PSO Tabanlı PID ve PID Denetleyiciler ile Senkron Motorun Uyartım Akım Denetimi ve Reaktif Güç Kompanzasyonu Benzetim Çalışması

A Simulation Study on Controlling Excitation Current of Synchronous Motor and Reactive Power Compensation via PSO Based PID and PID Controllers

Ahmet Gani[1], Hakan Açıkgöz[2], Ö. Fatih Keçecioğlu[1], Erdal Kılıç[1] ,Mustafa Şekkeli[1]
[1]Dept. of Electrical and Electronics Engineering, Kahramanmaras Sutcu Imam University Kahramanmaraş, Türkiye.
{agani, fkececioglu, ekilic,msekkeli}@ksu.edu.tr
[2]Dept. of Electrical Science, Kilis 7 Aralik University, Kilis, Türkiye
hakanacikgoz@kilis.edu.tr

***Özetçe*— Enerji talebinin her geçen gün daha da artması mevcut enerji kaynaklarının verimli bir şekilde kullanılmasını gerektirmektedir. Endüstriyel tesislerde harcanan yararlı güç aktif güç olduğundan bu tesislerde tüketilen reaktif güç minimuma indirilmeli, ya da bu ihtiyaç şebeke yerine başka bir kaynaktan sağlanmalıdır. Dolayısıyla şebekenin güç faktörü düzeltilerek kaynaktan çekilen reaktif güç azaltılır. Elektrik güç sistemlerinde güç faktörü düzeltilmesi işlemi reaktif güç kompanzasyonu olarak adlandırılmaktadır. Aşırı uyartılması durumunda kapasitif reaktif güç üreten senkron motorlar güç sistemlerinde dinamik kompanzatör olarak kullanılırlar. Senkron motorun hem mekanik güç üretmede hem de reaktif güç kompanzasyonunda kullanılması endüstriyel tesisler için daha ekonomik olmaktadır. Bu durum endüstriyel tesislerin verimini arttırmaktadır. Literatürde reaktif güç kompanzasyonu ile güç sisteminin verimliliğini, kapasitesini ve değişik çalışma koşullarında kararlılığını sağlayabilmek için birçok çalışma bulunmaktadır. Günümüzde biyolojik sistemlerden esinlenilmiş birçok optimizasyon tekniği bulunmaktadır. Bu tekniklerden biri de kuş sürülerinin davranışlarından esinlenerek ortaya çıkarılmış bir optimizasyon yöntemi olan Parçacık Sürüsü Optimizasyonudur (PSO). Bu çalışmada PSO tabanlı PID ve Ziegler Nichols (Z-N) tabanlı PID denetleyiciler ile senkron motorun uyartım akımı denetlenerek bir güç sisteminin reaktif güç kompanzasyonu yapılmıştır.**

Anahtar Kelimeler*— *Uyartım Akımı; PSO

***Abstract*— The increasing need for energy requires using existing energy sources more efficiently. Because it is the active power that supplies useful power for industrial facilities, reactive power must be minimized, and supplied by another source instead of electrical grid. Therefore, reactive power supplied by the grid can be reduced via by correcting power factor of the grid. In electrical power systems, power factor correction is called reactive power compensation. Generating reactive power during excessive excitation, synchronous motors are used as dynamic compensators in power systems. Synchronous motors are more cost-effective for industrial facilities when they are used to generate mechanic power and compensate reactive power, which increases the efficiency of industrial facilities. There are various studies focusing on the efficiency, capacity and stability of the power system via reactive power compensation in the literature. In today's world, there are numerous optimization techniques inspired by biological systems. One of these techniques is Particle Swarm Optimization (PSO) inspired by the movements of swarms of birds. This study focuses on the reactive power compensation of a power system by controlling the excitation current of a synchronous motor via PSO based PID and Ziegler Nichols (Z-N) based PID controllers.**

Keywords*— *Excitation Current; PSO

Bu çalışma ASYU-2017 Konferansında sunulmuş ve sadece özet olarak
Bildiri Özetleri Kitabı (ISBN: 978-605-84722-8-0)'nda yayımlanmıştır.

I. INTRODUCTION

As a result of technological improvements, energy consumption has increased in recent years due to the increasing use of inductive loads in industrial applications. Besides active power, inductive loads also absorb reactive power from the grid [1]. Although reactive power absorbed from the transmission line loads it, it cannot be converted to the energy [2]. Therefore, reactive power absorbed from the grid causes losses in electric power systems, and these losses must be minimized. The minimization of energy losses will reduce cable and other measurement and protection costs, thus creating a more cost-effective electric power system. This can only be achieved when reactive power needed by the inductive loads, which the transmission line feeds, is supplied to the load as closely as possible. Reactive power needed by the loads is supplied statically by a capacitor or reactor and dynamically by a synchronous motor [3-5]. Reactive power compensation via a synchronous motor can be achieved by changing the excitation current of the motor if the motor operates in a capacitive or inductive character [6]. In addition, the amount of reactive power that a synchronous motor absorbs from the grid can be adjusted thanks to the excitation current. An efficiently compensated system will improve the power factor, minimize losses and become efficient [7-9].

