Journal of Electrical Engineering and Automation (ISSN: 2582-3051)
www.irojournals.com/iroeea/

Optimized Boost Converter Controller Design using QBGA for R-Load

Reeba Rex S[1], Pravin Rose T[2], Amudaria S[3]

[1]Associate Professor, Department of ECE, Lourdes Matha College of Science and Technology, Kuttichal, India.

[2]Associate Professor, Department of EEE, Vidya Academy of Science and Technology, Trivandrum, India.

[3]Assistant Professor, Department of CSE, Arunachala College of Engineering for Women, Manavilai, India.

Email: [1]reebarex@gmail.com, [2]pravinrose25@gmail.com, [3]daria.amu@gmail.com

Abstract

A DC-DC boost converter is used for providing stabilized output to the variation in R-load. In this research, a suitable controller which can be practically realized for DC-DC boost converter has been designed. Moreover, an optimization technique that possesses simple implementation, better convergence quality and enhanced computational ability has been developed. The PID controller parameters are tuned optimally using various optimization algorithms for enhancing the dynamic response of the converter in the presence of R-load. Tuning the PID controller parameters using QBGA algorithms enhances the efficiency of about 80% with R-load. Furthermore, the technique's effectiveness is demonstrated in terms of settling time, rise time, overshoot, peak time, integral absolute error, integral time absolute value error, and integral square error.

Keywords: Queen Bee Genetic Algorithm (QBGA), PID, Integral Square Error (ISE), Integral Time Absolute Value Error (ITAE) and (Integral Absolute Error) IAE

1. Introduction

Power electronics deals with different types of converters that are generally used at power level rather than signal level. Power electronic converters are developed using some semiconductor devices that are integrated using integrated circuit [1][2]. The power semiconductor devices' switching capabilities enable a power electronic converter to transform the input power of one form into the output power of another form [3]. The diversity of Power

DOI: https://doi.org/10.36548/jeea.2023.1.009
Received: 11.03.2023, received in revised form: 11.04.2023, accepted: 26.04.2023, published: 06.05.2023
© 2023 Inventive Research Organization. This is an open access article under the Creative Commons Attribution-NonCommercial International (CC BY-NC 4.0) License

Electronics' applications is also bringing about a new kind of industrial revolution such as conservation of energy, energy storage for bulk utility, renewable energy system, and industrial automation. The DC-DC converter acts an important role with major equipment like laptops, Light Emitting Diode (LED) drivers, cellular phones, electric vehicles, and hydro power plants, maximizing the harvest of energy for photovoltaic systems and wind turbines, and so on [4][5]. For applications, the converter must boost load side efficiency and Power Factor, while simultaneously shrinking the cost and size of the equipment with the increase in availability [6][7]. A DC-DC converter either increases or decreases the input voltage, based on the need of the connected load, with the variable duty cycle given to switching device, MOSFET and IGBT [8][9]. The use of DC-DC converters with variable output voltage gain is one of the most popular areas of research [10][11]. Numerous control techniques, including PID controllers, Fuzzy Logic Controllers, and Artificial Neural Networks have been developed to ensure stability and quick transient responses. The optimization techniques, have been developed by [12]. Among all the converters, boost converter is the most commonly used. With a step-up converter, voltage at the load side higher than the voltage at the source side is obtained. Voltage regulation is inadequate and the boost converter's open loop mode of operation has a poor dynamic response. The closed loop method of operation is adopted to provide proper voltage regulation and performance improvement [13]. This research explains the optimized boost converter using Queen Bee Genetic Algorithm (QBGA). Here, the PID parameters are tuned using optimization algorithms.

A. Basic function of Boost Converter

According to [14], a converter is referred to as a boost converter if the voltage at its output is higher than the input voltage. The term "boost" or "step-up" converter refers to the increase in output voltage. The DC-DC boost converter requires only four external components, such as diode, electronic switch, inductor, and an output capacitor. The converter can thus be operated in two different modes based on its capacity to store energy and its relative duration of the switching period [15]. An inductor on the input side creates the ripple-free current corresponding to the voltage, and a capacitor on the resultant side ensures that the resultant voltage is free from ripple. Continuous Conduction Mode is typically used to analyse the boost converter.

