Optimal Control Of A Buck Converter By Using PI Controller Based On HSA Algorithm

Ercan Köse[1], Aydın Mühürcü[2], Gülçin Mühürcü[3], Muhammed Nurullah Temiz[4]
[1]*Mersin University/ Tarsus Technology Faculty, Mechatronic Engineering, Turkey; ekose@mersin.edu.tr*
[2]*Kırklareli University/ Technology. Fac., Mechatronic Eng., Turkey; amuhurcu@sakarya.edu.tr*
[3]*Kırklareli University/ Control and Autom.Tech. of Pinarhisar VHS, Turkey; gulcinmuhurcu@klu.edu.tr*
[4]*Sakarya University/ Engineering Fac. Elc-Elctr Eng., Turkey; muhammed.temiz@org.sakarya.edu.tr*

Abstract

In this work, the optimal control is aimed to ensure the output voltage level of the Buck converter, the power electronics circuit topology, is at the reference DC level with the lowest cost value. Control was performed using a discrete time PI algorithm. The Kp and Ki parameters of the controller are optimized over the Harmony Search Algorithm (HSA) in order to implement the intended control strategy. The closed-loop control process of the converter was simulated in Matlab-Simulink simulation environment and the success of the control process was observed and discussed.

Keywords: Optimization, Recursive, HSA, Cost Function, Discrete Time, PI, Control, Buck Converter.

HSA Algoritmasına Dayalı PI Denetleyicisi Kullanarak Bir Buck Dönüştürücüsünün Optimal Kontrolü

Özet

Bu çalışmada, optimum kontrol, güç elektroniği devre topolojisi olan Buck çeviricisinin çıkış gerilim seviyesinin, en düşük maliyet değerine sahip referans DC seviyesinde olmasını sağlamayı amaçlamaktadır. Kontrol işlemei, ayrık zamanlı PI algoritması kullanılarak gerçekleştirilmiştir. Kontrolörün Kp ve Ki parametreleri, amaçlanan kontrol stratejisini uygulamak için Harmony Arama Algoritması (HSA) üzerinde optimize edilmiştir. Dönüştürücünün kapalı çevrim kontrol süreci, Matlab-Simulink simülasyon ortamında simüle edilerek, kontrol sürecinin başarısı gözlemlenmiş ve buna bağlı elde edilen sonuçlar tartışılmıştır.

Anahtar Kelimeler: Optimizasyon, Özyinelemeli, HSA, Maliyet Fonksiyonu, Ayrık Zaman, PI, Kontrol, Buck Dönüştürücü.

1. INTRODUCTİON

Thanks to the algorithms that our technology brings to our lives, it is possible to obtain easy and fast solutions by transferring very unknown, linear or non-linear problems encountered in real life. Growing and complicating the problems have created the concept of the least cost solution and work has accelerated in this direction [1,2,3]. Some of the methods used in the solution process are intuitive algorithms based on nature.

Intuitive algorithms are algorithms that are inspired by natural phenomena to accomplish any purpose or to reach the goal [4,5,6]. Heuristic algorithms that give the lowest cost values in large-scale problems cannot guarantee a definite solution even though they have solution convergence feature; But the exact solution is convergence [7]. General purpose heuristic optimization algorithms can be grouped into six different groups, biology, physics, herd, social, music and chemistry based.

The Harmonic Search (HSA) Algorithm, a musical-based algorithm, is an intuitive algorithm proposed by Geem in 2001 that simulates musical notes played by musicians [8].

There are also a variety of up-to-date HSA-based control studies. The HSA algorithm can be used to determine the optimum design of the water distribution networks, the flood model, the solution of the environmental economic power distribution problems, the optimum design of the grid systems [8], the energy demand model [10] and the optimization of water distribution networks [3] such as was applied to the solution of various engineering problems.

