Ant Colony Optimized Tuned DC-DC Converter

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ABSTRACT

Ant Colony Optimization (ACO) used to tune the Proportional and Integral (PI) controller for Single Ended Primary Inductance Converter (SEPIC) is discussed in this paper. The SEPIC is based on DC to DC converter to maintain the constant output voltage but varying input voltage. PI controller maintains a constant output of the converter, without changing sign. MATLAB simulation designing is developed for ACO tuned DC-DC converter.

Keywords

SEPIC, PI controller, ACO, DC-DC converter.

1. INTRODUCTION

The non renewable source of energy is depleting rapidly and the demand for power is increasing day by day. To overcome this problem, generation of electric power from renewable source of energy should be made effective and efficient. This work focuses on designing a suitable DC-DC converter.

Converter system is used to denote a static device that converts ac to dc, dc to ac, dc to dc or ac to ac. There are various types of DC-DC converters such as, Buck converter, Boost converter and Buck-Boost converter [7]. The output of buck converter is less than the input voltage whereas the boost converter output is greater than the input voltage. The polarity of buck-boost converter is inversed of input signal. Whereas SEPIC is a special type of DC-DC converter which maintains a constant output voltage even under varying input conditions and load conditions [1].

The design methodology and the component selection of the SEPIC converter are described [2][3]. Stability of SEPIC is proved in [4]. The tuning of PID controller using various optimization techniques is studied in [11]. The tuning of PID and PI controller using ACO is presented in [14][16][17] and [12] respectively.

From the literature survey it can be understood that SEPIC is widely used converter topology in renewable source based energy generation. SEPIC converter also overcomes the drawback of buck-boost converter. The performance of SEPIC converter can further be improved by using a suitable control scheme. PI controller is a simple conventional controller that can be used in controlling many complex, linear process. The performance of PI controller depends on the selection of parameter. To enhance the performance of SEPIC and to improve the efficiency in utilizing renewable energy sources the parameters of the PI controller are tuned with optimization technique. Parameter selection and initialization are random in optimization techniques like Genetic Algorithms (G.A), Particle Swarm Optimization (PSO) [11]. To overcome these drawbacks Ant Colony Optimization is used in this work to select the parameters of PI controller.

2. SEPIC TOPOLOGY

The proposed converter is based on DC to DC converter to maintain the constant output voltage. The DC to DC Single-Ended Primary-Inductance Converter (SEPIC) will very above or below the input voltage without change in output polarity. A SEPIC is similar to a BUCK – BOOST converter but has advantages of having non-inverted output (the output voltage is of the same polarity as the input voltage). The inductors and the capacitors can also have large effects on the converter efficiency and ripple voltage. This converter transfers the energy between the inductance and the capacitance in order to change from the voltage to another. The transferred energy is controlled by switching device S_1 (MOSFET).[2]-[8]

Figure (2.1) The SEPIC converter will be operating in continuous conduction mode (CCM). The input current through the inductor (L_1) will never become zero, the capacitor voltage (V_{C1}) is equal to the input voltage because of C_1 the DC current is blocked and current across the capacitance I_{C1} will be zero. The inductor L_2 thought source to the load current, so that average of the I_{L2} current is same as load current. The input voltage V_{IN} is given as:

$$V_{in} = V_{L1} + V_{L2} + V_{C1} \qquad -1$$

Because of the voltage at V_{C1} is equal to the V_{in}, the value of two inductance are same, so that the inductor voltage is of the same magnitude, also the effect of the mutual inductance is zero and the polarity is different. The current I_{D1} is difference between I_{L1} and I_{L2} ($I_{D1}=I_{L1}-I_{L2}$). When switch S_1 turns ON the inductor current I_{L1} increases and inductor current I_{L2} decreases in negative direction and the voltage across capacitance C_1 is approximately same as the V_{IN}. The energy supplied by the capacitor C_1 will increase the magnitude of the inductor current I_{L1} and energy is stored in L_2.

When S_1 turns OFF the inductor doesn't allow instantaneous change in current, using Kirchhoff current law I_{L2} continues in the negative direction. The current I_{L2} adds to I_{L1} to increase the current delivered to the load and diode current is written as $I_{D1}=I_{C1}-I_{L2}$. The power distributed to the load from L_1, L_2 and C_1. L_1 is charged during the OFF cycle and L2 during the ON cycle.

