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PID Parameter Optimization By Using Ant Colony Optimization Algorithm For Boost Converter

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Abstract – One of the most well-known and easy-to-design converter of DC-DC converters is DC-DC Boost converter. DC-DC boost converters are widely utilized in industrial applications. Therefore, output voltage regulation of the boost converter is a popular issue that researchers focus on. In this study, to improve output voltage of a Boost converter, Proportional-Integral-Derivative (PID) controllers of which the parameters are tuned by meta-heuristic optimization algorithms are designed. The Ant Colony Algorithm (ACO) is the used optimization algorithm. The optimization algorithm results are compared with Matlab Pid Tuner results method and simulation results are obtained in MATLAB/Simulink platform. The simulation results show that the optimized PID controller by ACO is more effective in improving the transient and steady-state response of the DC-DC converter than the tuner. In the optimization process, the mean squared error(MSE) performance metric is used as objective function. The performances of the controllers designed by ACO, and trial-error method are also compared to each other using Integral Squared Error (ISE), Integral Absolute Error (IAE), Integral Time-weighed Absolute Error (ITAE) and MSE performance metrics.

Keywords – DC-DC Boost converter,PID, The Ant Colony Algorithm (ACO),ISE,IAE,ITAE,MSE

I. INTRODUCTION

The application areas of power electronics have increased especially in recent years and have spread over a wide area such as communication, defense, industrial processes and power generation. In industrial applications, the constant voltage dc power supply needs to be converted to a variable voltage dc power supply. One of the most well-known and easy-to-design converter of DC-DC converters is DC-DC Boost converter. DC / DC boost converters are the types of circuits that increase the input voltage, as the name implies.

The purpose of all control systems is to realize defined control criteria in order to bring the system to the desired state within the given time intervals by following the certain states and variables of the system. The control system has inputs and outputs called input and output. The input data is processed in the controller and provides the necessary output to the controlled system. This output is a control system used to control the system. In this study, the control of boost converter with PID is emphasized.

PID (Proportional-Integral-Derivative) control is a type of controller that combines the advantages of proportional, integral and derivative control into a single unit. PID is a widely used control method today. Applied in 75% of industry applications. Although there is a wide range of applications, there is no standard definition for PID applications.

The optimization algorithms that are developed based on natural events have been named as meta-heuristic methods. A parts of the heuristic optimization technique have been named as swarm intelligence algorithms. In this study, PID parameter values are calculated using ACO (Ant colony) optimization technique. ACO is an algorithm based on the analogy of ants' behavior to a mathematical model, and the first study in this field was conducted by marco dorigo et al. [1].The algorithms proposed are different from the actual ants because the ant ant colonies are evaluated as an optimization rather than the exact modeling of the behavior of the ant colonies. For example, artificial ants have a certain memory, whereas real ants do not have this feature. Dorigo et al. Introduced the ant algorithm as an approach to the distributed solution of difficult problems [1]. There are many studies in the literature that optimize PID parameters with meta-heuristic optimization algorithms.

To obtain optimal values of the gains of the PID controller controlling a DC-DC converter, there are studies using the cuckoo (CS) algorithm, genetic algorithm(GA), particle swarm optimization (PSO) and Fire Fly (FF) algorithm.[2],[3] The simulation results were compared with conventional PID methods and evaluated with overshoot time, rise time, and steady state error.[4][5]

And when compared to traditional PID methods, the PID controller whose parameters have been adjusted with optimization methods has shown better performance.[4]

The paper is organized as following: In the second section, the structure of DC-DC boost converter and PID controller is given, the third section deals with the controller design procedure with ACO, the fourth section consider

determination of designed boost converter parameters and the simulation process, the last section contains conclusion.

II. MATERIALS AND METHOD

A. *DC/DC Boost Converter*

The most basic DC / DC boost converter circuit structure is shown in Figure 1. These circuits perform the task of converting the $V_{(g)}$ input voltage of the systems in which they are used to $V_{(0)}$ output voltage, that is, the voltage supplying the battery or load in the system.