It is known that PID controller is widely used in industrial control systems. Therefore, the determination of optimal gain parameters for system control is of vital importance. One of the conventional methods, Z-N method is widely used in the determination of gain parameters. However, this method leads to problems such as the determination of the highest gain value or emission period. In this respect, various optimal control methods were developed in order to quickly and easily determine K_p, K_i and K_d parameters. These methods are genetic algorithm (GA), Artificial Bee Colony (ABC), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) [10-16].

In this study, gain parameters of PSO and PID controllers, which are among optimal control methods, were optimally adjusted, and reactive power compensation was performed by applying the excitation current of the synchronous motor to the system. First of all, gain parameters of PID controller were adjusted via conventional Z-N method, and optimal PID gain parameters were found via PSO to be applied to control system.

II. REACTIVE POWER COMPENSATION

Reactive power compensation plays an important role in the improvement of efficiency and capacity of electrical power systems. The current needed by consumers with inductive load is supplied by two components of the current. The former is the active current which is converted to energy while the latter is the reactive current that creates the magnetic field necessary for electric machinery and devices. If powers corresponding to these currents are defined as,

S = Apparent power (VA),

P = Active power (W),

Q = Reactive power (Var)

can be defined as;

$$S = \sqrt{P^2 + Q^2} \tag{1}$$

This equation can be geometrically defined as the power triangle shown in Figure 1. Here, φ is defined as phase angle.

Cosφ is the power factor which can be defined as follows [18-19].

$$\cos\varphi = \frac{P}{S} \tag{2}$$

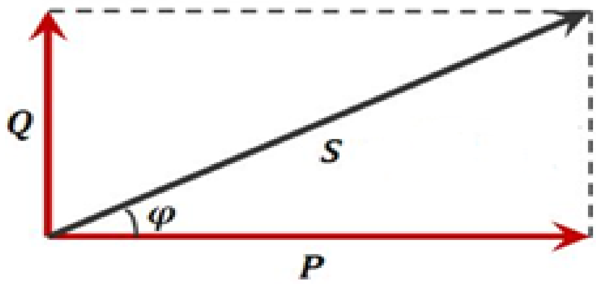

Figure 1. Power triangle [17].

III. THE CHARACTERISTICS OF SYNCHRONOUS MOTORS

Synchronous motor is an alternative current motor in which rotor rotational speed is equal to the rotational speed of the stator rotating field and the rotation speed does not vary in loading. When excitation current of the synchronous motor changes, it absorbs ohmic, inductive and capacitive current [20]. In a synchronous motor operating at a constant load and voltage, the characteristic which yields the relationship between excitation current and stator current is called V-current. Under the same conditions, the changes in load current is inversely proportional to the changes in power factor. The point at which excitation current forming the lowest load current at a constant load exists is called ohmic operating point of the motor. The synchronous motor operates inductively under an excitation current lower than that of the ohmic operating point while it operates capacitively under an excitation current higher than that of the ohmic operating point. V-curves which account for the relationship between load current and excitation current for different loads of the synchronous motor are shown in Figure 2.

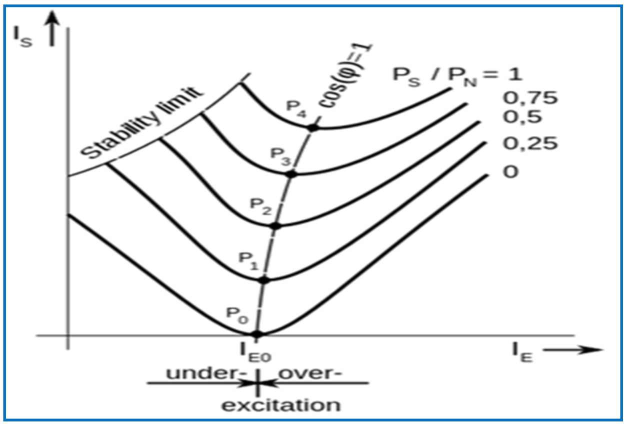

Figure 2. V-curves of the synchronous motor under different loads [21].

IV. THE DESIGN OF CONTROLLERS

Thanks to their durable performance and simple structures, PID controller is the most commonly used controller among controller systems. Proportional (P), integral (I) and derivative (D) gains, which comprise PID controllers, influence the system in various ways. Each of the parts comprising PID controller is governed by a coefficient. These coefficients take different values for each system. The block diagram of inner structure in a PID controller is shown in Figure 3. The output of PID controller can be defined as in Equation 4 [22].

