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PI Parameter Optimization by using Ant Colony Algorithm for Optimal Controlling of A Buck Converter's Output Voltage

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Abstract

In this paper, the output voltage of the buck type DC voltage reducer that is used for the aim of efficient energy transmission is controlled. The discrete PI algorithm is chosen for the control process. The controller parameters Kp and Ki in order to ensure the faultless pursuit of reference DC output voltage level with output voltage of the converter lowest overflow percentage and settling time is optimized. Ant Colony Algorithm that is one of the iterative algorithms has been used in the optimization process. Simultaneous studies have been realized and the results obtained are compared and discussed with the results in the literature. Compared to the performance criteria that are important for the controller, it is seen that the settling time is shorter and the overshoot values are lower.

Keywords: DC-DC converter, Buck converter, PI controller, Ant colony optimization algorithm

Buck Dönüştürücü Çıkış Geriliminin Karınca Koloni Algoritması Kullanılarak PI Tabanlı Optimal Kontrolü

Öz

Bu çalışmada, verimli enerji iletimi amacıyla kullanılan Buck tipi DC gerilim seviye düşürücüsünün, çıkış büyüklüğü kontrol altına alınmıştır. Kontrol süreci için ayrık zaman PI algoritması seçilmiştir. Kontrolöre ait Kp ve Ki parametreleri dönüştürücünün çıkış büyüklüğünün en düşük aşım yüzdesi ve yerleşme zamanı ile referans DC gerilim seviyesini hatasız takibini sağlanabilmesi amacıyla optimize edilmiştir. Optimizasyon, iteratif bir algoritma olan Karınca Kolonisi (ACO) algoritması ile sağlanmıştır. Kontrol sürecine ait eşzamanlı çalışmalar Matlab-Simulink üzerinden gerçekleştirilmiş; elde edilen sonuçlar literatürdeki sonuçlarla karşılaştırılıp tartışılmıştır. Kontrolör için önemli olan performans kriterleri açısında yapılan karşılaştırmalara göre, yerleşme zamanın daha kısa olduğu ve aşım değerlerinin daha düşük olduğu görülmüştür.

Anahtar Kelimeler: DC-DC dönüştürücü, buck converter, PI kontrolcü, Karınca koloni optimizasyon algoritması

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1. INTRODUCTION

Computers advancing technology encounter in real life are transferred into the virtual platform that provid to attain simple and fast solutions. Growing and complicating problems were revealed the notion of the optimal solution and the studies were started in this direction. Some of the studies conducted in this field are the nature-inspired algorithms. These algorithms are based on the fact that researchers who observe the heuristic behaviors exhibited by living creatures when they searching for food, the idea of use these behaviors to the solution of real-time problems in the virtual platform.

The switched-mode DC-DC converters are some of the most widely used power electronics circuit topology for its high conversion efficiency and flexible output voltage. These converters used for electronic devices are designed to regulate the output voltage against the changes of the input voltage and load current. This leads to the requirement of more advanced control methods to meet the intended demand [1]. The switched-mode power supplies consist of two parts, the power stage and the control stage. The power stage that is used to attain intended amplitude output voltage consists semiconductor switches and filter elements. The control circuit is used to generate the switching signals required for the semiconductor switch [2]. The circuit may consist of nonlinearity like delay, hysteresis etc. To settle the output voltage within minimum settling time and less overshoot different types of controllers are considered such as linear controller PI, PID and in nonlinear controllers SMC (sliding mode controller) [3]. In this paper, PI controller was used. PI controller mostly preferred because of its simple structure, robustness and high reliability [4]. The values of Kp and Ki parameters, which are the controller coefficients, must be suitable assigned in order to be sustainable with the lowest cost of the control process. In this study ACO algorithm which is one of the heuristic algorithm which is used to find the value of Kp and Ki parameters were used.