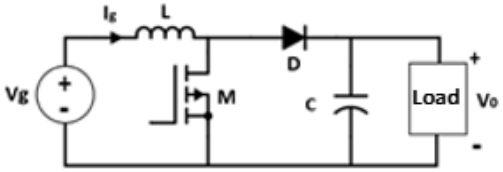


Figure 1. DC/DC Boost Converter

The energy conversion in the DC / DC boost converter is based on the magnetic induction principle in the coil (L) by transferring the current to the input voltage V (g) while the semiconductor power switch (S) transfers the energy to this inductor.), the power switch M is disconnected. Accordingly, the inverse electromotor force is generated by passing over the diode and filling the capacitor element in the circuit.
The relationship between the input voltage V (g) and the output voltage V0 assumed to be constant is shown in equation (1), and the relationship between the input current Ig and the output current I0 is shown in equation (2).

D in the equations is the rate at which the semiconductor power switch is transferred to the entire period for a period of time and is called the duty cycle.

$$V_g = \frac{1}{1-D} V_0 \quad (1)$$

$$\frac{I_g}{I_0} = 1 - D \quad (2)$$

1.1 Analysis of The Boost Converter

In the boost converter, the input voltage source only transmits additional energy to the coil when the semiconductor power switching element is in transmission, while the load is supplied to capacity.

When the semiconductor power diode is in transmission, both the accumulated energy in the inductance is directed to the output and the input voltage source supplies the output [6].

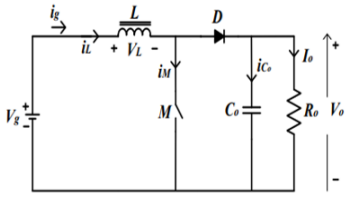


Figure 2. Circuit diagram of the boost converter

Since the DC / DC boost converter circuit is an active circuit containing a power switch, the analysis of the circuit is examined according to whether the switch is closed or open.

The equivalent circuit diagrams of the circuit that increases the active power according to whether the switch is closed or open are shown in Figure 3 and the waveforms of voltage-current values are shown in Figure 4.

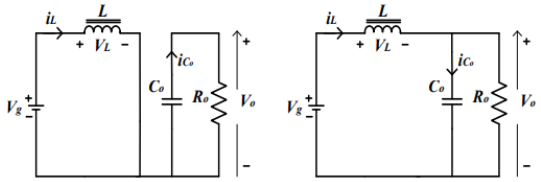


Figure 3. Equivalent circuit diagram of the boost DA / DA circuit; (a) when the M power switch is ON, (b) when the M power switch is OFF

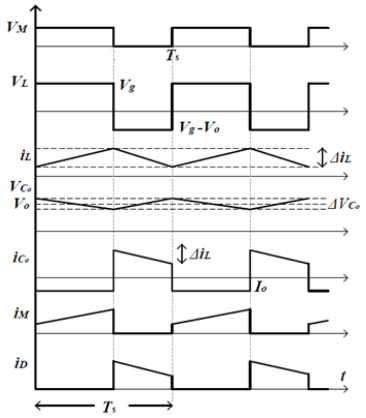


Figure 4. Voltage-current waveforms of the boost converter in continuous conduction mode

Coil voltage and capacity current when M power switch is in the ON position,

$$V_g = V_L \quad (3)$$

$$V_L = L \frac{\Delta I_L}{DT_s} \quad (4)$$

$$\frac{I_{C0=} - V_0}{R_0} \quad (5)$$

is represented by equations.

When the M power switch is in the OFF position;

$$V_{L=} V_g - V_0 \quad (6)$$

$$V_0 - V_g = L \quad (7)$$

$$I_{C0=} I_L - (V_0 / R_0) \quad (8)$$

equations are obtained.

