A Novel Methodology to Implement Non-Ideal Boost Inverter Using Genetic Algorithm based Sliding-PI Controller

Rajesh Guputa, Akhilendra Pratap Singh, Bhuvnesh Sharma, and Febin Prakash

Mr. Rajesh Guputa, Pro Chancellor, Department of Management, Sanskriti University, Mathura, Uttar Pradesh, India, Email Id- prochancellor@sanskriti.edu.in
Akhilendra Pratap Singh, Assistant Professor, Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Uttar Pradesh, India, Email Id- akhilendrasingh.muit@gmail.com
Bhuvnesh Sharma, Associate Professor, Mechanical Engineering, Vivekananda Global University, Jaipur, India, Email Id-sharma.bhuvnesh@vitj.ac.in
Febin Prakash, Assistant Professor, Department of Computer Science and Information Technology, Jain (Deemed to be University), Bangalore, India, Email Id-febin.prakash@jainuniversity.ac.in

Abstract: The paper introduces a Non-Ideal Boost Inverter with Linear Load as an alternative to the traditional Voltage Source Inverter. Unlike the traditional inverter, this new design is capable of generating a sinusoidal AC output voltage that can be either higher or lower than the DC input voltage, depending on the duty cycle. This eliminates the need for a second power conversion stage. To enhance the performance of the Boost Inverter, a Sliding-PI controller, a relatively new control topology, is employed. The K_p and K_i constants for the controller are determined using a Genetic Algorithm. The paper then proceeds to present the operations, analysis, control strategy, and simulation results of the proposed inverter design.

*Keywords:*VSI- Boost inverter; Sliding-PI controller; Genetic Algorithm.

1. Introduction

Traditional Voltage Source Inverter (VSI) topology has been used in many industrial and commercial systems like AC motor drives and UPS. VSI are used to convert DC input voltage to AC output voltage. These systems also consist of a control subsystem for suitable DC-AC conversion Bielet al. in [1].

Corresponding Author: prochancellor@sanskriti.edu.in

However, the conventional VSI does not provide an AC voltage greater than the dc input voltage. To overcome this drawback we have used a boost converter here. The boost inverter is capable of producing an AC output voltage that may vary in magnitude compared to the input voltage, based on the duty cycle as discussed by Biel et al. in [1].

Various control schemes are incorporated to ensure proper tracking of the output voltage. For instance, control schemes like PWM have been used for conventional VSI.

However, these schemes lead the output to be sensitive to the variation of parameters like input voltage, output load, etc. In this paper, the sliding mode controller combined with PI controller has been used. Moreover, the tuning constants K_p& K_i have been obtained using a genetic algorithm. This control technique not only ensures low harmonic distortion in the output voltage but also robustness. The output voltage is also less prone to load disturbances Jang and Jang has proposed in [4].

Genetic Algorithm is a randomly guided search Melanie proposed in [9], which is able to intelligently trace the global and most conducive outcome. Considering the process of evolution, individuals eliminated from the gene pool were the weakest and each of the following generation of individuals contains stronger characteristics.

A step by step process that is followed by the genetic algorithm is shown in Fig.1. Survival of the fittest is the basic algorithm and the processes of crossover and mutation will conspire to keep the fittest species very strong. Ultimately this search strategy is used to find a set of variables that optimizes individual fitness or the fitness of the whole population. This results in the GA technique having advantages over long-established non-linear solution strategies that cannot always procure a solution that is near to the conducive solution. The process of evolution commences with a group of randomly generated individuals within a population and progresses through successive generations. Each generation assesses the health of all individuals within the population. A new population is formed by selecting multiple individuals from the existing population based on their individual fitness and modifying them through crossover and reproduction.

Two parameters are required to define a particular genetic algorithm. They are a degree of goodness function to evaluate the solution domain and also a genetic representation of the solution domain. Bit arrays are commonly used as the standard solution, while arrays of different types and structures can be applied in a comparable manner.

The primary characteristic that renders genetic representations advantageous is the effortless alignment of their components owing to their predetermined size, thereby facilitating a straightforward crossover operation. Utilizing variable length representations can also be implemented, however, employing crossover execution proves to be more intricate in this scenario. The fundamental aspect of the selection process involves randomly choosing individuals from one generation to establish the foundation for the subsequent generation. The primary condition is that the most fit individuals possess a higher likelihood of survival compared to the less fit ones. The most common selection procedure to generate an offspring using the GA is using the roulette wheel mechanism. The mechanism replicates the traits of the stronger individuals, increasing their likelihood of survival and enhancing their chances of mating in the next generation. These individuals possess genetic coding that could prove to be extremely beneficial for future generations. The population size is directly proportional to the frequency at which the roulette wheel is spun. The most fit individuals have the greatest chance of being selected for the next generation and subsequent mating pool each time the wheel comes to a stop.