Generally, renewable energy generators, designed for DC-DC power supplies, high efficiency, small volume, low price and stable references that is based on error-free output and capabilities to be asked. These criteria cannot be achieved only by using switched power electronics circuit topologies. The system behavior should be controlled so that the efficiency can be increased and the circuit output size can be followed up with a steady reference. This control can be realized by control algorithms [9,10,11]. The parameters of the control algorithms to be used in power electronic circuit topologies should also be optimized so that energy transfer can be performed with the highest efficiency.

In this study, an optimal control is aimed at the output voltage level of the buck converter, which is one of the power electronics circuit topologies and serves as a squeezed voltage reducer, so that it can remain at the reference voltage level with the lowest cost value. Control was performed using a discrete time PI algorithm. The Kp and Ki parameters of the control were optimized using HSA so that the intended control cost could be at the lowest level. The closed-loop control process of the converter was simulated simultaneously in the Matlab / Simulink simulation environment and the success of the control process was observed and discussed.

2. HSA OPTİMİZATİON ALGORİTHM

During the music development, each artist performs the accordion of his instrument and performs within the possible sound ranges, and all the musicians together form a voice synergy vector. If the tunings created provide a nice melodious harmony, each artist's memory will record this melody contribution in memory. In addition, we try to develop beautiful sound tones in each step [12].

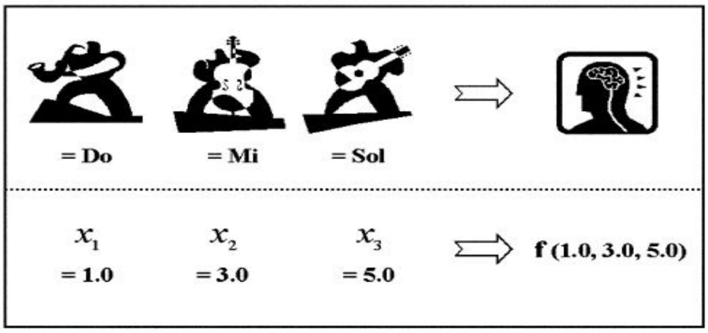

Figure 1: Link between music development and engineering optimization

In the HSA algorithm, the initial population is randomly generated from the harmonic vectors and stored in the harmonic memory (HH). New harmonies are produced from solutions in the harmony memory by methods such as memory solutions, adjustment correction and random selection. Then the worst harmony vector in the harmony memory vector and the candidate are compared using the update operator. In general, the Harmony search process is completed in 5 steps,

Step1.

This step is created in the installation problem and solution parameters. Eq. 1.

$$z = \min\{f(x)\},$$
$$x_i \in X_i = 1,2,3,\ldots N. \tag{1}$$

Here,

$f(x)$: The objective function to minimize.

x_i : Decision variable.

X_i : The solution used for each decision variable

N : Total number of decision variables

Step 2.

A harmonic memory is formed by randomly generated decision variables within the defined solution space. Eq. 2.

$$z = \min\{f(x)\}. \tag{2}$$

Step 3.

New harmony is created in this step. The selection process is given in Eq. 3.

$$x_i = \left\{ \begin{array}{l} x_i^{'} \in \left\{ x_i^1, x_i^2, x_i^3, \ldots, x_i^{HMS} \right\} \\ x_i^{'} \in X_i \end{array} \right\} \tag{3}$$

The HMS abbreviation used in Eq. 3 represents the harmonic memory size

$$x_i^{'} = \left\{ \begin{array}{ll} x_i^{'} \pm Rnd(0;1) * bw & \text{probability of PAR} \\ x_i^{'} & \textit{other condition} \end{array} \right. \tag{4}$$

bw: It represents the randomly selected bandwidth value in the range [0,1].

PAR : Ton adjustment ratio.

Step4.

In this step, newly created harmony values are compared with memory. The costly high harmony is removed from memory and replaced with the new one.

Step 5.

In this step, the lowest cost function value is checked. If the function value is not low enough, repeat step 3 to step 5.

3. BUCK SİMULATİON MODEL

The buck-type reduction power electronics circuit topology is reflected in Figure 2.

