ANFIS Based Firing Angle Control of TSC-TCR for Reactive Power Compensation

Istiyo Winarno, Mochamad Ashari and Heri Suryoatmojo
Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.
Universitas Hang Tuah, Surabaya, Indonesia.
istiyo.winarno@gmail.com

***Abstract*—Reactive Power Compensation is an interesting topic to discuss especially in power quality improvement scheme. The compensation is needed in purpose of compensating the reactive power affected by varied loads in the electric system. The appropriate amount of compensation could be achieved by triggering the TSC-TCR with an appropriate firing angle. This paper proposed the firing angle control strategy based on ANFIS. The results show that proposed controller could give the satisfaction result of the power system's need of reactive compensation with the average percentage error is 0.3796. Therefore, it can be used effectively in the TSC-TCR which already exists in the power system.**

***Index Terms*—Reactive Power Compensation; ANFIS, Firing Angle; TSC-TCR.**

I. INTRODUCTION

Reactive Power Compensation is one of the most interesting topics to discuss in the power quality improvement scheme. Reactive power compensation could be defined as how to manage the reactive power in order to improve the power system performance. In modern industry, a large number of varied loads are attached into the electric power system. These loads could produce the reactive power, positive or negative reactive power. Therefore, the electric system requires the reactive compensation in order to manage this condition.

The compensation devices and controlling technologies are already discussed [1] - [6]. Another control method studied in [7], which discuss the firing angle control of Asymmetric Cascaded Multilevel Inverter. The thyristor Switch Capacitor-Thyristor Controlled Reactor (TSC-TCR) is a Static Var Compensator (SVC) device that could give the negative and positive reactive power compensation simultaneously, depend on the loads condition. The exact value of firing angle of TSC-TCR is needed to produce the reactive power compensation appropriately [8]. Electromagnetic waves in a specified band of frequency for all incident angles and all polarization states are mentioned in [2]. As they are designed to prevent the propagation of a designated bandwidth of frequencies acting like filters, they can be used to reduce EMI that is generated from applications circuitry or to decrease the antenna coupling to enhance its performance.

This paper proposed the Adaptive Neuro-Fuzzy Inference System (ANFIS) as a control strategy for TSC-TCR firing angle control. The simulation results are obtained and verified. The proposed controlling method could overcome the reactive power compensation problems.

II. THE THYRISTOR SWITCHED CAPACITOR – THYRISTOR CONTROLLED REACTOR (TSC – TCR)

Static Var Compensator (SVC), according to its name, could be defined as the static device that produces reactive power (Var) for the purpose of compensating the reactive power produced by the attached loads. TSC-TCR is one type of SVC. It consists of n TSCs branches, where n = 1, 2, 3, … is the number of TSCs circuits in operation, and a single TCR that are parallel connected. The general configuration of TSC-TCR is shown in Figure 1.

The electric parameter of TCR, susceptance (B), is used in the calculation. The TCR susceptance, BTCR is given by Equation (1).

$$B_{TCR}(\alpha) = B_{\max}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha\right) \tag{1}$$

where

$$B_{\max} = \frac{1}{\omega L} \tag{2}$$

The conduction angle σ is related to the firing angle α by

$$\alpha + \frac{\sigma}{2} = \pi \tag{3}$$

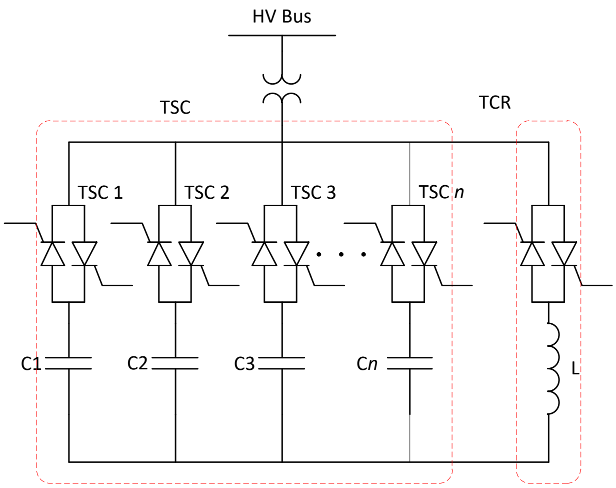

Figure 1: General TSC-TCR configuration

The variation value of B_{TCR} as a function of firing angle α is depicted in Figure 2. A variable susceptance of TCR which produced by the variation of firing angle changes the fundamental-current, which affect a variation of reactive power absorbed by TCR.