Where ΔI_L represents the amount of wavelength D of the coil current, duty cycle time; Ts indicates the switching period.

Since the wavelength of the coil current will be equal when the power switch M is in transmission or cut, the following equation can be written.

$$\Delta \dot{I}_L = \frac{V_g.D.T_s}{L} = \frac{(V_0 - V_g).(1-D).T_s}{L} \quad (9)$$

The relationship between the input and output voltage values of the boost converter circuit is shown in equation 10 by using equation 7.

$$V_0 = \frac{V_g}{1-D} \quad (10)$$

Considering that the efficiency of the circuit is 100%, the relationship between the input and output current values is expressed in equation 11.

$$\dot{I}_g = \dot{I}_L = \frac{I_0}{1-D} \quad (11)$$

B. *PID Control and Basic Features*

The structure of the PID controller consists of a combination of proportional gain, integral receiver and derivative receiver circuits.
Accordingly, the general expression of the PID controller is as follows.

$$U(t) = K_p * e(t) + \frac{1}{T_i}\int e(t)dt + T_d * \frac{de(t)}{dt} \quad (12)$$

Here
Kp = proportional gain;
Ti = integral time;
Td = derivative time
Transfer function of PID control

e (t) = expressed as the error between the given input value and output.
Transfer function of PID control

$$U(s) = K_p + \frac{K_i}{s} + K_d s \quad (13)$$

is obtained.

PID control; It is a control effect that combines the advantages of the three main control effects into a single unit. The integral effect resets the steady-state error that may occur in the system, while the derivative effect increases the response rate for the same relative stability of the system compared to the use of only the PI control effect. Accordingly, the PID supervisory body provides a quick response with zero steady-state error in the system. The effect of PID parameters on the feedback system is independent of each other and requires an interactive setting.
Many optimization methods are used to obtain the most appropriate PID parameters. The block diagram of the application of ACO algorithm used in this study to the PID system is given below.

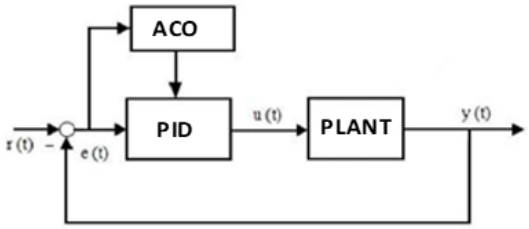


Figure 5. ACO-PID Controlled System

Here, Plant refers to the system to be controlled, ie the transfer function, and has been extracted using the parameters of the incremental inverter designed.
PID is the parameter used to reach the desired step value as soon as possible with the least possible error and the response signal to be responded to the desired input value.
ACO is expressed as an algorithm that provides Kp, Ki and Kd values that will provide the optimum values of the output.

C. *Behavior of Ant Colonies*

It is a fact that ants live in colonies and can solve the problem they face by making division of labor. The ants' ability to find food and adapt to environmental changes is also interesting. Moreover, ants do not have enough features such as seeing and watching their environment enough. However, ants find the shortest path from their nest to a food source they discover and can easily return without losing the way they came back to the nest. Moreover, when they encounter various obstacles on the road, they overcome these obstacles and establish a connection to the food source in a different way but again as the shortest way [7]. It is known that the most important substance that enables ants to find the shortest path to food sources starting from their nests is chemical pheromones. Again, it is a fact that ants leave certain amounts of pheromones on the way they go. The important point here is the amount of pheromone chemical. This is because ants are less likely to choose the direction in which the pheromone substance is low [7, 8]. In other words, ants tend to cross paths where the pheromone substance is concentrated. However, this does not mean that there are no ants in other ways. Ants use all the paths first from their nests to the food source.
Since more ants pass through the shortest path available per unit time, the amount of pheromones in that path increases and the ants prefer to pass there. As the possibility of ant crossing in other ways decreases, the pheromone evaporates over time.
Another interesting feature of ants is their ability to adapt to environmental changes. For example, when the road between the nests and the food sources is obstructed, they can reach the food source again by the shortest way. [9].
This situation can be explained as follows: when an obstacle is placed in the path of ants, ants try to overcome this obstacle. There are two ways that ants may prefer to overcome the obstacle. Therefore, the ants have the same probability of initially selecting the two sides of the obstacle. After a while, more ants will pass through the shorter direction per unit time, which increases the amount of the pheromone substance, so the likelihood of ants choosing the shorter direction increases. Since the pheromone chemical is an evaporating substance,