There are also current ACO-based control studies. For example, Maamri, Bououden, and Boulkaibet, used the Ant colony optimization algorithm to find the optimal control parameters of the nonlinear chaotic resonator for the aim of minimizing errors between the estimated and actual output [5]. In another study, Kour and Tiwari used the Ant Colony Optimization (ACO) technique in order to ensure low cost the design of a voltage controlled Induction Motor (IM) drive to the PI controller [6]. In 2012, Chonsatidjamroen, Areerak, and Areerak had realized optimal design of the buck type converter controlled by a PI controller with particle swarm optimization [7]. In 2016, Moursy, Khalil, Lecce, Poletto, Iskander and Louërat, had suggested an optimal design for current-mode DC-DC converters used in automotive applications [8].

In this study, The PI control algorithm is used which forces the buck converter output voltage to remain at the same value as the reference input voltage even though the ambient conditions are variable. PI controller had used in order to keep the oscillation and overflow to form in output voltage is at its lowest level and for settling time of the output voltage to keep at lowest time value. To ensure that conditions the controller was optimized by finding Kp and Ki parameters using ACO.

2. ANT COLONY ALGORITHM

The ACO algorithm was created by observing the intuitive behaviors exhibited by the ants while searching for their nutrients. Ants, when searching for food in daily life, they leave a kind of hormones secretion, called “pheromone”, in order to retain their way and their routes and to communicate with other ants [9].

When searching for food, ants initially explores the area surrounding their nest in a random manner. As soon as an ant finds a food source, it evaluates the quantity and the quality of the food and carries some of it back to the nest. During the return trip, the ant deposits a chemical pheromone trail on the ground. The quantity of pheromone deposited, which may depend on the quantity and quality of the food, will guide other ants to the food source.

Indirect communication between the ants via pheromone trails enables them to find shortest paths between their nest and food sources as given in Figure 1 [10].

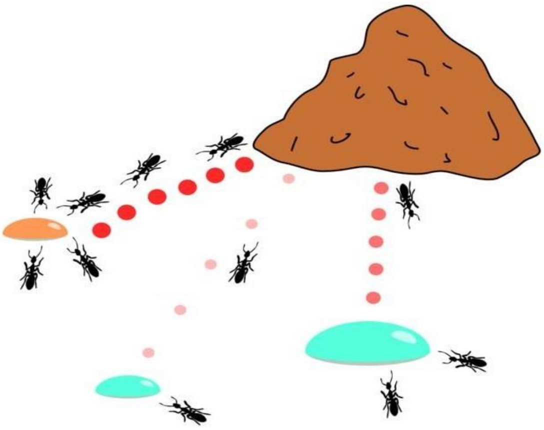

Figure 1. Ant colony and food search period [11]

Pheromone is a volatile material. This feature allows the long journeys between birds nests and food to quickly disappear as given in Figure 2.

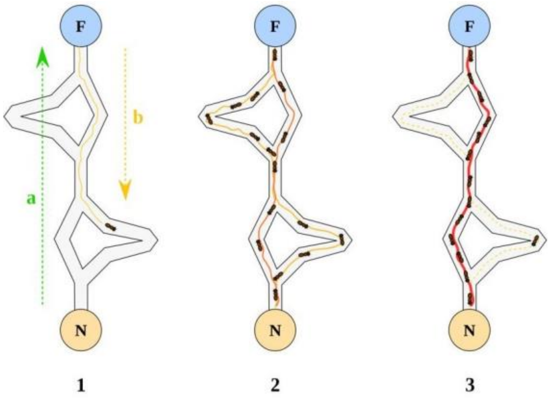

Figure 2. Shortest path finding behaviors of ants [12]

An ant colony algorithm is a computer based artificial intelligence algorithm inspired by ants to find optimal solutions for various problems. In this algorithm, first the artificial ants are formed and placed on a model. When modeling the ant colony optimization, the artificial ants have to obey certain rules like regarding the choice of point to go first, pheromone release, pheromone update and pheromone evaporation [13]. In the created model, the solution of the food searches problem of the ants, the road destination function that reaches the food, and the pheromone matter represents the memory concept [14].

