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SINGLE PHASE STATIC REACTIVE POWER COMPENSATION WITH ADAPTIVE FUZZY-PID BY USING PLC

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Abstract- This paper presents the static reactive power compensator control (SVC) with fixed capacity- thyristor controlled reactor (FC-TCR) which is implemented as a single phase system. The application is observed in real-time with energy analyzer, and algorithms are designed and implemented by using programmable logic controller (PLC). The results obtained from adaptive fuzzy logic (FL) controlled PID and PID (Proportional Integral Derivate) control algorithms are compared and discussed.

Keywords: SVC, PID, FL, FC-TCR, Adaptive Fuzzy-PID.

I. INTRODUCTION

Inductive loads draw active and reactive components of power from the network. Active power component is used as the power doing the work in machines, while reactive power component is used to maintain magnetic field. In power transmission and distribution systems, reactive power transfer to the loads through distribution lines results in power losses in the lines, reduces line transmission and distribution capacity, and causes extra fuel consumption in electric power stations. Therefore, generating the required reactive power to be consumed by the loads in the load area is more economical compared transferring it from the electric power stations [1, 2].

In recent years with the increasing environmental and global concerns, cleaner, safer and renewable energy sources have become very important. Accordingly, power quality in electric power systems as a whole has come into prominence as well. In industrial applications and power utilities, for decades employment of reactive power compensators have become compulsory for better quality and efficient use of energy, to lower transmission losses, preventing voltage dips, hence less financial losses for the utilities and consumers [3].

In accordance with these developments, the use of semi-conductor based practices is increasing in addition to traditional reactive power compensators in reactive power compensator applications.

This study presents thyristor controlled reactor based SVC with adaptive fuzzy-PID algorithm which has been implemented by using PLC and PLC practices for reactive power compensation of single phase unbalanced loads in low voltage electric utilities.

SVCs are used in many industrial applications today primarily for reactive power compensation and voltage regulation. In power systems SVCs have many positive effects and with its' reactor and capacitor switched based devices one of the best and cheapest methods available for reactive power control in power systems and industrial applications [2].

II. SVC AND CONTROL

SVCs are connected in parallel to the reactive power generating devices with capacitive or inductive current output, which are adjustable in a way that enables the control of parameters of electric power systems. The SVCs can eliminate the power system surges effectively in voltage controlled conversions and maintain the stability of power systems.

An ideal SVC is defined as a controller without active and reactive power losses, which stays within the reference voltage limits and responses rapidly in the presence of system variations [3]. SVC systems are commonly used in iron and steel facilities such as arc furnaces and rolling mills. In power transmission systems, employment of SVCs enhances the transient state stability of transmission lines. SVCs are commonly used in wind-power plants as well. The use of SVCs in wind-power plants enhances the voltage stability and prevents voltage drops in transmission lines and possible shut down of wind power plants in the presence of system disturbances [4].

SVC systems provide effective results for the compensation of unbalanced loads. These systems offer high safety with static switching method [5].

A. FC-TCR Model

As can be seen in Figure 1, the FC-TCR type compensation basic circuit layout consists of a reactor which is adjustable with a thyristor connected in parallel to a fixed capacitor. By changing the firing angles of thyristors, the reactor current I_r, and therefore the amount of inductive reactive power is controlled [5].

In Figure 1, the required inductive reactive power can be obtained by varying the effective value of voltage (V), in turn the reactor current (I_r) which is applied to the reactor circuit.

In each half period (50 Hz, 10 ms), the total susceptance value of the system can be changed by controlling shut down delay of thyristor that switches inductance which is called as delay time or firing angle. The reactive power obtained in this way is much more sensitive than a traditional automatic reactive power control relay which switches on or off star or delta connected capacitor banks according to required reactive power in a three phase system [5].