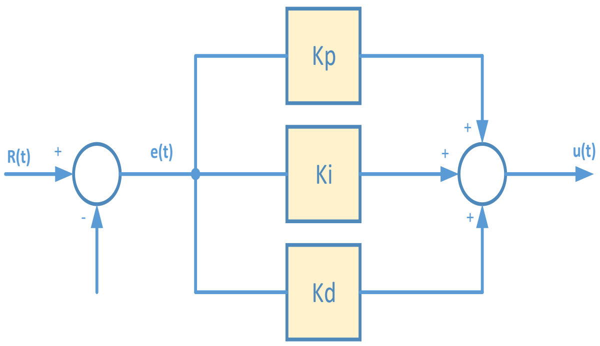

Figure 3. The block diagram of PID controller

where error signal e(t) is the difference between reference cosφ and system cosφ as defined in Equation 3.

$$e(t) = \cos\varphi^{ref} - \cos\varphi \quad (3)$$

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \quad (4)$$

A. Ziegler Nichols Method

In a closed loop PID system, I and D coefficients of the PID controller are set at 0 using Z-N method. P is increased slowly until the system reaches oscillation. The gain value is defined as K_u. Thus, the value between two peaks is defined as P_u. K_u and P_u values and wave oscillation are shown in Figure 4. PID coefficients are determined in accordance with Table 1[23].

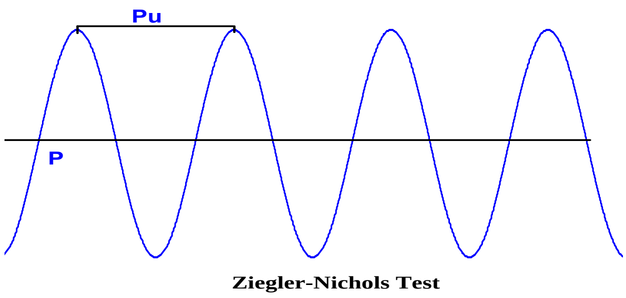

Figure 4. The answer of system entering the oscillation.

PID coefficients are determined in accordance with Table 1.

Table 1: Calculation of P, I, and D parameters for the Ziegler Nichols method

Controller	Kp	Ki	Kd
P	$K_u/2$	-	-
PI	$K_u/ 2.2$	$P_u/ 1.2$	-
PID	$K_u/ 1.7$	$P_u/2$	$P_u/8$

B. Particle Swarm Optimization Method

Inspired by the behaviors of living creatures and systems in the nature, PSO is a population-based optimization technique developed by J. Kennedy and R.C. Ebarhart who modelled their technique based on flying swarms of birds in 1995 [24]. It is commonly used to solve various engineering problems. Similar to genetic algorithm, PSO algorithm starts with candidate solutions and aims to reach an optimal value by iterating the function. However, PSO structure does not involve crossing or mutation, which makes it easier and more practice to apply. PSO contains candidate solutions called particles, each of which has their own position and velocity vector. Particles move around the solution space and are guided by the particle reaching the best solution. Each bird called a particle in a PSO algorithm defines a solution in the search space. A function which defines the distance to a known solution is created depending on the coordinates and velocity of a particle and this function defines the proximity to the solution. PSO algorithm starts when all particles take in a random position in the search space, and the position of each particle is iterated depending on the best neighboring and individual coordinates. Iteration process continues until the best solution is reached. Therefore, the best solution of each particle and coordinates of these solutions must be kept. Particles move around a real value search space of n dimension. Each particle in the state space has V_{ij}, i.e. velocity vector, and X_{ij}, position vector. Here, i denotes particle, and j denotes dimension. In addition, particles keep the best individual (P_{best}) and global (G_{best}) position vectors for the next state.

In any state, P_{best} vector belonging to i. particle is given Equation 5:

$$P_{best} = [P_{i1}, P_{i2}, \ldots\ldots, P_{in}] \quad (5)$$

G_{best} vector is same for all particles as given in Equation 6.

$$G_{best} = [G_1, G_2, \ldots\ldots\ldots, G_n] \quad (6)$$

The velocity (V_{ij}) and position (X_{ij}) matrixes of the particles in a swarm are given in Equation 7 and 8.

$$X_{ij} = [X_{i1}, X_{i2}, \ldots\ldots X_{in}] \quad (7)$$

$$V_{ij} = [V_{i1}, V_{i2}, \ldots\ldots V_{in}] \quad (8)$$

Velocity values of the particles are iterated in each step in order to reach $V_{(t+1)}$ thanks to the formula given in Equation 8. C_1 and C_2 in Equation 8 are usually acceleration coefficients at the interval of [0-2]. Similarly, normally distributed numbers which are generated randomly at the interval of [0-1] r_1 and r_2 represent inertia weight [25].

$$w_k = w_{\max} - (w_{\max} - w_{\min}) \frac{k}{k_{\max}} \quad (9)$$

where k is the current iteration number, k_{max} is the maximum iteration number of the algorithm, and w_{max} and w_{min} are the maximum and minimum inertia weights.Here, W_1 and W_2 are fixed start and end values, respectively. Similar, thanks to Equation 9, the new position of the particle can be determined by adding previous position value to the new velocity value.

$$X_{i,j(t+1)}) = X_{i,j(t)} + V_{i,j(t+1)} \quad (10)$$

The formula in Equation 10 involves the velocity of the previous step, cognizance, which represents the difference between the best position of the particle and position of the previous step, and social parts, which represents the difference between the best position of all particles and position of the particle in the previous step.

