid configurations.

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1. INTRODUCTION

The need for energy supply and utilization in the twenty-first century is just amazing. We must accept unconventional fuels like photovoltaic (PV), wind, and hydro to combat the depletion of fossil fuels and the following energy shortages. Due to its ecologically friendly qualities and ease of deployment, the PV is recognized as a most enticing sustainability component [1]. It should be used frequently since solar energy is drawn from the sun. Utilizing PV has as its primary objective weakening the strongest force through decreased losses.

Advanced power electronics innovation gives the energy that is used properly. The converter's setup and the efficient supply of power to the load primarily determine the power transfer capacity and modifications' efficacy. To get the desired voltage, voltage drop is used in changing processes including buck, boost, and buck boost decreased block down converter (BDC) switches [2], [3]. Power flow between input sources and the load is the capacity of a bidirectional converter, also referred to as forward direction. The reverse direction of power flow is that between the source and the load. The side tensions of a typical BDC are low and high, respectively. It benefits from smaller sizes, lighter loads, and less switching [4]–[6]. The transformer's benefits include increasing power output, providing clients with steady electricity, and reducing voltage slope and swell. This converter improves the device's power efficiency and is useful for voltage reimbursement.

The proportional integral derivative (PID) has specified benefit borders and is additive, comprehensive, and derivative. This refers to flawless tuning, which gives the machine its best output. Artificial intelligence (AI) control mechanisms like fuzzy logic and adaptive-network-based fuzzy inference system (ANFIS) are currently being researched [7]–[9]. These lines provide a number of benefits, but they also have some drawbacks. Delicate processing has recently been incorporated into innovation approaches. A Soft Computing Machine takes some time to resolve this issue [10]–[12]. This strategy leads to quick response and better performance as compared to current control approaches.

The long delay and settling times of conventional PID controllers, which are related to their inefficiency, are to be eliminated. This will be achieved by substituting the conventional PID controller with one optimized through the use of genetic algorithms (GA) [13]–[15]. Furthermore, the aim is to employ an interconnected grid system for the regulation of direct current (DC) connection voltage across diverse load conditions. This system will leverage photovoltaic (PV) technology to ensure a continuous electricity supply. Conduct research involving dual autonomous controls, such as the effective utilization of electricity during power interruptions and a sequential approach involving fuzzy battery tuning followed by genetic algorithm (GA)-based PID tuning for batteries. The recommended software platform for this system is MATLAB/Simulink.

2. BIDIRECTIONAL CONVERTER FOR PV BASED ON-GRID SYSTEM

An ON Grid system-based bidirectional DC-DC conversion is proposed for solar systems to shift electricity away from the DC connection with the grid. The unique single-phase AC load is coupled to an inverter circuit. The two-way DC-DC converter and the grid's center are where the fault is located. A DC-DC two-way transformer consists of 8 switches that can be lowered with a conventional dual working SST bridge-based transformer in the proposed configuration. The grid connected circuit scheme for the DC-DC bidirectional converter will be shown in Figure 1 depending on the panel.

The AC and DC grids are a part of the distributed generation (DG) system. Power usage is high and storm demand has recently grown, therefore less grid electricity is needed. It lowers the price of making electricity, which, in turn, lowers power loss [16]–[18]. The AC microgrid is shared via the DC microgrid because the source and the filters are not interconnected. The grid input of the bidirectional converter is 230V if both the grid side and the battery's supply of electricity are inadequate.