The capacitor C_1 and inductor L_2 ensures the buck/boost operation of the SEPIC. The voltage V_{S1} is higher than V_{IN}, which gets generated by boost converter. The boost converter comprises of inductor L_1 and switch S_1. The magnitude of V_{S1} is determined by the duty cycle of the switch S_1. The output voltage V_O can be found out using average voltage V_{IN} across C_1 by finding out the difference between V_{S1} and V_{IN}. The output voltage will be 2 times the input voltage for V_{S1} whether it is less (or) greater than V_{IN}. The change in inductor voltage for each interval determines the duty cycle (D) and will maintains output constant.

$$D = \frac{V_{out} + V_D}{V_{in} + V_{out} + V_D} \qquad -2$$

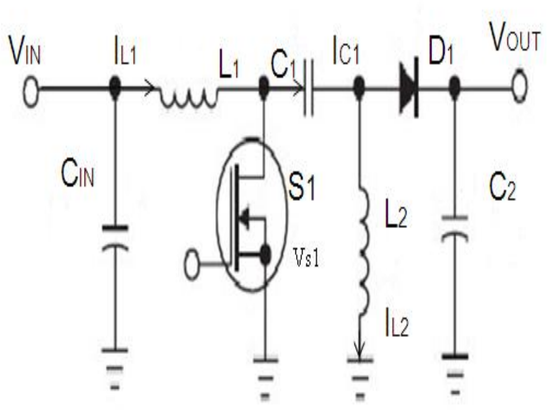

Figure 2.1: SEPIC converter topology

The simulation is carried out for different input and load (V_{in}) (from 42V to 84V) conditions while the output voltage (V_{out}) is maintained at a constant level (120V). To maintain a constant output voltage even in presence of variation in input voltage form 42V to 84V, the duty cycle of gate pulse to the MOSFET is changed. The switching frequency depends on the simulation parameters, in this work 100KHZ is used.

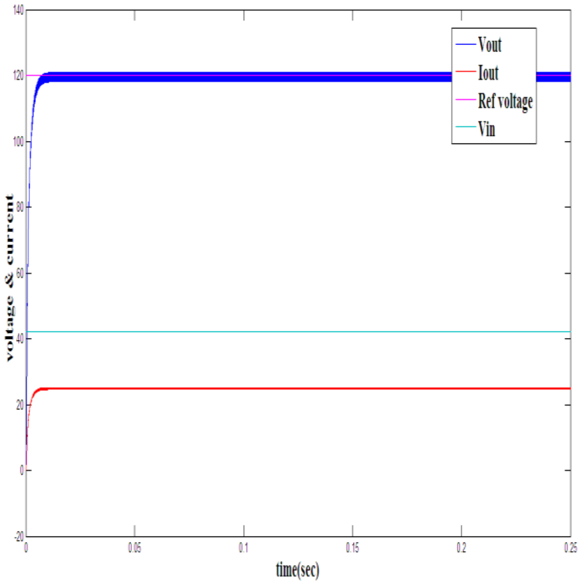

Figure 2.2: Simulation result for SEPIC Converter at input voltage 42V.

Figure (2.2) result of SEPIC converter output at 42V input voltage. Load resistance of 4.8 ohm. Figure (2.3) result of SEPIC converter output at 84V input voltage and Load resistance of 4.8 ohm.

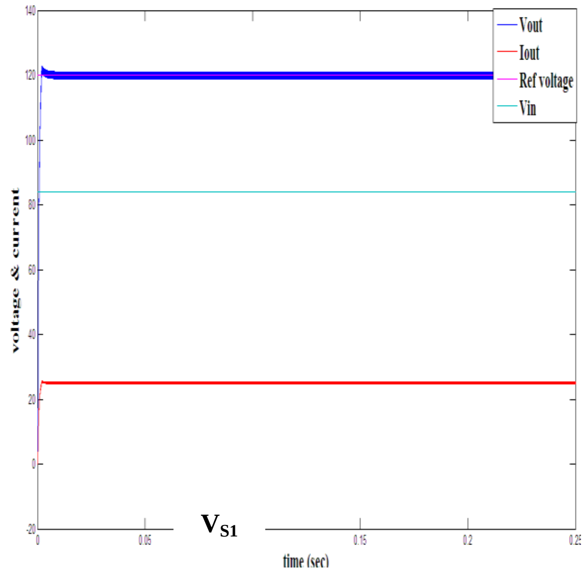

Figure 2.3: Simulation result for SEPIC Converter at input voltage 84V.