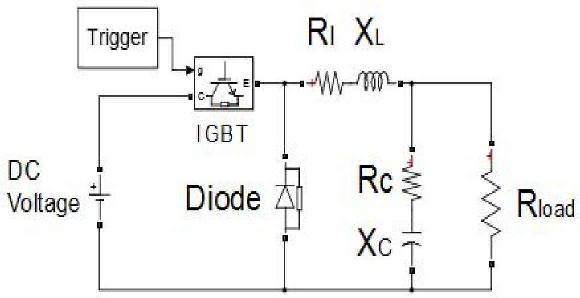

Figure 2: Buck Converter Topology

The basic elements of the circuit are the coil and capacitor. When power consumption is achieved by load R1; Battery is used as a power source. One PWM core is used as the pulse source and one IGBT is used for power transmission and cutting. The buck circuit topology in the simulation environment is also added to the Series Equivalent Resistance (ESR) of the capacitor and coil elements so as to be highly similar to that in the hardware environment. If the extraction of the system Transfer Function T(s) is solved based on electronic circuit analysis, the mathematical relationship between input and output voltages is reflected in Eq. 5 for the Laplace space.

$$T(s)=\frac{(X_c(s)+R_c)//R_{load}}{X_L(s)+R_l+(X_c(s)+R_c)//R_{load}} \tag{5}$$

In this formula,

$X_L(s)=sL$ and $X_C(s)=\dfrac{1}{sC}$ represent.

For the work to be performed in the simulation environment, Capacitor with 63V/ 2200µF/68mΩ values produced by the EPCOS Inc. and coil selection with value of 820µH / 3.8A / 110mΩ produced by Bourns Inc. and 10Ω load resistor If T (s) is rearranged, it becomes the final digit as in Eq. 6.

Figure 3: Bourns Inc., 820µH/3.8A/110mΩ coil

Figure 4: EPCOS Inc., 2200µF/63V/68mΩ capacitor

$$T(s)=\frac{82.38s+550.7*10^3}{s^2+261.7s+556.7*10^3} \tag{6}$$

The derivation of the T (s) transfer function should be tested for the correctness of the next step of the control process. For this reason, the switch regulated by the T (s) transfer function and the power electronics elements was run in a simultaneous Matlab-Simulink environment, Fig. 5.

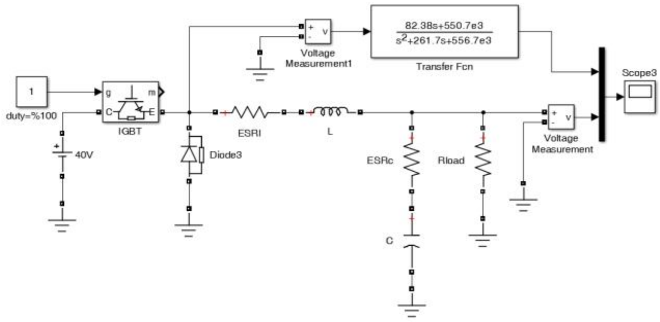

Figure 5: Simulation of system

In case of running both on systems with %100 duty cycle, the output voltage waveform of simulation is reflected in Fig. 6.