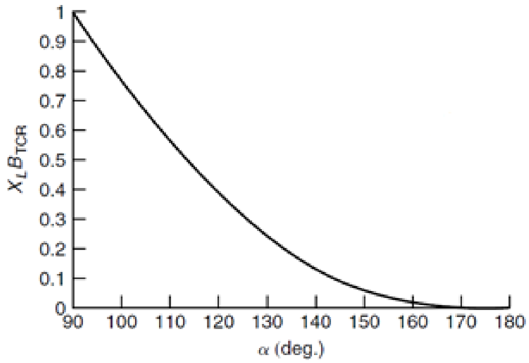

Figure 2: TCR susceptance characteristic

The compensator susceptance, B_{SVC}, is given by

$$B_{SVC} = \frac{B_\sigma (B_C + B_{TCR})}{B_\sigma + B_C + B_{TCR}} = \frac{1}{1 + \frac{B_C + B_{TCR}}{B_\sigma}} (B_C + B_{TCR}) \quad (4)$$

where B_σ is the B_{TCR} susceptance which varies from 0 to B_L, according to the firing angle from 180° to 90°. From Equation (4), the susceptance limits can be calculated. Susceptance at capacitive mode (production) limit obtained when $B_{TCR} = 0$ ($\alpha = 180°$), is calculated by

$$B_{SVC\max} = \frac{B_\sigma B_C}{B_\sigma + B_C} \quad (5)$$

Susceptance at inductive mode (absorption) limit obtained when $B_{TCR} = B_L$ at $\alpha = 90°$, is given by

$$B_{SVC\min} = \frac{B_\sigma (B_C + B_L)}{B_\sigma + B_C + B_L} \quad (6)$$

It must be remembered that BL is a negative quantity [8].

III. Adaptive Neuro-Fuzzy Inference System (ANFIS)

The Adaptive Neuro-Fuzzy Inference System (ANFIS) was introduced by Roger Jang in 1993 [9]. It is a control strategy that combines Fuzzy Logic Controller and Neural Network. ANFIS has equivalent characteristics and functions with Fuzzy Inference systems but has equivalent structure with Adaptive Network. The given inputs transformed by Fuzzy Logic into a desired output by utilizing interconnected Neural Network to map the input elements to output elements. ANFIS basic configuration is shown in Figure 3, a circle indicates a fixed node, and a square indicates an adaptive node.

ANFIS architecture is presented by two basic fuzzy Sugeno's IF-THEN rules, as describe in [10]

Rule$_{(1)}$ = ***IF*** *x is* A_1 ***AND*** *y is* B_1, ***THEN*** $f_1 = p_1 x + q_1 y + r_1$

Rule$_{(1)}$ = ***IF*** *x is* A_1 ***AND*** *y is* B_1, ***THEN*** $f_1 = p_1 x + q_1 y + r_1$

where :
- x and y are the inputs
- A_i and B_i are the fuzzy sets
- f_i are the outputs, and
- p_i, q_i and r_i are the design parameters

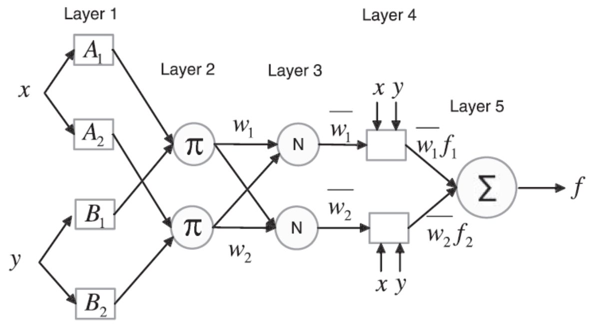

Figure 3: ANFIS basic configuration

Reference [10] explained several features that enable ANFIS to achieve great success in implementations. The training process involves mapping inputs and outputs through its membership functions respectively. The training data trained with Neural Network algorithm in order to achieve the relationship between input and output. Root Mean Square Error (RMSE) as defined in Equation (7) is used to monitor the training errors.

$$RMSE = \sqrt{\frac{1}{N} \sum_{j=1}^{N} \left(y_j - \hat{y}_j\right)^2} \quad (7)$$

where N is the total number of prediction, $\hat{y}_j$ is the predicted time series, and y_j is the original series.