The node where ant on the i node will go is selected as follows:

$$j=\underset{u\in J_k(i)}{\left[\mathrm{r}(\mathrm{i,u})\right]^{\alpha}}\times\left[\eta(i,u)\right]^{\beta},\ q\leq q_0 \tag{1}$$

Selection probabilities for all nodes are calculated as follows:

$$\left.\begin{array}{l} if\quad j\in j_k(i) \\ \\ P_k(i,j)=\dfrac{\left[\tau(\mathrm{i,j})\right]^{\alpha}\times\left[\eta(i,j)\right]^{\beta}}{\sum\limits_{u\in j_k(i)}\left[\tau(\mathrm{i,u})\right]^{\alpha}\times\left[\eta(i,u)\right]^{\beta}} \\ \\ else\quad P_k(i,j)=0 \end{array}\right\} \tag{2}$$

The parameters given in Equation 2,

$J_k(i)$: Represents the node where the ant on i-node never been before and can be.

$\eta(i,j):\ \dfrac{1}{d_{ij}}$, visibility.

d_{ij} : Distance between the (i,j) nodes.

α,β : Setting parameters.

α and β parameters indirectly effect on the decision making function by affecting the pheromone and visibility function. As the value of α is increased, the possibility of selecting the routes in which pheromone is dense is increasing. If $\alpha=0$, selection is made only according to visibility. When $\beta=0$, unattainable to the optimal solution because the selection made only according to pheromone trail. As the value of β amplifies, fortuitousness increases. So both parameters should be included in the function as commensurately [15].

2.1. Pheromone Updates

The pheromone renovation realizes in two levels, local and global in ant colony algorithm and the total pheromone level in a route is composed of the sum of the local and global pheromone levels, Equation 3 and 5.

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t+1) \tag{3}$$

$\tau_{ij}(t+1)$: new pheromone level.

$\Delta\tau_{ij}^{k}(t+1)$: pheromone evaporation level.

ρ : (0,1), evaporation rate of pheromone trail.

$$\Delta\tau_{ij}^{k}(t+1) = \begin{cases} \dfrac{1}{L^{k}(t+1)} & , \text{if } ant_k \text{ has used } way_{i,j} \\ 0 & , \text{if } ant_k \text{ has not used } way_{i,j} \end{cases} \tag{4}$$

$L^{k}(t+1)$, Total tour length of ant k.

Current pheromone calculation:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t+1) \tag{5}$$

$$\Delta\tau_{ij}^{k}(t+1) = \begin{cases} \dfrac{1}{L_{best}(t+1)} & , \text{if tour } e_{i,j} \text{ is the best} \\ 0 & , \text{if tour } e_{i,j} \text{ is not the best} \end{cases} \tag{6}$$

$L_{best}(t+1)$: Best tour length in current iteration

In each iteration of the algorithm; pheromone by evaporating at each edge, encourages the ants to discover more of the solution space and force it to block early convergence of the solution [16].

2.2. Buck Simulation Model

The buck type reducer power electronics circuit topology have shown in Figure 3.

The basic elements of the circuit are the coil and capacitor. While the power consumption is realized by RL load; battery is used as a power source. A PWM central has used as the pulse source, one IGBT has used for power transmission and cutting. Also the buck circuit topology in the simulation environment, for the purpose of to be highly similarity with that runned in the hardware environment is additioned the Series Equivalent Resistance (ESR) that is belonged to the capacitor and coil elements.

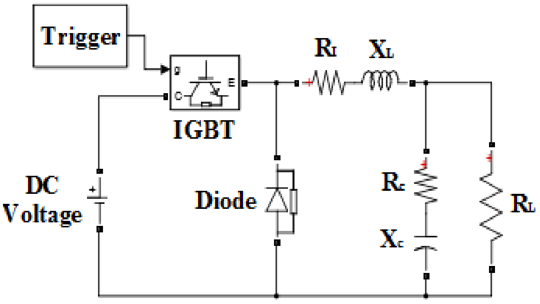

Figure 3. Buck converter topology

If the ejection of the transfer function $T(s)$ of the system is solved to be based on electronic circuit analysis, the mathematical relation between input and output voltages is reflected at the Equation 7 for the Laplace space.

$$T(s) = \frac{\left(X_c(s)+R_c\right)//R_{load}}{X_L(s)+R_l+\left(X_c(s)+R_c\right)//R_{load}} \tag{7}$$