there are no antimicrobials left in the path that passes with little ant and the obstacle is always overcome by the shortest path

C.1 Ant Colony Algorithm Parameters:

• Number of ants: This parameter determines the number of ants in the colony.
• Number of iterations: It is the parameter that determines how many iterations the search will take.
• Pheromone amplification ratio (α): It is the parameter that determines the importance of the amount of pheromone between the nodes.
• Intuition strength ratio (β): It is the parameter that determines the importance of the distance between the nodes.
• Pheromone evaporation rate (ρ): It is the parameter that determines the rate at which pheromones will evaporate at the end of each iteration [5].

The number of ants, ρ, α and β are editable parameters in the ant colony algorithm. The selection of effective values for these parameters significantly contributes to the solution performance of the algorithm.
Increasing the number of ants leads to an increase in the solution time, although it improves the solution. As a result of the experiments carried out in the solution of traveling vendor problems, it was concluded that the number of ants should be selected equal to the number of cities. The number of ants varies depending on the size of the problem and the application area [10].

The ρ value, which is the pheromone evaporation rate, is the parameter that determines the probability of transferring the best solution to subsequent iterations. ρ is usually selected as 90% for mobile vendor problems. This means that the current ant will follow the path that provides the best solution with a 90% probability and determine the path due to pheromone traces with 10% probability.

The α value, which is the pheromone amplification ratio, determines the significance level of the pheromone amount of the path. It allows the results of previous iterations to be transferred to subsequent iterations. The high α value increases the probability of selecting paths with dense pheromone content and decreases the randomness.

The intuition strength ratio β determines the effect of path lengths on the selection of the next point. The increase in β value increases the chance of choosing the next path. The low value of B reduces the possibility of searching for alternative solutions.

C.2. Ant Colony Algorithm

Ant colony algorithm (ACO) is an algorithm based on the analogy of ants' behavior to a mathematical model, and the first study in this field was conducted by marco dorigo et al. [10].
The algorithms proposed are different from the actual ants because the ant ant colonies are evaluated as an optimization rather than the exact modeling of the behavior of the ant colonies. For example, artificial ants have a certain memory, whereas real ants do not have this feature.

Dorigo et al. Introduced the ant algorithm as an approach to the distributed solution of difficult problems [10].
There are two main problems in the ant colony algorithm. The first is the possibility of route selection and the other is the rate of evaporation of pheromones. Although these problems are still the subject of research, there are several ways to solve them [3].
Possibility of selecting the j node from the i node of the ant for a network routing problem

$$p_{ij} = \frac{{\phi_{ij}}^{\alpha}.{d_{ij}}^{\beta}}{\sum_{i,j=1}^{n} {\phi_{ij}}^{\alpha}.{d_{ij}}^{\beta}} \quad (14)$$

$\alpha > 0$ is $\beta > 0$ and is called effect parameters. Typical values $\alpha \approx \beta \approx$ is 2. fer denotes the pheromone density of the path between node i and,, dij indicates the demandability of the same path. The distance matrix is sij often $d_{ij} \propto 1/s_{ij}$ related. Evaporation of pheromones at a constant γ rate decreases exponentially over time:

$$\phi(t) = \phi_0 e^{-\gamma t} \quad (15)$$

$\phi 0$ is the initial pheromone concentration at time t. Equation of pheromone update is given in the form.;

$$\phi_{ij}^{t+1} = (1-\gamma)\phi_{ij}^{t} + \delta\phi_{ij}^{t} \quad (16)$$

C.3. ACO Compliance Criteria

There are several evaluation criteria to determine the performance of the controller.
Some of those; criteria such as integral of absolute error (IAE), integral of time weighted absolute error (ITAE), integral of squared error (ISE), the mean squared error (MSE) [11,12].