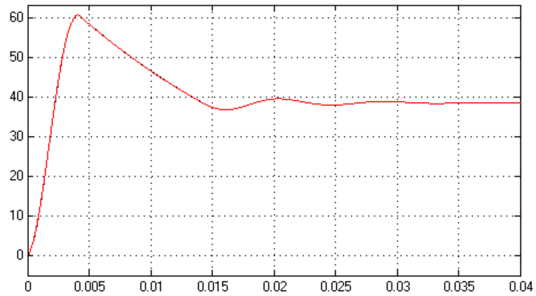

Figure 6: Buck power circuit and T(s) simultaneous simulation results

4. CLOSED LOOP CONTROL STRUCTURE

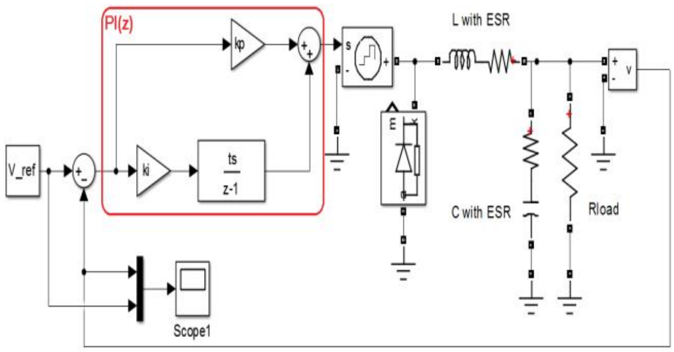

Figure 7: PI-based buck converter control block diagram

In Fig. 7, the output voltage of the Buck circuit is controlled by the PI controller at the discrete time. The signal obtained at the controller output is applied to the input of a dependent DC power supply.

The use of a dependent DC voltage source is not preferred in hardware operation. Instead, power is transferred to the LC circuit through the power electronics circuit elements, such as IGBT or FET, using the Pulse Width Modulation (PWM) signal generation method.

The discrete time integral transfer function reflected in Fig. 7 is derived from the continuous time using the Euler forward Rectangular method [14].

5. CALCULATİON OF KP AND Kİ PARAMETERS

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 so that it can perform the optimum controller parameter calculation. The ISE, IAE, ITAE and dTISDSE discrete time cost function was used to determine the cost of the control process [13]. Mathematical equations for cost functions are reflected in Eqs. 7,8,9 and 10, respectively.

$$ISE(e) = \sum_{k=0}^{t_{sim}/T_s} e_k^2 \tag{7}$$

$$IAE(e) = \sum_{k=0}^{t_{sim}/T_s} |e_k| \tag{8}$$

$$ITAE(e) = \sum_{k=0}^{t_{sim}/T_s} k|e_k| \tag{9}$$

$$dTISDSE(e) = \sum_{k=0}^{t_{sim}/T_s} k\left(e_k^2\right)^2 \tag{10}$$

The optimization process for the controller parameters can be summarized in the flowchart below, Fig. 8.

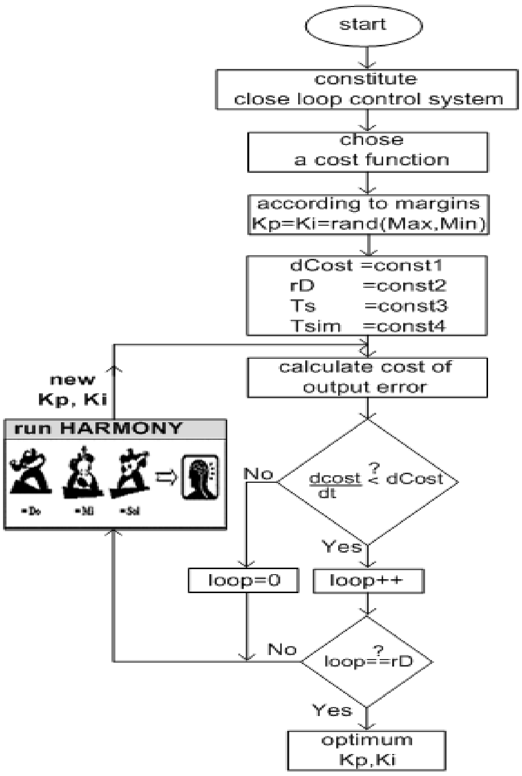

Figure 8: Kp and Ki optimization process

The flow diagram given in Fig. 8, the cost function graphs obtained in 4 different run results for 4 different cost functions are shown below, Figs. 9,10,11 and 12. The initialization parameters for optimization are given in Table 1. Four different cost functions are used in this study and the results of simulations are reflected below. Table 1 contains the initial parameters of the optimization process.

