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PID Controller Optimization using Genetic Algorithm Based Zeta Converter Application

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Abstract: The purposes of DC-DC conversion devices which are also known as switching regulators include reducing or increasing the resulting DC voltage in accordance with the load's requirement. The optimal parameters for adjusting the PID controller were obtained using genetic algorithm. The circuit's output voltage response and its ripples were compared with the GA optimized PID controller. The obtained results highlighted that the output voltage acquired from the scheme with GA optimized PID controller was regulated against the peak overshoot during transient condition even in varying load conditions and output voltage ripples as well. Along with that, the developed system also provided a constant output voltage in different load conditions.

Keywords: Zeta Converter, Genetic Algorithm (GA), PID.

I. INTRODUCTION

The output DC voltage is either reduced or increased with the help of DC-DC converters which are commonly cited as switching regulators in accordance with the load's requirement. This can be achieved with the help of switches in the circuits by varying the duty cycle either up or down. Various applications require a regulated DC voltage to function properly; for instance, PV implementations, switched mode power supplies (SMPS), and DC motor drives. Therefore, highly efficient and accurate DC-DC converters, with minimal losses, are required for such applications, which are used in our daily lives. However, currently, the DC-DC converters have nonlinear characteristics throughout their operation and they provide higher output voltage ripples and peak overshoot during peak transient conditions. Hence, due to such non-preferred nonlinear characteristics and responses, a controller with a dynamic response is required, which can be added to the converter in order to minimize. Pulse Width Modulation (PWM) is among many well-known methods used for switching control.

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The objectives of this research are to design a zeta converter with varying input voltage and constant output voltage for PV application, to develop a genetic algorithm (GA) optimized PID controller for the zeta converter and to analyze the effectiveness of the zeta converter in term of the resulting voltage ripples and peak overshoot during the transient condition.

This section of thesis provides with the explanation regarding basic concepts of DC-DC conversion and describes previous research done in this area. This section is categorized into three segments in which the first segment presents well-known types of converters, second segment emphasizes on the modelling techniques of zeta converters and the third segment discusses regarding DC-DC converters and genetic algorithm (GA).

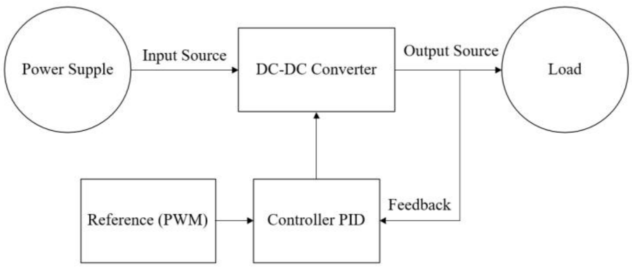

Fig. 1.Block diagram DC-DC converter [1]

A power electronic converter is constituted by a controller, power processor and voltage reference as portrayed in Figure 1. The power-supply provides the input power to the power processor which may either be a frequency or a current or a voltage converter, which then converts the power and feeds the load [1]. The output voltage of the power processor which is made of power electronic components, is compared with the feedback voltage in order to minimize the difference in error. Both, switching and linear voltage regulators work on this basic regulation principle.

II. GENETIC ALGORITHM

In the development of controllers which do not have a proper mathematical mode, two issues are faced. First issue is the establishment of the controller's structure and second is the identification of control parameters. Usually, these issues are resolved with the help of various techniques including qualitative model-based methods, machine learning and manual design of the controllers.

In a research by Varsek (1993) [2], implications of genetic algorithms are observed in terms of learning controller structure as well as tuning the control parameters. Figure 2 depicts the flowchart of genetic algorithm (GA).

The GA is a general-purpose optimization method motivated by the laws of natural genetics and selection, used for searching and optimization of machine learning problems. Genetic algorithms have shown remarkable performance in controlling dynamic systems without any previous knowledge regarding the system.

