

## Genetic algorithm based PI controller for DC-DC converter applied to Renewable energy applications

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### Abstract

This paper shows a system for tuning Genetic Algorithm based PI(proportional Integral ) feedback controller for DC-DC converter (Buck -Boost Converter) which is applied to self excited Induction Generator used in WECS(Wind energy conversion System). Due to non linear characteristic of the converter, a controller with better execution is required. Pulse Width Modulation strategy is utilized for the converter gating pulses. PI controller is choose because large values tend to instabilities in the system response and to reduce steady state error. PI Controller is used for better gain and accuracy. GENETIC ALGORITHM is an adaptive method to solve search and optimization problems, The controller parameters are optimized to produce reasonable transient response without affecting the stable operation. Output voltage value of DC DC converter is either more important or lesser than the input data voltage measured. The variable AC voltage from self excited Induction Generator is

converted into variable DC voltage and is connected to DC DC converter to get constant DC output voltage. Proposed methodology is modeled by using MATLAB/SIMULINK results are verified.

**Key Words :** DC-DC converter ; Pulse Width Modulation ; Duty cycle; PI controller; Genetic Algorithm.

## 1 INTRODUCTION

DC-DC converter is needed in Industrial applications .It is required to convert a DC voltage to a different DC voltage level with a regulated output. It can be used to step down (Buck mode) and step up (Boost mode) a dc voltage source [1].Renewable energy source like WECS output is AC supply of different level. Need to convert different level of AC supply into constant AC supply, by using DC- DC converter . This conversion can be achieved by variety of circuit switching devices[1][2]. The widely used switching devices are diodes, thyristors, power MOSFETs etc. The yield voltage of DC-DC converter is controlled by working it in the closed loop and by modifying its MOSFETs Gate signal.PWM technique is implemented to achieve switching logic of ON-

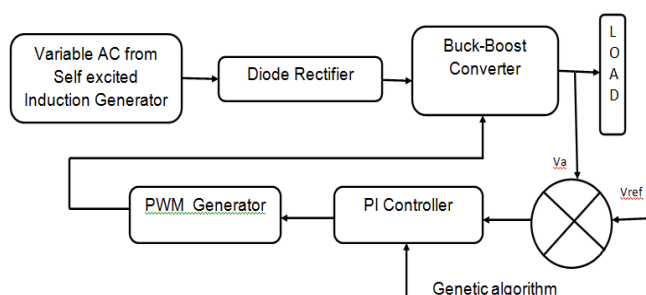


Fig . 1 Block Diagram

The control is joined by varying the duty ratio of an external fixed frequency through least one feedback loops whatever input parameter varies [3]. Proportional Integral controller is tuned based

on the Genetic Algorithm [4]. To enhance the transient response of a framework by lessening (i) the peak overshoot, (ii) steady state error and (iii) shortening the settling time of the system[5]. Genetic Algorithm is an optimization technique that performs a parallel, stochastic however immediate search to evaluate. The most common method of Roulette wheel selection is implemented [6]. The advantages are GA searches a population focuses rather than single solution[7]. They are basically straight forward and robust but it can be extended to wide variety of working conditions [8].

The present paper proposes Genetic Algorithm based PI controller for Buck Boost converter. The feedback loop contains a PI controller which keeps the reference voltage and the output voltage of the plant as the error input and PWM technique used for operating the gating signal. The Inductor in the plant stores the energy during ON time [8]. The expressions are derived from switched model of Buck Boost converter, small signal module of DC-DC converter, feedback controller design. The performance is found from WECS parameters, the recreated simulated Waveforms are presented in the succeeding areas.

## 2 Buck Boost converter performance analysis

In spite of the fact that the Buck-Boost converter is practically the least difficult type of DC-DC converter, steady state operation demonstrates yield voltage relies on upon duty cycle 'D'. The buck boost converter works two states for every switching cycle in continuous conduction mode.