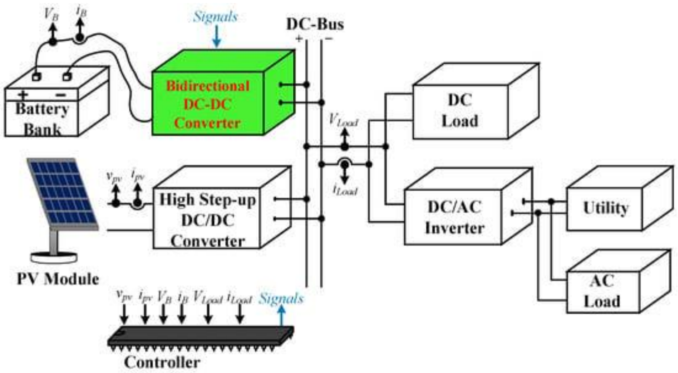


Figure 1. Diagram of the PV-based bidirectional converter for the ON grid system

2.1. Photovoltaic array system

The photovoltaic array system is a sustainable energy solution designed to harness solar power efficiently. Its primary goal is to convert sunlight into electricity through an array of photovoltaic panels. This system plays a pivotal role in generating clean and renewable energy, reducing carbon emissions, and promoting environmental sustainability. The present research is focused on the single-diode PV model, which involves parallel interaction with the current source and serial strength. The actual output from the source is directly correlated with the incident sunlight on the cell. Three essential criteria dictate the design of PV cell layouts: ideality, short-circuit current (I_{SC}), and open-circuit voltage (V_{OC}). Ideality, determined by output voltage, current, diode reverse current, ideality factor, PV, and Boltzmann constants, ensures precise and straightforward PV system design.

$$I_0 = I_{irradiance} - I_{01}[e^{((V_0+IR_1/Na*\frac{kT}{q}))} - 1] - \frac{V_0+IR_1}{R_2} \tag{1}$$

The Sun's electromagnetic radiation is caused by irradiation on each region of the device. Radiation causes a low output voltage of the plate. A single PV cell diode platform for solar panels is seen in Figure 2.

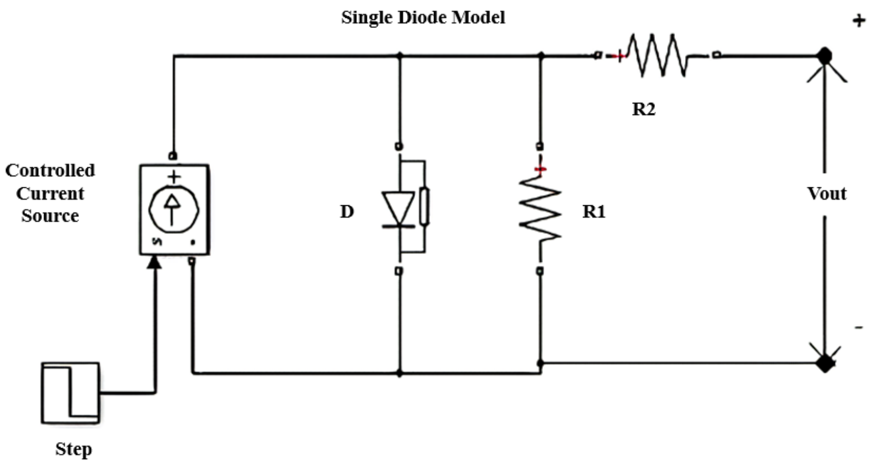


Figure 2. PV cell equivalent circuit

2.2. Bidirectional converter with 2 switches

Eight switches are present in the conventional transformer of the DC -DC bidirectional converter, which is connected by two active bridges. The converter that is being suggested has fewer switches and is quite effective. The grid's bidirectional voltage regulation is very important. The components of a two-way boost converter are two MOSFET switches (S1, S2), condensers, and inducers (L1). Every switch follows the same servicing cycle. There are two operating modes.

The BDC is used as an alternative to buck and boost converters. The main aim of the BDC is to eliminate the boost and buck converter's primary drawback—its excessive component count, and in the same circuit, the voltage rises and breaks [19]–[21]. The BDC is composed of one inductor (L1), one condenser (C1), and two active switches (S1, S2) (SA SF). There are two operating modes for this BDC.

2.2.1. Charging mode

The power flow direction of the proposed BDC can be used to charge the present I_{batt} battery from a DC bus to a bank. The suggested BDC act as a buck converter when in charging mode. Figure 3 depicts the buck converter. In this buck mode/reverse flow, S1 always turns ON, whereas S2 always turns off. Electricity flow from a high to a low. This low voltage is delivered to the battery so it can be used later.