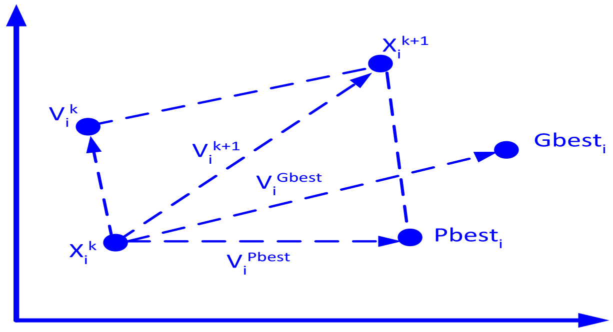

Figure 5. PSO parameters given as vectors

Particles change their positions in PSO until the iteration is completed in the multiple search space. The changes in search space in PSO are shown in Figure 5. PSO flow diagram developed for this study is given in Figure 6.

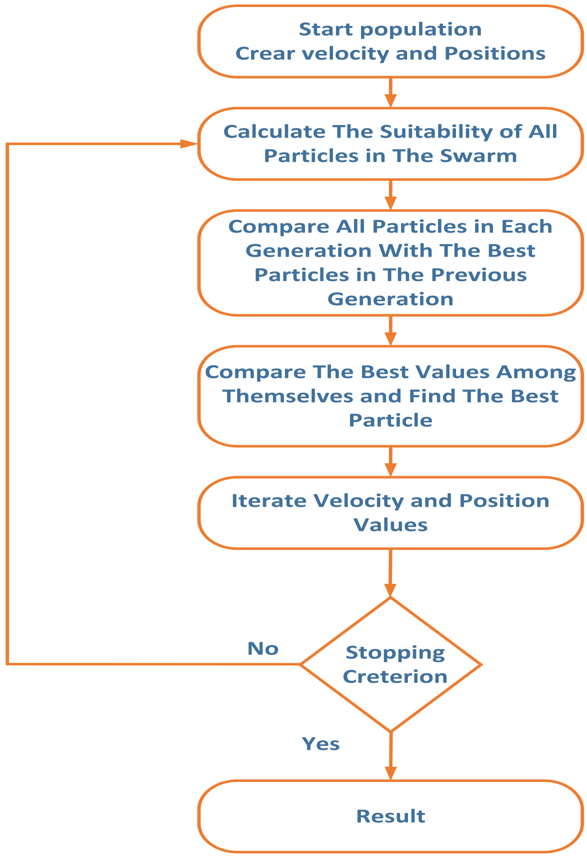

Figure 6. PSO flow diagram

Bu çalışma ASYU-2017 Konferansında sunulmuş ve sadece özet olarak Bildiri Özetleri Kitabı (ISBN: 978-605-84722-8-0)'nda yayımlanmıştır.

V. SIMULATION STUDIES

In recent years, PSO has a widely used optimization method in control engineering. In this study, gain parameters of PID controller were determined via PSO, and it was applied to the excitation current of the synchronous motor. The model developed in Matlab/Simulink is shown in Figure 7. Three-phase stator currents supplied by the power system to the asynchronous motor at a nominal load are shown in Figure 8. Three-phase stator currents supplied by the power system to the synchronous motor at a nominal load are shown in Figure 9. The velocity of synchronous motor at a nominal load is given in Figure 10. The velocity of asynchronous motor at a nominal load is given in Figure 11.Values belonging to the synchronous and asynchronous motor used in the simulation studies are given in Table 2 and 3.