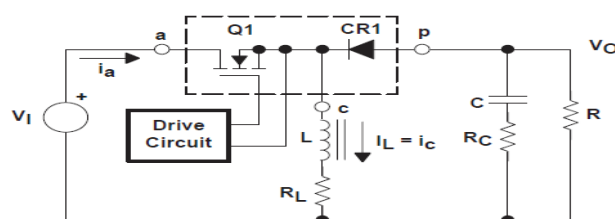


Fig.2 Circuit Diagram

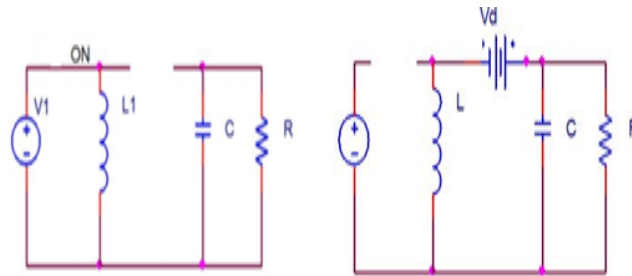


Fig.3 Mode of operation

During ON state transistor is ON and CR is OFF, during OFF state when transistor is OFF and CR is ON. The duration of the ON state is  $D \times T_S = T_{ON}$ ,  $D$ =duty cycle varied by the control circuit, communicated as a ON time to the time of one whole switching cycle  $T_S$ . Duration OFF state is called  $T_{off}$ .  $T_{off} = (1 - D) \times T_S$ . During ON state, the voltage drop across the transistor and DC resistance of the inductor is equal to  $I_L \times R_L$ . There is small voltage drop across the inductor  $L$ . The period of the ON condition is  $D \times T_S = T_{ON}$  where  $D$ =Duty cycle. The ratio as switch ON time to the time of the one complete switching cycle  $T$ . decreasing of Off state is called  $T_{off}$ . At the time of the ON state of the transistor, input voltage  $V_{in}$  supplied to the inductor, therefore CR is OFF during this time [1][8]. Because diode is reverse biased. Inductor current  $I_L$  flows from input source  $V_{in}$  through transistor Q and to ground. Inductor current increases linearly. The amount of increased inductor current can be calculated by using

$$V_L = L \times \frac{di_L}{dt} \quad (1)$$

$$I_L = \frac{V_L}{L} \times \Delta T \quad (2)$$

$$V_L = V_{in}(V_D S + I_L \times R_L) \quad (3)$$

When Q is OFF, impedance in transistor is increased and the inductor  $L$  current cannot change instantaneously, the current shifts from Q to LCR. Due to decreased inductor current, the voltage

across the inductor reverses its polarity until the rectifier CR becomes forward biased. The inductor current  $I_L$  flows from the output capacitor and load resistor combination through CR and ground. Output voltage to be a negative voltage. Inductor current decreases during OFF time. During ON time of the transistor from equation (3).

$$T_{on} = L \frac{\Delta I}{V_s} \quad (4)$$

Energy stored in Inductor is

$$E_L = \frac{1}{2} L \left( \frac{V_{ston}}{L} \right)^2 \quad (5)$$

During OFF time of transistor , Inductor current linearly decreases from  $I_2$  to  $I_1$  .

$$V_a = -V_s \frac{D}{1-D} \quad (6)$$

$D$  ———> output conversion factor for buck converter  
 $(1-D)$  ———> out put conversion factor for boost convertor  
 Input power = output power ,

$$V_s I_s = V_a * I_a , \text{ then } V_s I_s = I_a * V_s D / (1-D)$$

$$L = -V_s \frac{(1-D)*V_a}{\Delta I * f_s} \quad (7)$$

The average capacitor charging current during OFF time must be equal to the average capacitor discharging current during ON time. The peak to peak ripple capacitor voltage  $V_c$  can be calculated by integrating the average capacitor discharging current during ON time[10]. Then the expression for capacitor value

$$C = \frac{D}{(Rf_s)*(V_{co}/V_o)} \quad (8)$$

$V_o$  can be varied by varying the duty cycle  $D$ .