- State 1

The D2 diode is inverted in state 1 and the MOSFET S1 is switched on while the MOSFET S2 is turned off. In this case, the voltage loads the filtering inductor Lp linearly. Voltage across the inductor in this mode will be the difference between the bus voltage and battery voltage and it is represented in (2). The current through the inductor is represented in (3).

$$V_L = V_{bus} - V_{batt} \tag{2}$$

$$I_L = (V_{bus} - V_{batt}) / L_P \tag{3}$$

- State 2

State 2 turns off the power MOSFETS S1 and S2, and the D2 diode starts to conduct the Lp filtering mechanism. Voltage across the inductor in this mode will be the opposite of battery voltage and it is represented in (4). The current through the inductor is represented in (5).

$$V_L = -V_{batt} \tag{4}$$

$$I_L = -V_{batt} / L_P \tag{5}$$

2.2.2. Discharging mode

In this mode, the proposed BDC functions as a boost converter in conjunction with the current control function. As a result, the proposed BDC's recommended power flow direction is discharged from battery bank to DC bus by the current battery $I_{batt.}$ S2 is the primary switch and S1 is the auxiliary switch in Figure 4 which shows the boost mode converter and power transfer from low to high in boost mode/forward flow [22]–[25]. During this functioning state, S1 switches on OFF and S2 turns on. This mode comprises of two state.

- State 1

This makes it possible for the MOSFET S2 power to be turned on while the MOSFET S1 power is turned off, causing the current flowing through the filtering Lp inductor to drop to zero before charges are applied. The voltage across the Lp filtering inductor is in this state.

$$VL = -Vbatt \tag{6}$$

$$IL = -Vbatt / Lp \tag{7}$$

- State 2

In this situation, the power to S1 and S2 is turned off, and the diode D1 starts to operate. In this situation, Lp filter voltage. So that Lp filters the current linearly with the path decreases.

$$V_L = V_{bus} - V_{batt} \tag{8}$$

$$I_L = (V_{bus} - V_{batt}) / L_P \tag{9}$$

The PID controller is one of the earliest controls in industrial control systems because of how straightforward it is to use and how it is implemented. The three signals that make up PID-proportional, integral, and derivative are typically utilized in the plant model to provide an error-correcting signal. The gains for each signal are proportional (Kp), Integral gains (Ki), derivatives gain (Kd) shown in Figure 5. Here the PID controller is used to calculate the error values e(t). The error values make the different between a desired set point Sp = r(t). Where, the system gets a desired set point then the process variable is Pv = y(t) and finally which declares as the error e(t) = r(t) – y(t). Though, the correction is based on the PID controller that is endeavours to diminish the mistake over time by regulating control variable u(t).

$$\text{PID output} = \text{Kp} * \text{e(t)} + \text{Ki}\int \text{e(t)} * \text{dt} + \text{Kd} * (\frac{\text{de}}{\text{dt}}) \tag{10}$$

For the execution of this FLC PID controller on the BDC, modeling of bidirectional converter is very important. The modeling of BDC with properly chosen R, L and C describe in (9)-(17).

$$L\, di/dt + Ri + 1/C\,(\int idt) = V\,in \tag{11}$$

$$1/\text{C}\,(\int \text{idt}) = \text{Vout} \tag{12}$$

By taking Laplace transform:

$$\text{sL I(S)} + \text{R I(S)} + \frac{1}{\text{C}}\,\text{I(S)} = \text{Vin(S)} \tag{13}$$

$$\frac{1}{\text{sC}}\,\text{I(S)} = \text{Vout(S)} \tag{14}$$

On simplification, $\frac{((\text{LCs}*\text{s}\,)+\text{RCs}+1)\text{I(S)}}{\text{Cs}} = \text{Vin(S)}$:

$$I(S) = \text{Vin(S)}\,\frac{\text{Cs}}{((\text{LCs}*\text{s})+\text{RCs}+1)} \tag{15}$$

Substituting (15) in (14).

$$\frac{\text{Vout(S)}}{\text{Vin(S)}} = \frac{1}{\text{LC(s}*\text{s)}+\text{RCs}+1} \tag{16}$$

By choosing proper values of R, L, and C. Transfer function is as in (17).

