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Performance Enhancement of Boost Converter for Solar Panels System using Genetic Algorithm

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ABSTRACT- Solar Panels System (SPS) is a renewable power source with an essential drawback of low output voltage due to the effect of aspects like the intensity of light and ambient temperature. The DC-DC boost converters are significantly used to boost up the SPS voltage under a certain set of conditions. The converter's output voltage and current are unstable, complex, and varied. A three-term controller (proportional, integral, and derivative) is often used because it can control the system's behavior effectively. The challenge is the selection of the optimum gain parameters of the controller. In this paper, the optimum gain parameters of the controller are selected based on Genetic Algorithm (GA) for the boost converter of SPS. The best operation function of GA based on the tournament, uniform, and constraint dependent is selected by testing and evaluating various genetic algorithm operators, while the objective function based on Integral Time Absolute Error (ITAE) is used to minimize the fitness function. MATLAB code and GA optimization solver are used for simulation results. The simulated results prove the effectiveness of the proposed approach to stabilize and control the boost converter system due to the best specifications of the system. The proposed system enhances the transient response by about (40%) which leads to an increase in the efficiency of the system.

Keywords: Control system; Three-term controller; Genetic algorithm; Solar panel; Boost converter.

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1. INTRODUCTION

The output power from the SPS is fed to the inverter circuit after passing through the boost converter system. The boost converter is widely applied for SPS in power generation systems where the output current and voltage of a single SPS are very low. Therefore, boost circuits are required for boosting the voltage and current to maintain the stability of the output voltage after power conversion [1]. The output power generated from the SPS is fed to the voltage source inverter upon completion the boost circuit. The output from the inverter can either directly power the load, or be connected to the power grid. Voltage boosting and stability, insulating properties, and current ripple reduction is the most essential functions of the boost circuit [2]. The three-term controller is frequently employed for controlling the boost circuit, due to its ability to successfully manipulate the controlled system based on the properties of the controlled item. This controller is used to achieve stability and satisfactory performance of the output voltage. However, when the system is nonlinear and complex, these parameters of the controller will be difficult to select. The genetic algorithm is the suitable optimization technique that can be used to select the best value of the three-term controller [3].

In [4] and [5] GA was utilized to select the three-term controller to get the optimum response for various systems, like the attitude of the drone and the continuously stirred tank reactor. The authors concluded that the GA algorithm is effective in tracking the performance of the input system with optimal stability.

In [6], the intelligent control method based on the fuzzy logic controller (FLC) was proposed for maximum power point tracking (MPPT) of solar panel systems under various temperature conditions. The FLC was improved by using the GA optimization technique and the simulation results showed better performance.

In [7], GA optimization technique with Artificial Neural Network (ANN) based MPPT in solar panel system of direct-coupled induction motor drive is presented.

This method was proposed in order to eliminate the accompanying losses of D.C - D.C converter. While, GA optimization was employed to calculate the number of neurons in a multi-layer perceptron of ANN. The results proved the effectiveness of the proposed method. The GA was combined with back propagation neural network (GA-BPPID) and PID controller in [8] to enhance the anti-interference and the dynamic performance of the boost circuit, the authors used the ability of global optimization and the adaptive characteristics of a neural network to improve the system response. The effectiveness of GA relies upon different operators. The selection of the operator is affected the performance of GA. S. Legg et al [9] compared the performance of fitness uniform selection function (FUSS) with the tournament selection the theoretical results proved that (FUSS) outperform another selection operation due to its simple concept.

In this paper, the GA technique is implemented to tune the three- terms controller parameter gains for the boost converter of SPS. Since the other available algorithms like evolutionary programing and evolutionary strategy are difficult to debug and expensively computation. This algorithm is used in order to get the optimal parameters gain. The only limitation of GA is the slow of operation due to the iteration process. Some genetic algorithm function operators are tested and evaluated to select the best function operation. Where, uniform, tournament and constraint dependent are selected for the selection, mutation and crossover operators respectively which are suitable for the boost converter system. The fitness function is minimized through the using of the objective function (ITAE). The best performance results are compared with another work in term of system specification which proved the effectiveness of the proposed technique.