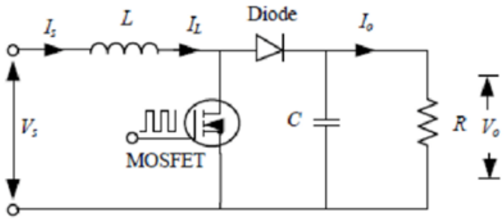

Figure 1. DC-DC Boost Converter [16]

a) Switch-on state

During the “ON” state of the switch, the diode gets reverse-biased with the isolation of the output stage, and thus the inductor is supplied with energy from the input.

b) Switch-off state

During the "OFF" state of the switch, the output obtains energy from the input side and from the inductor. To ensure a constant voltage at the output, a very large output capacitance is necessary. To achieve the desired output by adjusting the set voltage, the power converters' output must be regulated within a predetermined tolerance limit. The error value is utilized to regulate the duty cycle and the result is compared to the reference value [15].

B. Fitness evaluation

The term fitness is termed as the minimal value of error signal that is estimated as the difference among the acquired value of the boost converter and the reference value. The error for fitness is estimated for R load as,

$$V_{error} = V_{ref} - V_{out} \tag{1}$$

The represents the output of the boost converter and is the reference voltage. The fitness or objective functions taken are rise time, settling time, Integral Square Error (ISE), Integral Absolute Error (IAE), and Integral Time Absolute Value Error (ITAE) and the error is the output, which is expressed in Equation (1).

2. QBGA-PID Optimization

The QBGA-PID optimization is an iterative process that is performed until an optimum solution is obtained. The objective is to minimize the fitness function of rise time, settling time, ISE, IAE, and ITAE. The successive steps of the QBGA are mentioned below, and by applying QBGA, the PID parameters are optimized.

Step 1: Initialization of algorithm parameters and the optimization problem

The optimization is performed to obtain the optimal values of k_p, k_i, and k_d. In this step, the optimization problem (Minimize (rise time, settling time, ISE, IAE, and ITAE)), and the decision variables (n) are defined. In addition, the population size (R), the recombination probability (p_r), and the maximum iterations $(I_{\max})$ are also defined. The objective function is represented as,

$$F(x) = (1 + t_r)(1 + t_s)(1 + E_{ISE})(1 + E_{IAE})(1 + E_{ITAE}) \quad \textbf{(2)}$$

where, $F(x)$ is the objective, with settling time (t_s), rise time (t_r), ITAE, IAE, ISE, and D is the count of decision variables. The parameters of QBGA algorithm are also specified in this step.

Step 2: Generation of bees

Let the number of bees that are involved in the solution space be represented as $B_1, B_2, ..., B_i, ..., B_n$, where n is the population size of bees.

Step 3: Queen Bee Identification

Among the bees that are generated in random, the best queen bee, B_q possessing better binary structure in optimizing the function $F(x)$ with settling time (t_s), rise time(t_r), ITAE, IAE, and ISE, is chosen. The closed loop feedback control system is simulated digitally with all the bees, and $F(x)$ is evaluated for each bee. Equation (3) provides the queen bee denoted as B_q from the n number of bees.

$$B_q = Max\left(\frac{1}{1 + F(x_i)}\right) \quad \textbf{(3)}$$

Thus, the best queen bee is obtained and is separated from $(n-1)$ bees, from which drone is identified.

Step 4: Reproduction

In order to reproduce the next generation of bees, the queen creates a mating flight. All drones lack the ability to fly swiftly enough to go to a queen that has a provision for

ISSN: 2582-3051

incorporating a recombination probability linked with all drones. For this, the probability of recombination, represented as p_r , is fixed between 0 and 1. The probability of each drone is represented as p_i . For the condition $p_i \geq p_r$, the queen bee recombines with the drone resulting in two virgin queen bees. The recombination process of queen bee with the drone is exactly similar to the process of crossover in the standard GA. However, in QBGA, the multipoint crossover is suggested for increased efficiency while the crossover for a single parameter is provided for clarity. Recombination produces two offspring, but only the most fit one lives, and the other one is abandoned, which is analogous to the virgin queen bee killing her offspring.