Table 1. Initialization Parameters For Optimization

Parameters	**Values**
Tsample	10µs
Tsim	100µs
Harmony M. Size	150
N.New Harmony	50
H.Memory Consid. Rate	%40
Pitch Adj	%10

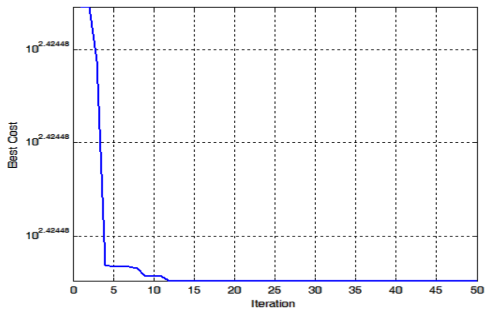

Figure 9: ISE cost function value decline

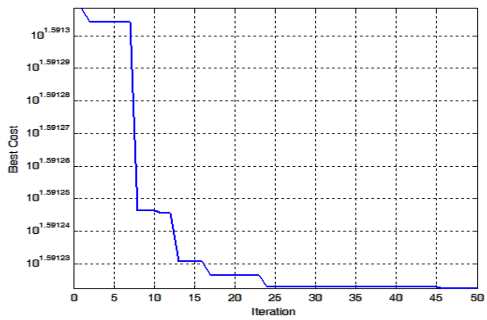

Figure 10: Decrease in the cost function of the IAE

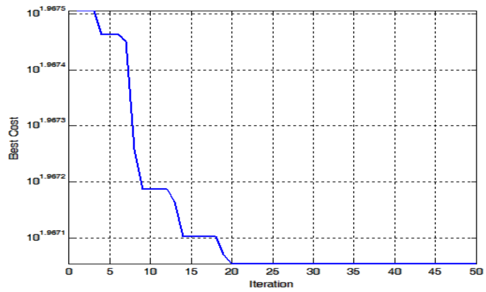

Figure 11: Decrease in ITAE cost function value

Table 2. Kp and KI Values based on cost functions

	Performance Criteria Functions			
Controller Parameters	***IAE***	***ISE***	***ITEA***	***dTISDSE***
K_p	635.3	548.2	661.2	535.7
K_i	128.8	178.2	347.6	6.476

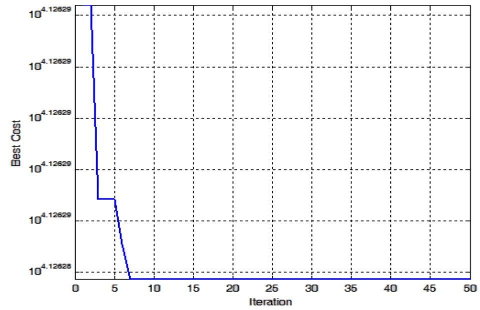

Figure 12: dTISDSE cost function value decrease

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

6. SİMULATİON RESULTS

The closed loop control system shown in Fig. 7 has 4 different control systems installed in Matlab-Simulink simulation environment for 4 different optimum controller parameters obtained by using 4 different cost functions in the Fig. 13.

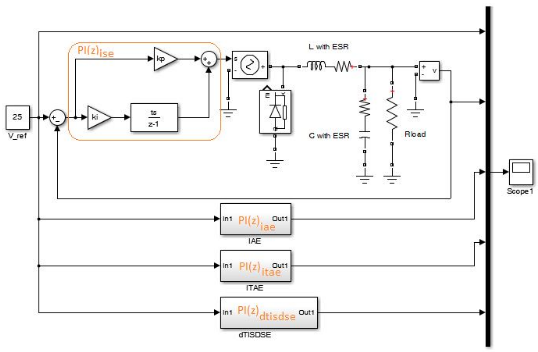

Figure 13: Four control systems with different controller parameters

For the reference output voltage 100V, the dynamic behaviors of the output voltages of the Buck converters controlled by the discrete time PI controller is shown in Fig. 14.