$$T.F = \frac{20}{((s*s)+10s+20} \tag{17}$$

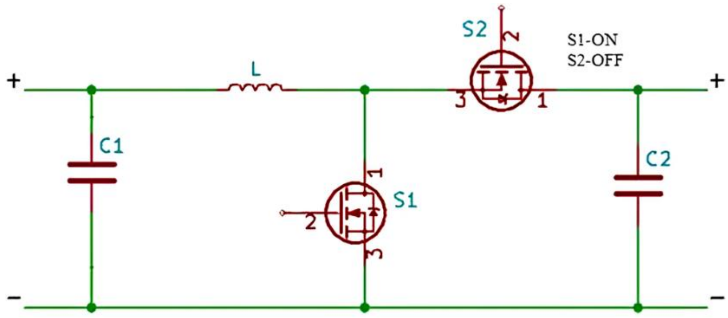


Figure 3. BDC circuit diagram at buck mode

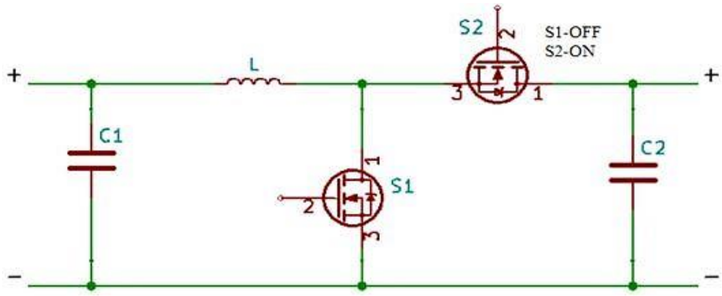


Figure 4. BDC circuit diagram at boost mode

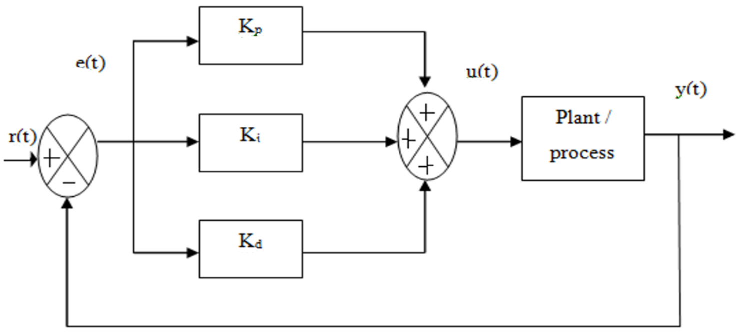


Figure 5. PID controller block diagram

2.3. Tuning of PID controller

The balance effect is achieved by producing a loop tuning for the optimal control function which is used in control applications by tuning constant K. An approximation of the constant values can usually be initiated according to the types of applications to reach tuning values or normally refined. Finally, the bumping processes are introducing to change a set point and observe the system response.

2.3.1. Zeigler-Nichols frequency method

In control systems engineering, the Zeigler-Nichols frequency method is a well-liked tuning technique for proportional-integral-derivative (PID) controllers. The steps involved are as follows: Set the integral (I) and derivative (D) gains to zero when starting with a proportional (P) controller. In order to get the system to oscillate at a constant amplitude, raise the proportional gain (Kp). Calculate the ultimate gain (Ku) by measuring the oscillation period (P). Using Ku and P, calculate the PID controller parameters in accordance with pre-established guidelines. PID controllers uses this technique to get the required control system performance.

$$Kp = 0.6\, Kc,\ \text{Ti} = 0.5\ \text{Tc} \tag{18}$$

Tc is the time period of sustained oscillation.

$$Td = 0.1(2Tc) \quad (19)$$

Where Kc is the gain or sustained oscillation of the system.

$$Ki = Kp / Ti, Kd = KpTd \quad (20)$$

Thus, initial values of Kp, Ki, and Kd are chosen.