These four performance criteria have several advantages and disadvantages. The disadvantage of the IAE and ISE criteria, for example, is the long residence time. Because all errors in the ISE performance criteria are time-independent. Although the MSE performance criterion can overcome the disadvantage of the ISE criterion, the derivative process of the analytical formula is time consuming [13,14].
According to this; IAE, ISE, ITAE, MSE performance criteria can be expressed as follows.

$$\text{IAE} = \int_0^{\infty} |r(t) - y(t)|\, dt = \int_0^{\infty} |e(t)|\, dt \quad (17)$$

$$\text{ISE} = \int_0^{\infty} e^2(t)dt \quad (18)$$

$$\text{ITAE} = \int_0^{\infty} t\,.\,|e(t)|\, dt \quad (19)$$

$$\text{MSE} = \int_0^{\infty} t.e^2(t)dt \quad (20)$$

III. RESULTS

A.Determination of Designed Boost Inverter Parameters

The design of the boost converter to be designed for continuous conduction mode shall be realized and the given parameters are presented in the following table.

Table 1. The given parameters of the boost converter (GES)

Given parameter	**Value**
Input Voltage(Vg)	30 V
Output Voltage(V0)	50 V
Load	10 Ω
Switching Frequency(fs)	30 kHz
Output Power(Po)	250 W
Peak-to-peak Fluctuation of Inductance Current(ΔIL)	30%
Peak-to-peak Fluctuation of capacitor voltage(ΔVc)	2%

The inductance value is first determined in the converter to be designed. The average value of the inductance current in the boost converter is equal to the average value of the input current. ($I_g = I_L$)
If the efficiency of the inverter is assumed to be 100%;

$$V_0 * I_0 = V_g * I_g \quad (21)$$

from the equality

$I_0 = V_0/R$ and I_0=5 A is obtained.

This value is also the average value of the inductance current. The inductance current increases when mosfet is ON and decreases when mosfet is OFF. The peak-to-peak fluctuation of the inductance current (ΔI_L), is given in equation 22, and the graph of ΔI_L is shown in Figure 6.

$$\Delta I_L = I_{Lmax} - I_{Lmin} \quad (22)$$

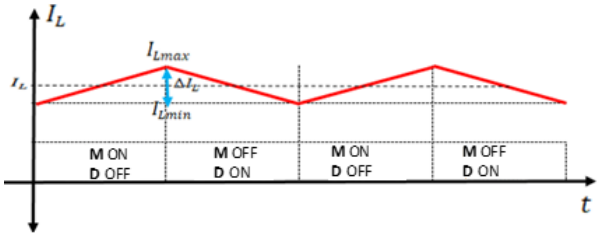


Figure 6. Variation of inductance current over time (GES)

Since $I_g = I_L$ =8.33A in the boost converter and ΔI_L =%30

$\Delta I_L = \frac{8.33*30}{100}$ =2.5 is obtained.

In this case I_{Lmax}=8.33+2.5=10.83 A,

I_{Lmin}=8.33-2.5=5.83A is obtained.

$$\Delta I_L = \frac{Vgmin*D}{L*f_s} \quad (23)$$

L value can be found in the formula.