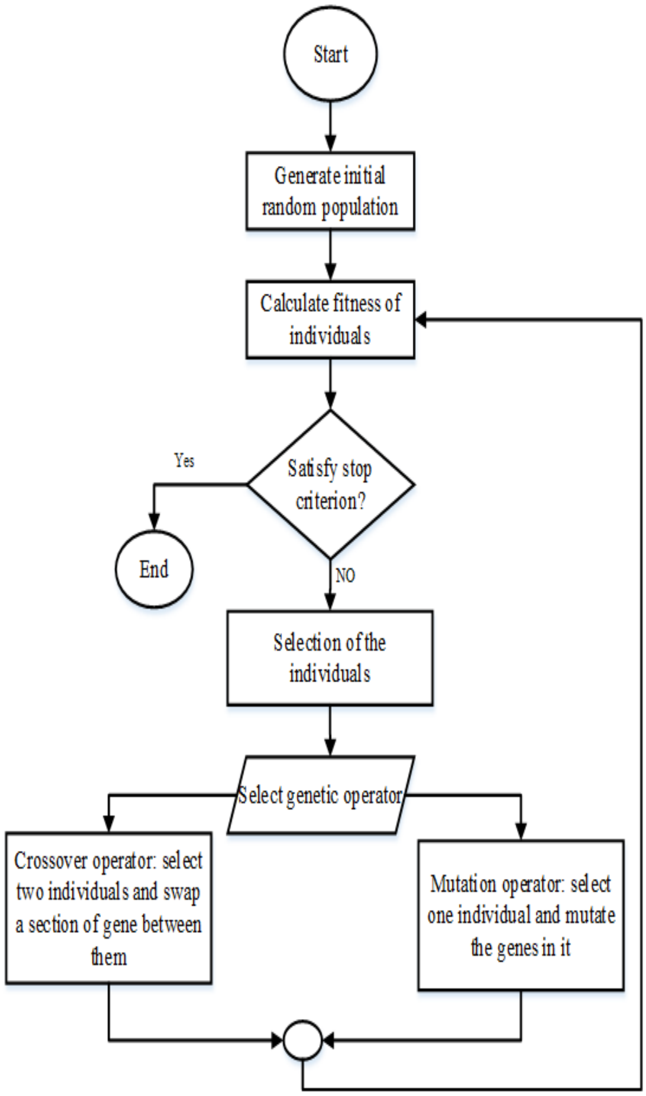

Fig. 2.Flow chart of genetic algorithm (GA) [3]

Genetic algorithm (GA) has been observed with various types of DC-DC converters for instance, buck by Kostov (2005) [4], boost by Elshaer (2010) [5], buck-boost by Olranthichachat (2009) [6], Cúk by Eshtehardiha (2008) [7] and SEPIC converters by Durgadevi (2017) [8].

III. ZETA CONVERTER

The DC motor drives, and switch-mode DC voltage applications are controlled extensively with the help of DC-DC converters. Figure 3 depicts the block diagram for PV module and zeta converter. Usually, an unregulated DC voltage (variable voltage) is fed as the input to these converters from the PV model acquired by rectifying mains voltage as depicted in Figure 3. Hence, it has the tendency to oscillate because of the variations in the magnitude of the line-voltage. Therefore, a constant steady voltage is obtained with the help of switch-mode DC-DC converters which convert the input DC voltage (unregulated) into a fixed output at an intended voltage level.

