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Real Coded Genetic Algorithm Based Improvement of Efficiency in Interleaved Boost Converter

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ABSTRACT

The reliability, efficiency, and controllability of Photo Voltaic power systems can be increased by embedding the components of a Boost Converter. Currently, the converter technology overcomes the main problems of manufacturing cost, efficiency and mass production. Issue to limit the life span of a Photo Voltaic inverter is the huge electrolytic capacitor across the Direct Current bus for energy decoupling. This paper presents a two-phase interleaved boost converter which ensures 180 angle phase shift between the two interleaved converters. The Proportional Integral controller is used to reshape that the controller attempts to minimize the error by adjusting the control inputs and also real coded genetic algorithm is proposed for tuning of controlling parameters of Proportional Integral controller. The real coded genetic algorithm is applied in the Interleaved Boost Converter with Advanced Pulse Width Modulation Techniques for improving the results of efficiency and reduction of ripple current. Simulation results illustrate the improvement of efficiency and the diminution of ripple current.

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1. INTRODUCTION

A Grid-synchronized Photo Voltaic (PV) power system is constructed from a group of power converters a DC–DC converter ensuring the Maximum Power Point Tracking (MPPT) cascaded by a grid-synchronized inverter [1], [2]. For a PV power generation system, the actual power-generating device is the solar panel, and it has a longer life than the power converters. Photo Voltaic module embedded power-electronics topology derived from a battery equalizer, which eliminates the multiple maximum power point peaks common to partial shading in PV modules [3]. In particular applications such as military uses in a battlefield or in extreme weather conditions, repair or alternate of the converter is difficult, and a highly reliable PV-based power system, which is compact and highly mobile in nature, is needed. Abusaleh M. Imtiaz et al [4] describes the power Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is to ensure that the uninterrupted operation of the inverter, even though it gives higher manufacturing cost. This high cost could be eliminated using high band-gap semiconductors.

For designing high efficiency solar power systems, a suitable DC-DC converter is necessary. The DC-DC Boost converter is used to increase the voltage level in the solar system. In order to improve the efficiency of boost converter, a two phase interleaved boost converter is used. The use of a Switched Capacitor (SC) DC–DC converter for tracking the Maximum Power Point (MPP) of a photovoltaic array with the possibility of partial shading is described in [5]. The SC converter topology can be reconfigured to maximize conversion efficiency depending on the solar radiation and load. Generally speaking about high step-up DC–DC converters for these applications have the following features such as high step-up voltage gain, high efficiency. Naayagi et al. [6] explained the steady-state analysis of the bidirectional Dual Active Bridge DC–DC converter. An analysis of Zero Voltage Switching (ZVS) boundaries for the buck and boost modes while considering the effect of snubber capacitors on the DAB converter is also presented.

Boost converters are widely used as power factor corrected pre regulators. Due to an inductor of boost converter the ripple current is increased, harmonics also increased and power factor is reduced. In high power applications, interleaved operation of two or more boost converters has been proposed to increase the output power and to reduce the output ripple. Genc et al. explored [7] a non isolated, high boost ratio hybrid transformer DC–DC converter with applications for low-voltage renewable energy sources. The proposed converter employs a hybrid transformer to transfer the inductive and capacitive energy and then achieving a high boost ratio with a smaller magnetic component. However, the drawback of this converter is that the voltage across the switch is very high during the resonance mode components [8]. Lee et al. [9] described the optimal design of the resonant components and the interleaved method is proposed for resonant current reduction. That the interleaved method distributes the input current to each phase, the current rating of the switching devices can be decreased by using interleaved method. Also, it can reduce the input current ripple, output voltage ripple, and size of the passive. Yong et al. [10] illustrated an Interleaved Soft Switching Boost Converter (ISSBC) for a PV power generation system. The topology used to raise the efficiency of the DC-DC converter. The converter of the PV Power Conditioning System (PVPCS) and it minimizes switching losses by adopting methods of soft switching. Chien et al. [11] described a ZVS-PWM Interleaved Boost Rectifier.