The inductor provides current to the output only during OFF state of the power period [7] . This average current over a entire switching cycle is equal to the output current because the average current in the output capacitor should be equal to zero.

$$I_L(Avg) = \frac{-I_o}{(1-D)} \quad (9)$$

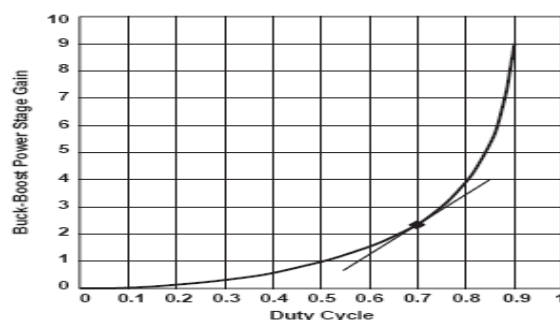


Fig.4 Duty cycle Vs Gain

Table ( i ) Variable input voltage,variable duty cycle,constant out-put voltage

| I/P Voltage (V) | Duty Cycle (%) | $T_{on}(m\ sec)$ | Output Voltage (V) |
|-----------------|----------------|------------------|--------------------|
| 100             | 70.58          | 0.14             | 240                |
| 150             | 61.58          | 0.123            | 240                |
| 210             | 51.87          | 0.103            | 240                |
| 275             | 47.13          | 0.094            | 240                |
| 350             | 40.45          | 0.00809          | 240                |
| 400             | 37.70          | 0.00754          | 240                |
| 430             | 36.21          | 0.00724          | 240                |
| 510             | 32             | 0.0064           | 240                |

The above table shows the variable input voltage , constant out-put voltage, variable ON timeOf transistor, Duty cycle of DC-DC Converter for Buck-Boost Converter. Buck mode  $D \leq 0.5$ , Boost mode  $D \geq 0.5$ . . From Small signal Modeling of Buck-Boost Converter transfer function equations for both buck and boost mode are derived ,then the transfer function equations are given below for finding error signal[12].

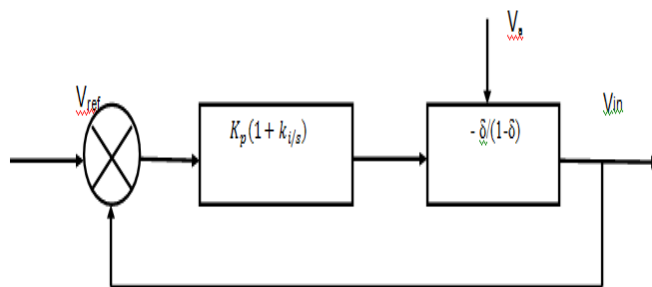


Fig. 5 Transfer Function of Buck Boost Converter

$$V_o(S) = (K_p K_I) \left( \frac{-\delta}{1-\delta} \right) (V_{ref}(s) - V_o(s)) \quad (10)$$

$$V_o(S) (1-\delta) = (K_p K_I) - (\delta) (V_{ref}(s) - V_o(s)) \quad (11)$$

$$V_o(s) - \delta V_o(s) = (K_p K_I) - (\delta) (V_{ref}(s) - V_o(s))$$

$$V_o(s) - \delta V_o(s) = -K_p K_I \delta V_{ref}(s) + K_p K_I \delta V_{ref}(s)$$

$$V_o(s) = -K_p K_I \delta V_{ref}(s) + K_p K_I \delta V_{ref}(s) + \delta V_o(s)$$

$$V_o(s) = [-K_p K_I \delta V_{ref}(s) + K_p K_I \delta V_{ref}(s) + \delta V_o(s)] \delta$$

$$V_o(s) = [-K_p K_I \delta V_{ref}(s) + K_p K_I \delta V_{ref}(s) + \delta V_o(s)] \delta \quad (12)$$

$$V_o(s) = \frac{V_o(s)}{[-K_p K_I \delta V_{ref}(s) + K_p K_I \delta V_{ref}(s) + \delta V_o(s)]} \quad (13)$$

#### Transfer Function GA-PI controller

$$HV\alpha(s) = \frac{(E_e - V_{ce}) * (1-\alpha) - \frac{\alpha}{(1+\alpha)^2} \frac{E}{R} L}{LCs^2 + \frac{L}{R} s + (1-\alpha)^2}$$