The rest of the paper is arranged as: The boost converter mathematical model in *section 2*, the principal concept of GA is arranged in *section 3*. The three- term controller is organized in *section 4*. Modeling the proposed control system is presented in *section 5* which contains GA proposed steps and the proposed control approaches, while *section 6* contains the simulation results and discussion and conclusions are arranged in *section 7*.

2. THE BOOST CONVERTER MATHEMATICAL MODEL

The SPS generates the maximum power that transferred to the load by D.C-D.C converter [10]. The boost converter called step-up converter which its output D.C voltage greater than input voltage [11]. *Figure (1-a)* shows the boost converter circuit, which consists of an inductor, diode, capacitor, and switch. The switch is fed from a PWM signal to control the output voltage by adjusting the duty cycle. Where D and T represent the duty cycle and the switching period respectively as shown in *figure (1-c)*. The output voltage (V_O) or (V_{ref}) for the circuit as shown in *figure (1-a)* is calculated as follows.

$$V_O = V_{ref} = \frac{1}{T}\int_0^{DT} V_g(t)dt = V_g \quad (1)$$

Where V_g represents the input voltage. If the switch is closed as shown in *figure (1-a)* with ON time equal to DT *figure (1-c)*, the inductor gets charge by the solar panel or battery, the diode prevents the current to flow, the inductor current is supplied by the discharge of the capacitor remains constant as in equation below.

$$V_L = V_g = L\frac{di_L}{dt}; \quad \frac{di_L}{dt} = \frac{V_g}{L} \quad (2)$$

Where L represents the inductor, V_L represents the inductor voltage and i_L the inductor current. Since the current rate of change is constant, the current grows linearly when the switch is closed and *equation (2)* will be

$$\Delta i_{L\ closed} = \frac{V_g DT}{L} \quad (3)$$

If the switch is opened as shown in *figure (1-b)* with OFF time equal to *(1-D) T*, the diode is conducted and the inductor started to discharge the energy stored, while the capacitor charged. So that, i_L be constant during this operation [12] as in equation below.

$$\Delta i_{L\ opened} = \frac{(V_g - V_{ref})(1-D)T}{L} \quad (4)$$

The change in inductor current must be zero at a steady state [13]

$$\Delta i_{L\ closed} - \Delta i_{L\ opened} = 0$$

Then the output voltage will be.

$$V_{ref} = \frac{V_g}{1-D} \quad (5)$$

According to *figure (1-b)* when the voltage source is shorted and the current source is opened the input voltage (V_g) is as follows.

$$V_g = Z_i * I_i \quad (6)$$

Where Z_i represents the input impedance and I_i represents the input current. Z_i can be derived as in *equation (7)* below

$$Z_i = \frac{R(1+\frac{SL}{R}+S^2LC)}{(1-D)^2(1+SRC)} \quad (7)$$

Where the R represents the load resistor and C represents the capacitor. The output voltage (V_{ref}) is calculated in the same manner in *equation (6)*. $V_{ref} = -Z_o * I_l$. And the output impedance (Z_o) has derived in the same way as in *equation (7)*

$$Z_o = \frac{SL}{(1-D)^2(1+\frac{SL}{R}+S^2LC)} \quad (8)$$

To find the equivalent impedance for boost converter as in equation below

$$Z_{eq} = \frac{1}{(1-D)^2(1+\frac{SL}{R}+S^2LC)} \quad (9)$$

To find the transfer function of the boost converter by finding the relation between the output voltage to control switch and multiplying the equivalent impedance by (V_{ref} -VL) as in *equation (10)*

$$G(S) = Z_{eq} * (Vref - VL) \quad (10)$$

By compensating *equations (2)* and *(5)* into *equation (10)*. The details of the mathematical model in [8]. The transfer function of the boost converter in [13] as in *equation (11)*.

$$G(S) = \frac{v_g((1-D)^2 R - SL)}{(1-D)^2((1-D)^2R + SL + S^2RLC)} \quad (11)$$

