Solar Powered Battery Charging System Using Optimized PI Controller for Buck Boost converter

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Abstract. The basic framework for tuning Genetic Algorithm (GA) is to bring the system to stable condition with proportional Integral controller for DC-DC converter (Buck -Boost Converter) which is applied to PV source. Due to its non-linear characteristics, the performance of the controller needs to be improved in order to improve its efficiency. The gating pulses of the converter uses Pulse Width Modulation (PWM) technique in order to reduce its THD level. The main purpose of PI controller is to bring down the large values of instabilities in the system response and to reduce steady state error which in turns improves the gain and accuracy. Genetic Algorithm (GA) is a search algorithm to solve optimization problems. The controller parameters are optimized to produce reasonable transient response without affecting the stable operation. Output voltage magnitude of DC–DC converter is either greater than or lesser than the input voltage magnitude. Variable DC voltage from PV panel is applied to DC – DC converter to get constant DC output voltage. The modelling of the Proposed system is modelled using MATLAB/SIMULINK and its results are verified.

1. INTRODUCTION
The future dominance towards solar technologies are moving all around the world due to its resounding characteristics and search for alternative resources to power up. Slowly every country has started moving to develop PV plant to solve their present-day needs [1][2]. Developing countries like India would adopt renewable sources of energy (solar or wind) due to huge power demand. With increase in temperature across the globe, climatic changes around artic melts the icebergs. So, every country started moving for alternative techniques to bring down the pollution level [3]. There are few issues one would face during integration and conversion process to the grid [4]. Conversion process generally takes place when one system is converted to another system such as DC to DC and DC to AC conversion. Among them most important conversion system is DC to DC [5-7]. As DC-DC converter is required in Industrial applications, one needs to change over the input voltage to an alternate DC voltage level with a regulated output. It very well may be utilized to step down (Buck mode) and step up (Boost mode) a DC voltage source [8]. This conversion can be accomplished by variety of circuit switching device [9]. The generally utilized exchanging components are diodes, thyristors, power MOSFETs and so on.
The output voltage of DC-DC converter is constrained by working it in the closed loop and by changing its MOSFETs Gate signal [10]. PWM exchanging procedure is executed to accomplish exchanging switching logic of ON-OFF states [11]. The control is implemented by differing the duty ratio proportion of an external fixed frequency clock through at least one or more feedback loops at whatever input parameter varies [12]. Proportional Integral controller is tuned based on the Genetic Algorithm [13][14]. To improve the transient response of a system, the following parameters need to be reduced (i) steady state error (ii) peak overshoot, and (iii) shortening the settling time of the system [15].

Genetic Algorithm is an optimization technique that performs stochastic operation on non-linear equations based on the population size. The most common method of Roulette wheel selection is implemented based on mutation and crossover which changes based on the population size [16]. The main advantages are Genetic Algorithm is its search algorithm based on population of points rather than single solution [17]. They are structurally simple and robust but it can be varied wide range of operating conditions [18]. The present paper discusses about Genetic Algorithm based on PI controller for Buck Boost converter. The feedback loop contains a PI controller which maintains the reference voltage and the output voltage of the plant as the error input and PWM switching technique used for operating the gating signal. The Inductor in the plant stores the energy during ON time which is discussed in Mode 1 of Figure 3. The expressions for Mode 1 are derived based on the mode of operation of Buck – Boost converter, small signal module of DC-DC converter, feedback controller design [19-20].

![Figure 1. Block Diagram](image)

**2. PERFORMANCE ANALYSIS OF BUCK BOOST CONVERTER**

Although the Buck-Boost converter is almost the simplest form of DC-DC converter. Steady state operation shows output voltage depends upon the duty cycle ‘D’. In continuous conduction mode, there are two modes of operation in the buck boost converter. During the operation of the transistor(Q1) to be turned ON, the corresponding diode connected with it is open circuited and inductor across the supply (L) gets charged and voltage drop across the transistor is multiplied with load current and load resistance. The duration of the ON state and OFF state are decided based on the duty cycle where D is duty cycle which is varied by the control circuitry.
There is a very small voltage drop across the inductor L. The period of the ON condition is \( D \times T_s = T_{ON} \) where \( D \) = Duty cycle. During OFF state of the transistor, the inductor across the inductor supply current towards the load which short circuit the diode connected with the inductor (L) and inductor current linearly decreases from \( I_2 \) to \( I_1 \). During this period, the average capacitor value across the load starts charging which is almost equal to the average capacitor discharging current during turning OFF of transistor where Input power is equal to output power. The peak to peak ripple capacitor voltage (\( V_c \)) can be calculated by integrating the average capacitor discharging current during ON time [10]. Time of the one complete switching, Energy stored in Inductor and capacitor is shown in Equation (5) and Equation (6).