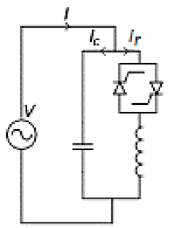


Figure 1. Basic FC-TCR circuit [5]

In the system while fixed capacitor produces capacitive reactive power, the thyristor controlled reactor produces inductive reactive power as required. As the capacitor draws a certain amount of capacitive current constantly, the inductive reactive power generation of the system is provided by changing firing angle of the reactor [4].

B. PID Control

PID control method is basically a control loop feedback mechanism that is commonly used in common industrial control systems [6]. In this method, the PID controller calculates the "error" value by finding the difference between a measured process variable and a desired setpoint over a period of time. The controller adjusts the process control input and executes the algorithm in order to minimize the error. Figure 2 shows the PID block diagram which is defined as three stage control algorithm where proportional is shown with P, integral is I, and derivative is indicated with D [6].

In the implementation of the algorithm, the changes in P, I, and D are considered intuitively, where P can be interpreted as present error, I the sum of past errors, and D can be taken as the prediction of future errors respectively [6].

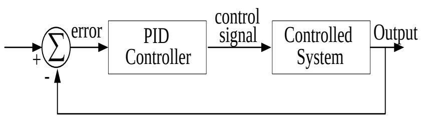
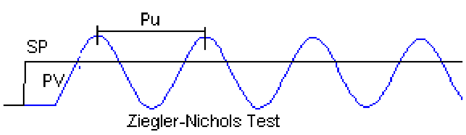


Figure 2. PID control block diagram [6]



	K	T_i	T_d
P Control	$K_u/2$	-	-
PI Control	$K_u/2.2$	$P_u/1.2$	-
PID Control	$K_u/1.7$	$P_u/2$	$P_u/8$

Figure 3. Ziegler-Nichols method PID parameters calculation table [8]

In this study the PID control block in PLC software is used for the realization of PID control. In PLC software the PID input and outputs are set as reactive power and firing angle of signal, respectively. In the implementation stage the PID control which is available in PLC software has been used for PID control. The PID input and outputs have been selected as reactive power and signal firing angle respectively and the PID has been set to "0 VAr". Figure 3 shows the Ziegler-Nichols method calculation table which has been used to calculate the PID parameters of the controller. In this process, initially the "I" and "D" parameters were set to zero. Then the "P" parameter was increased until the system starts oscillation. When the system starts oscillation the "P" value is called as "K_u", and oscillation frequency is called as "P_u" [9].

C. FL Control

The theory of Fuzzy Logic (FL) was first proposed in 1965 by Lotfi Zadeh which attempts to provide a way of mathematically expressing the uncertainty of information. FL is basically defined applying the human like thinking into a control system. FL control can be regarded as a way of converting linguistic control information to mathematical control information. It is able to simultaneously handle numerical data and linguistic knowledge and performs the control of a complicated system without the knowledge of its mathematical model.

FL differs from classical logic in that an object takes on a value of either zero or one. Whereas fuzzy sets provide a means of calculating intermediate values between absolute true and absolute false with resulting real value between 0 and 1, representing the degree to which an element belongs to a given set and can include linguistic variables, as such low, high, cold, hot, and very. FL deals with problems in engineering as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership [4, 10, 14].

Nowadays, FL expert systems are becoming widespread in many fields such as linear and non-linear control, sample recognition, financial systems, business researches and data analyses. Modelling, and even copying of many systems with the help of fuzzy logic systems enabled the developments in science and our daily lives. Fuzzy systems use both fuzzy logic algorithms and receptors measuring changing input conditions [11].

Figure 4 presents the flowchart of FL system. The FL defines a cluster that associates the all inputs with all outputs according to the rules of the system and that consists of overlapping areas. In this context, Fuzzy systems are similar to a mathematical cause and effect function or equation. These functions can be a set of rules that tell a micro-processor how to adjust the power of an air conditioner or the speed of a washing machine in accordance with the latest measurement [12, 13].