A novel grid-connected boost half- bridge PV micro inverter system and its control implementations are presented in [12]. In order to achieve low cost, high efficiency, for easy control and higher reliability, a post-half-bridge DC–DC converter using minimal devices is introduced to interface the low-voltage PV module. An ultra large voltage conversion ratio converter is proposed by integrating a Switched Capacitor circuit with a coupled inductor technology. A DC-to-DC converter is required to couple the electrolyzer to the system DC bus [13]. A direct connection of DC bus to the electrolyzer is not suitable because it lacks the ability to control the power flow between the renewable input source and the electrolyzer. Gopinath et al. [14] and Arulmurugan et al. [15] illutrated the interleaved boost Converter with PI controller is used to feedback the output signal to the input for the reduction of ripple current and improvement of efficiency. Compared to a PID controller, PI controller has increased the efficiency and reduces the ripple current. Ahmad et al. [16] developed the various pulses or duty cycle is applied in this Converter using PWM Techniques.

Astrom [17] has developed the PI controller parameters are chosen incorrectly, the controlled process input will not be stable. Tuning a control loop is the adjustment of its control parameters to the optimum values for the desired control response. Ziegler-Nichols [18] has developed PI based on open loop and closed loop test. It has to be noted that controllers tuned using this procedure are tuned to control, not tracking. Thus, controllers with parameters tuned according to Ziegler-Nichols recommendation will perform well in disturbance rejection, but it will perform poorly in tracking reference changes. Also, computing the PI controller parameters by Ziegler-Nichols method does not provide optimum system response since they are dependent on the exact mathematical model of the process. In this Converter PI Controller with Ziegler and Nichols method are proposed. The improvement of efficiency is not sufficient, so that the optimization of real coded genetic algorithm is proposed. And then the conventional method of PI controller, which means Ziegler- Nichols, is not suitable for Interleaved Boost Converter. So, that the GA is ideally suited for unconstrained optimization problems. But, most of the search and optimization problems are constrained in nature. Hence it is necessary to transform it into an unconstrained problem. The binary coded GA has Hamming cliff problems [19], which sometimes may cause difficulties in the case of coding continuous variables. To overcome the above difficulty this chapter proposes a real-parameter genetic algorithm [20] in which the optimization variables are represented as floating point numbers.

This artificial evolution process of real coded genetic algorithm is the foundation of the three main different evolutionary based algorithms: Evolutions Strategies (ES) [21], Evolutionary Programming (EP) [22], and Genetic Algorithms (GA) [23]. The proposed real coded genetic algorithm approach has been applied for controller tuning (controlling parameters) in Interleaved Boost Converter. The simulation results show that the proposed algorithm has resulted in minimizing ripple current and improving efficiency than the conventional method and the traditional binary coded genetic algorithm. The proposed of real coded GA-based approach is applied to tune the PI controller in the Interleaved Boost Converter. Also, the proposed algorithm obtains less time for convergence compared to the binary coded genetic algorithm.

2. INTERLEAVED BOOST CONVERTER

A Boost Converter is a power converter with an output DC voltage is higher than its input DC voltage. It is a set of Switching Mode Power Supply (SMPS) with at least two semiconductor switches and one energy storage element. This converter boost up the voltage at doubled than the other converter. The filters made of capacitors or inductors are normally added to the output of the converter to reduce output voltage ripple. Inductor and Input supply are together in series connection for adding the input and stored energy in the inductor. It is not suitable for high power. The output of the boost converter having an amount of ripple, due to ripple current, distortion is increased.

Interleaved Boost Converter has a number of boost converters connected in parallel, which have the same frequency and phase shift, mainly used for renewable energy sources. In case of boost converter ripple is present in the input current due to rise and fall of the inductor current. This problem can be eliminated by using the Interleaved Boost Converter which is shown in Figure 1.

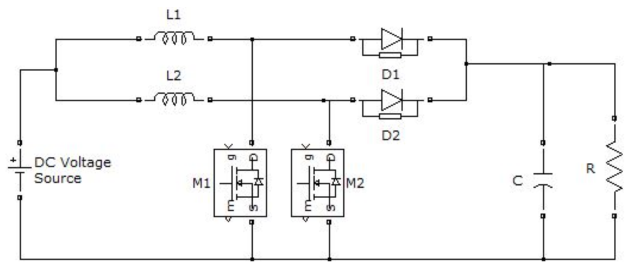

Figure 1. Circuit Diagram of Interleaved Boost Converter

In an Interleaved Boost Converter two boost converters operated in 180° out of phase. The input current is the sum of two inductor currents I_{L1} and I_{L2}. Because the two inductor ripple currents are out of phase, they cancel each other and reduce the input ripple current.