IV. Simulation

The model of proposed system with the complete configurations: power source, transmission line, power load and the compensator with the ANFIS controller are shown in Figure 4.

The input of ANFIS controller is reactive power of the load (QLoad) and the output of ANFIS is firing angle (□) which used for triggering TSC-TCR. The reactive power of TSC-TCR could be negative or positive, in other words TSC-TCR could absorb or produce reactive power. The variation of power loads are simulated in different conditions to represent the real condition of the system as described in Table 1. The Load VI configuration simulates the condition where several loads removed from the system simultaneously.

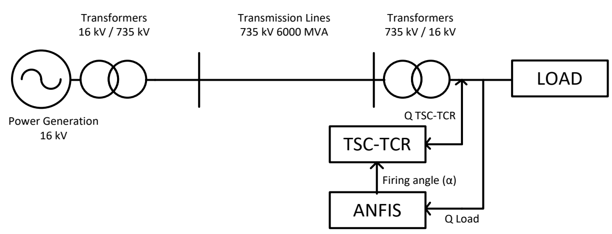

Figure 4: Simulation configuration of proposed system

ANFIS structure of the proposed controller designed with 1 (one) input, 10 (ten) membership functions and 1 (one) output. Reactive Power of the load (Q_Load) used as the input and Firing Angle of the TSC-TCR (Alpha) as the output. Input and output data pair in Table 2 is used for ANFIS training process. ANFIS model structure of the proposed controller depicted in Figure 5.

Table 1
Load Configurations

Configurations	Time	Loads
Load I	0 s – 0.1 s	no load
Load II	0.1 s – 0.6 s	P=200 MW; Q=-94MVar
Load III	0.6 s – 1.0 s	Load II configuration + P=200 MW; Q=140MVar
Load IV	1.0 s – 1.4 s	Load III configuration + P=200 MW; Q=140 MVar
Load V	1.4 s – 2.0 s	Load IV configuration + P=200 MW; Q=110 MVar
Load VI	2.0 s – 3.0 s	Load III configuration

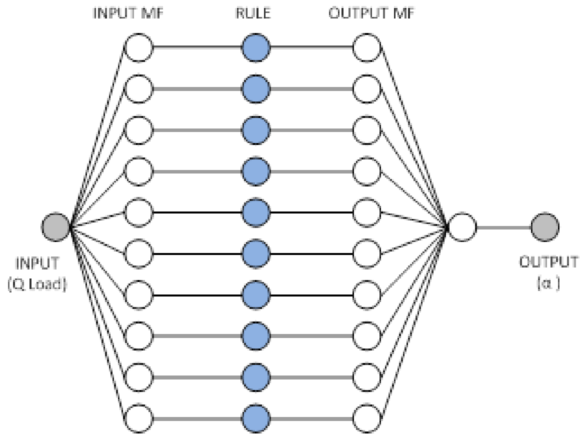

Figure 5: ANFIS model structure

The performance of the proposed system will be investigated by comparing it with another control method, Neural Network [3].

V. Results and Discussions

The simulation results of the proposed controller with the various load conditions, as described in Table 1, will be explained. The TSC-TCR at Configuration Load I, with no load conditions, gives no compensation, because at this configuration there is no reactive power needs to be compensated. Load II configuration provides -91.08 MVar reactive power to the system, therefore the compensator should produces 91.08 MVar as compensation. ANFIS controller trigger the TSC-TCR with α = 95.35° and no TSC set ON. TSC-TCR provides 91.24 MVar as compensation, that percentage error equal with 0.1757%.