The input voltage is changed from 42V to 60V and then finally changed to 84V. From the figures (2.4) it can be observed that the output voltage contains peak overshoot and ripples. So PI controller is used to reduce the peak over shoot and ripples.

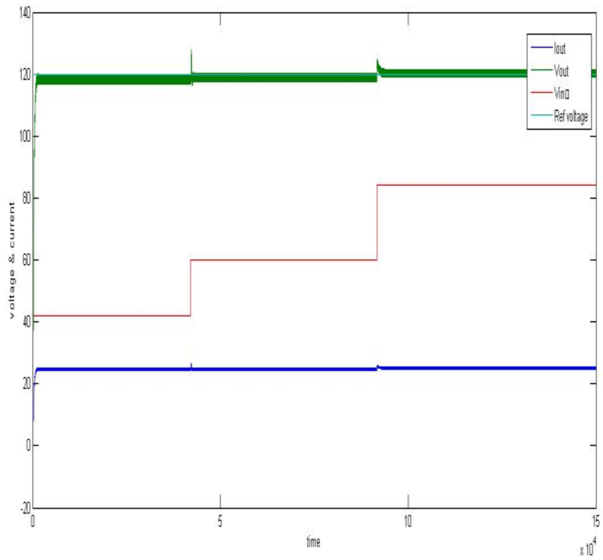

Figure2. 4: Simulation result for SEPIC converter for varying input voltage

3. SEPIC CONVERTER USING PI CONTROLLER

This PI controller guarantees stability, offers rapidity and steady state error is zero, so that their disadvantages are compensated at the same time at P & I controllers. The governing equation of PI-controller is:

$$\mathbf{P(t) = K_p E_p + K_p K_i \int E_p(t)dt + P_0} \qquad (3)$$

When there is no error (E_p=0), the controller output P(t) remains constant at P_0. We have chosen t=0 as the time at which the observation starts. If the error does not settle at zero, then the proportional term contributes a correction and the integral term begins to increase or decrease the accumulated value (initially P_0), depending on the sign of the error and whether the action is direct or reverse. The main advantage of this method is that it implements one-to-one correspondence of proportional control and makes use of integral action to eliminate offset.

The combination is favourable for systems in which large load change occurs. The proportional mode provides the stabilizing influence, while reset (integral) mode provides the necessary action to continue correction until the controlled variable is returned to the set point.

SEPIC, controlled by the PI controller, maintains constant output voltage even in the presences of varying input voltage. The converter output voltage and reference voltage is compared to determine the error. Based on the error value, the PI controller's output determines the change in duty cycle to keep the converter output constant.[13]

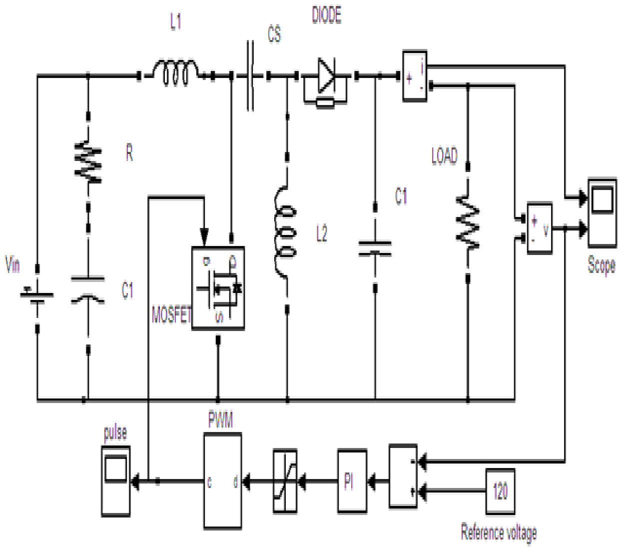

Figure 3.1: MATLAB Simulations for SEPIC Converter with PI Controller.