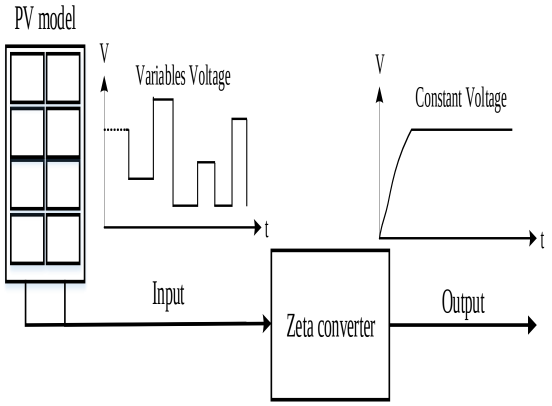

Fig. 3.Block diagram for PV module and zeta converter

A. Continuous Conduction Mode (CCM) Zeta Converter

In continuous conduction mode (CCM), the zeta converter is controlled with the help of switch (MOSFET or BJT) in a manner that when the switch changes its state, the diode also changes state (ON or OFF). There are two inductors (L_1 & L_2) to reduce the input current ripple as shown in Figure 4. There are also two capacitors (C_1 & C_2), which are assumed to be large enough and the voltage in C_1 is equal to V_{Out}.

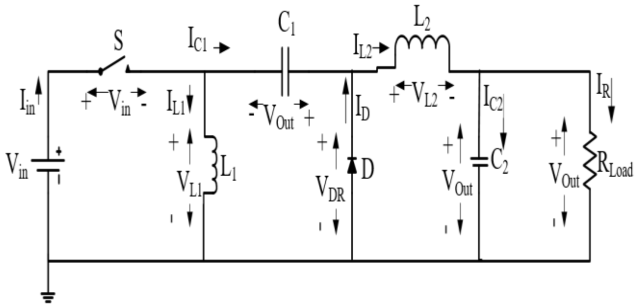

Fig. 4.Circuit of the zeta DC-DC converter

B. Zeta Converter Control Strategy

The designed PID control-system is used to manage the operation of zeta converter so that it has a mechanism of feedback loop. Also, according to that requirements, the controller also performs corrective action by adjusting the process.

C. PID controller

The PID controller controls the varying input voltage of zeta converter to provide a steady output DC voltage level and its block diagram is shown in Figure 5. A PID controller system has a mechanism of feedback loops and it is capable of rectifying the errors among required set point and calculated process values. The controller also performs corrective action by adjusting the procedure in accordance with the requirements. Hence, the calculation for configuring the PID controller comprises of three different variables. First is P, the proportional value which computes the response to the present error. Second, I, the integral which computes the response relying on the summation of previous errors.

Lastly D, the derivative which computes the response of the rate of change of the error. The weighted summation of P, I, and D parameters is required to modify the procedure of elements during the tuning of the three constants during the PID controller operation. It is capable of providing controlling actions intended for particular conditions. Therefore, the modelling of the converter is done in SSA which can precisely determine the state variables such as requirements of capacitor voltage and inductor current as well to get a steady output voltage. The values for the PID parameters are including delay time t_d, peak time t_P, rise time t_r *and s*etting time t_s.

In the design of PID controllers, the purpose is to obtain automatic control features based on a PID controller with state space analysis (SSA) and for the calculation of optimum coefficients of PID, genetic algorithm is used [9]. The objective is to highlight that with the help of GA method for tuning a plant, the optimization can be obtained that yield suitable PID parameters.

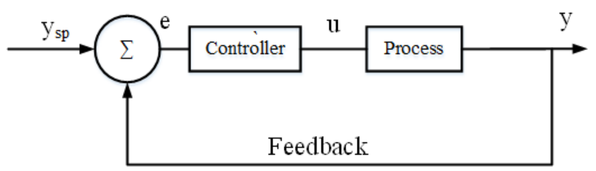

Fig. 5.General block diagram for PID controller [10]

D. Optimization of PID Controller using Genetic Algorithm

The GA is based on a theoretical algorithm for natural selection which is an all-inclusive searching method which imitates the process of natural evolution. GA has proven its capability in finding superior zones in complex areas without encountering the troubles related to high-dimensionality or false-optima as may happen with other gradient-descent methods. Consequently, the GA will be used for tuning the controller as it will be provided with optimum controlling parameters which will be evaluated the system operates. The steps are involved in GA to obtain the optional values K_p, K_i and K_d.