$E_e$  = Source Voltage

$V_{ce}$  = Capacitor Voltage

$\alpha$  = Duty cycle

$R$  = Load Resistance

$C$  = Capacitor

### 3 Structure of GA-Proportional Integral (PI) Controller

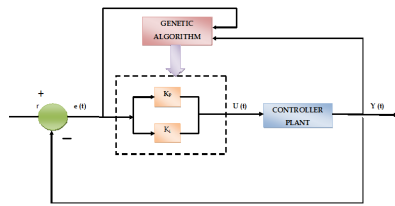


Fig.6 Structure of GA-PI Controller

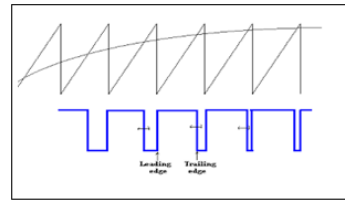


Fig.7 Pulse Width modulation.

The combination of proportional Integral term is important to increase the speed of response and also to eliminate steady state error[13].  $K_p$  and  $k_i$  tuning knobs are adjusted to obtain the desired output. PI is given by  $U(t) = K_p e(t) + K_i \int e(t) dt$

In order to maintain the constant output voltage, it is necessary to contrast the output voltage to reference voltage, if  $V_{out} = V_{ref}$ , the error signal  $e = V_{out} - V_{ref}$  which is the controller then manipulate in such a method so as to adjust  $V_{out}$  is equivalent to  $V_{ref}$ . The tuning parameters  $K_p$  and  $K_i$  are tuned based on Genetic Algorithm [8]. The duty cycle of Buck-Boost converter calculated by  $K_p$  and  $K_i$ . Pulse width modulation technique is used to produce gating pulse  $T_{on}$  by comparing saw tooth waveform with the PI output. The frequency is 5 KHZ. To ensure that this occurrence does not excessively affect a controllers score, the complete error is multiplied by time to reduce its impact [10]. From the state feedback controller design for buck- boost converter the tangent linearization model of the average normalized Buck boost converter[11][14].

$$\dot{X}_1 = V_{av} X_2 + (1 - U_{av}) \quad \dot{X}_2 = -U_{av} X_1 - X_2 / Q \quad (12)$$

Feedback gains for linear controller two gains obtained are,

$$K_1 = -\left[-\frac{1}{Q} + 2\xi\omega_n - \frac{vd(1-vd)}{Q}(\omega_n^2 - \frac{1}{(1-vd)^2})\right] \quad (13)$$

$$K_2 = -\left[\frac{1-2V_d}{Q} + \left(-\frac{1}{Q} + 2\xi\omega_n\right) - (1-V_d)(\omega_n^2)\frac{1}{(1-V_d)^2}\right] \quad (14)$$

$$\text{Where } r = \frac{1}{(1-V_d)\left(1 - \frac{V_d(1-2V_d)}{Q}\right)} \quad (15)$$

Table(ii) Design formula and parameters for buck- boost converter

| Parameter      | Design Equation                           |
|----------------|-------------------------------------------|
| Output Voltage | $V_s = -V_r D/(1-D)$                      |
| Inductor       | $L_r = (1-D) V_d/(\Delta I_o) f_s$        |
| Capacitor      | $C_o = D/ \{ (R f_s) (\Delta V_o/V_o) \}$ |

**Input Voltage** : 100 V to 510 V  
**Output voltage** : 240v  
**Frequency** : 5 KHZ  
**Inductor** : 7.845mH  
**Capacitor** : 8.4696 mF  
**Load Resistor** : 40  $\Omega$   
**Load Current** : 6A

Calculated Value of design Values are L = 7.845mH, C = 8.6496mF

## 4 WORKING OF GENETIC ALGORITHM

Genetic Algorithm generates solution to optimization trouble using technique is initialized by natural evolution, such as inheritance, selection, crossover and mutation. This below diagram shows generalized GA for optimizing [13] .GA presumes that the possible resolution of a problem is an individual and can be represented by a place of parameters by binary form.