In this study reactive power is used as fuzzy input, and transferred to the PLC after having been transformed to 0-20 mA signal by energy analyzer. The angle of firing signals of thyristors is controlled as fuzzy-PID output which has been transformed to 0-20 mA signal with the help of PLC.

In fuzzy-PID controller the K_p, K_i and K_d gain parameters are continuously adjusted and updated by fuzzy controller according to response of the system rather than using fixed parameters in PID controller without any fuzzy inference. As can be seen in Figure 5, numerical equivalent of center of gravity (COG) of membership functions define the parameters of PID controller within the rules [10, 11].

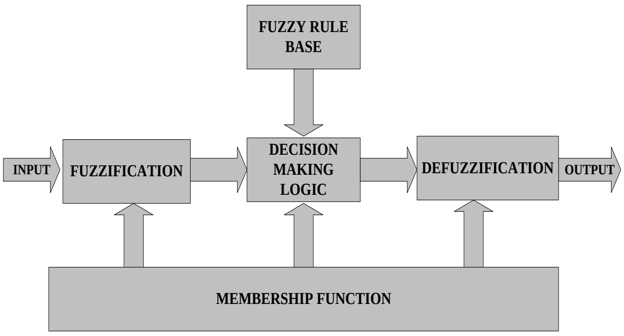


Figure 4. Basic fuzzy system block diagram [8]

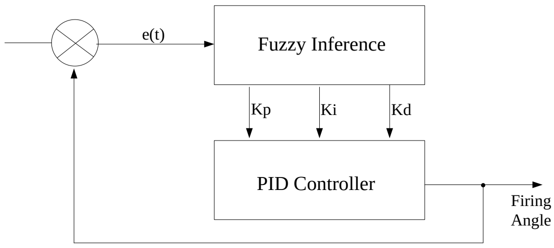


Figure 5. Fuzzy-PID block diagram

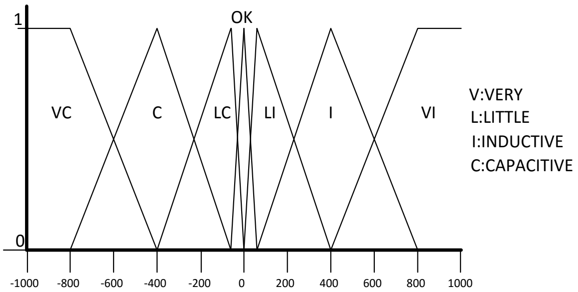


Figure 6. Reactive power-Fuzzy input membership function

Figure 6 shows the fuzzy input with seven-member triangle membership function [9]. Figures 7, 8 and 9 define the P, I, and D parameters as fuzzy output with four-member triangle membership function respectively [10, 14].

Rule statements are;

- If reactive power is VC (Very Capacitive) then P (Proportional band) is High.
- If reactive power is C (Capacitive) then I (Integral time) is Medium.
- If reactive power is LC (Little Capacitive) then D (Derivate time) is Low.