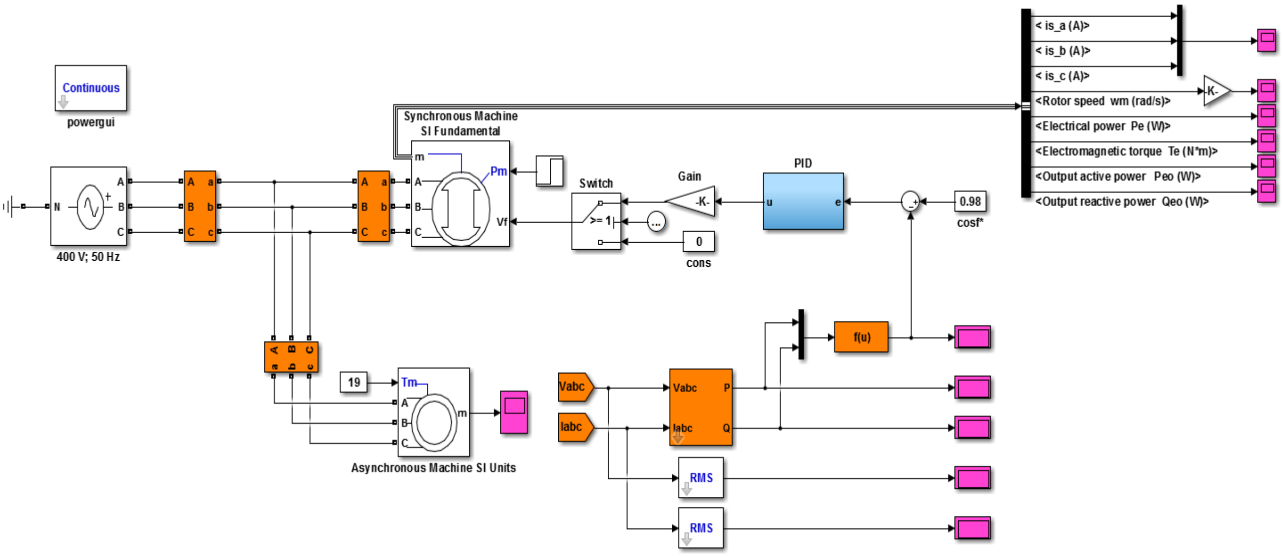

Figure 7. PSO based PID excitation current controller system

Table 2. Asynchronous motor parameters

Parameter	Value
Nominal Power(P)	3 kW
Nominal Revolution[n]	1430 rpm
Nominal Voltage(V)	400 V
Nominal Current(I)	6.7 A
Nominal Load Torque(M)	19 Nm
Pole pairs(p)	2
Frequency(f)	50 Hz
Rotor Type	Squirrel-cage
Stator Resistance[R_s]	1.45 ohm
Stator Inductance[L]	12.2 mH
Rotor Resistance[R_r']	1.93 ohm
Rotor Inductance[L_r']	2.66 mH
Mutual Inductance[L_m]	187.8mH
Friction Factor[F]	0.03 N.m.s
Mechanical Inertia[J]	0.03 kg.m^2

Table 3. Synchronous motor parameters [26].

Parameter	Value
Nominal Power(S)	8.1 kVA
Nominal Revolution[n]	1500 rpm
Nominal Voltage(V)	400 V
Nominal Field Current(I)	4 A
Nominal Load Torque(M)	7 Nm
Pole pairs(p)	2
Frequency(f)	50 Hz
Rotor Type	Salient pole
Stator Resistance[R_s]	1.62 ohm
Stator Inductance[L]	4.527 mH
Field Resistance[R_f']	1.208 ohm
Field Inductance[L_f']	0.01132 H
Mechanical Inertia[J]	0.0923 kgm^2
Friction Factor[F]	0.009 N.m.s

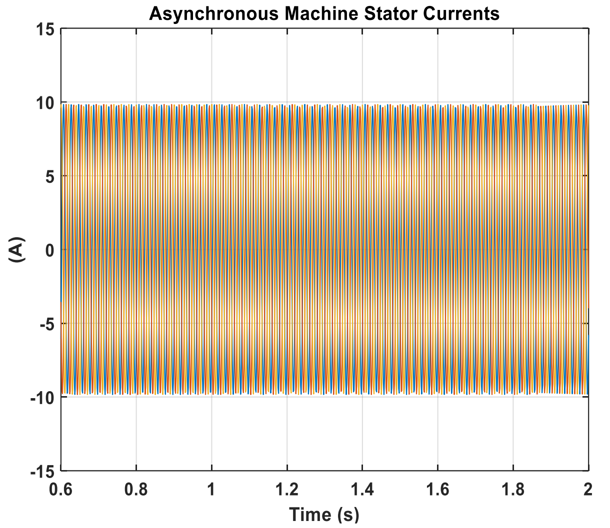

Figure 8. Three phase stator currents of the asynchronous motors at a nominal load

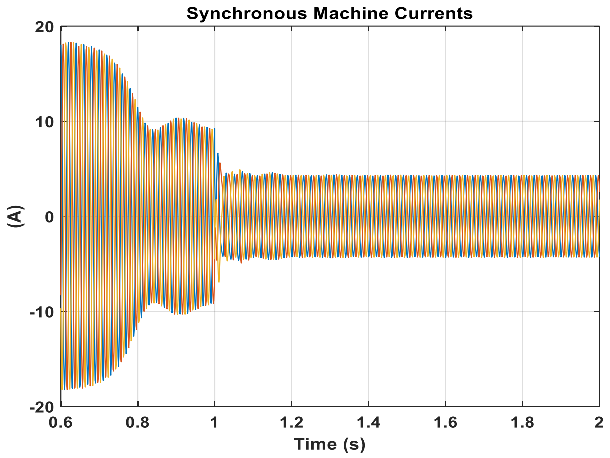

Figure 9. Three phase stator currents of the synchronous motors at a nominal load.