\[
E_L = \frac{1}{2} L \left( \frac{V_{\text{max}}}{L} \right)^2
\]  
(1)

\[
V_a = -V_o \frac{D}{1 - D}
\]  
(2)

\[
V_o I_o = V_o \times I_a
\]  
(3)

\[
V_o I_o = I_o \times V_o \times D/(1 - D)
\]  
(4)

\[
L = \frac{(1 - D) \times V_o}{\Delta f \times f_o}
\]  
(5)

\[
C = \frac{D}{(Rf) \times (V_{co} V_o)}
\]  
(6)
Table 1. Variable input voltage, Duty cycle and constant output voltage

| Input voltage(V) | Duty cycle | Ton (msec) | Output voltage(V) |
|------------------|------------|------------|-------------------|
| 12               | 57.14      | 1.42       | 16                |
| 14               | 53.33      | 1.33       | 16                |
| 20               | 38.46      | 0.866      | 16                |
| 45               | 26.22      | 0.655      | 16                |
| 50               | 24.24      | 0.606      | 16                |
| 55               | 22.53      | 0.563      | 16                |
| 60               | 20         | 0.5        | 16                |

where Vo can be varied by varying the duty cycle D. Table 1 shows the variable input voltage, constant output voltage, variable ON time of transistor, Duty cycle of DC-DC Converter for Buck-Boost Converter. Buck mode D < 0.5, Boost mode D > 0.5. Table 2 shows the parameters of PV module.

Table 2. Modelling Parameters for PV module

| Parameter                  | Design conditions |
|----------------------------|-------------------|
| Open Circuit Voltage (Voc) | 64.2 V            |
| Short Circuit Current (Isc)| 5.96 A            |
| Parallel resistance (Rp)   | 993.15Ω           |
| Series resistance (Rs)     | 0.0379Ω           |
| Rated Output Power         | 300W              |

3. TRANSFER FUNCTION OF BUCK BOOST CONVERTER

The transfer function equations are derived based on small signal modelling of buck boost converter for both buck and boost mode using equations (7)-(9). Transfer function formation for uncompensated and compensated system for the proposed buck boost converter is modelled for finding error signal where α indicates Duty cycle, R indicates Load Resistance and C indicates Capacitor. The step response and bode plot for uncompensated system is plotted based on the derivation obtained from the transfer function equation (8) which is shown in Figure 6 and Figure 7 and bode plot for compensated system is derived from the transfer function shown in Figure 8.

\[
G_{dc}(s)=G_o(s)G_m(s)H(s) \tag{7}
\]

Transfer function of uncompensated system

\[
G_o(s) = \frac{1.2 - 3.1 \times 10^{-4}s}{1.28 \times 10^{-5}s^2 + 5.33 \times 10^{-4}s + 0.4096} \tag{8}
\]

Transfer function of compensated system

\[
G_c(s) = \frac{0.438 + 5.694 \times 10^{-3}s}{1 + 5.894 \times 10^{-3}s} \tag{9}
\]
Figure 4. Duty cycle Vs Gain

Figure 5. Transfer Function of Buck Boost Converter

Figure 6. Step response of uncompensated system

Figure 7. Bode of uncompensated system

Figure 8. Bode of compensated system
### Table 3. Parameter formation for Buck-Boost converter

| Parameter defining | Design values   |
|--------------------|-----------------|
| Input voltage      | 12 V to 60 V    |
| Output voltage     | 16 V            |
| Switching frequency| 5KHz            |
| Inductor           | 5 mH            |
| Capacitor          | 600 μF          |
| Load resistance    | 10 Ω            |
| Load current       | 6 A             |

### 4. STRUCTURAL IMPLEMENTATION OF GA-PI CONTROLLER

The structural implementation of Genetic Algorithm combined with Proportional Integral (PI) controller is done in order to improve the performance of the system which mainly increases the response time and reduces the steady state error (Ess) tremendously [13]. The tuning parameters of Kp and Ki are tuned based on the results obtained simulated results of Genetic Algorithm [8]. The values of Kp and Ki are tuned by the knobs which gets adjusted to obtain the desired output of the controller. The output of PI controller is given by

\[ U(t) = K_p \times e(t) + K_i \int e(t) dt \]

\[(10)\]

### 4.1. SIMULATED PARAMETERS OF GENETIC ALGORITHM

The objective function of Genetic Algorithm (GA) is written based on the dynamic parameters obtained from the step response such as Peak Overshoot (Po), Rise time (Tr), Settling time (Ts) and Steady state error (Ess). The structural block diagram of GA-PI controller is illustrated in Figure 9.