The reactive power produced by Load III configurations is 41.84 MVar. It means that -41.84 MVar reactive power compensations needed to be injected to the system. The proposed control system gives the result: 1 TSC in ON conditions, TCR's firing angle is 105.6°. By this condition, -42.02 MVar produced by the TSC-TCR as the reactive power compensation, and it affected the reactive power of the system equal with -0.1827 MVar. The percentage error for this load configuration is 0.4302%.

Load IV configuration provides 155.7 MVar reactive power injected to the system, therefore the compensator should produces -155.7 MVar as reactive power compensation. ANFIS controller trigger TCR with □ = 120.8□ and 2 TSCs set ON. The TCR provides 12.35 MVar and TSC provides -169.1 MVar as compensation, that percentage error equal with 0.7069% and reactive power of the system equal with -1.069 Mvar.

Table 2
Training Data

Data	Q Load (MVar)	Alpha (°)	Data	Q Load (MVar)	Alpha (°)
1	-5.813	128.0	11	-63.94	102.0
2	-11.63	122.0	12	-69.90	100.5
3	-17.46	119.0	13	-75.45	99.0
4	-23.26	116.0	14	-81.37	97.5
5	-29.12	113.5	15	-87.29	96.0
6	-34.96	111.5	16	-93.23	95.0
7	-40.69	108.9	17	-99.17	94.0
8	-46.57	107.0	18	-104.40	92.5
9	-52.32	105.0	19	-110.30	91.0
10	-58.13	103.5	20	-116.20	90.0

The reactive power produced by Load V configurations is 223.1 MVar. It means that -223.1 MVar reactive power compensations needed to be injected to the system. The proposed control system gives the result: 3 TSCs in ON conditions, TCR's firing angle is 127.2°. By this condition, -223.5 MVar produced by the TSC-TCR as the reactive power compensation, with 6.157 MVar provided by TCR and -229.7 Mvar provided by TSC. It affected the reactive power of the system equal with -0.425 MVar. The percentage error for this load configuration is 0.1793%. Load VI configuration simulates the load shedding conditions, where the load set back to Load II configuration. The complete result for all load configurations depicted and summarized in Figure 6 – Figure 8 and Table 3.

The proposed control system's performance will be investigated by comparing it with Neural Network based control method. Figure 9 shows the comparison results of the two control methods for Load I configuration. The ANFIS control method provides better result than the Neural Network control method. It clearly depicted that ANFIS control method achieve the steady state conditions at 0.4538 second while NN control method at 0.6 second. The comparisons of all Load configurations are depicted in Figure 10.