E. Objective Function of the Fitness

The use of the main objective functions is to determine the performance in the problem domain. Therefore, in the current problem, the fit contains an individual with the least mathematical value of the related objective as function. However, the raw computation of the fitness is generally utilized for obtaining the performance metrics of every individual at the intermediate stage.

Therefore, usually the use of fitness function is to convert the value of objective function into many measures of relative fitness in which f is the objective function and g is the transform value of the objective functions for non-negative numbers and F is the obtained relative fitness. Such representation is regularly required to filter the individuals as in various conditions, the value of function relates to the value of OFF springs that are expected to be produced by an individual in the coming generation.

Hence, now the most challenging task is to design the objective functions according to design in this project and the optimum PID controller specifications are to be achieved with the help of objective function. The PID controller that provides with the fastest rise time and the least overshoot is known as the optimal PID controller. Equation 1 is used as the objective function which are utilized to assess the fitness of every chromosome.

The performance indices appear on equation 1 are indicated as the mean of the square error (MSE), integral of time multiplied by absolute error (ITAE), integral of absolute magnitude of the error (IAE), and integral of square error (ISE).

Hence, for combining all of the objective indices that are chosen to propose an objective function capable of reducing the error of the entire control-system rather than every chromosome belonging to that population which is moved into the objective function at the time. This evaluated chromosome has been given a numerical value to show its fitness, for instance, the larger value indicates a better fitness. The chromosome is used by the genetic algorithm for creating a new population containing the fitter members. In this way, the final solution will be obtained with a minimum percentage error. The error signal is reduced using PID controller, while the fitness of the chromosomes is defined by equation 2.

$$MSE = \frac{1}{t}\int_0^{\tau} (e(t))^2 dt$$

$$ITAE = \int_0^{\tau} t|e(t)|dt$$

$$IAE = \int_0^{\tau} |e(t)|dt$$

$$ISE = \int_0^{\tau} e(t)^2$$

$$ITSE = \int_0^{\tau} te(t)^2 dt \quad (1)$$

Where $e(t)$ *is the error signal in time domain.*

$$Fitness\ value = \frac{1}{Performance\ index} \quad (2)$$

F. Parameter Calculation of Zeta Converter

The zeta converter system takes the input voltage from the PV module output voltage of 38 V. The PV module usually provides variable voltage while the output voltage of zeta converter is 13 V for DC applications. The ripple value of current inductors limit is 0.15 A, the ripple voltage across the capacitors limit is 0.2 V and the overshoot limit is 1% while the switching frequency (f_{SW}) is 25 kHz and the applied load is 10 Ω.

Table-I: Parameters of design zeta converter

Parameters	Values
Input Voltage, V_{in}	18 V
Output Voltage, V_{out}	13 V

Duty Cycle, D	0.4194
Frequency, f	25 kHz
Resistor, R	10 Ω
Ripple current inductor 1, ΔI_{L_1}	0.15 A
Inductor 1 L_1	2 mH
Ripple current inductor 2, ΔI_{L_2}	0.15 A
Inductor 2, L_2	2 mH
Ripple voltage capacitor 1, ΔV_{C_1}	0.03 V
Capacitor 1, C_1	750 uF
Ripple voltage capacitor 2, ΔV_{C_2}	0.03 V
Capacitor 2, C_2	25 uF

Table-II: Initiate a random population for the K_d, K_p and K_i

K_d	K_p	K_i	Fitness
0.0815	0.0103	165.605	1226657.10
0.0906	0.0038	157.795	1364818.68
0.0127	0.0071	154.8338	36744.45

IV. SIMULATION RESULTS

The MATLAB Simulink were used to design zeta converter. The transfer function and SSA were obtained for zeta converter circuit. Finally, checked the system stability lead to design the PID controller using genetic algorithm (GA), as well as shows the performance of transfer function. The development of Simulink model used to design zeta converter model was based on the parameters shown in Table-I and the parameters of PID controller were taken from Table-I. The results obtained from the PID models were noted down while using the genetic algorithm (GA) as an optimization technique for the PID specifications.