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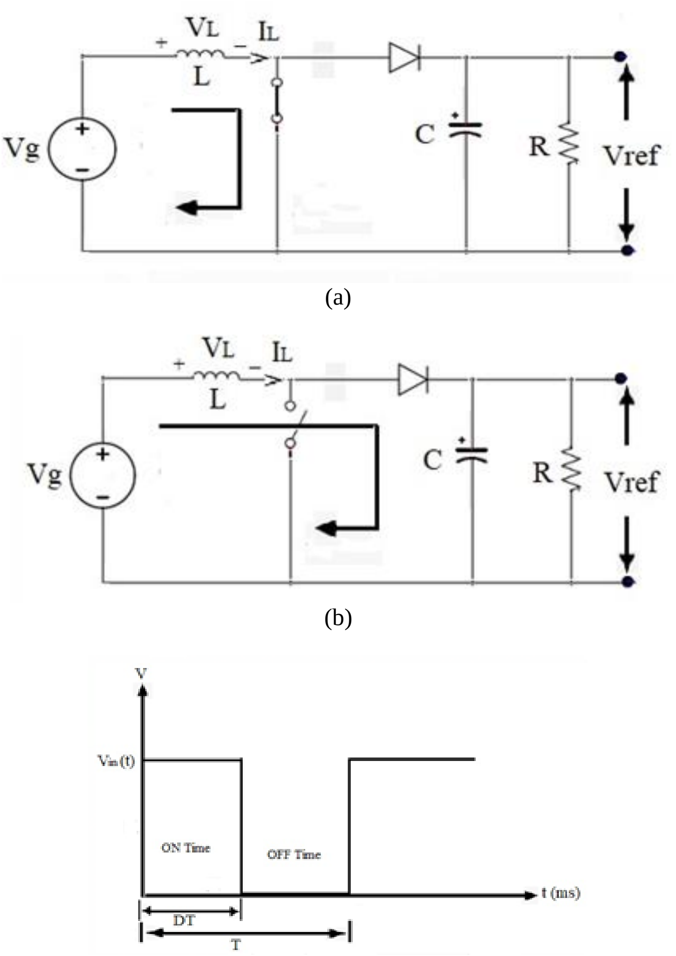

Figure 1: The block diagram of the boost converter, (a) when the switch is closed, (b) when the switch is opened and (c) the duty cycle of the time

3. THE PRINCIPAL CONCEPT OF GA

GA one of the random search algorithms that depends on the genetic mechanism and natural selection biology [8]. This algorithm uses a probabilistic global optimization technique.

The population of coding strings created by the parameters to be optimized is introduced using the biological of evolution the principle of "*survival of the best fittest*", and each individual is screened using a particular fitness function and set of genetic operations [14].

The individuals that have high fitness will remain and create a new group. This new group generation has a large and better amount of information from the earlier generation. Due to its distinctive working theory, GA can perform a global optimization search in a high dimensional feature space and has a high level of robustness [15], [16].

Furthermore, GA dose not required any limitations on the search space, like continuity, differentiability. The mean feature of this technique is the ability to deal with difficult-to-solve nonlinear, complex optimization problem. In GA, the population and chromosome both represent sets of potential solutions to the optimization problem, and the fitness function frequently reflects the objective function of the optimization problem. The fundamental concept of it is to begin with a variety of solutions and gradually iterate *via* specific guidelines to obtain new solutions.

4. THE THREE TERM CONTROLLER

The three-term controller is often utilized to control the boost converter switch in order to achieve output voltage stability due to its simple technique and uncomplicated implementation [17].

This controller consists of three parts which are the proportional part, the integral part that used to eliminate the steady state error, and the derivative part. The error function represents the input to this part of the system, which is the difference between the reference input signal and the output signal [18]. The general form of the controller as follows in [19], [20].

$$e(t)=R(t)-y(t) \tag{12}$$

$$u(t) = k_p\ e(t) + ki \int e(t)dt + k_d\ \ de/dt \tag{13}$$

Where k_p, ki, and kd are represent the proportional, integral, divertive gains, respectively. While, *e(t), u(t), R(t),* and *y(t)* represent the error function, output controller function, input and output signals respectively.

5. MODELING OF PROPOSED SYSTEM

5.1. GA Proposed Steps

GA deals with population of potential solution (chromosomes) which developed iteratively. Through the use of a fitness function and genetic operators like reproduction or selection, mutation, and crossover the development of solutions is simulated. GA initialized by random number of populations [21].