When switch M_1 is on and switch M_2 is off:

$$\frac{dIL1}{dt} = \frac{Vin}{L1} \quad (1)$$

$$\frac{dIL2}{dt} = \frac{Vo-Vin}{L2} \quad (2)$$

When switch M_1 is off and switch M_2 is on:

$$\frac{dIL1}{dt} = \frac{Vo-Vin}{L1} \quad (3)$$

$$\frac{dIL2}{dt} = \frac{Vin}{L2} \quad (4)$$

The two inductor currents will be out of phase and cancel out the ripple of each other if:

$$\frac{Vin}{L1} = \frac{Vo-Vin}{L2} \quad (5)$$

$$\frac{Vo-Vin}{L1} = \frac{Vin}{L2} \quad (6)$$

The above Equation (5) and (6) will be satisfied if and only if L1 = L2 = $0.713e^{-3}$H.The duty cycle of the system is 0.4. Hence the duty cycle is calculated the Equation (7) which is given below:

$$D = 1 - \frac{V_{IN(min)} X \eta}{V_{OUT}} \quad (7)$$

The capacitor value (C = 4.79μF) is calculated from the Equation (8) and the switching frequency of the converter is set at the value of 50 KHz.

$$C_{OUT(min)} = \frac{I_{OUT}XD}{f_s X \Delta V_{OUT}} \quad (8)$$

The calculation of basic parameter is used to design the circuit diagram of both Boost and Interleaved Boost Converter.

$$Efficiency = \frac{V_{OUT}XI_{OUT}}{V_{IN}XI_{IN}}X100 \quad (9)$$

The parameter of efficiency is calculated from the above Eq. (9) also it is represented by the ratio of output and input power. Energy conversion efficiency (η) is the ratio between the useful output of an energy conversion and the input.

2.1. Signal Generators

Pulse Width Modulation is the signal generators that conforms the width of the pulse based on modulator signal information. It is a way of delivering energy through a succession of pulses rather than an analog signal. In this paper, different types of PWM techniques are examined that are single pulse width modulation, sinusoidal pulse width modulation and modified sinusoidal pulse width modulation. In this PWM, the switch between supply and load is turned on/off at a very fast pace so as to control the average value of voltage and current fed to the load. Thus the switch basically operates on the above mentioned principle using PWM switching scheme. The term duty cycle expresses the ratio of on time to the entire period of the time in percentage. It is generated by comparing DC reference signal with a saw tooth signal as a carrier wave. PWM switching scheme thus offers an advantage of bearing low power loss in the switching devices.

In single pulse-width modulation control, one pulse per half-cycle and the width of the pulse is varied to control the output voltage. In multiple-pulse modulation, all pulses are the equal width. Vary the pulse width according to the amplitude of a sine wave evaluated at the center of the different pulse. Figure 2 shows the modified sinusoidal pulse modulation signal.

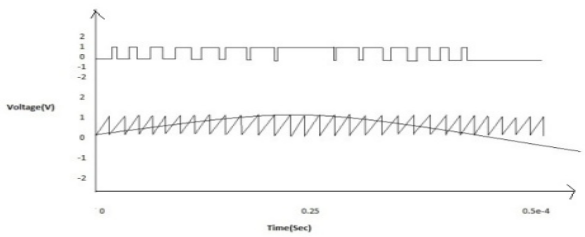

Figure 2. Modified Sinusoidal Pulse Width Modulation

2.2. Design of Controllers

The Interleaved Boost Converter with PI controller is proposed in order to reduce the ripple current and improved efficiency. A Proportional Integral controller (PI) is a generic control loop feedback mechanism widely used in industrial control systems. A PI controller calculates an "error" value as the difference between a measured variable and a desired set point. The controller efforts to minimize the error by adjusting the process control inputs.

A block diagram of a simple closed-loop system consisting of a plant and a PI controller with unity feedback is shown in Figure 3. The purpose of the system is to keep the process output (Y) close to the desired output (Y_d) in spite of disturbances. This is achieved by manipulating the process input (U) through the controller. The perception of the closed loop system is defined by the Integral performance measures and time response specifications.