Step 5: Recombination

For pi<pr, no recombination occurs, and hence, no offspring is generated at this condition. It is observed that the generation of virgin queen bees is lower than the bee population after stages 3 and 4, or after the conclusion of reproduction.

Step 6: Piping

All the virgin queens in a bee hive fight one another, and only the most fit queen survives. Equation (3) is used to reevaluate the population of all virgin queen bees, together with their mother queen bee, and to identify the new queen bee. Finally, every bee except the one chosen is removed from the hive.

Step 7: Termination

When the termination criterion is met, the programme is stopped and the newly formed queen bee is picked as the best candidate. If not, it is moved on to the next phase.

Step 8: Growth of a new population of drone for next mating flight

All drones die after mating with the queen bee, so a new population of (n–1) drones is randomly created for the following generation. Step 4 follows as the newly hatched queen bee develops the population for the following generation with the help of the randomly created drones.

Table 1. Parameter setting of QBGA –PID

Parameters	**Values**
Decision variables, n	10
Population size, R	10
Mutation probability	0.2
Cross over probability	0.8
Recombination probability, p_r	0.8
No. of iteration, $I_{\max}$	500

3. Results and Discussion

The MATLAB/SIMULINK platform is used for simulation. The best control parameters for QBGA algorithm was selected, and the *m.files* were performed to partition the data of fitness and the gain values. The algorithms were executed with 10 simulation-runs. Each simulation-run has 500 numbers of iterations. The count of simulation runs acts as stopping criteria in QBGA algorithm. From the overall simulation-runs, the runtime that returned the least fitness and best optimal solution was selected. The solution is enhanced in all successive iterations and the process is continued until finding the optimal solution. The simulation is done with R-load for QBGA tuned PID controller. Thus, QBGA tuned PID is used to find the better parameters of fitness $k_p, k_i,$ and k_d . Table 2 shows the gain parameters that were determined for the QBGA tuned PID controller.

Table 2. Gain Parameters of QBGA tuned PID Controller

Method	k_p	k_i	k_d
QBGA Tuned PID Controller	0.8101	0.6863	0.0220

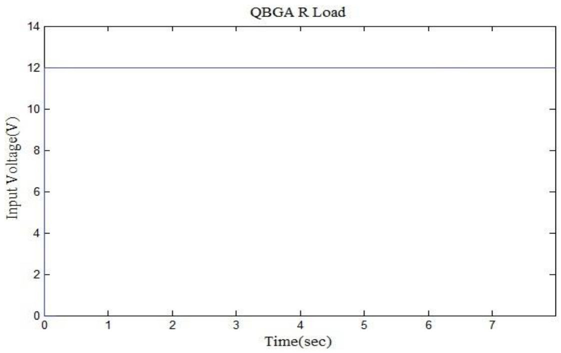

Figure 2. Boost Converter Input Voltage using QBGA based PID with R-Load

Figure 2 depicts the input voltage of boost converter in QBGA based PID with R-load and was examined that the voltage remains constant after 0 sec.

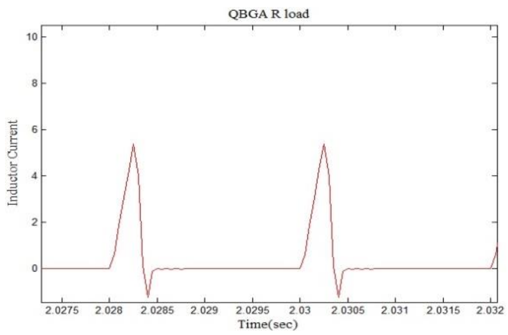

Figure 3. Inductor Current of Boost Converter using QBGA based PID Controller with R-Load

Figure 3 shows the inductor current of boost converter using QBGA based PID controller with R-load

The inductor current obtained is 5.5 A at 2.029 sec and 2.0303 sec.