The X statements used in the equation,

$$X_L(s) = sL\,,\ X_C(s) = \frac{1}{sC}$$

defined in this format. For the study to be realized in the simulation environment Capacitor with 1000 µF/35 V/30 mΩ values produced by the Kemet Inc; with a coil selection of 100 µH /10 A /30 mΩ produced by the Vishay Inc. as given in Figures 4 and 5, $T(s)$ for the 10 Ω load resistor is regulated to become final numeral form as in Equation (8).

$$T(s) = \frac{299.1s+9.97*10^{6}}{s^{2}+698.8s+10^{7}} \tag{8}$$

Accuracy of the derivation process that belongs to the $T(s)$ transfer function must be tested to ensure that the next step of the control process can be passable. For this reason, the buck circuit, which was designed with $T(s)$ transfer function and power electronic elements, was run in the simultaneous Matlab-Simulink environment, as seen in Figure 6. The simultaneous stimulation results have shown in Figure 7.

Figure 4. 100 μH/10 A/30 mΩ coil

Figure 5. 1000 μF/35 V/30 mΩ capacitor

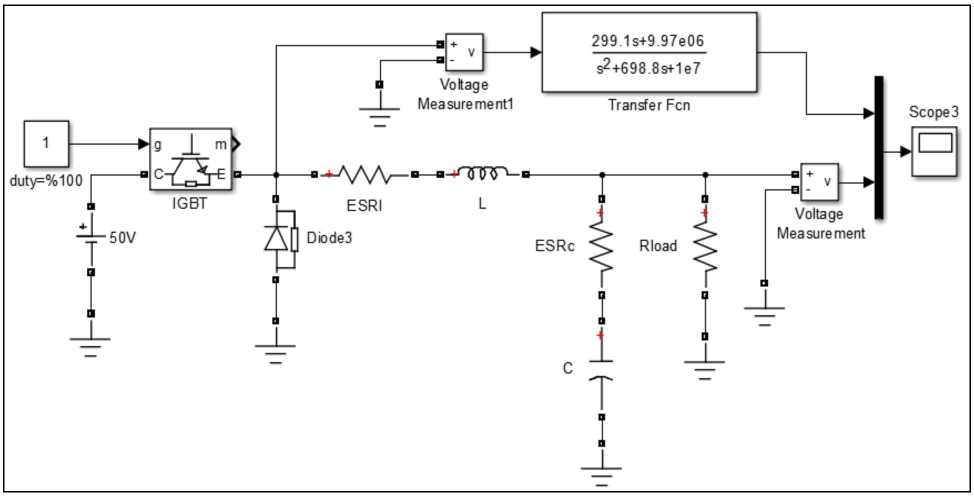

Figure 6. The simulation environment for the accuracy test of $T(s)$

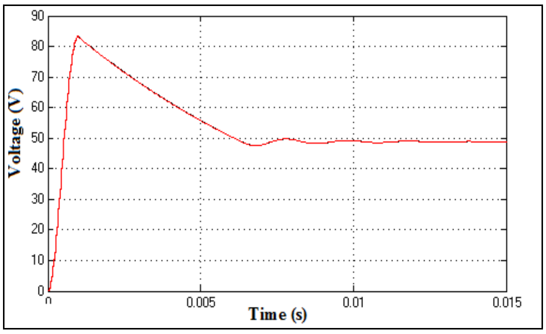

Figure 7. Buck power circuit and $T(s)$ stimultaneous simulation results

The superimposed output voltage waveforms obtained as result of both systems running for %100 duty cycle value given in Figure 6 are reflected in Figure 7.

3. CLOSED LOOP CONTROL STRUCTURE

In Figure 8, the output voltage of the Buck circuit is controlled reference-based by the PI controller at the discrete time. The signal obtained at the controller output has applied to the input of a dependent DC voltage level power supply. The use of a dependent DC voltage source is not preferred in hardware studies. Instead, power is transferred to the LC circuit through the power electronics circuit elements, such as IGBT and FET, using the control signal Pulse Width Modulation (PWM) signal generation method. The discrete time integral transfer function, which is reflected in Figure 8, has derived from continuous time using the Euler forward Rectangular method [17].