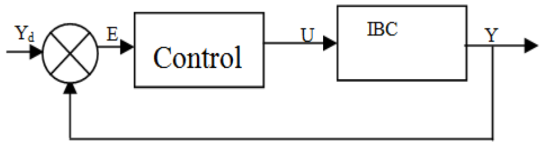

Figure 3. Block diagram representation of a closed-loop system

The PI controller makes the plant less sensitive to changes in the surrounding environment and facilitates small changes in the plant. The transfer function of the PI controller is:

$$G_c(s) = K_p + \frac{K_i}{s} \tag{10}$$

Where K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain. In the PID controller, the proportional part deals with the error of the system at present; the integral part takes the past into account that will happen in the future. The proportional gain of the controller reduces error responses to disturbances. The integral of the error eliminates the steady state error, thus improves the stability of the system. The controller has two parameters that can be adjusted like proportional gain (K_p), and Integral gain (K_i). The control loop performs well if the parameters are chosen properly. It performs poorly otherwise. Improper tuning may make the system become unstable. The procedure of finding the controller parameter is called tuning.

3. REAL CODED GENETIC ALGORITHM

In real world industrial applications, optimization algorithms take part in an important role, as these algorithms are used to automate several industrial processes. The manual search of a solution for optimizing requires a great deal of insight and patience. Furthermore, manual optimizing often limits the scope of the search process to what the human expert is trained to consider as a good solution. Conversely, optimization algorithms automate the search and are not biased in scope regarding the solutions. The wide range of real-world optimization problems and the importance of finding good approximate solutions have lead to a great variety of optimizations. This chapter presents the details of GA, for solving the search and optimization problem.

In a standard Genetic Algorithm, binary strings are applied to represent the decision variables of the optimization problem in the genetic population, irrespective of the character of the decision variables. The use of floating point numbers in the GA representation has a number of advantages over binary coding. The effectiveness of the GA is increased as there is no need to convert the solution variables to the binary type, less memory is essential, there is no loss in precision by discretization to binary or other values, and there is liberty to use different genetic operators. With floating point representation, the evaluation process and reproduction operator remain the same as that in binary-coded GA, but crossover operation is made variable by variable. Also, the uniform mutation is used for the real parameter mutation operator. The details of the crossover and mutation operator are presented in the following subsections.

3.1. Crossover Operation and Mutation

The crossover operator is mainly accountable for the global search property of the GA. Crossover basically merges substructures of two parent chromosomes to create new structures, with the preferred probability typically in the range of 0.6 – 1.0. The Blend crossover operator (BLX-α) (Devaraj 2005) is utilized in this study. Figure 4 illustrates the BLX-α crossover operation for the one-dimensional case. In the BLX-α cross over the off springy is sampled from the space $[e_1, e_2]$ as follows:

$$\text{y} = \begin{cases} e_1 + r \times (e_2 - e_1) : if\ u^{\min} \le y \le u^{\max} \\ repeat\ \ sampling\ :otherwise \end{cases} \tag{11}$$

Where, $e_1 = u_1 - \alpha\,(u_2 - u_1)$ (12)

$$e_2 = u_2 + \alpha \times (u_2 - u_1) \tag{13}$$

r : Uniform random number $\in [0,1]$

It is to be noted that e_1 and e_2 will lie between $u_{\min}$ and $u_{\max}$, the variable's lower and upper bound respectively. In a number of test problems, it is examined that α = 0.5 provides good results. The feature of this type of crossover operator is that the created point depends on the location of both parents. If both parents are nearer to each other, the new child will also be close to the parents. On the other hand, if parents are distant from each other, the search is similar to a random search.

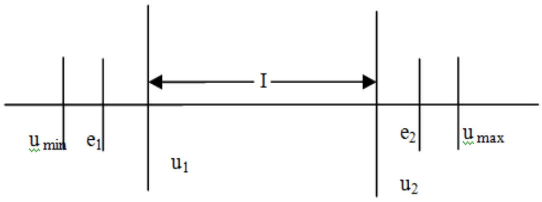

Figure 4. Schematic representation of BLX-α crossover

After crossover is completed, mutation takes place. The mutation operator is used to introduce new genetic objects into the population. Mutation randomly adjusted a variable with a small probability. In this work, the Uniform Mutation operator is applied, which is the variable set between the lower to upper limit.