A. Optimization of PID controller using Genetic Algorithm

The genetic algorithm GA is utilized as an optimization technique to obtain optimal parameters for designing a PID controller. The genetic algorithm is based on a stochastic algorithm for natural selection. The stochastic algorithm is a global search method in genetic algorithms (GAs) that mimics the process such as natural evolution.

B. Initiate a Random Population

The random population of first three chromosomes is given below along with their fitness as shown in Table-II. From the Table-II, each chromosome fitness is found and placed in the 4th column.

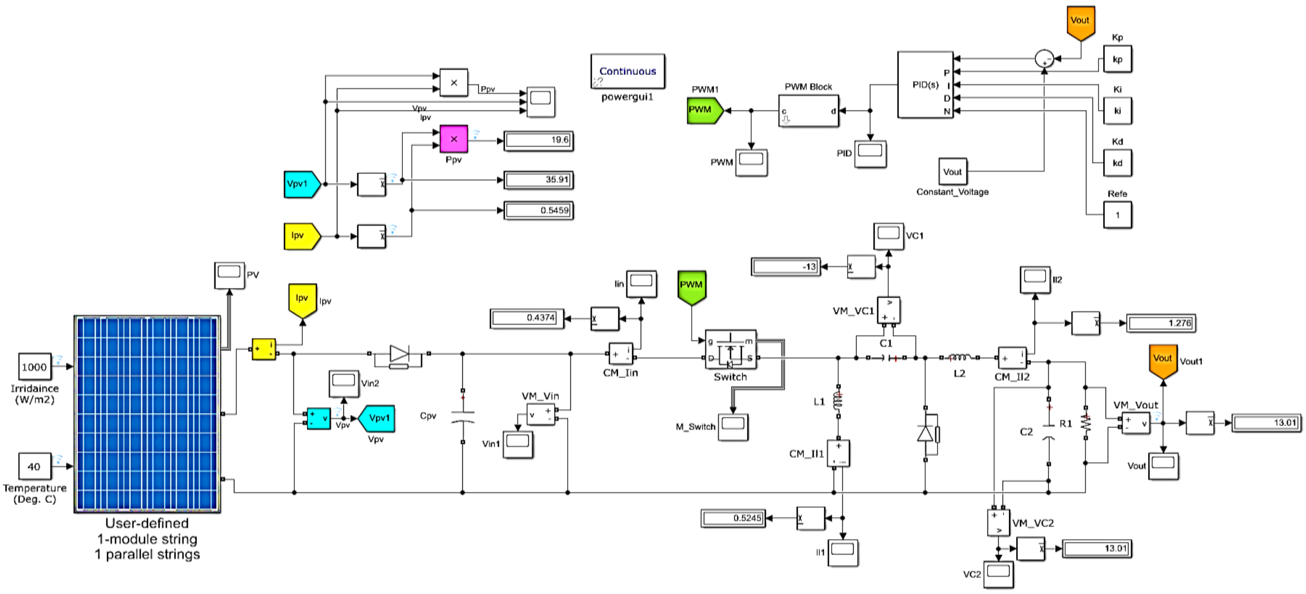

Fig. 6.Circuit for zeta converter in Simulink MATLAB

At this stage the control parameters for the zeta converter were finalized and the operation of this PID controller was checked using the Simulink PID block as portrayed in Figure 7 and the circuit parameters.

Figure 7 depicts the graph indicates the input voltage was 18 V which shows an increase in voltage and time as the line goes over and the voltage ripple for ΔV_{C_1} and $\Delta V_{C_2} = 2.2 \times 10^{-2} V$.