![Figure 9. Structure of GA-PI controller](image-url)
The fitness function for the Genetic algorithm is written for duty cycle which is based on the configurational parameters for the Buck Boost converter such as Rise time, settling time, Peak overshoot and Steady state error. The best fitness value can be applied to the controller to tune the parameters to produce pulses for the converter gates. The variation of the duty cycle of Buck-Boost converter is normally calculated using Kp and Ki values of the PI controller.

\[
F(\phi) = [(1+Tr) * (1+Ts) * (1+Ess) * (1+Po)]
\]

Constraints

\[
K_p \text{ (min)} < K_p < K_p \text{ (max)} \\
K_i \text{ (min)} < K_i < K_i \text{ (max)}
\]

(11)

| Table 4. Design parameters for Genetic algorithm |
|-----------------------------------------------|
| Parameter       | Design values |
|-----------------|---------------|
| Population size | 30 to 100     |
| Mutation (Pm)   | 0.01 to 0.001 |
| Crossover (Pc)  | 0.6 to 0.9    |
| Kp (max)        | 0.0907        |
| Ki (max)        | 0.85          |
5. SIMULATION AND HARDWARE RESULTS

The open loop and closed loop implementation of buck boost converter is simulated using MATLAB/Simulink in order to check its feasibility towards hardware implementation. The input voltage is fixed to perform constant input voltage control with variation in load changes. Also performed constant output voltage control by keeping varying input variations.

![Simulation diagram for closed loop analysis of Buck Boost converter](image1)

**Figure 11.** Simulation diagram for closed loop analysis of Buck Boost converter

![Simulation diagram for open loop analysis of Buck Boost converter](image2)

**Figure 12.** Simulation diagram for open loop analysis of Buck Boost converter

This is done by varying the pulse width of the gating pulses of the transistor and varying duty cycle (D). Among them, the most important technique is Pulse-width modulation technique which is used to gate pulses obtained from the PI controller. Gating pulse generation during boost mode ‘D’ is 0.767 and buck mode ‘D’ is 0.368. It is the comparison of carrier wave with the error output from the controller as the reference. Gate pulse is applied to gate of the converter switch. Figure 11 and Figure 12 shows the simulation model of closed loop and open loop of Buck-Boost converter. Pulse width modulation scheme is used to produce gating pulse ‘Ton’ by comparing saw tooth waveform with the PI output. The switching frequency of the converter in this case is taken as 5 KHz.
Table 5. COMPARISON OF CONVERTER

| Parameter | Rise time (ms) | Settling time (ms) | Peak overshoot | Steady state error (E_{ss}) |
|-----------|---------------|--------------------|---------------|-----------------------------|
| Set point | 0.834         | 1.56               | 0.053         | 25%                         |
| Without GA| 0.75          | 1                  | 0.038         | 20%                         |
| With GA   | 0.2           | 0.72               | 0.028         | 3 to 5%                     |

Table 5 provides the comparative study of the converter with parameters using set point, without GA and with GA. The basic parameters are measured for all the cases such as rise time, settling time, Peak overshoot and steady state error in order to find its feasibility in implementation. By using GA-PI controller value Rise time is 0.01 m sec, settling time reduced to 0.2 m sec and the steady error is 0.0001 V. Steady state response is performing well in using GA-PI controller. The simulation results of both open and closed loop is shown in Figure 13 and Figure 14.

![Figure 13. Simulation result of closed loop analysis of buck boost converter](image1)

![Figure 14. Simulation result of open loop analysis of buck boost converter](image2)

![Figure 15. Hardware Implementation for Buck Boost converter](image3)
From the analysis, one could able to find the feasibility is high when it is implemented using Genetic Algorithm because of its resounding parameter values. The overall steady state error (Ess) using GA is comparatively low (3-5%) and its settling time is quicker when compared to other two parameters. The hardware implementation is done using small PV Panel which is interconnected to the converter circuit to provide constant DC voltage which is shown in Figure 15.

6. CONCLUSION
The analysis of buck boost converter using GA based PI controller by MATLAB SIMULINK M-file coding is implemented during normal PI controller steady state error is 20%. It is reduced to 3 to 5%. Buck-boost converter is applied to renewable energy application such as PV Panel whose output is constant voltage. The controller design of the buck boost converter is evolved as a part of search algorithm obtained from Genetic Algorithm which provides the base value of the controller constants. By varying the duty cycle and PWM pulses obtained from controller output, there can be input and output variation obtained which reduces the effect of controller parameters obtained from the input step response curves such as rise time, settling time, peak overshoot which produces comparatively better results compared to conventional methods.

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