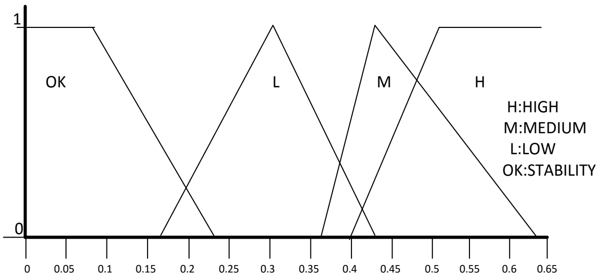


Figure 7. Proportional band Fuzzy output cluster membership function

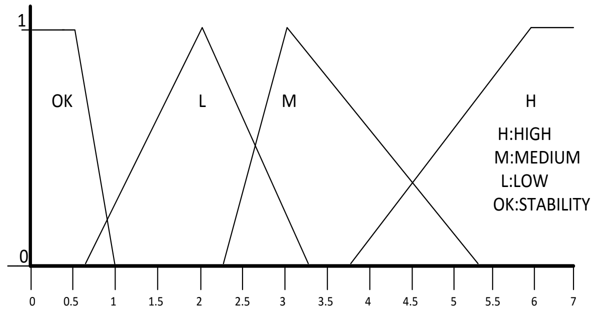


Figure 8. Integral Fuzzy output cluster membership function

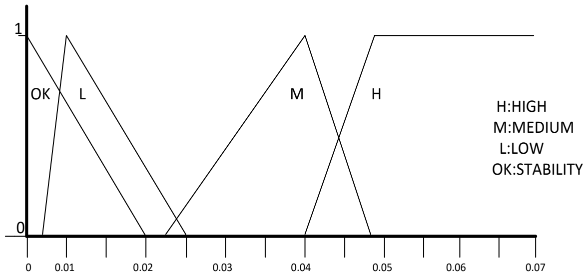


Figure 9. Derivative Fuzzy output cluster membership function

III. MATERIAL AND METHOD

A. Material

Figure 10 presents the designed single phase SVC system. The present study is conducted with ABB PM-571 PLC with 8 analogue input, 8 analogue output modules, 1 kVAr reactor, 0.5 kVAr capacitor, and energy analyzer that can measure until 51st harmonic, 15/5 A current transformer (CT) and 40 A reactor driver (ENDA) and a single phase 200 Watt asynchronous motor with a power factor of 0.6 lagging. By using Honeywell SymmetrE SCADA (Supervisory Control and Data Acquisition) program. The system was continuously monitored at real time with an interval of 1s [10].

B. Method

In FC-TCR circuit, a system which continuously monitors and controls the reactive power has been designed. The PID and FL algorithms have been executed on PLC and two different control methods are compared. CodeSys V2.3 programming editor has been used to write the PLC program. Figures 11 and 12 show sections from the PID control program which has been implemented in PLC. The FL control membership functions are defined by using function blocks within the PLC [11].

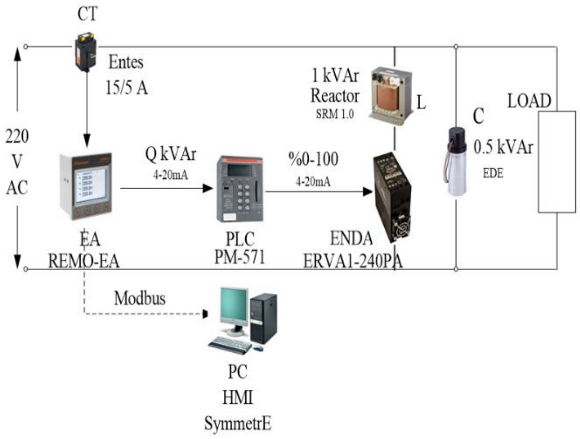


Figure 10. Designed SVC system

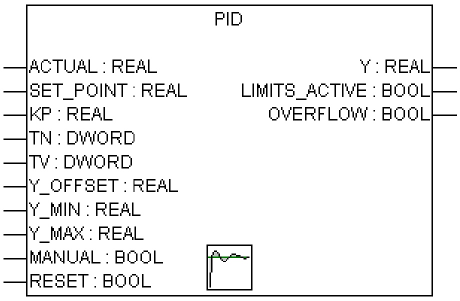


Figure 11. A section from PID control software

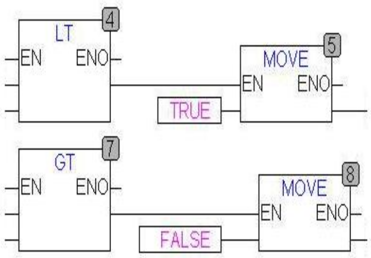


Figure 12. A section from Fuzzy-PID control software

IV. EXPERIMENTAL FINDINGS

The designed FC-TCR SVC system has been tested by loading it with a single-phase asynchronous motor. By using Honeywell SymmetrE SCADA program samples are taken out with an interval of 1 s by conducting PID and Fuzzy-PID control algorithms. The time-dependent changes in reactive power (*Q*) in real-time has been observed and given in graphical form in Figures 14 and 15.