A binary string or real value number is termed a chromosome which is typically used to identify this population. The performance of each chromosome is assessed, and measured by an objective function which evaluates each individual according to a factor called fitness [22].

Each chromosome's fitness is evaluated, and the selection of a fittest strategy is used. Thus, the proposed work utilizes the error function to evaluate the fitness of the chromosomes during the sequences of operation of GA technique which consists of selection, crossover, and mutation.

Figure 2 describes the GA operation steps in detail. In this figure, the parameter's initial value is set to a population of random solutions, the fitness function is evaluated and measured. Crossover and mutation operations should continue, creating the new group, these operations are repeated till obtaining the optimum value.

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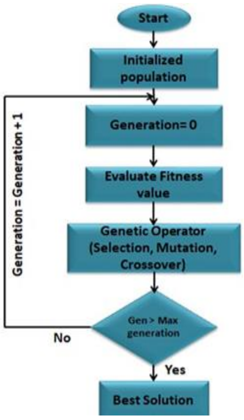

Figure 2: The flow diagram of GA operation

5.2 The proposed control approaches

In this section the controller parameters' gain are tuned based on GA in order to select the appropriate parameters. Where the input to the controller is the error function *e(t)* as in *equation (12)* and *U(t)* is the controller output as in *equation (13)*. To achieve optimum parameter's gain, the error function criteria which is Integration Time Absolut Error (ITAE) must be used [23]. ITAE is formulated as in *equation (14)* which is utilized as objective function to get these parameters with minimum error through GA [24].

$$ITAE = \int_0^\infty t|e(t)|\, dt \qquad (14)$$

The proposed approach is illustrated as follows: In order to enable the controller to be tuned and converge more quickly, GA first produces a stochastic population that is performed with a small size population [23]. The three-term controller parameters k_p, ki, and kd are encoded into binary strings known as chromosomes to set the initial population [25], [26]. Each chromosome's fitness is determined by translating its binary code into such a real value which stands for the controller parameters gain, which will be the input to controller. The overall system response for each parameter of the controller and its initial fitness function (ITAE) are computed. The process of evaluation the fitness value; as shown in *figure 2* as illustrated in *section (5-1)*; begins until the generational period in which the highest fitness value is attained. The main objective of GA is to find the values of controller parameter (k_p, ki, and k_d) with the lowest fitness value to control the boost converter. The complete control approach of the proposed work is shown in *figure 3*.

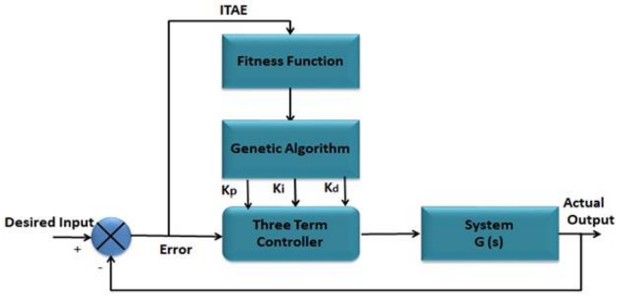

Figure 3: The proposed control approach of the overall system due to GA technique

6. SIMULATION RESULTS AND DISCUSSION

The details of the boost converter simulated parameters and GA technique for the system are illustrated in *table 1* as in [8]. Also, for the proposed system, the size of population is between 50-200, maximum number of iterations (*m*) is equal to 105, the lower and upper band of the controller parameters array are [0 0 0], [100 100 100] respectively.

Table 1: Simulation System Parameters

Symbol	Quantity	Magnitude
R	Resister	5Ω
L	Inductance	0.08 H
C	Capacitance	0.007
V_g	input voltage	5V
Vref	output voltage	7V
D	Duty cycle	0.2857

The proposed technique is simulated by using MATLAB code, and the GA optimization solver to obtain the best value of controller parameters (k_p, ki, *and* k_d). The objective function (ITAE) is used to minimize the error. The transfer function due to the simulation system parameters according to *equation (11)* becomes as,

$$G(S) = \frac{-0.754S+25}{0.00028S^2+0.08S+2.551} \qquad (15)$$

Figure 4 shows the response of the system, where the parameters of (k_p, ki, *and* k_d) is selected with (*m*) equal to 105. The operation functions due to GA technique for selection is stochastic uniform, for mutation and crossover is constraint dependent. The setup parameters gain of the controller is illustrated in *table 2*. The results show the effectiveness of the proposed control strategy for damping the maximum overshoot of the system and stabilize the system with less settling time.