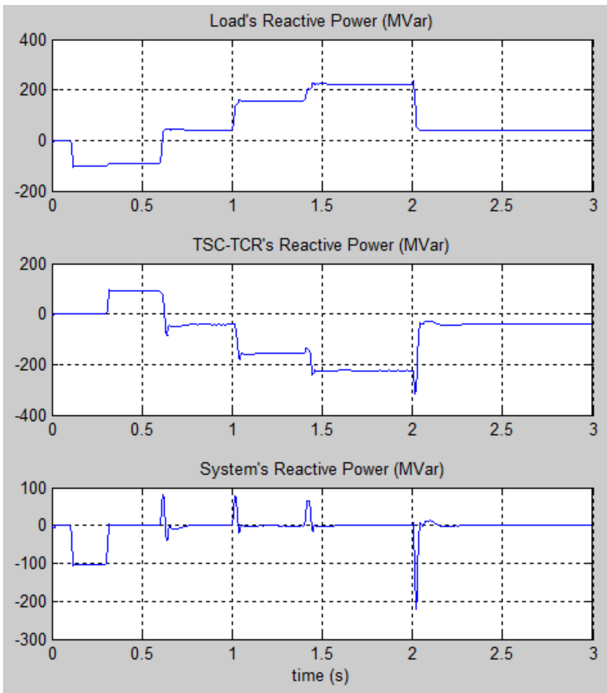

Figure 6: Reactive power results

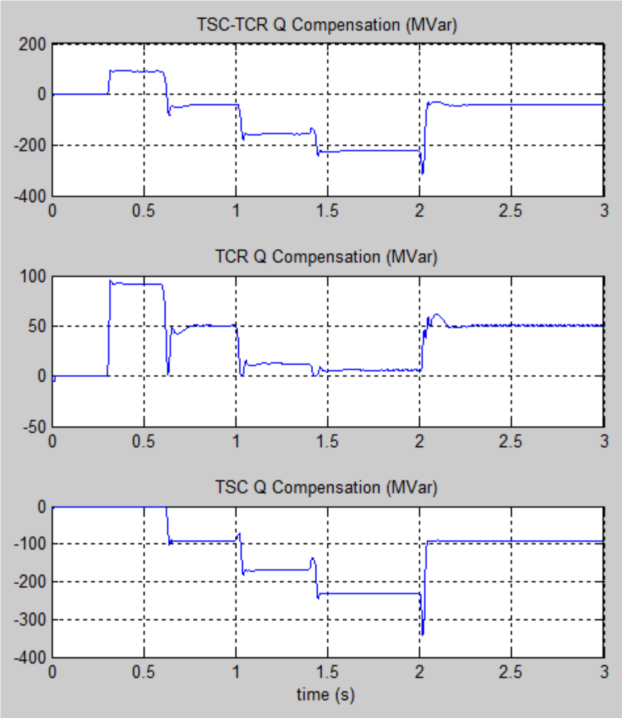

Figure 7: Reactive power compensations

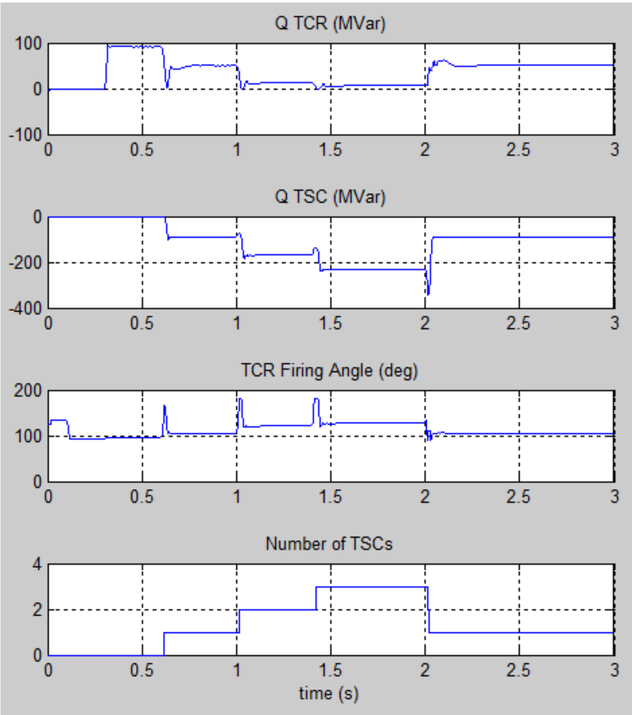

Figure 8: TSC-TCR control state

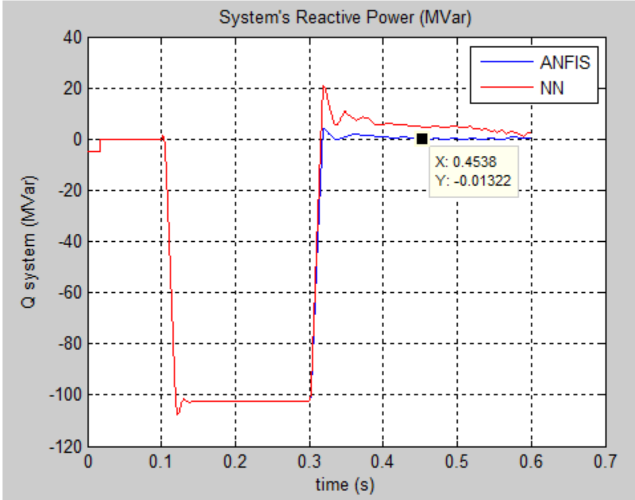

Figure 9: Comparison of system's reactive power Load I

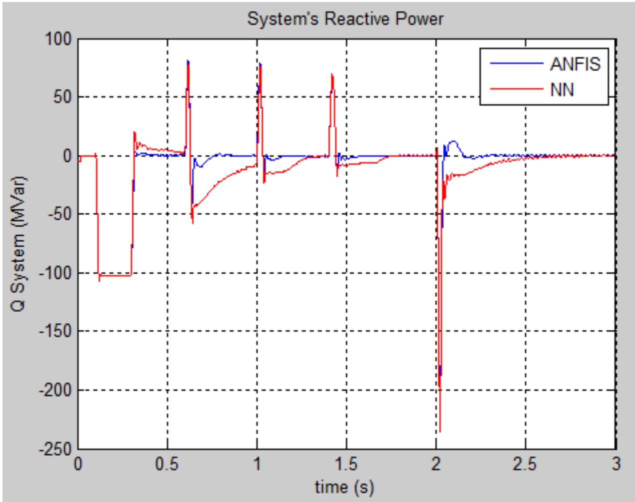

Figure 10: Comparison of system's reactive power

VI. CONCLUSION

This paper proposed ANFIS based firing angle of TSC-TCR for reactive power compensation. The TSC-TCR could provide the appropriate value of reactive power compensation by setting the firing angle of the thyristor in exact value. The proposed controller, ANFIS control method, could give better results compare with Neural Network control method in providing the firing angle of the TSC-TCR. As a result for Load Configuration I, the system's reactive power could achieve the steady state conditions at 0.4538 second, while NN control method at 0.6 second. From the results, it could be concluded that the ANFIS based firing angle control method could be used effectively in the TSC-TCR in purpose of reactive power compensations.

REFERENCES

[1] Dixon J., Moran L., Rodriguez J. and Domke R., 2005. Reactive power compensation technologies: State-of-the-art review, Proc IEEE, 93: 2144-2164,

[2] Gyugyi L., 1979. Reactive power generation and control by thyristor circuits, IEEE Trans. Ind. Appl., 5, 521-532,

[3] Bayindir R., Sagiroglu S. and Colak I., 2009. An intelligent power factor corrector for power system using artificial neural networks, Electr. Power Syst. Res., 79:152-160,