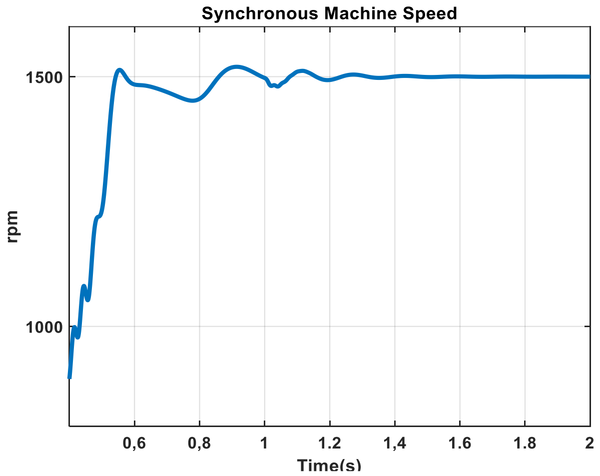

Figure 10. The velocity of synchronous motor at a nominal load.

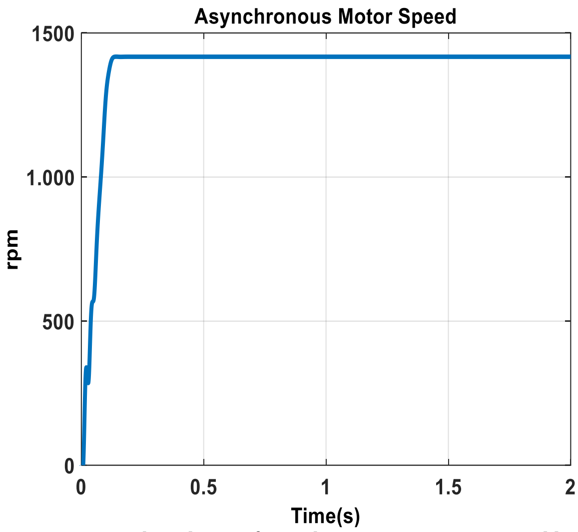

Figure 11. The velocity of asynchronous motor at a nominal load.

First, Z-N method was used in order to determine gain parameters of the PID controller. Then optimal PID gain parameters were determined via PSO method, and PID controller designed using these two methods was applied to the excitation current control system. PSO parameters used in this study are as follows:

Population size: 100
W_{max}- W_{min}: [0.9– 0.3]
C_{1-2}: 2
k_{max}:5
K_p [100-1000], K_i [4-16] and K_d [4-42].

Optimal PID gain parameters used in this study via PSO method are as follows:
Kp=200 , Ki =15 and Kd =20

PID parameters used in this study are as follows:
K_p=105 , K_i =12 and K_d =8

The fitness functions frequently used in the studies on PID controller are error-related performance criteria, which are integral of absolute error (IAE), integral of time weighted absolute error (ITAE), integral of squared error (ISE) and integral time weighted squared error (ITSE). In this study, IAE criterion was often used as a fitness function.

$$IAE = \int_0^\infty |r(t) - y(t)|\,dt = \int_0^\infty |e(t)|\,dt \qquad (11)$$

For the PSO method, the stopping criterion for the algorithm is a maximum of 20 iterations. The PSO algorithm can also be stopped when the fitness value reaches the intended level. The strategy of linear reduction of the inertia weight increases the PSO's efficiency and performance. Experimentally, the inertia weight from w_{max}=0.9 to w_{min}= 0.3 yields excellent results. The efficiency of electrical energy is directly influenced by reactive power compensation. Asynchronous motors are electrical machinery with feedback power factor. Synchronous motors can move forward and backward when power factor excitation current is adjusted. When voltage is applied to the stator windings of the synchronous motors, they cannot move directly due to their inertia. Therefore, various methods were proposed in order to start synchronous motors. In this study, the synchronous motor was started like an asynchronous motor. In addition, as an inductive load, a nominally loaded asynchronous motor connected in parallel to the power system at 0.8 feedback power factor. As shown in Figure 12 and Figure 13 synchronous motor was started like an asynchronous motor for 1 second. At the end of 1 second, after synchronous motor reaches synchronous speed, the excitation current of the synchronous motor is controlled by PSO based PID controller and PID controller in order to give capacitive reactive power to the synchronous motor. Thus, synchronous motor behaves like a dynamic synchronous compensator and supplies reactive power for the system.