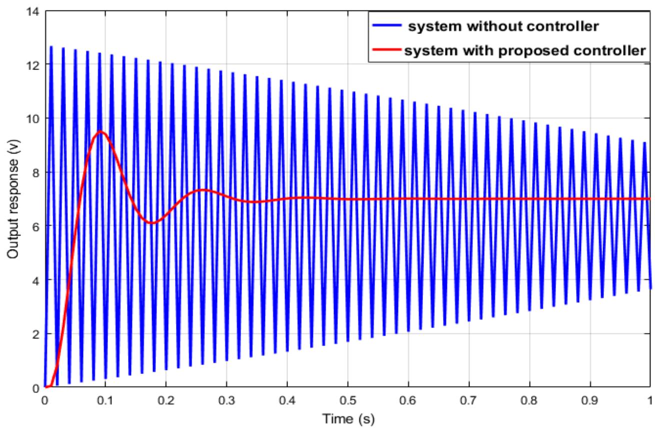

Figure 4: Comparison between the response of the system without controller and with the proposed controller due to the selection is stochastic uniform, and mutation and crossover are constraint dependent

Table 2: **The Parameters of Gain due to the Function Operators and the Factors of Specification for the System**

The proposed controller system due to function operators	$\mathbf{k_p}$	$\mathbf{k_i}$	$\mathbf{k_d}$	**System specifications parameters**				**m**	**The system without controller (maximum over shoot) %**	**System specifications**
				maximum overshoot (M_P)%	Settling time(t_s) (sec)	Delay time(t_d) (sec)	Rise time(t_r) (sec)			
selection is stochastic uniform, mutation, and crossover are constraint dependent (figure (4))	0	4.483	0	34.2%	0.39	0.0373	0.0422	105	Unstable	Unstable
the selection and mutation are uniform the crossover operation is constraint dependent (figure (5))	0	3.496	0	26%	0 .3	0.0423	0.051	92	Unstable	Unstable
the selection and mutation are uniform the crossover operation is heuristics (figure (6))	0.881	1.292	0	50.4%	0.622	0.033	0.006	51	Unstable	Unstable
the selection operator is uniform, the mutation is adaptive feasible and the crossover operation is constraint dependent (figure (7))	0.287	20.712	0	38.5%	0.08	0.0108	0.0145	75	Unstable	Unstable
the selection operator is tournament, mutation is uniform the crossover operation is constraint dependent (figure (8))	0.37	14.64	0.001	4.14%	0.062	0.0079	0.0113	53	Unstable	Unstable
selection operator and mutation are uniform, and the crossover operation is intermediate (figure (9))	0	1.579	0	5.35%	0.269	0.067	0.089	97	Unstable	Unstable

Figure 5 and *figure 6* show the response of the system where the operation function due to GA technique for selection and mutation are uniform. While the crossover operation for the two figures is constraint dependent and heuristics respectively. Through the two simulations the parameters of (k_p, ki, and k_d) is selected with (m) equal to 92 and 51 respectively as shown in *table 2*.

The results show that the output performance of the system reaches a steady state with less settling and rise time. While the maximum overshoot is about (26%) and (50.4) % for these figures respectively which is acceptable for *figure 5* and not allowed for *figure 6*. Also, *figure 6* contains oscillation in starting of the operation this leads to more duration time until stabilize.