SEPIC converter is operated for a varying input voltage (V_{in}) i.e, from 42V to 84V, and for various load conditions. The output of PI controller depends on the error signal. For a given input voltage, the output signal of PI controller determines the duty cycle of the gate pulse given to the MOSFET figure (3.1).

The reference voltage (120V) is compared with converter output voltage to determine the error and the error is given as input to the PI controller. Maintaining the output voltage (V_{out}) at a constant value of 120v depends on the PI controller. As the input voltage changes from 42V to 84V, the duty cycle also changes. The duty cycle depends on the PWM. The PWM switching frequency will be 100 kHz.

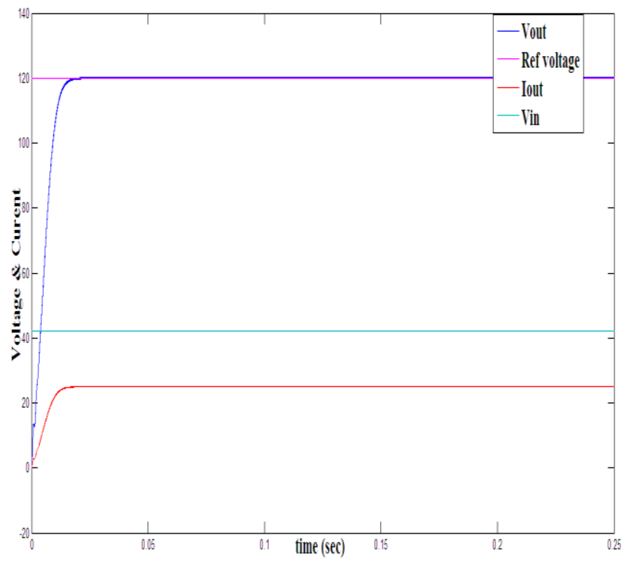

Figure 3.2 Simulation result for SEPIC converter with PI Converter for an Input voltage of 42V

For a constant input voltage of 42V, load resistance of 4.8 ohm and PI controller parameters of KP =0.002 and KI=1.7, the simulation output of SEPIC converter with PI controller is shown in figure 3.2. The output voltage is maintained at a constant level of 120V.

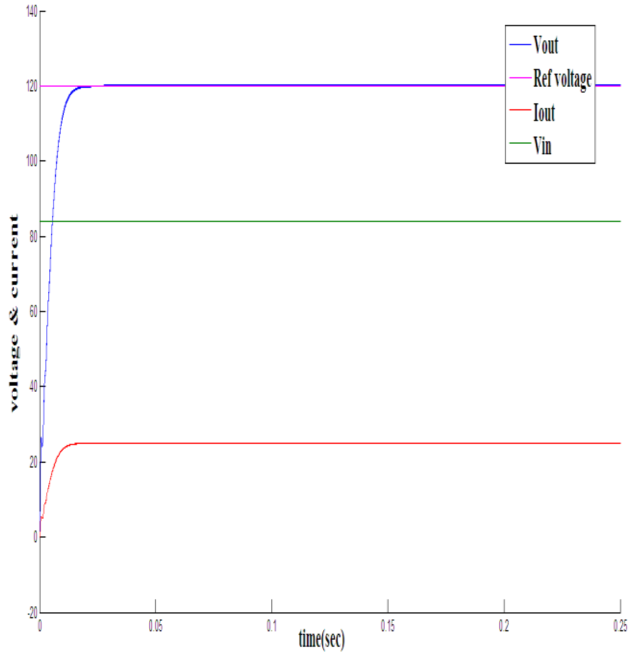

Figure 3.3: Simulation result for SEPIC converter with PI Converter for varying Input voltage

For a constant input voltage of 84V, load resistance of 4.8 ohm and PI controller parameters of KP =0.002 and KI=1.7, the simulation output of SEPIC converter with PI controller is shown in figure 3.3. The output voltage is maintained at a constant level of 120V.