D, including duty cycle,

$$D = 1 - \frac{Vg}{V_o} \quad (24)$$

from the equality D=0.40 is obtained
The value of inductance we will use in converter design

$$L = \frac{Vgmin*D}{\Delta I_L * f_s} \quad (25)$$

from the equality L= $\frac{30*0.4}{2.5*30000}$ = 0.16 mH is obtained

In order to calculate the capacitor value, the second important parameter of the power circuit, the wavelength of the output voltage (ΔV_c) will be taken into account.
The graph of the change of capacitor current over time is as follows.

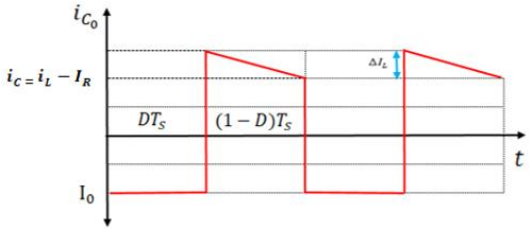


Figure 7. Variation of capacitor current over time (GES)

During the DT_S, the capacitor feeds the output load while the mosfet is in condution. Therefore, since the capacitor current will be equal to I_0 value , ($I_0 = V_0/R$ den I_0=5 A), the current value during DT_S will be -5 A.

In the $(1-D)T_S$ period, Since mosfet is OFF, the diode is ON $i_C = i_L - I_R$. i_C will show oscillation between 5.83 A and 0.83 A, since the $i_L$value shows oscillation between 10.83A and 5.83A.

$$C = \frac{Iomax*D}{\Delta V_c * f_s} \quad (26)$$

from the equality C= $\frac{5*0.4}{1*30000}$ = 66 µF is obtained

The values found are shown in the table below.

Table 2. Calculated parameters of the boost converter (GES)

Calculated Parameter	**Value**
Duty Cycle	0.4
Inductance	0.16 mH
Capacitor	66 µF

The transfer function of boost converter according to these values is presented below.

$$G(s)_s = \frac{-1.33e{-}3\ s + 3}{0.105e{-}9\ s^2 + 16e{-}6\ s + 0.36} \quad (27)$$

B.Simulation Results of the Designed Boost Converter

In this study firstly, the PID coefficients were obtained from the Matlab PID Tuner and the step response of the designed

boost converter was plotted. The step response presented in Figure 11 shows that the system has 7.86% overshoot, a rise-time of 43.3ms and settling time of 154ms.

Secondly, To eliminate the system overshoot and improve the transient response the PID coefficients are optimized with ACO and the step response of the system is given. The performance of boost converter with PID Tuner and proposed ACOPID controllers are analyzed in terms of time response specifications such as rise time(t_r) settling time (t_s) in seconds, maximum peak overshoot (Mp) in percentage and steady state error (e_{ss}).

The gains of PID controller are obtained by the execution of twenty trials and the best solutions are tabulated in Table 3. The necessary coefficients for ACO optimization are presented below.

Controller	Kp	Ki	Kd
PID Tuner	0.16051	6.4165	-0.000291
ACOPID	0.02	5.02	0.06

```
n_iter=5; % number of iteration
NA=100; % Number of Ants
alpha=0.9; % Alpha
beta=0.8; % Beta
roh=0.7; %  Evaporation rate
n_param=3; %  Number of paramters
LB=(0.01).*ones(1,27); %  lower bound
UB=10.*ones(1,27); %  upper bound
n_node=1000; % Number of nodes for each param
cost_best_prev=inf;
```

Table 3. The gains of PID controller

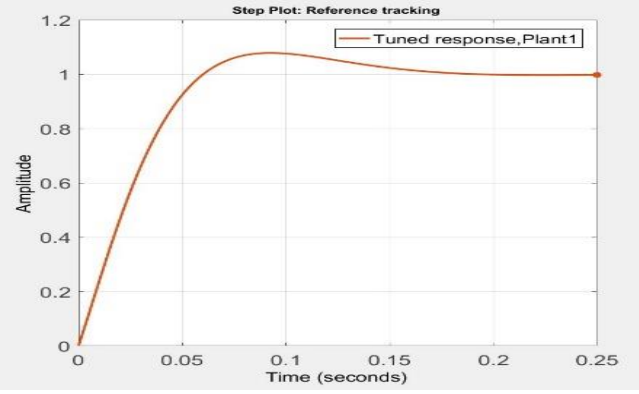


Figure 8: the step response of the designed boost converter with PID Tuner

Controller	t_r	t_s	Mp (%)	e_{ss}
PID Tuner	0.0433	0.154	7.86	0
ACOPID	0.0297	0.08	0.50	0