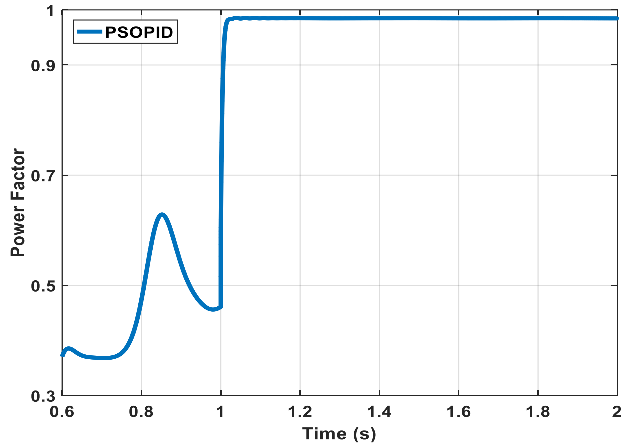

Figure 12. Responses of PSO-PID against excitation current control system.

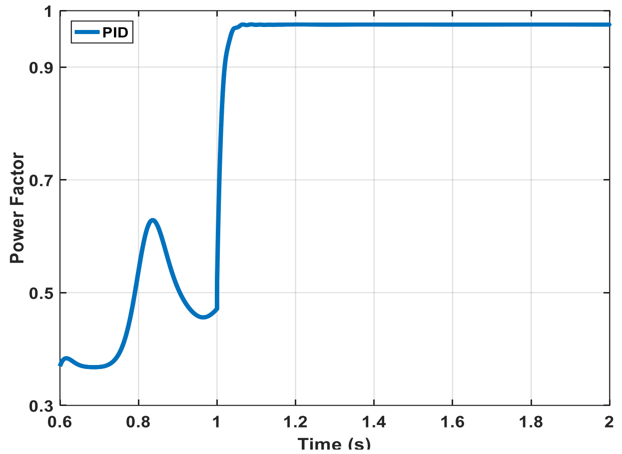

Figure 13. Responses of PID against excitation current control system.

Power factor responses of both controllers based on the PSO-PID and PID controllers against excitation current control system in Figure 12 and Figure 13. Then optimal PID gain parameters were determined via PSO method, and PID controller designed via these two methods was applied to the excitation current control system. PSO parameters used in this study are as follows; As shown in Figure 12 and Figure 13, power factor of PSO-PID reached the intended power factor more quickly compared to that of the PID controller, and increased the stability of the system.

VI. CONCLUSION

In this study, the parameters of a PID controller were adjusted via PSO, which has been an iterative optimization method widely used in different disciplines in recent years, and conventional Z-N method, and these two methods were applied to the excitation current control system. PID gain parameters were calculated in for K_p, K_i and K_d values via PSO and Z-N methods, and power factor and error graphs were evaluated in terms of time. When the controller parameters were adjusted via PSO, the evolutionary optimization became simpler, less code lines were needed and the number of iterations was reduced. Therefore, reaction speeds of PSO based PID controller was better compared to ZN-PID controller. In addition, IAE was used as a performance criterion for the controller. Other criteria may be used to apply different PID gain parameters to a system. In conclusion, PSO based PID controller yielded better results when the system is analyzed in terms of control parameters such as rise time, settling time, overtime, steady state error and response speed.

REFERENCES

[1] R. Bayindir, M. Yeşilbudak, I. Colak, S. Sagiroglu, " Excitation Current Forecasting for Reactive Power Compensation in Synchronous Motors: A Data Mining Approach." *Machine Learning and Applications (ICMLA)*, 11th International Conference on, vol. 2, (2012).

[2] S.F. Mekhamer, M.E. El-Hawary, M.M. Mansour, M.A. Moustafa, S.A. Soliman, "State of the art in optimal capacitor allocation for reactive power compensation in distribution feeders," *Large Engineering Systems Conference on Power Engineering (LESCOPE 02)*, 2002.

[3] G. Bal, I. Çolak, "Reactive power compensator using constant capacitor and thyristor controlled reactor, "*Gazi University, Journal of Institute of Science and Technology*, vol. 8, No. 2, pp. 9-15. (1995).

[4] S. Sagiroglu, I. Colak and R. Bayindir, "Power factor correction technique based on artificial neural networks," *Energy Conversion and Management*, vol. 47, no. 18-19, pp. 3204-3215. (2006).

[5] I. Colak, R. Bayindir, "A novel dynamic reactive power compensator based on PIC," *Electric Power Components and Systems*, vol. 33, no. 8, pp. 861-876. (2005).

[6] M.M. Al-Hamrani, A. Von Jouanne, *A.* Wallace, "Power factor correction in industrial facilities using adaptive excitation control of synchronous machine," *Pulp and Paper Industry Technical Conference, Conference Record of the Annual*, pp.148–154, (2002).

Bu çalışma ASYU-2017 Konferansında sunulmuş ve sadece özet olarak
Bildiri Özetleri Kitabı (ISBN: 978-605-84722-8-0)'nda yayımlanmıştır.