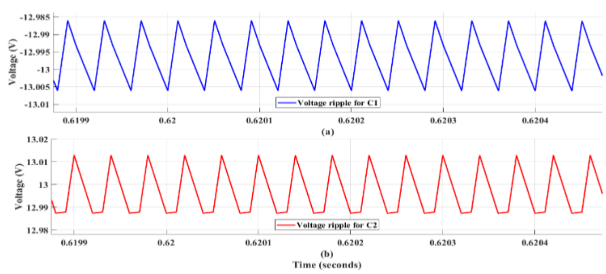

Fig. 7.: Shows voltage ripple for (a)ΔV_{C_1} and (b)ΔV_{C_2}

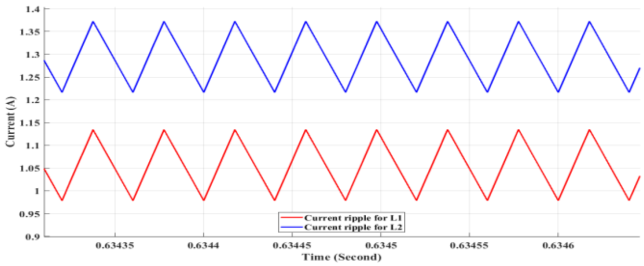

Fig. 8.Shows current ripple for ΔI_{L_1} and ΔI_{L_2}

The simulation results of the output current are depicted in Figure 8 in which the resulting output voltage was 13.01 V while the input voltage was 18 V.

The current ripple for ΔI_{L_1} was $1.561 \times 10^{-1} A$ and also the current ripple for ΔI_{L_2} was $1.561 \times 10^{-1} A$ which shows that the same constant ripple current of $1.561 \times 10^{-1} A$.

The zeta converter circuit was controlled with the help of a PWM switch in which, when the switch was closed, the current flowed through the circuit and when the switch was opened, the input current of zeta converter was 0 A. Figure 9 shows the information regarding multiple parameters of the zeta converter including current ripples across the inductor, output current, input current, voltage ripples across the capacitor and switch, output voltage, and the input voltage.

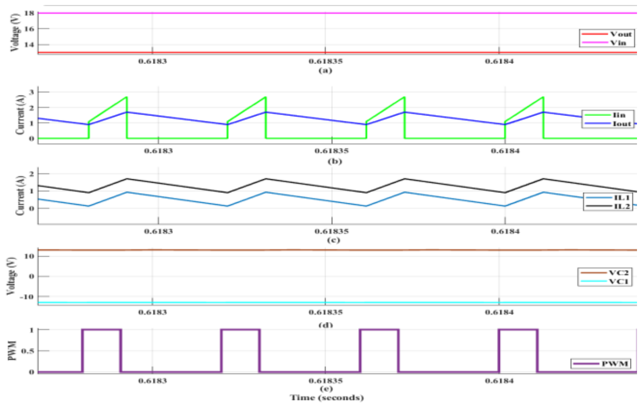

Fig. 9.(a) input and output voltage, (b) input and output current, (c) current ripple cross inductor, and (d) voltage ripple cross capacitor and switch (PWM) of zeta converter

V. CONCLUSION

The analysis, design, and implementation of zeta converter were achieved successfully in MATLAB Simulink. Good results from the proposed simulation were achieved as well, that will improve the theoretical studies regarding zeta converter and its implications in Simulink. Flowchart for the designed zeta converter as depicted in Figure 2. The result of the simulated zeta converter regulated to a fixed value while the input voltage was dynamically depending on the PV model output. The PV model output depends on irradiance intensity, temperature and PV model parameters. The issues faced during the testing that was the simulations carried based on assuming a fixed resistive load. Furthermore, in simulations, the effects of temperature are taken into account, hence, some variations in results are expected when testing in the real world. Finally, the implementation process can become more robust when the simulations of the zeta converter run wealthy.

The ideal variables for tuning the PID controller were obtained by using a genetic algorithm. The results obtained highlighted that the output voltage acquired from the system with GA tuned PID controller was regulated against the peak overshoot during transient condition even in varying load conditions and output voltage ripples as well. Furthermore, the implemented system can also provide a constant output voltage in different load conditions.

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