A genetic algorithm has the proficiency to scrutinize an extensive solution set. The bad manifesto has no undesirable consequences on the end solution as they are simply relinquished. The inherent regulations of the GA enable it to operate without any prior knowledge of the problem's rules, showcasing its inductive nature. This is very useful for composite problems that are loosely elucidated Sanchis et al. in [5] and Albea and Gordillo have proposed in [6].

2. Proposed system configuration

Fig.2 shows the schematic circuit diagram of a boost inverter with asliding-PI controller. Two dc-dc converters are present, and the load is connected differentially between them. Each of the two converters generates a unipolar voltage by producing a DC biased sine wave output. The modulating outputs from each converter are precisely 180 degrees out of phase with each other. Hence, a direct current bias emerges across both ends of the load in relation to the ground, while the differential direct current voltage overload is null. The DC-DC converters are bi-directional for the generation of thebipolar voltage at the output Cáceres and Barbi has proposed in [2].

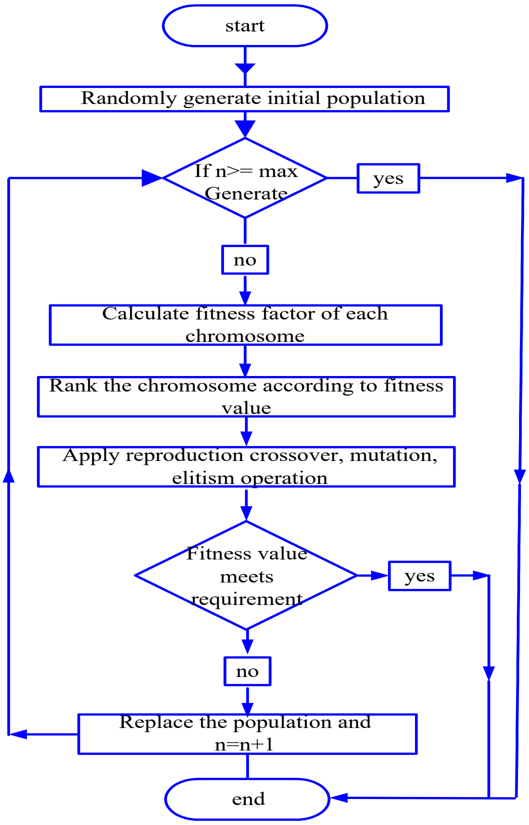

Fig. 1. Design flow of the GA strategy.

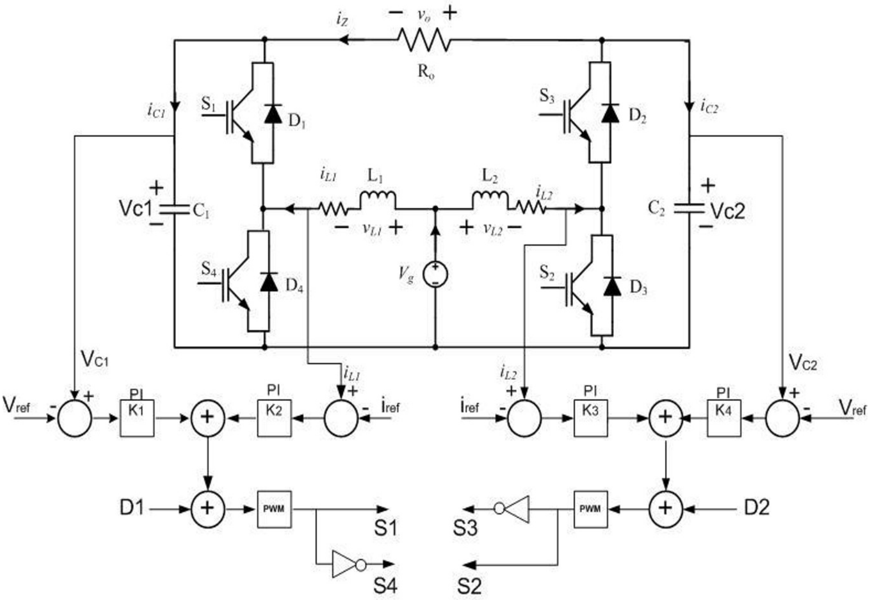

Fig. 2. Boost Inverter with sliding PI controller.

2.1. System Description

The power stage of boost inverter consists of input voltage V_g, freewheeling diodes D_1-D_4 internal resistances, power switches S_1-S_4, inductors and capacitors are L_1 L_2, and C_1 C_2, and load resistance R_L.