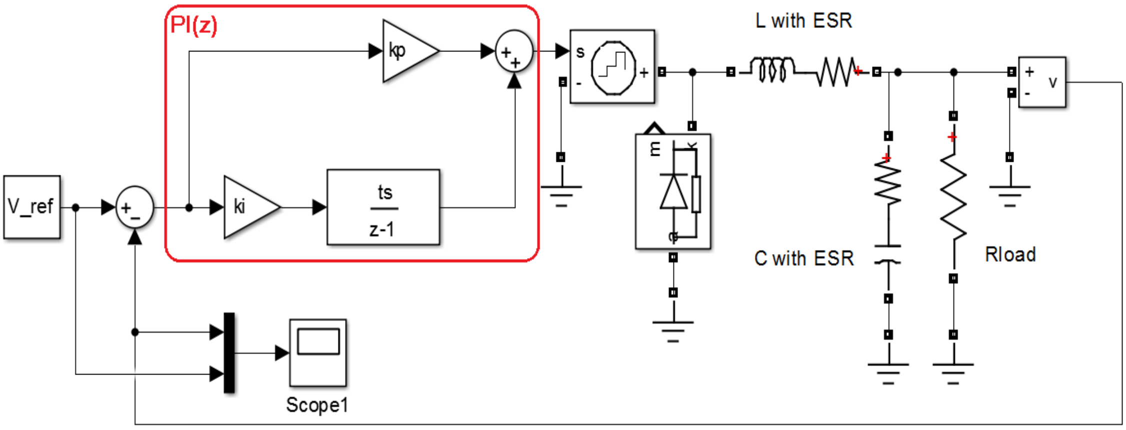

Figure 8. PI based Buck converter control block diagram

3.1. Kp and Ki Parameters Calculation

In this study, Kp and Ki parameters are optimized using the ACO heuristic optimization algorithm. The ACO algorithm should observe the cost value of the control process for the aim of the optimum controller parameter calculation can be realized. The ISE, IAE, ITAE and dTISDSE discrete time cost functions were used to determine the cost of the control process [18]. Mathematical equations that belongs to the cost functions are reflected respectively in Equations 9, 10, 11 and 12.

$$ISE(e) = \sum_{k=0}^{t_{sim}/T_s} e_k^2 \quad (9)$$

$$IAE(e) = \sum_{k=0}^{t_{sim}/T_s} \left| e_k \right| \quad (10)$$

$$ITAE(e) = \sum_{k=0}^{t_{sim}/T_s} k \left| e_k \right| \quad (11)$$

$$dTISDSE(e) = \sum_{k=0}^{t_{sim}/T_s} k \left(e_k^2 \right)^2 \quad (12)$$

The optimization process that belongs to the controller parameters can be summarized in the flowchart below, Figure 9. The flow diagram given in Figure 9 is reflected Figures 10, 11, 12 and 13 in below, the cost function graphs obtained in 4 different run results for 4 different cost functions. The initialization parameters for optimization are given in Table 1.