2.3.2. Genetic algorithm (GA) based PID

Kp, Ki, and Kd are manually configured using GA to produce a Kp, Ki, and Kd value. GA made detailed improvements to the computer system's appearance and operation. It is reliant on how evolutionary forces like reproduction, hybridization, and mutation respond. The problem is examined and initialized within an AG by population, development, exercise measurement, population fitness selection, and production, which yields the optimal answer in terms of fitness. The objective is to discover the optimum value for constants Kp, Ki, and Kd. The optimization vector X is defined according to (21).

$$X = [K_P, K_i, K_d] \quad (21)$$

The aim function to reduce the e(t) error by the root mean squared error (RMSE).

$$RMSE = \sqrt{\frac{\sum_{t=0}^{T}(V_{out}(t) - V_{ref}(t))^2}{T}} \quad (22)$$

Subject to $K_{PL} < K_P < K_{PU}$, $K_{iL} < K_i < K_{iU}$, and $K_{dL} < K_d < K_{dU}$. Where t is the time to measure voltage, T is the total time for simulation, Vout(t) is the voltage measured on the converter output, and Vref(t) the voltage of reference for the converter.

3. RESULTS AND DISCUSSION

The DC-DC converter is bidirectional executed by GA PID for suitable customer (load side) and network use of PV voltage. MATLAB/Simulink was developed and it appeared in the Figure 6 of the projected circuit as well as control strategies like fuzzy logic controller (FLC) and GA PID. Figure 7 radiation and radiation free PV output.

The responsiveness of the two-way DC-DC converter is 250 V under various load resistance conditions (100 ohm, 150 ohm, and 50 ohm, respectively), when utilizing the GA PID controllers based on the ON grid system DC connection voltage at 0 to 2.5 seconds. The system peak surpasses 0.038 seconds, while the GA PID set up time is 0.2 seconds. Voltage is sustained during the period of simulation as well as is shown in Figure 8.

Here, the bidirectional DC-DC converter's responses to the employment of the GA PID controller are displayed. The output voltage of the grid system is 250 V under varied one-phase load resistance circumstances (100 ohm, 150 ohm, and 50 ohm) with a time interval of 0–2.5 seconds. The BDC's response to GA PID varies from 2.5 A to 100-ohm single phase load resistance at 0-0.5 sec; 1.6 A for 150 ohm 0.5-1 sec; and 4.2 A for resistive loads at 50 ohm at 1-2.5 sec. as illustrated in Figure 8. PI, FLC, and GA PID are the three controllers used to investigate this experimental setup. The effectiveness of different controllers is tabulated below based on settling time. Table 1 contains a comparison of the settling times of several controllers. The simulation results of a GA-based, PID-controlled bidirectional converter are described in Table 2. The Simulink limitations for the GA PID-based BDC system are displayed in Table 3. Figure 9 shows the convergence chart of GA PID based bidirectional converter with fitness value.

3.1. Hardware layout of BDC

The bidirectional hybrid source energy converter and inverter feeding system was tested in this stage using the apparatus in Figure 10. The two-way inverter is controlled by a wireless signal control platform called PIC16F877A, and the analytical results are shown. The MOSFET IRF 840, which powers the 3-phase inverter, is driven via the MOSFET’s 8-pin TLP 250 IC optocoupler. With the aid of a charge controller, solar power is supplied to the suggested circuit, which is powered by 12 V, 1.3 Ah batteries. Figure 11 depicts the proposed circuit's testing. The three-phase inverter's output voltage is shown in Figure 11. In Figure 12 the stress on the DC circuit interface during the redirect direction is shown.