### 4.1 STEPS FOR GENETIC ALGORITHM

The steps involved in creating and implementing a genetic algorithm are as follows Generate an initial, random population of individuals for a fixed size (according to conventional methods Kp, ki ranges are declared [15].

- Evaluate their fitness
- Select the fittest members of the population
- Reproduce using a probalistic method (roulette wheel selection)

- Implement crossover operation on the reproduced chromosomes
- Execute mutation operation with low probability
- Repeat step 2 until a predefined convergence criterion is met.

## 4.2 PSEUDO CODE AND FLOW CHART FOR GENETIC ALGORITHM

Begin

$t=0$ ;

Initialize  $P(t)$ ;

calculate  $P(t)$ ;

While ( not termination condition ) do

Begin

Apply crossover and mutation to  $p(t)$  to yield  $c(t)$ ;

Evaluate  $c(t)$ ;

Select  $P(t+1)$  from  $P(t)$  and  $c(t)$ ;

$t = t+1$ ;

End

End

The flowchart explains how genetic algorithms work is showing in the figure.11The process continuous till the best solution is found out.

A scheme called roulette wheel selection is one of the most commonly used techniques in such a proportionate selection mechanism. Selection procedure is listed above figure. The choice of  $P_m$ ,  $P_c$  as the control parameters can be a complex , nonlinear optimization problem[15].

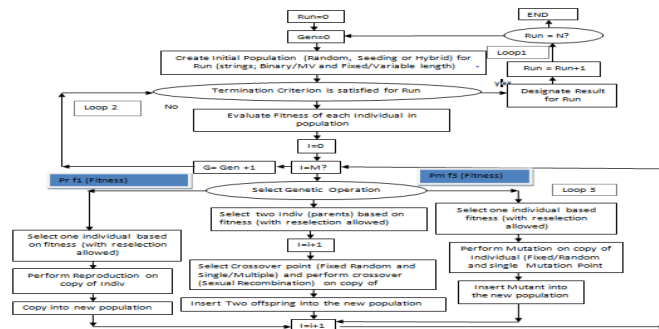


Fig.8 Flow chart of Genetic Algorithm

|                 |             |
|-----------------|-------------|
| Population size | 30 to 100   |
| Mutation Pm     | 0.01 ,0.001 |
| Crossover Pc    | 0.6,0.9     |

| Population | Kp    | Ki   |
|------------|-------|------|
| 50         | 0.089 | 0.76 |
| 70         | 0.09  | 0.77 |
| 80         | 0.091 | 0.78 |
| 90         | 0.092 | 0.79 |
| 120        | 0.093 | 0.8  |
| 150        | 0.094 | 0.81 |
| 160        | 0.095 | 0.82 |
| 180        | 0.096 | 0.83 |
| 200        | 0.097 | 0.85 |

Fig.9 Genetic Algorithm based PI controller values

### 4.3 Summarizes the Genetic algorithm

CLOSED LOOP GA- PI CONTROLLER

Kpmax =0.0907

Ki max=0.85

Dynamic parameter

- Rise time ( $T_r$ )
- Settling time ( $T_s$ )
- Peak Overshoot  $P_o$ )
- Steady state error  $E_{ss}$ )

Optimization Problem is

$$F(\phi) = [(1 + T_r) * (1 + T_s) * (1 + E_{ss}) * (1 + p_o)]$$

Constraints are

$$K_p \text{ (min)} \leq K_p \leq K_p \text{ (max)} \quad K_i \text{ (min)} \leq K_i \leq K_i \text{ (max)}$$