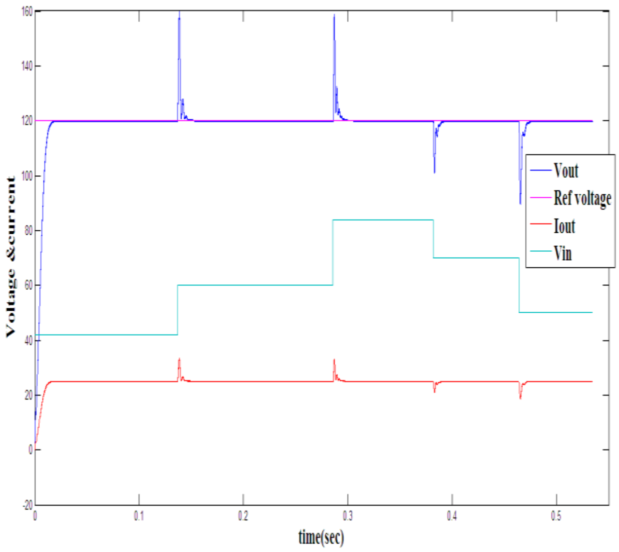

Figure 3.4: Simulation result for SEPIC converter with PI Converter for varying Input voltage

In the simulation outputs shown in figures (3.4) it can be observed that the output voltage is without ripples but contains peak overshoot. When the input voltage V_{in} is changed from 42V to 60V and 60V to 84V. The output have high peak over shoot (maximum peak over shoot) can be observed. This peak over shoot will damage the load, switching devices and output capacitance. This problem can be reduced by varying PI parameters as variation in the input voltage conditions. The ACO is used to find the optimal PI parameters (K_P, K_I) for varying input voltage [12].

4. ANT COLONY OPTIMIZATION

4.1 ACO

The ACO will be one of most popular soft computing techniques method. The ACO belongs to the biological inspired heuristic algorithm, this based on the real ant behavior and originally inspired by ability to find the shortest path between nest and a food source [12][18] [20][21] A colony of artificial ants cooperates to find good solutions, which are an emergent property of the ant's co-operative interaction. The main traits are artificial ant exits in colonies of cooperating individuals and they communicate indirectly by deposition of pheromone also they use a sequence of local moment to find the shortest path from a starting position [14][16], to a destination point. They apply a stochastic decision policy, using local information only, to find the good solution.

When a colony of ants is resented with two possible path, each ants initially chooses one randomly. The ant that choose shortest path will come back faster. Therefore more pheromones will be deposited on the shortest path [14].

ACO uses a pheromone $\tau=\{\tau_{ij}\}$ for the construction of potential good solutions. The initial value of τ is:

$\tau_{ij=}\ \tau_0\,(i,j)$, where $\tau_0 > 0$.

The probability ($P_{ij}^A(t)$) of choosing the node j at node I is defined in the equation (12). At each generation of the algorithm, the ant constructs a complete solution using (), starting at source node.

$$P_{ij}^{A}(t) = \frac{\tau_{ij}^{\alpha} * \eta_{(ij)}^{\beta}}{\sum_{i,j\in T^A} \tau_{ij}^{\alpha} * \eta_{(ij)}^{\beta}}$$

If i, j € T^A - 4

Where $\eta_{(ij)}$ =1/K_j, J = [P,I], representing heuristic functions.

α and β are constants that determines the relative pheromone and the heuristic function on the decision of the ant.

T^A is the path effectuate by the ant A at a given at a time.

The quantity of pheromone $\Delta\tau_{ij}^A$ on each path is written as:

$$\Delta\tau_{ij}^{A} = \{ \begin{matrix} 1/L^A \rightarrow if i,j \in T^A \\ 0 \end{matrix} \}$$

Where

L^A – is the value of the objective function.

The pheromone evaporation is a way to avoid unlimited of pheromone trails.

$$\tau_{ij} \leftarrow (1-\rho) * \tau_{ij} + \sum_{A=1}^{NA} \Delta\tau_{ij}^{A}(t)$$

Where ρ is the evaporation rate, NA is the number of ants.

ACO algorithm is a powerful tool to solve a diverse set of optimization problems such as the traveling salesmen problem (TSP)[12]-[20] and optimization problems in power system[15].