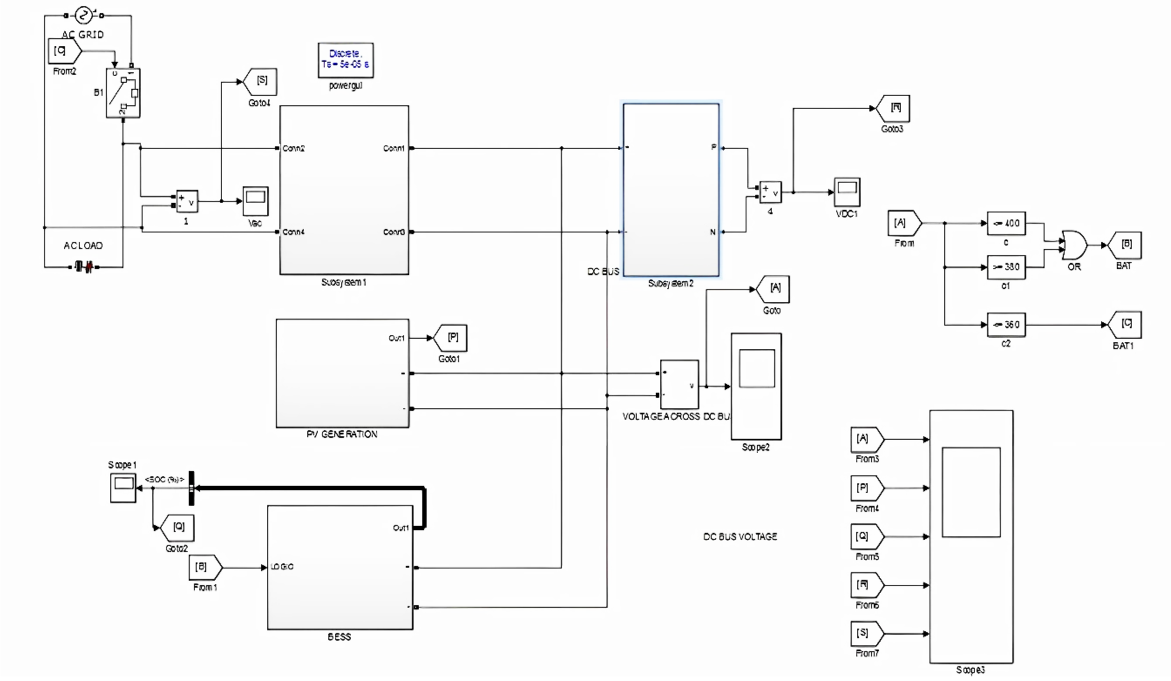


Figure 6. Overall simulation diagram of the BDC

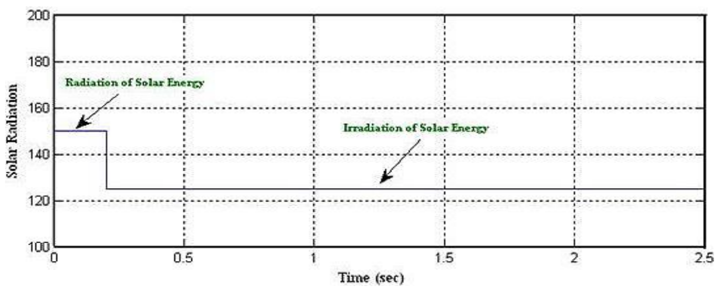
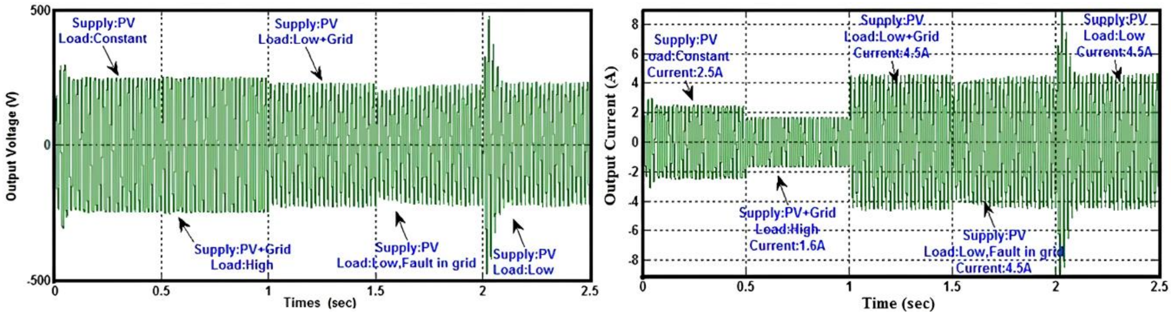


Figure 7. PV Output in radiation and in darkness



(a) (b)

Figure 8. When a load is changing, (a) the output voltage and (b) the current through a GA PID controller

Table 1. Comparison of the DC link's settling time using the PI, FLC, and GA PID

Rated load status	PI controller settling time (in sec)	FLC settling time (in sec)	GA PID controller settling time (in sec)
Rated load	0.32	0.21	0.12
Above rated load	0.72	0.61	0.41
Below rated load	1.27	1.15	1.0

Table 2. Simulation results for GA based PID controlled BDC

Sl No.	Parameter	Values
1	Voltage switching stress on switch (Vsw)	282 V
2	Output voltage at load	255 V
3	THD at load current	16.10%
4	Switching losses in (mW)	32.9 mW