The graphics show the "a" point where the load has been connected to the circuit, and "b" where it has been disconnected. The graphics both show that the reactive power remains close to zero with PID and Fuzzy-PID algorithm controls and reactive power stability could be achieved in both control algorithms. Table 1 presents the performance of both control methods.

As can be seen from Table 1, although both controllers have yielded better results, Fuzzy-PID controller has attained better forward overshoot, lower time of settlement, PID controller attained slightly lower back overshoot and relatively lower steady-state error.

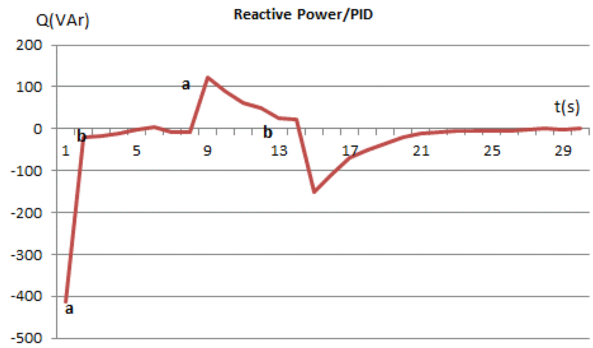


Figure 14. SVC system with PID control

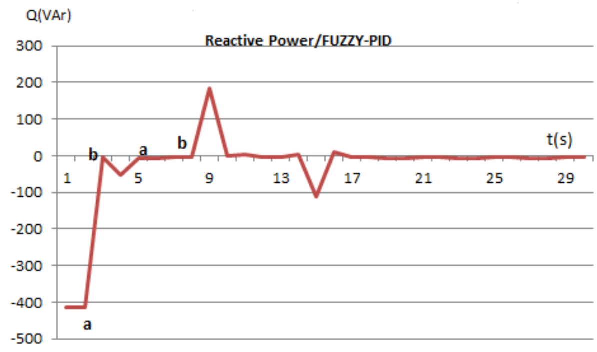


Figure 15. SVC system with Fuzzy-PID control

Table 1. SVC system PID and Fuzzy-PID control performance

Controller	PID Controller	Fuzzy- PID Controller
Forward Overshoot (VAR)	4.8 VAR	0 VAR
Back Overshoot (VAR)	-5.4 VAR	-6.4 VAR
Time of Settlement (s)	8 s	5 s
Steady-State Error (VAR)	-0.22 VAR	-4.55 VAR

V. CONCLUSION AND DISCUSSION

In this study a control system that can stable the system power factor at the desired level using SVC system with PID and adaptive Fuzzy-PID control algorithm that can be implemented in low voltage facilities is presented. The developed system adjusts the system power factor at desired level with SVC system and FC-TCR methods. In the implementation stage of the study, due to robustness, simplicity, low cost for data recognition and wide spread availability in industrial environment PLC has been preferred.

In the study by using Adaptive Fuzzy PID approach, according to the error of the system output the parameters of the PID controller are continuously self-adjusted and updated. Hence in industrial applications where the variations in error are considerable, adaptive fuzzy PID approach can be used as an alternative method to the classical PID controller with fixed parameters.

Although in reactive power control, similar stabilities are obtained from two different control methods, from the comparison of two methods it is seen that Fuzzy-PID control is faster, and had more steady-state errors with relatively lower forward and back overshoots compared to PID control algorithm. Fuzzy-PID offers a more stable performance and better results may be obtained by increasing the number of membership functions during the fuzzification.