4.2 ACO TUNED PI CONTROLLER

In this work ACO is used to find the optimal K_I and K_P parameters to reduce maximum over shoot. The objective of the optimal controller design is to maintain constant output voltage and reduce the over shoots. [13]-[19]

The PI controller parameters are randomly selected by the nodes and each node gives a solution. Based on Figure (4.2.a) the KP and KI nodes are selected. The source to destination between KP, KI parameters keep on change. The more accuracy trails are updated after the complete path is constructed and the solution found. For each node the minimum error (over shoot) is computed and is compared with solutions of other node to define the good solution. [13]-[19]

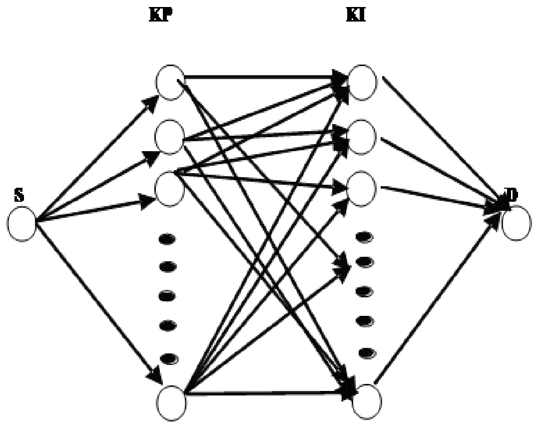

Figure 4.2.a: Graphical representation of parameters in pi controller for ACO

4.3 ACO tuned DC-DC converter

In SEPIC Converter there is a variation in input voltage and also change in the load, due to which the output voltage is not maintain at 120V. So PI controller is used to maintain a constant output voltage. But sometimes due to variation in input voltage and load conditions more peak over shoot, settling time and oscillation occurs in the output response. These problems can be reduced by varying PI controller parameters used to find good solution at the percent time inputs.[15][16][19]

Figure 8: shows the implementation of Ant colony optimization (ACO) to find the optimal value of PI controller parameter. These optimized parameters are used to get the optimal voltage and minimum output peak over shoot.

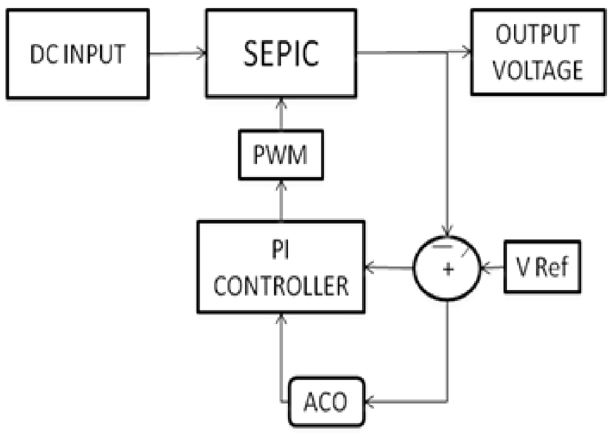

Figure 4.3.a: SEPIC converter with ACO tuned DC-DC converter

Figure (4.3.b) flow chart for implementation the ACO tuned PI controller using for SEPIC converter.

Step 1: Initialize - number of ants, Pheromone, Probability selected path. Place each ant in a randomly chosen the PI parameters ant input voltage.

Step 2: Each ants choices to run the process model.

Step3: Find the each ants evolution of the fitness function, update the pheromone and probability.

Step 4: visit all the nodes of the PI parameters. And Update the KP and KI parameters and minimum error.

Step 5: check all the varying input again and PI parameters and Maximum iteration number reached stop the process and Update the KP and KI parameters at each change in input voltage.