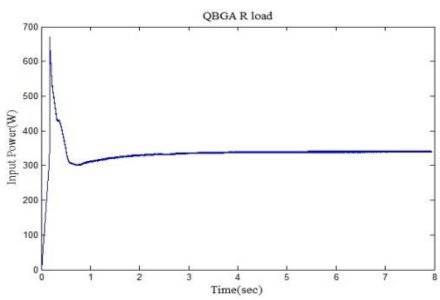

Figure 4. Boost Converter Input Power using QBGA based PID Controller with R-Load

Figure 4 depicts the input power of boost converter using QBGA based PID controller with R-load. From the figure, it is observed that the power achieved is 340 W, which remains constant after 1 sec. Initially, the power raises to 680 W at 0.2 sec and drops to 340 W at 1 sec.

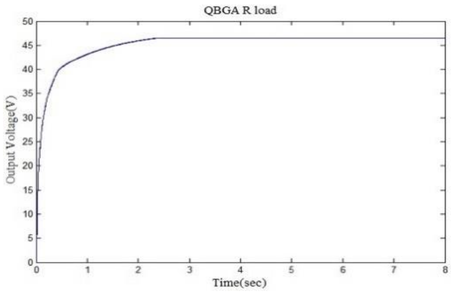

Figure 5. Boost Converter Capacitor Voltage of using QBGA based PID with R-Load

Figure 5 depicts the capacitor voltage of boost converter using QBGA based PID controller with R-load. It is observed that 42 V is obtained at 1 sec and a constant voltage of 48V is noticed from 5 sec.

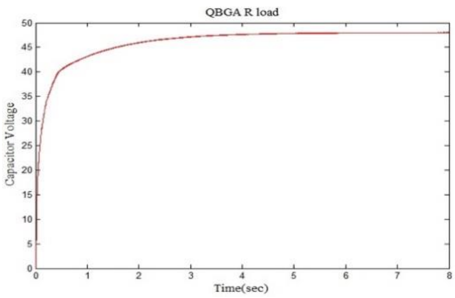

Figure 6. Boost Converter Output Voltage of using QBGA based PID and R-Load

Figure 6 portrays the output voltage of boost converter using QBGA based PID controller with R-load. From the Figure, it is perceived that the voltage remains constant after 2.2sec.

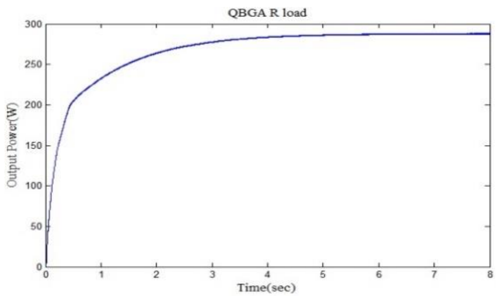

Figure 7. Boost Converter Output Power of using QBGA based PID and R-Load

Figure 7 depicts the output power of boost converter using QBGA based PID controller with R-load. It is evident that output power obtained is 280 W and maintained constant after 4 sec.

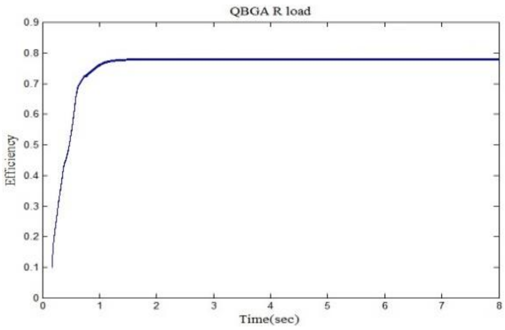

Figure 8. Boost Converter Efficiency of using QBGA based PID and R-Load

Figure 8 shows the efficiency of boost converter using QBGA based PID controller with R-load. The efficiency noted in QBGA based PID controller with R-load is 78%. The response curve with respect to IAE using QBGA based PID controller with R-load is shown in Figure 8. In this Figure, the error convergence of zero is achieved within 5.7 sec.