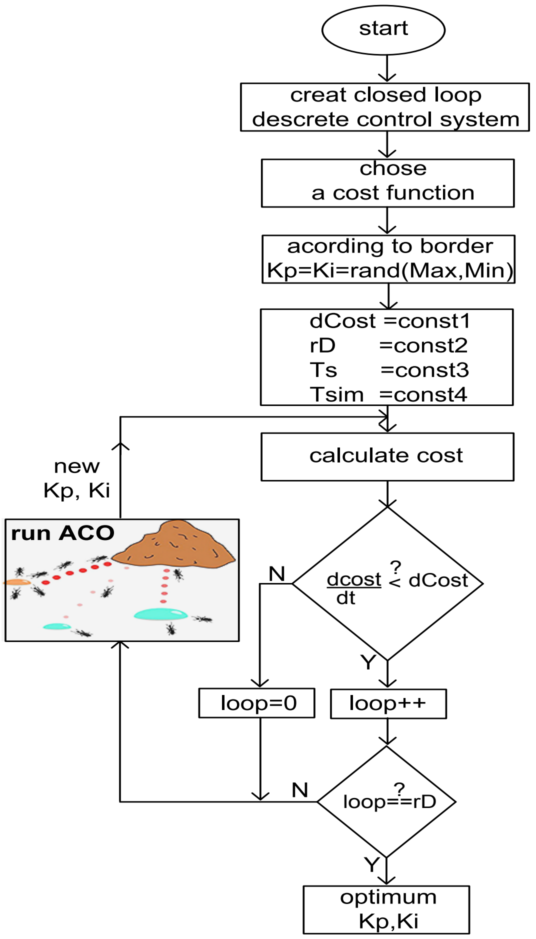

Figure 9. Kp and Ki parameters optimization process

Table 1. The initialization parameters for optimization

Parameters	**Values**
Tsample	25µs
Tsim	1000µs
Iteration	20
Ant Number	250
α	0.1
β	0.1
Evaporation	%1
In.Phromone	0.01

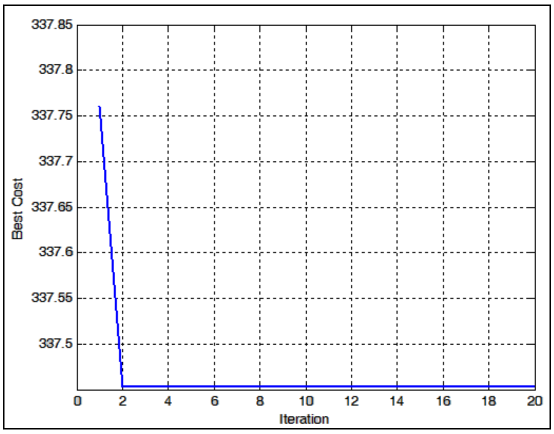

Figure 10. ISE Cost function value decrement

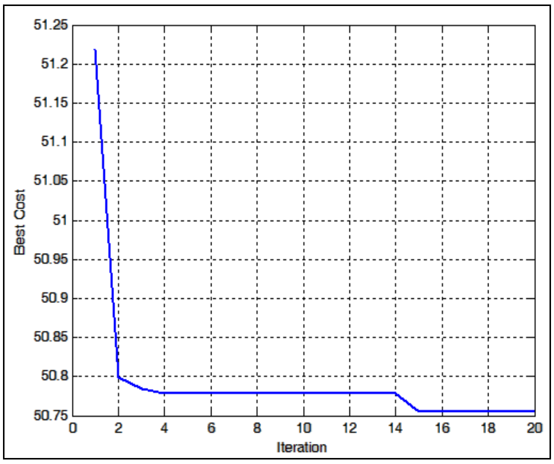

Figure 11. IAE Cost function value decrement

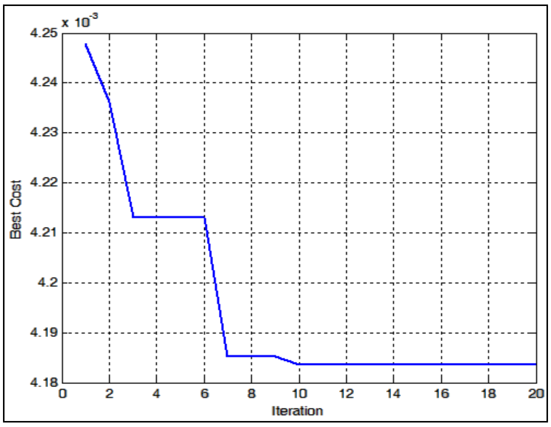

Figure 12. ITAE Cost function value decrement

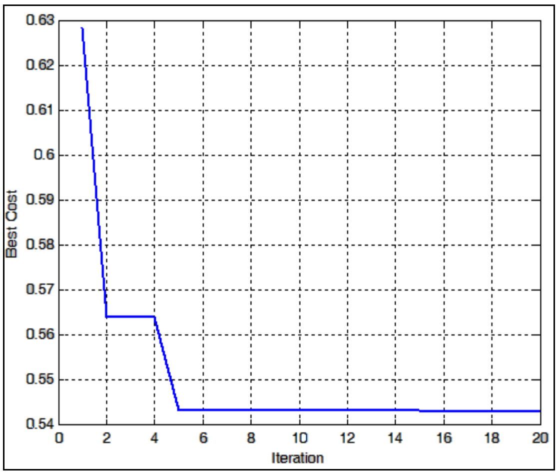

Figure 13. dTISDSE Cost function value decrement

The numerical values of optimized Kp and Ki controller parameters based on 4 different cost functions are given in Table 2.