REFERENCES

[1] T. Vardar, F. Yildirim, E. Cam, "New Generation Compensator System, SVC", Electrical Engineering Journal, Ankara, Turkey, Vol. 14-17, 2011.
[2] R. Arnold, "Solution to the Power Quality Problem", Power Engineering Journal, Vol. 15, pp. 65-73, 2001.
[3] O. Akgun, "Static VAR Compensator and Designed of Thyristor Controlled Reactor", Master Thesis, Science Institute, Nigde University, Turkey, Vol. 18, 2006.
[4] B. Mumyakmaz, K. Vardar, "Reactive Power Compensator Based on Fuzzy Control Design for Arc Furnaces", ELECO Symposium, 2002.
[5] C. Kocatepe, "Realization of Static VAR Compensation System for Reactive Power Compensation
[6] R. Amenedo, J.L. Alves, R. Arnaltes, S. Rios, "Improving Voltage Stability in a Wind Farm by using SVC", European Wind Energy Conference, p. 3 , 2004.
[7] M. Kiyan, "Thyristor Controlled Reactor Implementation of Low Voltage Reactive Power Compensation", Master Thesis, Science Institute, Hacettepe University, Ankara, Turkey, p. 20, 2010.
[8] A. Karabegovic, Z. Avdagic, M. Ponjavic, "Applications of Fuzzy Logic in Geographic Information Systems for Multiple Criteria Decision Making", www.gis.ba, Tuzla, Bosnia and Herzegovina, 2015.
[9] H. Kuscu, "Automatic Control Course Notes", Trakya University, Turkey, Vol. 3, 2009, http://hilmi.trakya.edu.tr/der_notlari/Otomatik_kontrol/Otomatik_Kontrol_6_PI.pdf.
[10] Y. Dogrul, Y. Aslan, "The Static Reactive Power Compensation with Different Algorithms by Using PLC", ELECO Symposium, pp. 115-119, 27-29 November, 2014.
[11] Y. Dogrul, Y. Aslan, "Real Time PLC Control of Single Phase Static VAR Compensator with PID and Fuzzy-PID", 11th International Conference on Technical and Physical Problems of Electrical Engineering (ICTPE-2015), Number 24, pp. 109-113, 10-12 September 2015.
[12] I. Guler, A. Tunca, E. Gulbandilar, "Detection of Traumatic Brain Injuries Using Fuzzy Logic Algorithm", Expert Systems with Applications, Vol. 34, pp. 1312-1317, 2008.
[13] M. Alci, E. Karatepe, "Fuzzy Logic and Matlab Applications", Ege University Publications, Turkey, p. 118, 2010.
[14] H. Kurt, Y. Aslan, "Optimization of Power Output of a Micro-Hydro Power Station Using Fuzzy Logic Algorithm", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 14, Vol. 5, No. 1, pp. 138-143, March 2013.
[15] N.M. Tabatabaei, A. Jafari, N.S. Boushehri, "A Survey on Reactive Power Optimization and Voltage Stability in Power Systems", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 18, Vol. 6, No. 1, pp. 220-233, March 2014.

BIOGRAPHIES

Yalcin Dogrul was born in Kutahya, Turkey, 1982. He received the B.Sc. degree from Marmara University, Istanbul, Turkey in 2004. He started M.Sc. degree in Department of Electrical Engineering, Dumlupinar University, Kutahya, Turkey in 2011. Currently, he works as a Technical Manager at Tourism Facility, Turkey. His research interests are fuzzy logic, programmable logic controllers, renewable energy and SCADA systems.

Yilmaz Aslan was born in Trabzon, Turkey, 1965. He received the B.Sc. degree in Electrical Engineering in 1986 and the Ph.D. degree in Electrical Engineering from University of Bath, UK, in 1997. Currently, he is an Associate Professor at Electric and Electronic Engineering Department, Dumlupinar University, Kutahya, Turkey. His research interests are analysis of shunt faults in power systems, load forecasting and renewable energy.