4. GA IMPLEMENTATION

In the Real-coded Genetic Algorithm implementation, the following modifications are made to improve the efficiency of formulating controller parameters. With a real-coded form of representation, the selection scheme remains the same, but modifications are desired for crossover and mutation operators. While solving an optimization problem using GA, each individual in the population signified a candidate solution. Each individual in the population represents the parameters of the PI controller. For the Interleaved Boost Converter the controller parameters are K_p and K_i. Where $K_i=K_c/\tau_i$. In this work, the parameters of the controller are represented as floating point numbers. A typical chromosome with floating point representation is given below.

This type of representation has a number of advantages over binary representation. The efficiency of the GA is improved as there is no need to convert the input variables to the binary type. The proposed Genetic Algorithm searches for the optimal solution by maximizing or minimizing the function and therefore an evaluation function which provides a measure of the quality of the problem solution is needed. The Equation (14) indicates the objective function.

$$f = f_{MSE} \tag{14}$$

During the GA run, GA searches for a solution with maximum fitness-function value. Hence, the minimization objective function is given by (3.4) is transformed as:

$$\text{Fitness}=\frac{K}{1+F} \tag{15}$$

K is a constant. In the denominator a value of '1' is added with 'f ' in order to avoid division by zero.

5. RESULTS AND DISCUSSION

This section presents the simulation results and analysis of DC to DC interleaved boost converter. In closed loop, the output is feedback to the gate poles of the switch (transistor) this using Pulse Width modulator. The software for the proposed genetic algorithm is written in MATLAB and executed on a PC with 2.4 MHZ and 256 MB RAM. The MATLAB Simulink diagram of the boost converter is shown in Figure 5. The response of the Boost Converter with Single Pulse Width Modulation is shown in Figure 6. From the figure, it is found that for a nominal input voltage is 24V the converter produces the output voltage 47V.

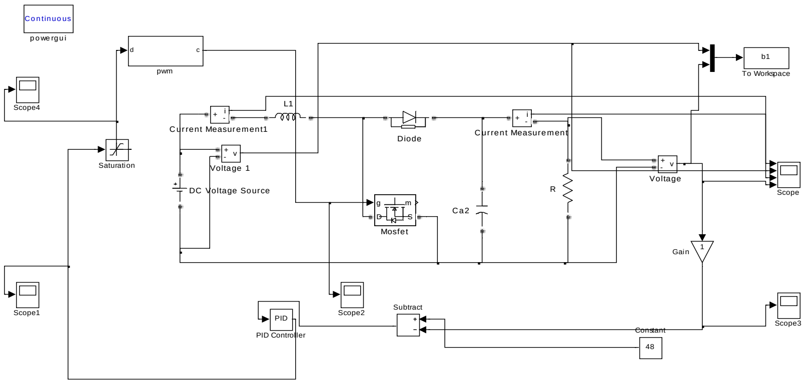

Figure 5. MATLAB Simulink diagram of Boost Converter

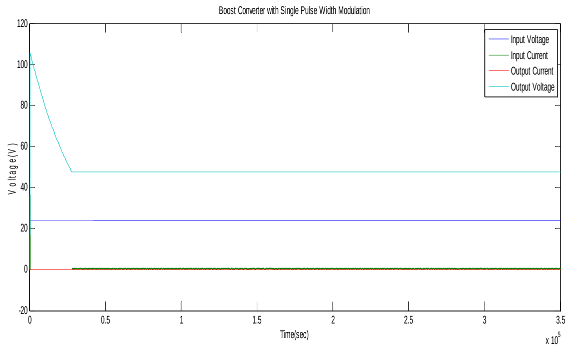

Figure 6. Response of Boost Converter with Single PWM technique

The response of a boost converter with sinusoidal PWM technique is shown in Figure 7. From the response, it is found that the output settling time is high. With nominal input voltage is 24V, the converter produces the output voltage 48V. The output current is oscillating between 0 to 6A. This shows the high ripple current in this method.