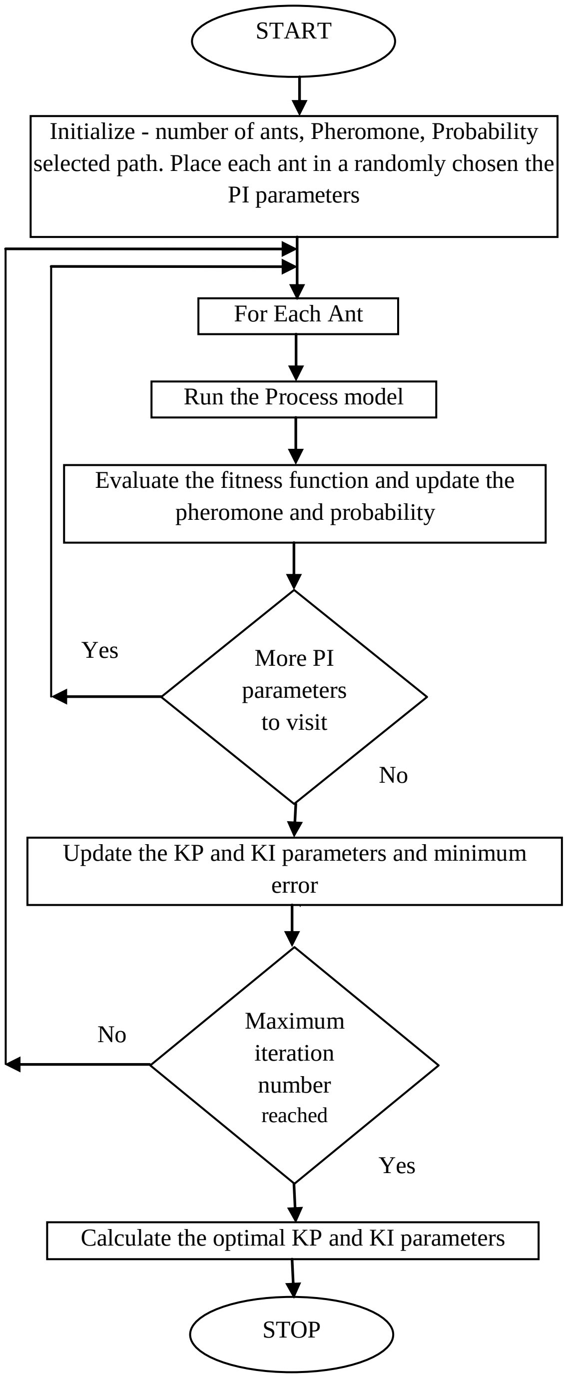

Figure 4.3.b: flow chart for ACO tuning PI controller parameters

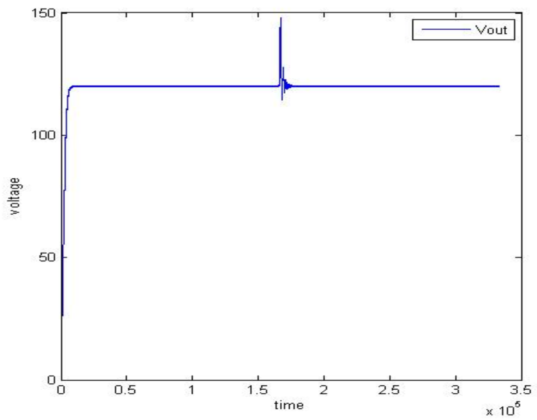

Figure 4.3.c: Simulation result for ACO tuned DC-DC Converter for varying Input voltage

ACO tuned DC-DC converter result in figure (4.3.c) input ranges change to 60V to 84V. Number of ants depends on the number of PI parameters nodes on the particular change in input used to find the overshoot. The each KP, KI parameters is used to find the minimum peak overshoot, pheromone and probability and then find the minimum error for the particular inputs. This optimal KP, KI parameters are used to minimize the peak overshoot and ripple on the SEPIC output.

5. CONCLUSION

A comparison between output results of the SEPIC converter, SEPIC with PI controller and ACO tuned DC-DC converter were discussed above. The Performance of the ACO tuned DC-DC converter with different KP, KI was used to find the minimum peak over shoot on the particular input voltage. The SEPIC output has peak over shoot and ripples and SEPIC with PI controller has no ripple voltage but has peak overshoot. The ACO tuned DC-DC converter's output is without ripple voltage, has minimum peak overshoot and settles at constant voltage (120V). ACO algorithm was utilized to design the PI controller to have the most optimal solution. The objective function due to minimizing the error was solved using ACO algorithm. The most optimal solution for the controller was determined using the algorithm.

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