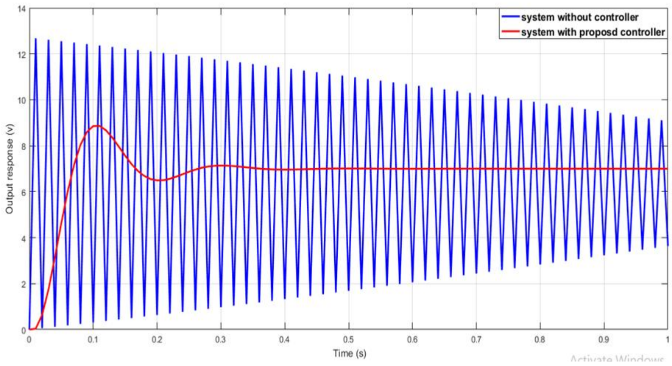

Figure 5: Comparison between the response of the system without controller and with the proposed controller due to the selection and mutation are uniform, the crossover operation is constraint dependent

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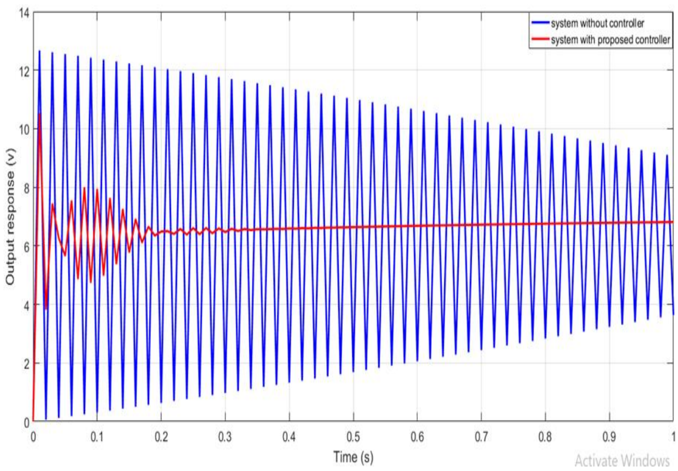

Figure 6: Comparison between the response of the system without controller and with the proposed controller due to the selection and mutation are uniform the crossover operation is heuristics

Figure 7 and *figure 8* show the response of the system where the crossover operation function due to GA technique of the two figures is constraint dependent. The selection operation function is uniform and tournament respectively. While the mutation operation function is adaptive feasible and uniform for these figures respectively. Through the two simulations the parameters of (k_p, ki, and k_d) is selected with (m) equal to 75 and 53 respectively as shown in *table 2*.

The results show that the output performance of system reaches the steady state with less time rising. Whereas the overshoot is about (38.5%) for *figure 7*, which is need more development due to using these operation function. While in *figure 8*, the maximum overshoot equal to (4.14%) and rising time equal to (0.0113) which is high performance and more stable output response due to the system specifications

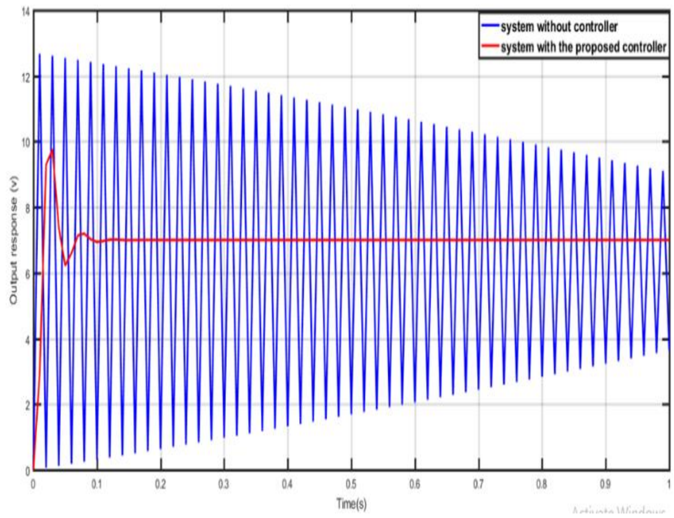

Figure 7: Comparison between the response of the system without controller and with the proposed controller due to the selection operator is uniform, the mutation is adaptive feasible and the crossover operation is constraint dependent