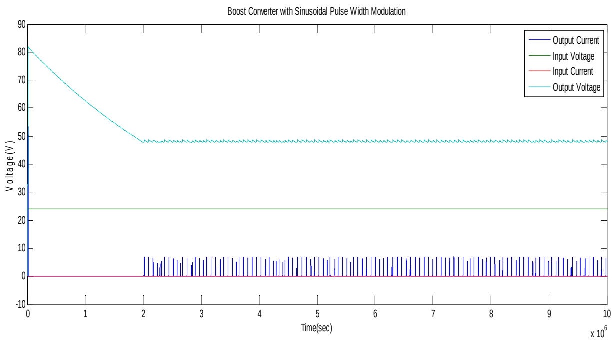

Figure 7. Response of Boost Converter with SPWM technique

The response of a boost converter with Modified Sinusoidal PWM technique is shown in Figure 8. From the response, it is instigate that the output settling time is high. With nominal input voltage is 24V, the controller produces the output voltage between 48V to 50V and the output current is oscillating between 0 to 2A. This shows the efficiency is high and the ripple current is less.

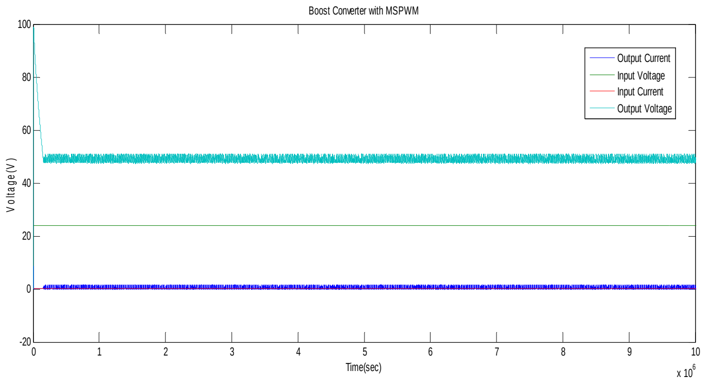

Figure 8. Response of Boost Converter with MSPWM technique

Interleaved Boost Converter reduces the ripple current due to the rise and fall of inductor current by the parallel connection of two boost converters. Figure 9 shows the Simulink diagram of Interleaved Boost Converters. The response of IBC with single pulse width modulation is shown in Figure 10. The response of IBC with single pulse width modulation is shown in the Figure 11.