The response curve with respect to IAE using QBGA based PID controller with R-load is depicted in Figure 9. The response curve with respect to ISE using QBGA based PID controller with R-load is depicted in Figure 10. Here the error convergence of zero is achieved within 2.2 sec. The response curve with respect to ITAE using QBGA based PID controller with R-load is portrayed in Figure 11. Here the error is converged to zero at 7 sec.

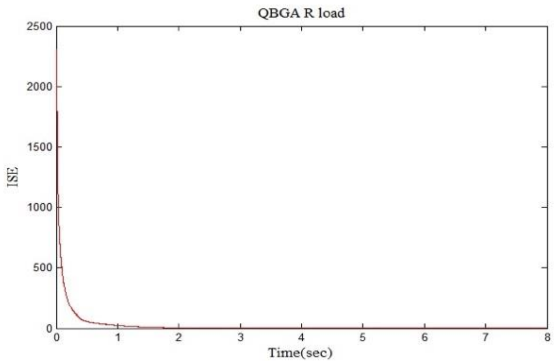

Figure 9. Response Curve in terms of IAE using QBGA based PID Controller with R-Load

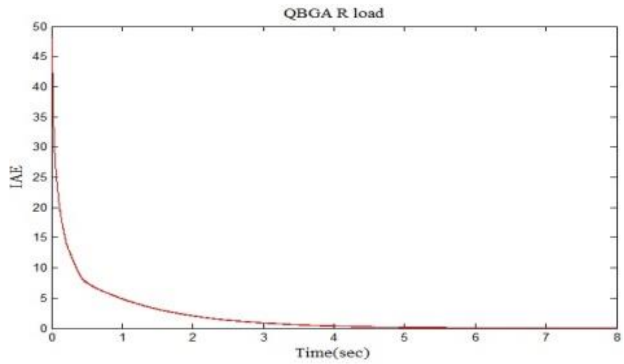

Figure 10. Response Curve with Respect to ISE using QBGA based PID Controller with R-Load

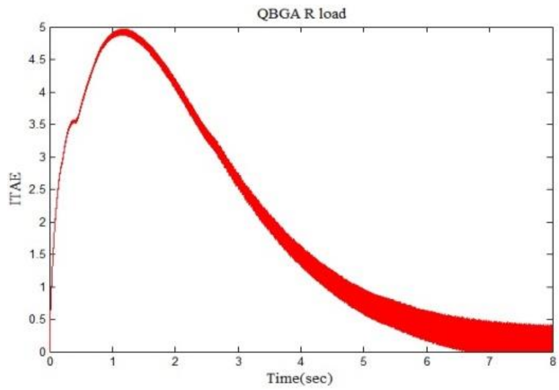

Figure 11. Response Curve with Respect to ITAE Using QBGA based PID Controller with R-Load

The time domain specification for QGBA tuned PID controller with R-load is tabulated in Table 3. The rise time of 0.5150sec, settling time of 2.2602sec, settling (Max) of 48.0190 (V), peak overshoot of 0.0480, and peak value of 48.0190 (V) are obtained.

Table 3. Time Domain Specifications for QBGA Tuned PID Controller (R-Load)

Sl.No.	Parameters	QBGA
1.	Rise Time (sec)	0.5150
2.	Settling Time (sec)	2.2602
4.	Settling (Max) (V)	48.0190
5.	Peak Over Shoot	0.0480
6.	Peak Value (V)	48.0190

Table 4. Performance Indices of QBGA Tuned PID Controller (R-Load)

Sl. No.	Type of Error	QBGA Tuned PID Controller
1.	ISE	0.3048
2.	IAE	0.6118
3.	ITAE	0.1657

The performance indices for QBGA tuned PID controller with R-load is tabulated in Table 4. The performance indices, such as ISE of 0.3048, IAE of 0.6118, and ITAE of 0.1657 are obtained.