Table 3. Simulink parameters

Parameter	Value	Parameter	Value
Rated solar voltage	120 V	Filter inductance (L_F)	47 mH
Switching frequency	5 kHz	Filter capacitance (C_F)	80 µF
Inductor (L)	5 mH	Resistive load	150 *Ω*
Capacitor (C)	130 mF		

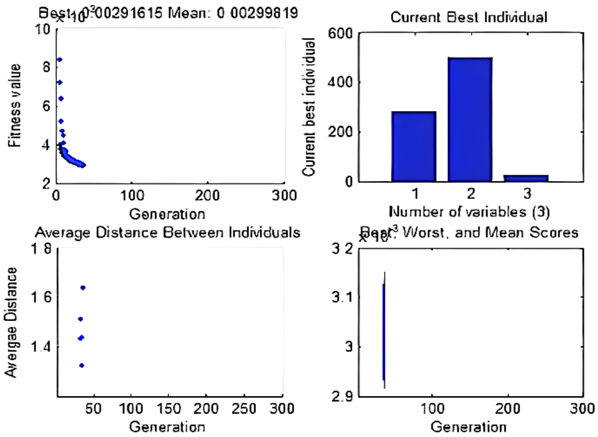


Figure 9. Convergence chart of GA PID based BDC

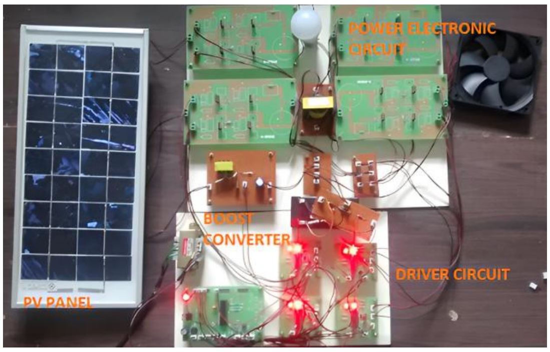


Figure 10. Experimental set up

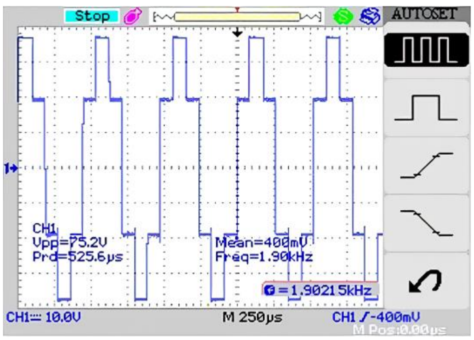


Figure 11. Bidirectional inverter's output voltage

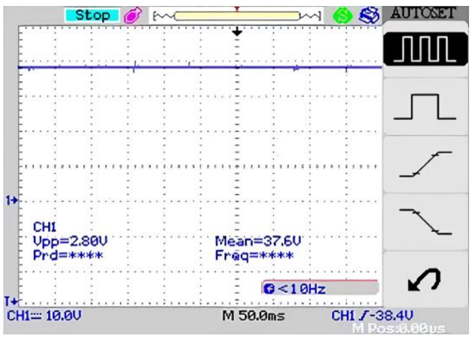


Figure 12. DC link voltages during forward

4. CONCLUSION

In conclusion, the project's primary objective is to address the inherent limitations of traditional proportional integral derivative (PID) controllers, characterized by prolonged delays and settling times. This will be accomplished by replacing the conventional PID controller with a genetically optimized variant using genetic algorithms (GA). We conducted an analysis of the relationship between PI, FLC, and GA PID controllers within a bidirectional converter operating under different load conditions. Compared to the PI controller, the GA-based PID controller demonstrates superior performance with reduced oscillations and a faster setup time of 0.1 seconds. The bidirectional ON-grid system converter, as proposed, generates a lower-speed DC connection voltage. To assess various solar charging scenarios, a boost converter is employed for validation purposes. The system is segregated during simulation, with experimental results set to be utilized in generating power. This will be achieved by utilizing a microcontroller to generate gate pulses that will be input into a bidirectional PV panel converter.

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