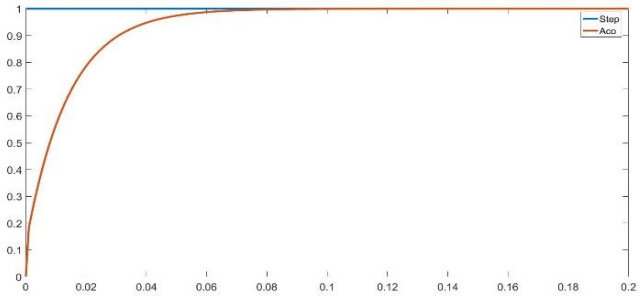


Figure 9: the step response of the designed boost converter with ACOPID

The PID controller tuned with ant algorithm using MSE cost function is compared with PID Tuner gains. It is observed that the proposed ACO PID controller exhibits the lowest value of rise time,settling time and overshoot.

Table 4. Comparison of Performance characteristics

Using four different cost functions (ITAE, IAE, ISE and MSE), tuning process with ant algorithm is applied to the model. Because of the probabilistic nature of the ant algorithm, ant algorithm was run twenty times with 100 ants and 5 iterations. Among twenty runs for each cost function, the best result with the lowest cost for step input is shown in Table 5. As can be seen from Table 5, MSE outperforms the other three cost functions.

Table 5: Comparison of Performance Indices.

	ITAE	IAE	ISE	MSE
PID Tuner	0.125	0.5	0.5	0.1247
ACOPID	0.0001769	0.01253	0.005951	0.00003877

The closed loop control system shown in Figure 14 was installed in Matlab-Simulink simulation environment by using 4 different cost functions;

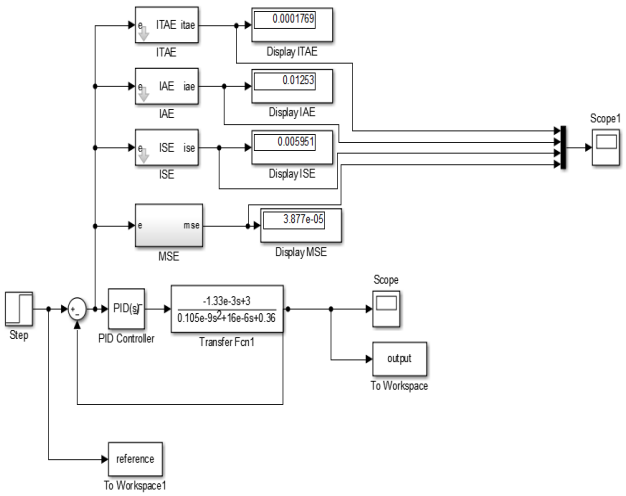


Figure 10. Block diagram of PID controlled the boost converter.

IV.CONCLUSION

In this paper, a novel tuning design method for determining the PID controller parameters based on the Ant Colony (ACO) optimization was developed for the designed boost converter. Firstly, A DC-DC boost converter has been modelled. After that the step response of the designed boost converter with ACOPID and PID Tuner was compared. it can be seen that ACOPID gives good results in terms of rise time, settling time and overshoot in comparison to PID Tuner. Also, ACO with different cost functions was used to tune PID parameters. According to this, MSE cost function gives a good performance such that it has the less rise time, settling time and overshoot.

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