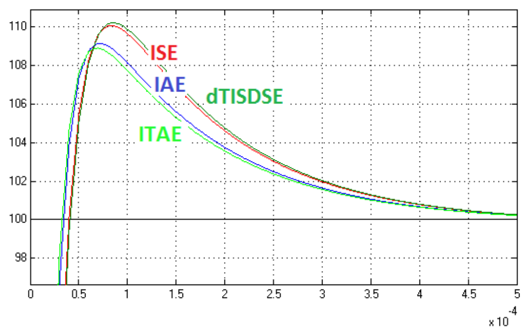

Figure 14: Optimized Kp and Ki control success with 4 different method

7. CONCLUSİON

In this study, the circuit output voltage was stabilized at a desired DC level using a Buck-type voltage-dropping power electron circuit topology. The buck converter has also turned into a closed loop system by adding a discrete time PI control circuit. The Kp and Ki parameters were optimized so that the efficiency of the closed loop control system could still be maintained at a high level. The optimization was based on HS, an intuitive algorithm. It has been observed that the type of cost function affects the HS optimization power. It has been observed that in the experiments performed with different cost functions in the simulation environment, the ITAE cost function enables the HS optimization algorithm to be operated in the most efficient way. In this study, parameters were calculated by using the controller parameters optimized with the HS algorithm running using the ITAE cost function, with the minimum overrun, the shortest settling time and the lowest continuous error.

REFERANSLAR

[1] Akyol S., and Alataş B., (2012)"Güncel sürü zekâsı optimizasyon algoritmaları", Nevşehir Üniversitesi Fen Bilim. Enstitü Derg., vol. 1, pp. 36–50.

[2] Geem Z. W., Kim J. H., Loganathan G. V., (2001)"A new heuristic optimization algorithm: harmony search", Simulation, 76(2), pp. 60–68.

[3] Geem Z. W., (2006)"Optimal cost design of water distribution networks using harmony search", Eng. Optim., 38(3), pp. 259–277.

[4] Mukherjee S., Satakshi, and Mittal R. C., (2005)"Model order reduction using response-matching technique", J. Franklin Inst., 342(5), pp. 503–519.

[5] Mukherjee S., Satakshi, and Mittal R. C., (2007)"Linear time invariant system order reduction using multipoint step response matching," Int. J. Syst. Sci., 38(3), pp. 211–217.

[6] Kim J. H., Geem Z. W., and Kim E. S., (2001)"Parameter estimation of the nonlinear muskingum model using harmony search", J. Am. Water Resour. Assoc., 37(5), pp. 1131–1138.

[7] Özyön S., Yaşar C., and Temurtaş H., (2011)"Harmoni arama algoritmasının çevresel ekonomik güç dağıtım problemlerine uygulanması", Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Derg., vol. 26(2), pp. 65–76.

[8] Saka M. P., (2009)"Optimum design of steel sway frames to BS5950 using harmony search algorithm", J. Constr. Steel Res., vol. 65(1), pp. 36–43.

[9] Uran S., and Milanovic M., (2003),"Advanced control of buck converter", IEEE International Conference on Industrial Technology, vol. 1, pp. 602–607.

[10]Ayvaz M. T., Karahan H., and Güraslan G., (2007)"Su dağıtım şebekelerinin armoni araştırması optimizasyon tekniği ile optimum tasarımı", 5. Kentsel Altyapı Ulusal Sempozyumu.

[11]Abu-Qahouq J. A., Wen Y., Yao L., Shoubaki E., Batarseh I., and Potter G., (2005)"Digital controller for an isolated half-bridge DC-DC converter", Twentieth Annual IEEE Applied Power Electronics Conference and Exposition, vol. 2, pp. 1217–1223.

[12]Durmuş B., Gün A., (2011)"Parameter identification using particle swarm optimization", 6th International Advanced Technologies Symposium (IATS'11), pp.188-192.

[13]Nagar S. K., and Singh S. K., (2004)"An algorithmic approach for system decomposition and balanced realized model reduction", J. Franklin Inst., vol. 341(7), pp. 615–630.