[7] R. Bayindir, S. Sagiroglu and I. Colak, "An intelligent power factor corrector for power system using artificial neural networks," *Electric Power Systems Research*, vol.79, no.1, pp. 152-160, (2009).

[8] I. Colak, R. Bayindir and O.F. Bay, "Reactive power compensation using a fuzzy logic controlled synchronous motor," *Energy Conversion and Management*, vol.44, no.13, pp.2189-2204, (2003).

[9] V.Kamaraju, " Synchronous motors for reactive power compensation and power factor improvement," *Electrical Power Distribution System*, pp. 128-130, (2009).

[10] C. Li, J. Lian, " The Application on Immune Genetic Algorithm in PID Parameter Optimization for Level Control System," *IEEE International Conference on Automation and Logistics*, Jinan, China, pp. 782-786, (2007).

[11] H. Aygun, H .Demirel, "Comparison of PSO-PID, FLC and PID in a circulating fluidized bed boiler," *7th International Conference on Electrical and Electronics Engineering (ELECO)*, (2011).

[12] D. Karaboga, B. Akay, "Artificial Bee Colony (ABC) Algorithm on Training Artificial Neural Networks," .*IEEE 15th Signal Processing and Communications Applications, (SIU)* ,(2007).

[13] N. Pillay, P. Govender, "A particle swarm optimization approach for model independent tuning of PID control loops,"*AFRICON* 2007.

[14] Y. Luo, "The Controlling Parameters Tuning and its Application of Fractional Order PID Bacterial Foraging Based Oriented by Particle Swarm Optimization, "*IEEE International Conference on Intelligent Computing and Intelligent Systems*,vol. 1, pp. 4-7, (2009).

[15] G. Shabib, A.G. Moslem, A.M. Rashwan, "Optimal tuning of PID controller for AVR system using modified particle swarm optimization recent advance in neural networks, " *Fuzzy Systems and Evolutionary Computing*, pp. 104-110, 2005.

[16] W.D. Chang, S.P. Shih, " PID controller design of nonlinear systems using an improved particle swarm optimization approach, "*Department of Computer and Communication Journal*, (2010).

[17] R. Bayindir, S.Demirbas, O. Sesveren, " Design and implementation of an intelligent simulator for reactive power compensation, " *Journal of the Faculty of Engineering and Architecture of Gazi University*, vol. 23, no. 3, pp. 681-688, (2008).

[18] E. Irmak, R. Bayindir, A. Kose. "Design and experimental analysis of an advanced static VAR compensator with computer aided control, " *ISA Transactions,* Vol.64, pp.384-393,(2016).

[19] O. Sesveren , R. Bayindir, "An Intelligent Tool for ANN Based Power Factor Correction," *12th International Conference on Machine Learning and Applications (ICMLA)*, Vol.2 ,pp.218-223, (2013).

[20] R. Bayindir, I. Colak, E. Kabalci, A. Gorgun, "PID controlled synchronous motor for power factor correction",*International Conference on Power Engineering, Energy and Electrical Drives*, pp.408-412,(2009).

[21] A. Gani, O.F. Kececioglu, H.Acikgoz, C.Yildiz, M.Sekkeli, "A Study on Power Factor Correction Using Fuzzy Logic Excitation Control of Synchronous Motor,"*3rd International Conference on Advanced Technology & Sciences (ICAT'16)*, (2016).

[22] R. Bayindir, I. Colak, S.Sagiroglu, H.T. Kahraman, "Application of Adaptive Artificial Neural Network Method to Model the Excitation Currents of Synchronous Motors "*11th International Conference on Machine Learning and Applications (ICMLA)* (2012).

[23] H.Açıkgöz A. Gani, Ö.F. Keçecioglu, , M.Şekkeli, "Sıvı Sıcaklık Denetiminde PSO Tabanlı PID Denetleyicinin Başarımının İncelenmesi" *Otomatik Kontrol Ulusal Toplantısı* (TOK) (2014).

[24] J. Kennedy, R. Eberhart,. "Particle Swarm Optimization", *IEEE International Conference on Neural Networks,Perth, Australia, IEEE Servive Center, Piscataway*, NJ,1942-1948, (1995).

[25] T. Adel, C. Abdelkader, "A Particle Swarm Optimization approach for optimum design of PID controller for nonlinear systems," *International Conference on Electrical Engineering and Software Applications (ICEES*A), (2013).

[26] A. A. Partillo , M. Frye, C. Qian, "Particle swarm optimization for PID tuning of a BLDC motor," *IEEE International Conference on Systems, Man and Cybernetics (SMC)*, (2009).

Bu çalışma ASYU-2017 Konferansında sunulmuş ve sadece özet olarak
Bildiri Özetleri Kitabı (ISBN: 978-605-84722-8-0)'nda yayımlanmıştır.