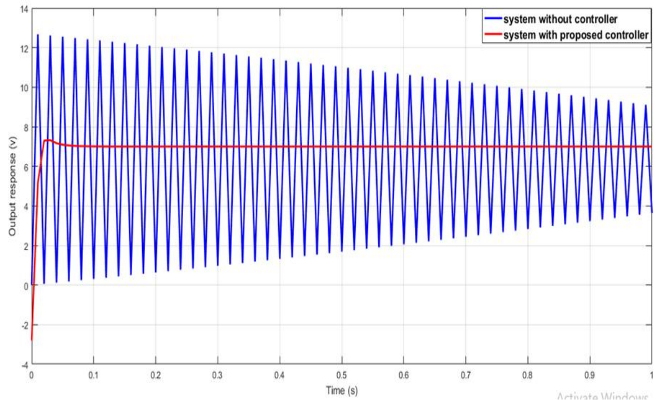

Figure 8: Comparison between the response of the system with proposed controller and without controller due to selection operator is tournament and mutation is uniform the crossover operation is constraint dependent

Figure 9 illustrates the response of the system where, the operation function due to GA technique for selection and mutation is uniform. The crossover operation is intermediate. The parameters of (k_p, ki, and k_d) selected with iterations equal to 97 as shown in *table 2*. The results show that the output performance of system reaches the steady state with acceptable time settling and good maximum percentage overshoot. But the number of iterations is high which need more computational time to get the results as compared with *figure 8*.

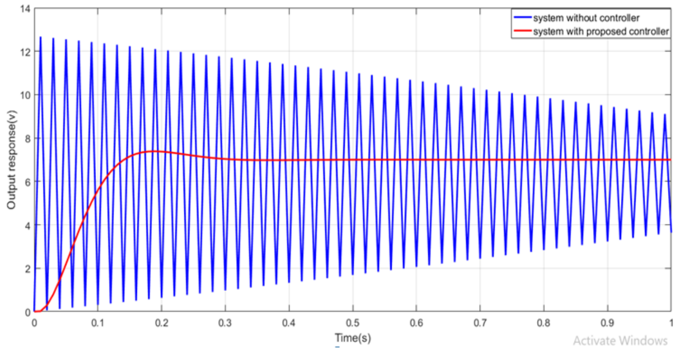

Figure 9: Comparison between the response of the system without controller and with the proposed controller due to selection operator and mutation are uniform, and the crossover operation is intermediate

The results of the proposed technique are also compared with the results of [8] and [15] which used the GA-BPID technique and PID- based GA technique respectively. Where the settling time, delay time, rise time, and the number of iterations are (0.136s, 0.046s, 0.195s, and 120) and (0.12s, 0.1s, 0.175s, and20) for [8] and [15] respectively as shown in *table 3*. Whereas the results of the proposed system due to the function of selection, mutation, and crossover; which are tournament, uniform, and constraint dependent respectively; for the same specification parameters of the system are equal to 0.062 s, 0.0079 s, 0.0113 s and 53 respectively. The comparison shows that the proposed control system improves and enhances the behavior of the transient response of about (40%). Also reduces the computational time and doesn't require more complex circuit like GA-BPPID. Finally, the proposed system increases the system efficiency. The only limitation of GA is the slow of operation due to the iteration process.

Table 3: A Comparison of the Proposed Controller with another Controller due to System Specification

method	system specification parameters			m
	Settling time (*ts*) sec	Delay time (*td*) sec	Rise time (*tr*) sec	
GA-BPPID [5]	0.136	0.046	0.195	120
PID- based GA [15]	0.12	0.1	0.175	20
Proposed controller	0.062	0.0079	0.0113	53

7. CONCLUSION

This paper introduces the three-term controller based on GA technique to control the boost converter of solar panel system. The process for detailed design and system modeling is presented. The optimum parameters of the three-term controller are selected based on GA. These optimum parameters are implemented to control the overall system response. Some functions operations of GA are evaluated and selected due to the best system specification, stable response, and less overshoot. These functions operations are tournament, uniform, and constraint dependent. This approach leads to enhance the efficiency of the solar panel system. The (ITAE) objective function utilized to minimize the computed error. The results obtained as compared with GA-BPID controller achieve less settling time, delay time, rise time and number of iterations. Also, the proposed system is stabilizing the response of the system faster, doesn't require a complex circuit, has less computational time, and improves the transient response of the system by about (40%), hence, the efficiency of the system increases. The neural network instead of three-term controller will be used in future studies to assess the effectiveness of the process of optimizing control parameters.

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