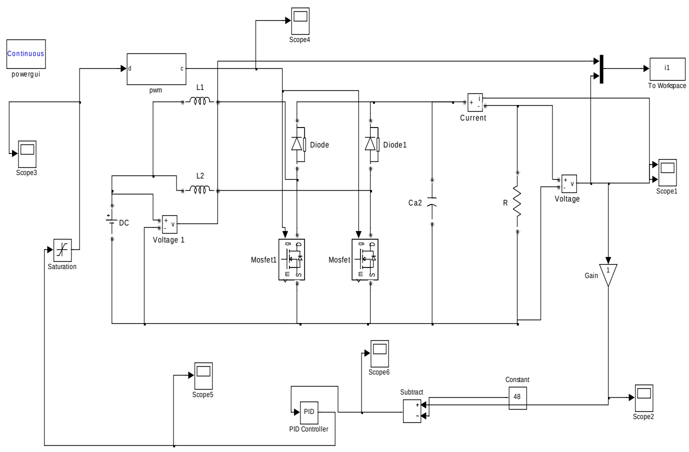

Figure 9. MATLAB Simulink diagram of IBC with PI controller

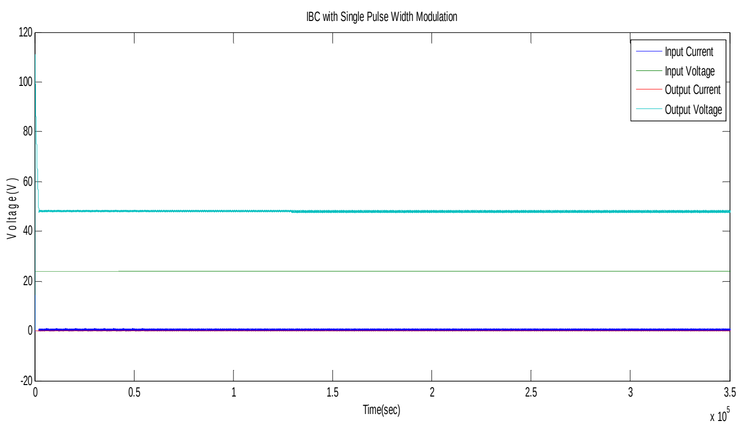

Figure 10. Response of IBC with Single PWM technique

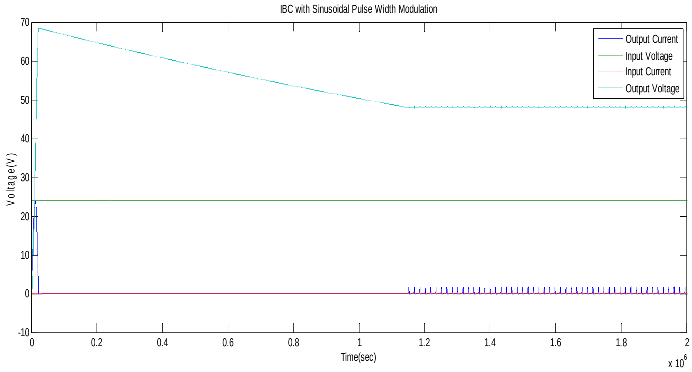

Figure 11. Response of IBC with SPWM technique

The response of an interleaved boost converter with Modified Sinusoidal PWM technique is shown in Figure 12. With nominal input voltage is 24V, the converter produces the output voltage 50V. The output current is less compared with the boost converter. It shows the efficiency of the interleaved boost converter is high due to the reduction of ripple current. Although the efficiency is high, the oscillation in output current shows the ripple and real coded GA is proposed to tune the controller parameters.

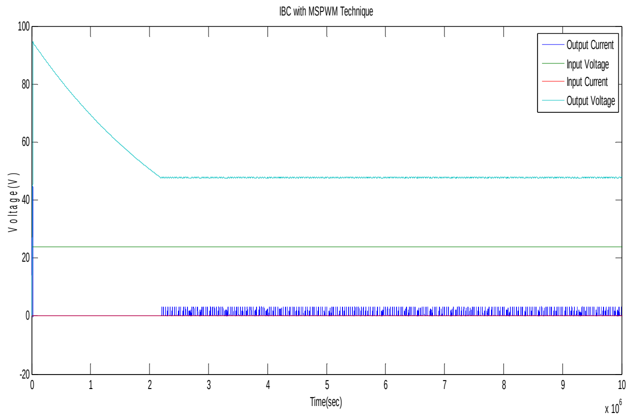

Figure 12.Response of IBC with MSPWM technique

The closed loop proportional Integral controller cascaded with the process is tuned for the optimal values of K_p and K_i using a binary coded GA algorithm and Real coded GA.

The optimal GA settings are

Number of generations	: 10
Population size	: 10
Crossover probability	: 0.8
Mutation probability	: 0.06

Both GA is applied to obtain the parameters of the PI controller for the Boost Converter and Interleaved Boost Converter. The boundaries of the optimization variables are taken as $0<K_p<10$; $0<K_i<5$. The optimal control gains obtained by the proposed algorithm along with the efficiency and ripple current of both genetic algorithm with Boost and Interleaved Boost Converter are given in Table 1. The performance of the system is found to be satisfactory with the control gains obtained using the proposed algorithm. From the table, it is found that the proposed real coded GA with interleaved boost converter is having minimum ripple current and maximum efficiency. Also, the computation time requirement is minimum in Proposed GA. That all requirements of real coded GA produce better result compared than the binary coded genetic algorithm.

For an interleaved boost converter with single PWM Kp and Ki values are 7 and 1.9, this converter produces the efficiency at 73% and ripple current at 0.002A for generation size of 10. The K_p and K_i values of an interleaved boost converter with Modified Sinusoidal PWM are 9 and 2, this shows the efficiency of 89% and ripple current is 0.0009A. From the Table 1 comparing the entire techniques, interleaved boost converter with Modified Sinusoidal Pulse Width Modulation technique shows the best result compared to boost converter.