When the switch S_4 is closed and S_1 is open, the current i_{L1} increases in a linear manner. The diode D_2 experiences reverse polarity, while the capacitor C_1 provides energy to the output stage. Consequently, the voltage V1 decreases, as stated by Albea et al. in [7]. After opening switch S1 and closing switch S4, the current iL1 will pass through capacitor C1 and the output stage. Franco-González et al. [8] observed a decrease in the current iL1 as capacitor C1 undergoes the process of recharging.

The equations governing Boost Inverter are given by:

$$V_{c1} = \mathrm{Vdc} + \frac{\mathrm{Vm}}{2}\mathrm{Sin}(\omega t - 180) \tag{1}$$

$$V_{c2} = \mathrm{Vdc} + \frac{\mathrm{Vm}}{2}\mathrm{Sin}(\omega t) \tag{2}$$

Where V_{c1} and V_{c2} are output voltages of each boost converter

$$V_0 = V_{c2} - V_{c1} \tag{3}$$

$$\mathrm{Vdc} > \frac{\mathrm{Vm}}{2} + \mathrm{Vg} \tag{4}$$

Where V_m is the peak amplitude of Boost Inverter output voltage V_o and V_{dc} is the minimum DC Bias voltage for the Converters.

The Duty Cycles of Converters are given by D_1 and D_2:

$$D1 = \frac{Vg}{V_{c1}} \tag{5}$$

$$D2 = 1 - \frac{Vg}{V_{c2}} \tag{6}$$

2.2. GA based Sliding -PI Controller

The process of thegenetic algorithm will arrive at the best values of K_p and K_i from the range of $K_p$values obtained by the manual tuning of PI controller. These parameters implemented in the genetic algorithm used in the GA based boost inverter are tabulated in Table 1. Amplifiers frequently generate intricate waveforms with pulse width modulation and low-pass filters due to their rapid on and off switching capability.

There are certain cases, where the load disturbance and the line disturbance parameters such as rise time (t_r), settling time (t_s), peak overshoot (P_O) and steady state error (E_{SS}) will influence the system response.

The aim of this work is to minimize the effect of the above-said parameters. In order to achieve abetter dynamic response, we formulate the scenario into the given optimization problem given by Equations (7) and (8) below.

Table 1. GA parameter specifications.

GA Parameters	Specifications	GA Parameters	Specifications
Population Size	75	Crossover operation	Multipoint crossover
Chromosome structure	Binary coding	Number of iterations	10
Reproduction	Probabilistic crossover followed by mutation		

Objective function:

$$F = (1 + t_r)(1 + t_s)(1 + P_o)(1 + E_{ss}) \tag{7}$$

$$\textit{Subject to}\quad \varphi_{(lower)} \leq \varphi \leq \varphi_{(upper)}\ \textit{Where,}\ \varphi = \left\{K_p, K_i\right\} \tag{8}$$

Fitness function = 1/F(Φ)

When good transient response of the output voltage is needed, a sliding surface is chosen as:

$$S\left(i_{L1}, V_1\right) = K_1\varepsilon_1 + K_2\varepsilon_2 \tag{9}$$

Where coefficients $K_1(K_p\& K_i)$ and $K_2(K_p\& K_i)$are PI controller gains, ε_1 is the feedback current error and ε_2 is the feedback voltage error,

$$\varepsilon_1 = i_{L1} - i_{ref} \quad (10)$$

$$\varepsilon_2 = V_{C1} - V_{ref} \quad (11)$$

By substituting equations, we obtain

$$S\left(i_{L1}, V_1\right) = K_1\left(i_{L1} - i_{ref}\right) + K_2\left(V_{C1} - V_{ref}\right) \quad (12)$$

The signal $S(i_{L1}, V_1)$, obtained by simulation of above equation and applied to PWM generator block and compared with duty cycle of converter 1 (D_1), and generate the pulses to supply the power semiconductor switches S_1 and S_4.Similarly,

$$S\left(i_{L1}, V_1\right) = K_3\varepsilon_3 + K_4\varepsilon_4 \quad (13)$$

And above equation can be written as,

$$S\left(i_{L1}, V_1\right) = K_1\left(i_{L1} - i_{ref}\right) + K_2\left(V_{C1} - V_{ref}\right) \quad (14)$$

The above signal S (i_{L2}, V_2) is applied to PWM generator block and when compared with the duty cycle of converter 2 (D_2), will provide the pulses for power semiconductor switches S_2 and S_3. 1. The current in the inductor consists of two parts, with one of them oscillating at the operational frequency. Another high-frequency ripple is generated due to switching. The inductor current is determined through the use of continuous conduction mode.,

$$i_{L1(\max)(t)} = \frac{V_g - \sqrt{V_g^2 - 4 \times R_a\left(-V_{1(t)} \times \left(\frac{V_{2(t)} - V_{1(t)}}{R_1}\right)\right)}}{2 \times R_1} \quad (15)$$