Table 2. Kp and Ki values based on cost function

Controller Parameters	**IAE**	**ISE**	**ITEA**	**dISDSE**
Kp	1714	1192	4711	4038
Ki	320	224	372	257

4. SIMULATION RESULTS

The closed loop control system given in Figure 8 shows 4 different control systems installed in the Matlab-Simulink simulation environment for 4 different optimum controller parameters obtained using 4 different cost functions, Figure 14.

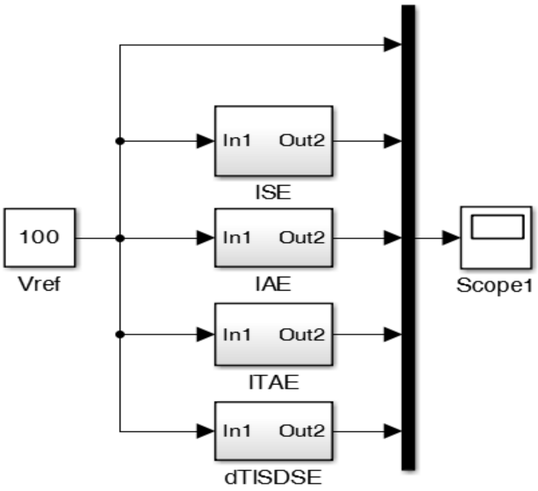

Figure 14. 4 control system with different control parameters

For the reference output voltage 100V, the dynamic behavior of the output voltages that belongs to the Buck converters controlled by the discrete time PI controller have showen in Figure 15.

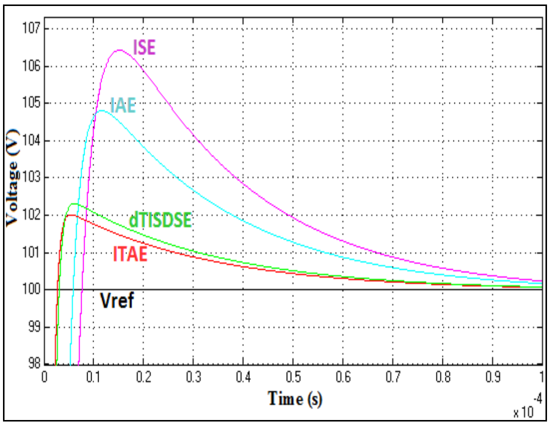

Figure 15. Optimized Kp and Ki control success with 4 different methods

Selection of the cost function for the ant colony optimization process affects the optimization as is seen given in Figure 15. The velocity of reach to lowest error value is up to the kind of the cost function as given in Figures 10-13. The rate of reaching the lowest error value depends on the type of cost function to be selected. The increases in iteration lowers over shoot and settlement time in the optimization process as given in the Figure 15. The results obtained in this study show that the Ant Colony based system has lower settling time and overshoot than the PSO based control system. The results of dynamic behavior of the Buck converter are compared after the optimization of PSO based discrete time PI controller parameters by Mühürcü and Köse [19].

5. CONCLUSION

A closed loop control system can be created by using a discrete time PI controller in order to anchor the buck circuit output voltage to the desired reference value by eliminating the changing conditions. The Kp and Ki controller parameters can be optimized using the ACO heuristic algorithm in order to preserve the high efficiency that belongs to the Buck circuit. 4 different cost functions are used in the optimization process. The lowest over shoot and lowest settlement time can be obtain by using ITAE cost function. The rate of reaching the lowest error value depends on the type of cost function to be selected. As the iteration increases in the optimization process, it is observed that lower over shoot and settlement time result values can be achieved.