Table 1. Comparison of Performance Analysis

PWM Techniques	GA	Gn Size	Pop Size	K_p	K_i	Time	η	Ir
Boost Converter with Single Pulse Width Modulation	BGA	5	5	7	2	1.11e3	13.42	0.05
	RGA	5	5	6	1	425.53	24.09	0.009
	BGA	7	7	9	0.02	2.18e3	18.41	0.05
	RGA	7	7	6	1.5	1.09e3	24.94	0.009
	BGA	10	10	9	0.02	4.70e3	27.86	0.05
	RGA	10	10	6	1.9	1.88e3	29.19	0.009
Boost Converter with Sinusoidal Pulse Width Modulation	BGA	5	5	8	0.3	8.25e3	18.22	0.03
	RGA	5	5	8	4	212.27	25.13	0.005
	BGA	7	7	9.6	0.5	2.35e4	40.83	0.03
	RGA	7	7	8	4	249.93	45.44	0.005
	BGA	10	10	9	0.5	3.14e4	60.69	0.03
	RGA	10	10	8	4	759.12	65.60	0.005
Boost Converter with Modified Sinusoidal Pulse Width Modulation	BGA	5	5	9	2	1.12e3	11.77	0.04
	RGA	5	5	9	2	154.40	10.76	0.004
	BGA	7	7	9	0.5	1.15e3	25.27	0.04
	RGA	7	7	9	1	195.32	26.52	0.004
	BGA	10	10	6	1	1.12e3	72.36	0.04
	RGA	10	10	6	1	503.20	71.11	0.004
Interleaved Boost Converter with Single Pulse Width Modulation	BGA	5	5	9	0.5	1.15e3	25	0.05
	RGA	5	5	9	1.9	199.15	15.14	0.001
	BGA	7	7	9	0.7	1.29e3	49	0.05
	RGA	7	7	8.2	1.9	381.56	30.57	0.001
	BGA	10	10	9	1.2	5.47e3	67	0.05
	RGA	10	10	7	1.9	840.46	71.71	0.001
Interleaved Boost Converter with Sinusoidal Pulse Width Modulation	BGA	5	5	9	0.8	5.18e3	33	0.04
	RGA	5	5	6	1.9	153.29	45.23	0.002
	BGA	7	7	9	1.1	5.23e3	61	0.04
	RGA	7	7	6.7	1.9	270.65	50.77	0.002
	BGA	10	10	9	1.5	5.67e3	72	0.04
	RGA	10	10	7	1.9	750.24	73.17	0.002
Interleaved Boost Converter with Modified Sinusoidal Pulse Width Modulation	BGA	5	5	9	1.2	6.12e3	34	0.03
	RGA	5	5	8.9	0.8	120.25	35.50	0.0009
	BGA	7	7	9	1.1	1.13e4	59	0.03
	RGA	7	7	9	1	209.20	56.36	0.0009
	BGA	10	10	9	1.5	1.25e4	84	0.03
	RGA	10	10	9	2	683.32	89.17	0.0009

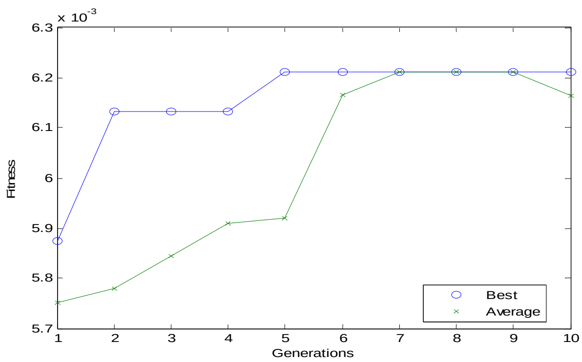

Figure 13. Real Coded GA for IBC with MSPWM

Figure 13 shows the convergence of proposed real coded genetic algorithm and it is observed that the fitness value increases rapidly in the 2nd generation on the genetic algorithm. During this stage, the GA concentrates mainly on finding feasible solutions to the problem. Then the value increases slowly and settles down near to the optimum value of 5th generation with most of individuals in the population reaching that point.

6. CONCLUSION

Improving the efficiency of the photo voltaic power system, a grid connected boost converter is used. However the improvement is not sufficient and also it produces some amount of ripple current and it takes long time to settle the output voltage. To reduce the ripple current and improve the efficiency is possible by an Interleaved Boost Converter with different PWM techniques. Both binary and real coded genetic algorithms are proposed for reducing computation time, increasing efficiency and reducing the ripple current. The simulation results were done by using Matlab Simulink for real and binary coded genetic algorithm of an Interleaved Boost Converter. The results shows interleaved boost converter produces the minimum ripple current with minimum computation time.

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