The high-frequency oscillation is derived from the fundamental framework and provided by

$$\Delta i_{L1(t)} = \frac{\left(V_g - R_a \times i_{L1(t)}\right) \times \Delta_{t1}}{L} \quad (16)$$

The switch is operated by the controller in order to track a low-frequency sinusoidal reference with the voltage V1(t). V1(t) is subjected to a high-frequency ripple (switching) as defined by.

$$\Delta V_{C(t)} = \left| \frac{V_{2(t)} - V_{1(t)}}{C_1 \times R_1} \right| \times \Delta_{t1} \qquad (17)$$

Where Δ_{t1} is the conduction time of switch S_1 and V_{c1} and V_{c2} are the voltages across capacitors C_1 and C_2 respectively.

3. Results with Simulation

The boost inverter depicted in Figure 2 underwent simulation in MATLAB/SIMULINK under the assumption that all components within the circuit were ideal. The parameters of thecircuit are given in Table.1. The various simulation results of the sliding-PI boost inverter are provided from Fig.3. and Fig.4.

Table 1. An example of a table.

Parameters	Values	Parameters	Values
Input Voltage (V_g)	48 V	Inductors: L_1 , L_2	700 µH
Output Voltage (V_o)	229.3 V	Parasitic resistance of inductors r_{L1}, r_{L2}	0.2 Ω
Load Resistance (R_L)	500 Ω	Capacitors: C_1 , C_2	12.7 µF

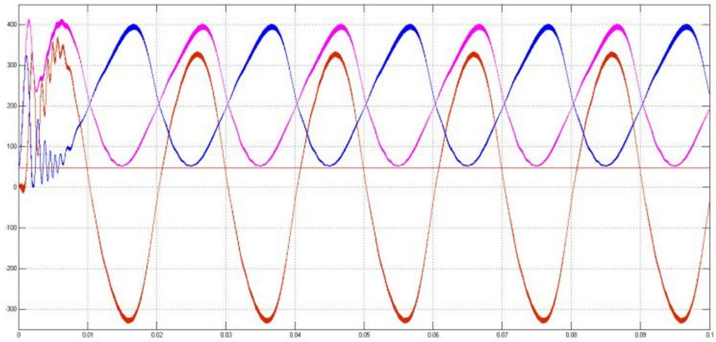

Fig. 3. Boost Inverter Vo, Vc1, Vc2, Vin waveforms.

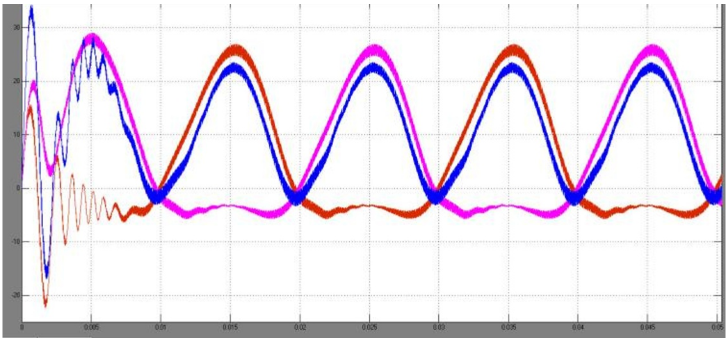

Fig. 4. Inductor currents and Source current waveforms.

Simulations have been performed using asliding controller, PI controller and Sliding-PI controller and the values so obtained has been tabulated below. The Sliding-PI Controller has been tuned with Genetic Algorithm. From the table we may conclude that the sliding-PI controller topology is the most preferred topology as the THD value of Sliding-PI controller is comparatively lesser than the other two.

Table 2. Comparison of the results.

Parameters	Sliding Controller	PI Controller	Sliding-PI Controller
Input Voltage (V_{in})	48 V	48 V	48 V
Output Voltage (V_o)	229.3 V	229.3 V	229.3 V
Load Resistance (R_L)	500 Ω	500 Ω	500 Ω
Inductors: L_1 , L_2	700 µH	700 µH	700 µH
Parasitic resistance of inductors r_{L1}, r_{L2}	0.2 Ω	0.2 Ω	0.2 Ω
Capacitors: C_1 , C_2	12.7 µF	12.7 µF	12.7 µF
THD	2.5 %	2.29 %	1.19 %

4. Conclusion

A boost inverter with sliding-PI control scheme has been implemented. The K_1, K_2 values have been further tuned using Genetic Algorithm to get the best controller constants which would provide enhanced quality of sinusoidal output. The system delivers an output voltage that is either higher or lower than the input voltage. The output voltage obtained has very low harmonic distortion and the system provides robustness, good transient response, and steady state response.

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