6. REFERENCES

1. Biswal, M., 2011. Control Techniques for DC-DC Buck Converter with Improved Performance, Master of Technology, Department of Electrical Engineering National Institute of Technology, Rourkela, 17-40.
2. Ürgün, S., Erfidan, T., Çoruh, N., 2008. DA-DA Buck Dönüştürücü Tasarımı ve Gerçeklenmesi, Elektrik-Elektronik-Bilgisayar

Mühendisliği Sempozyumu (ELECO 2008), 358-361.

3. Arti Kamalakar, S.B., Kulkarni, N.R., 2012. Performance Verification of DC-DC Buck Converter using Sliding Mode Controller for Comparison with the Existing Controllers–A Theoretical Approach" International Journal of Advances in Engineering&Technology, 2(1), 258-268.

4. Besheer, A.H., Adly, M., 2012. Ant Colony System Based PI Maximum Power Point Tracking for Stand Alone Photovoltaic System, IEEE International Conference on Industrial Technology, 693-698.

5. Maamri, F., Bououden, S., Boulkaibet, I., 2015. An Ant Colony Optimization Approach for Parameter Identification of Piezoelectric Resonator Chaotic System, 16th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), 811-816.

6. Kour, J., Tiwari, S., 2013. Ant Colony Optimization-a Tool for Online Tuning of a PI Controller for a Three Phase Induction Motor Drive, IEEE, Control, Automation, Robotics and Embedded Systems (CARE), International Conference.

7. Chonsatidjamroen, S., Areerak, K.N., Areerak, K.L., 2012. The Optimal Cascade Pi Controller Design of Buck Converters, Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 9th International Conference, 6254130.

8. Moursy, Y., Khalil, R., Lecce, S., Poletto, V., Iskander, R., Louërat, M., 2016. Mixed-signal PI Controller in Current-mode DC-DC Buck Converter for Automotive Applications, Circuits and Systems (ISCAS), IEEE International Symposium, 7538873, 1610-1613.

9. Goss, S., Aron, S., Deneubourg, J.L., Pasteels, J.M., 1989. Self-organized Shortcuts in the Argentine ant, Naturwissenschaften 76, 579-581.

10. Dorigo, M., Blum, C., 2005. Ant Colony Optimization Theory: A Survey, Theoretical Computer Science, 243–278.

11. Wikimedia, https://en.wikipedia.org/wiki/Ant_colony_optimization_algorithms

12. Toksari, M.D., 2016. A Hybrid Algorithm of Ant Colony Optimization (ACO) and Iterated Local Search (ILS) for Estimating Electricity Domestic Consumption: Case of Turkey, Electrical Power and Energy Systems 78, 776–782. Also,
Wikimedia, https://commons.wikimedia.org/wiki/File:Aco_branches.svg

13. Ünsal, M., Şahingöz, O.K., 2011. Etmen Tabanlı Teknolojilerin Karınca Kolonisi Eniyileme Uygulamalarında Kullanımları, Internet Konferansı, (INETTR'11), 1-11.

14. Özdağ, H., Aygör, N., Parlak, A., Karınca Kolonisi Algoritmasının Zaman Çizelgelemesi Üzerine: Bir Modellemesi ve Uygulaması, Akademik Bilişim'12- XIV. Akademik Bilişim Konferansı, Uşak Üniversitesi, 329-333.

15. Çayıroğlu, İ., İleri Algoritma Analizi, Ders Notları, Karabük Ün. Mühendislik Fakültesi.

16. Dereli, T., Daş, G.S., 2010. Konteyner Yükleme Problemleri için Karınca Kolonisi Optimizasyonu Yaklaşımı, Gazi Üniv. Müh. Mim. Fak. Der. Cilt 25, No 4, 881-894.

17. Gohari, P., 2006. Lecture 6: Discrete Equivalents, ELEC 6061, Ders Notu.

18. Köse, E., Mühürcü, A., 2016. The Control of A Non-Linear Chaotic System using Genetic and Particle Swarm Based on Optimization Algorithms", IJISAE, 4(4), 145-149.

19. Mühürcü, A., Köse, E., 2017. Parameter Optimization of PI Controller By PSO for Optimal Controlling of A Buck Converter's Output", IEEE-International Conference on Artificial Intelligence and Data Processing (IDAP17), September 16-17 2017, Malatya, Türkiye.