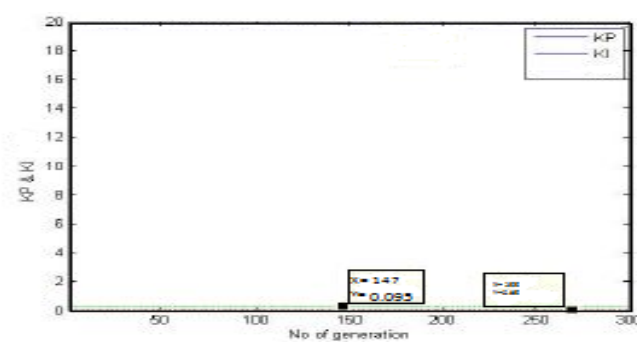
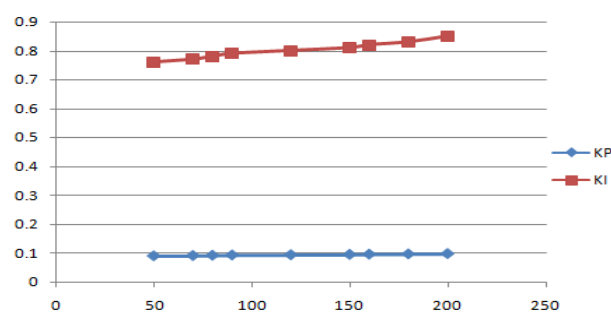


Fig 10. GA-PI controller  $K_p$ ,  $K_i$

## 5 SIMULATION RESULTS.

### 5.1 Model of wind mill

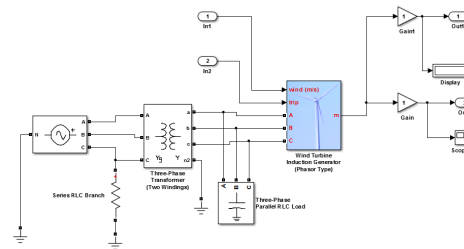


Fig 11. Simulation diagram of Wind mill

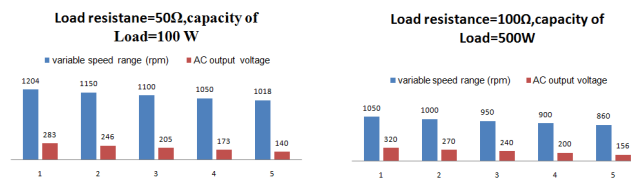


Fig 12. Parameters of self excited Induction generator

### 5.2 simulation diagram for Open loop of buck boost converter

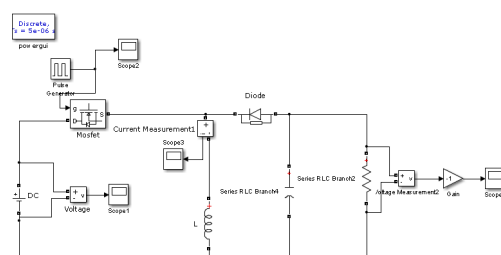


Fig.13 simulation diagram for open loop buck boost converter

### 5.3 Simulation diagram of Closed loop GA-PI controller buck boost converter

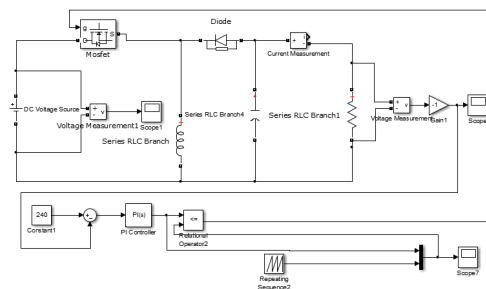


Fig.14 simulation diagram for closed loop GA-PI buck boost converter

### 5.4 Simulation result of Buck-Boost converter

Simulation circuit and result shows as per design values of Buck Boost converter L, C and Load Resistance 40 , switching frequency of 5KHZ 100V input voltage is increased to 240V (BOOST MODE ).For the same parameter values 510V input voltage is decreased to 240V (BUCK MODE ).As per the Mat lab code value GA-PI value of Kp and Ki are found out to reduce rise time, minimize the steady state error when the normal PI controller operation.