4. Conclusion

The modeling, simulation, and the implementation of QBGA optimized boost converter for voltage regulation and its dynamic characteristics evaluation in the presence of R-load have been discussed in this research. This proposed method provides better efficiency and good dynamic response when compared to open loop analysis of Boost converter. This involves in the optimal tuning of the parameters of PID controller to adjust the boost converter's duty cycle in order to obtain a regulated DC output.

References

[1] Khabou H., Souissi M., and Aitouche A., (2020), MPPT implementation on boost converter by using T–S fuzzy method, Mathematics and Computers in Simulation, 167, 119–134.

[2] Abdelmalek S., Dali A., Bettayeb M., and Bakdi A., (2020), A new effective robust nonlinear controller based on PSO for interleaved DC–DC boost converters for fuel cell voltage regulation, Soft Computing, 24, 17051–17064.

[3] Acharya D. and Mishra S. (2020), Parameter Optimization of a Modified PID Controller Using Symbiotic Organisms Search for Magnetic Levitation Plant. In International Conference on Intelligent Computing and Smart Communication 2019, 937–948. Springer.

[4] Adnan M. F., Oninda M. A. M., Nishat M. M., and Islam N., (2017), Design and Simulation of a DC-DC Boost Converter with PID Controller for enhanced Performance, International Journal of Engineering Research & Technology (IJERT), 6(09), 27–32.

[5] Águila-León J., Chiñas-Palacios C. D., Vargas-Salgado C., Hurtado-Perez E., and García E. X. (2020), Optimal PID Parameters Tunning for a DC-DC Boost Converter: A Performance Comparative Using Grey Wolf Optimizer, Particle Swarm Optimization and Genetic Algorithms. In 2020 IEEE Conference on Technologies for Sustainability (SusTech), 1–6. IEEE.

[6] Alam M. A., Singh N., and Singh V. P. (2018), Impact of PPAM for Power Modulation in Solar & Battery Bi-directional DC-DC Converter. In 2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC), 29–33. IEEE.

[7] Ali N., Othman M. A., Husain M. N., and Misran M. H., (2014a), A review of firefly algorithm, ARPN journal of engineering and applied sciences, 9(10), 1732–1736.

[8] Ali R. S., Aldair A. A., and Almousawi A. K., (2014b), Design an optimal PID controller using artificial bee colony and genetic algorithm for autonomous mobile robot, International Journal of Computer Applications, 100(16), 8–16.

[9] Arora S. and Singh S., (2013), The firefly optimization algorithm: convergence analysis and parameter selection, International Journal of Computer Applications, 69(3).

[10] Arulselvi S., Uma G., and Chidambaram M. (2004), Design of PID controller for boost converter with RHS zero. In The 4th International Power Electronics and Motion Control Conference, 2004. IPEMC 2004., 2, 532–537. IEEE.

[11] Askarzadeh A., (2016), A novel metaheuristic method for solving constrained engineering optimization problems: crow search algorithm, Computers & Structures, 169, 1–12.

[12] Åström K. J. and Hägglund T., PID controllers: theory, design, and tuning, volume 2. Instrument society of America Research Triangle Park, NC, 1995.

[13] Aung T. and Naing T. L., (2018), Modeling and Simulation of DC-DC Boost Converter-Inverter System with Open-Source Software Scilab/Xcos, Software Engineering, 6(2), 27.

[14] Awasthi A. and Patel N. (2017), Quantitative process control theory based H-wPID controller design for boost converter. In 2017 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), 1–5. IEEE.

[15] Badis A., Mansouri M. N., and Boujmil M. H. (2017), A genetic algorithm optimized MPPT controller for a PV system with DC-DC boost converter. In 2017 International Conference on Engineering & MIS (ICEMIS), 1–6. IEEE.

[16] Irwanto, M., Leow, W. Z., Ismail, B., Baharudin, N. H., Juliangga, R., Alam, H., & Masri, M. (2020). Photovoltaic powered DC-DC boost converter based on PID controller for battery charging system. In Journal of Physics: Conference Series (Vol. 1432, No. 1, p. 012055). IOP Publishing.