[4] Dalci K. B., Uzunoglu M. and Kucukdemiral I. B., 2004. Genetic algorithm based optimal self-tuning fuzzy logic controller for power system static VAR stabiliser," Int J Electr Eng Educ, 41:71-89,

[5] Colak, I. Bayindir R. and Bay, Ö. F. 2003. Reactive power compensation using a fuzzy logic controlled synchronous motor, Energy Conversion and Management, 44:2189-2204,

[6] Kulkarni D. and Udupi G., 2009. Optimum switching of TSC-TCR using GA trained ANN for minimum harmonic injection, in 2009 2nd International Conference on Emerging Trends in Engineering and Technology (ICETET), , 527-532.

[7] Sujanarko B., Ashari M. and M. H. Purnomo, 2010. Universal Algorithm Control for Asymmetric Cascaded Multilevel Inverter, International Journal of Computer Applications 8:0975–8887

[8] Mathur R. M. and Varma R. K., 2002. Thyristor-Based FACTS Controllers for Electrical Transmission Systems. John Wiley & Sons

[9] Jang J. R., 1993. ANFIS: adaptive-network-based fuzzy inference system, Systems, Man and Cybernetics, IEEE Transactions on, 23:665-685,

[10] Al-Hmouz, A., Shen, J., Al-Hmouz R., and Yan J., 2012. Modeling and simulation of an Adaptive Neuro-Fuzzy Inference System (ANFIS) for mobile learning, Learning Technologies, IEEE Transactions on, 5:226-237.

Table 3
Complete Simulation Results with ANFIS based Firing Angle Control

Configurations	QLoad (MVar)	QTSC-TCR (MVar)	QSystem (MVar)	QTCR (MVar)	QTSC (MVar)	Alpha (deg)	Number of TSCs	Perc. Error (%)
Load I	0	0	0	0	0	-	0	-
Load II	-91.08	91.24	0.161	91.31	-0.07	95.35	0	0.1757
Load III	41.84	-42.02	-0.1827	50.08	-92.09	105.6	1	0.4302
Load IV	155.7	-156.8	-1.069	12.35	-169.1	120.8	2	0.7065
Load V	223.1	-223.5	-0.4251	6.157	-229.7	127.2	3	0.1793
Load VI	41.84	-42.01	-0.1813	50.08	-92.09	105.6	1	0.4063