#### 5.4.1 Simulation result of input and output voltage of buck boost converter (input voltage is 100V and output voltage is 240v)

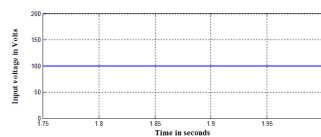


Fig.15 Simulation result of input voltage

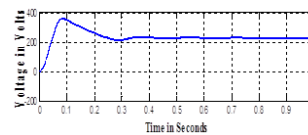


Fig.16 Simulation result of output voltage

Rise time is 0.1 msec, settling time is 0.8 m sec and the steady error is 0.1v

#### 5.4.2 Simulation result of Gate pulse for buck- Boost mode converter

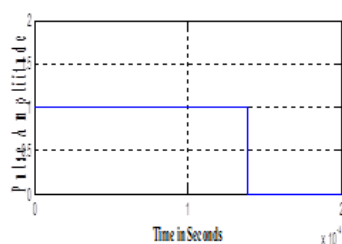


Fig 17. Gating pulse of Boost Converter

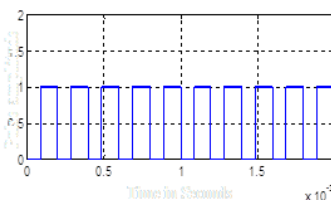


Fig 18. Gating Pulse of Buck Converter

#### 5.4.3 Simulation result of Closed loop GA Parameter value of $K_P=0.0905$ , $K_i=0.85$ , INPUT VOLTAGE =510v, OUTPUT VOLTAGE =240v

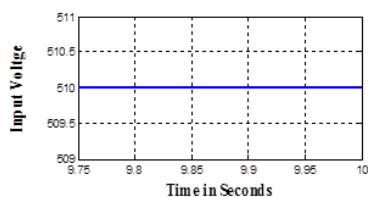


Fig.19. GA-PI Input Voltage

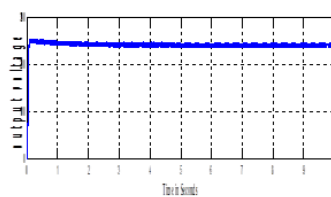


Fig.20. GA-PI Output Voltage

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 0.01v. Steady state response is performing well in using GA-PI controller.

#### 5.4.4 Simulation Result of Inductor current and Load current

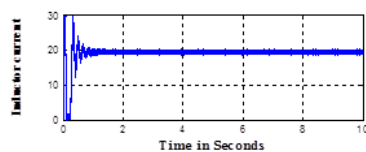


Fig.21. Converter Inductor Current

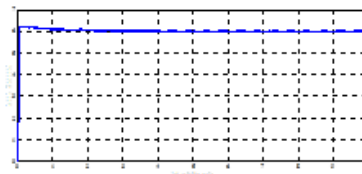


Fig.22. Converter Load Current

By using GA-PI controller inductor current is 17Amps and as per design value of 40ohm Load, Inductor current is 6Amps.

## 6 Simulation result and future work

Hierarchical intelligent control for the electronic buck boost power converter using a newly developed small signal model, PI controller design of Pulse width modulation (PWM) switching is introduced in this paper. The hierarchical intelligent control uses the GA based tuning of PI controller to counteract the existence and effect of high amplitude disturbances. The simulation result shows open loop buck boost converter, closed loop GA based PI controller for PWM pulses, succeeds in minimizing the effect of noise even when noises several folds higher than the normal buck boost generated output signal. Further work will investigate the implementation of introduce versatile GA based PI controller for buck boost converter, fuzzy GA based PI controller for buck boost converter. Neuro-fuzzy PI controller for buck converter boost converter, buck-boost converter and cuk converter.

## 7 CONCLUSION

This paper exhibits the investigation of buck boost converter utilizing GA based PI controller by Matlabsimulink M-file coding is executed amid typical PI controller steady state error is 20%.It is de-

creased to 3 to 5% .buck-boost converter is connected to renewable vitality application, for example, WECS whose yield is steady voltage[16] .The outline of the controller for the buck boost converter is seen as an advancement errand and the controller constants are assessed through developmental pursuit algorithms[17]. At first the plans of PI controller parameters for the buck boost converter were outlined in view of routine technique and Genetic Algorithm (GA) By observing the rise time, settling time, peak overshoot from the input response curves which are obtained by using the controller parameters from the GA based parameter identification good and robust response compared to conventional methods.

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