

# Voltage Regulation of Non Linear Load Using STATCOM with Fuzzy Technique

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**Abstract:** In distribution systems, sudden change in load draws non-sinusoidal currents and causes the load harmonics, excessive neutral currents creates disturbance and changes in Power factor. Static Synchronous Compensator (STATCOM) is used to provide reactive power to the transmission line. In this paper proposes with Fuzzy Logic Controller (FLC) to tune PI controller gain values under different operating condition. Tuned values operate with PI controller and provides gate signal to voltage source converter which decides amount of reactive power to be injected into bus. Power factor value also improved. This method not affected by the initial gain settings, changes of system conditions and produces better and desired response. By providing reactive power and power factor correction system performance increased and also improves voltage regulation.

**Keywords:** Fuzzy logic controller, PI controller, STATCOM, Voltage regulation, Power factor correction, Reactive power compensation, non linear load

## 1. Introduction

In the recent decade, the world's electric power supply systems are widely interconnected to have the advantages like sharing of sources, diversity of loads, reduced fuel and operating cost and improved reliability [1]. The interconnection of power systems have also created problems like low frequency electro-mechanical oscillations caused by electrical disturbances [2]. Recently, with the growth of nonlinear loads in industrial manufactures, the electric power quality plays major role in power transmission. Flexible ac transmission systems (FACTS) technology is a promising solution that can change natural electrical characteristics of the power systems to provide better transmission capability, power flow control, oscillation damping. The main function of a static synchronous compensator (STATCOM) is to regulate the voltages at the point of common coupling (PCC) in transmission and distribution systems. The main role of a STATCOM is to provide voltage support at critical points of a transmission system. Due to their high control bandwidth, static compensators (STATCOMs), based on three phase voltage source converters, have been proposed for this application. The static synchronous compensators do not require large energy storage units and, as a result, they are smaller in size. It has faster response speed and better robustness properties.

In the past control methods have been proposed for STATCOM control. References [4]–[11] mainly focus on the control design rather than exploring how to set proportional integral (PI) control gains. In many STATCOM models, the control logic is implemented with the PI controllers. The control parameters or gains are main key factor in STATCOM performance. Presently, few studies have been carried out in the control parameter settings. For instance, in [17]–[19], linear optimal controls based on the linear quadratic regular (LQR) control are proposed. This control depends on the designer's experience to obtain optimal parameters. A self-tuning proportional-integral (PI) controller gains are adapted using the particle swarm optimization (PSO) technique is

proposed for a static synchronous compensator (STATCOM). However, this method usually needs a long running time to calculate the controller gains. Thus, highly efficient results may not be always achievable under a dynamic operating condition.

Different from these previous works, the motivation of this paper is to propose a control method that can ensure a quick and consistent desired response when the system operating condition varied. Based on this fundamental motivation, STATCOM with PI controller tuned by fuzzy logic controller for voltage regulation is presented in this paper. With this adaptive method, the PI control parameters can be self-adjusted automatically and dynamically under different disturbances in a power system.

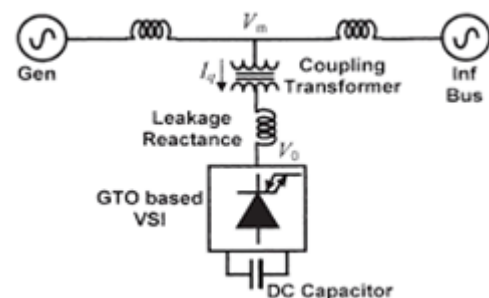


Figure 1: Equivalent Diagram of STATCOM

## 2. System Configuration

### 1.1 STATCOM

The STATCOM is a shunt-connected reactive-power compensation device that is capable of generating and or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system.

It provides system voltage support and stabilization by smooth control over wide range of operating condition. STATCOM consists of a three phase inverter (generally a

PWM inverter) using SCRs, MOSFETs or IGBTs. A DC capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the ac supply side, filter components to filter out the high frequency components due to the PWM inverter. During non-linear load condition STATCOM is used to provide reactive power to the load. Equivalent diagram of STATCOM shown in Figure 1. STATCOM is connected to the transmission line at the point of common coupling (PCC).

The instantaneous active and reactive power obtained as follow [1], [2] is given as

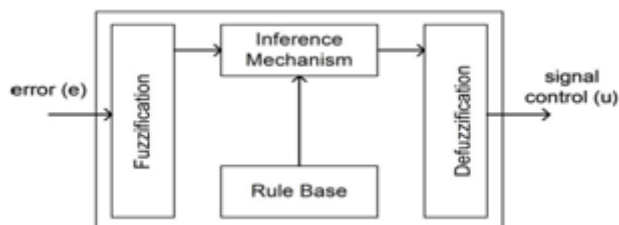
$$p_i = \frac{3}{2} V_{dl} i_{ds} \quad (1)$$

$$q_i = \frac{3}{2} V_{dl} i_{qs} \quad (2)$$

Based on the above equations, the traditional control strategy can be obtained. In the traditional STACOM phase locked loop (PLL) provides the basic synchronizing signal which is the reference angle to the measurement system. Measured bus line voltage is compared with the reference voltage, and the voltage regulator provides the required reactive reference current. The droop factor is defined as the allowable voltage error at the rated reactive current flow through the STATCOM. The STATCOM reactive current is compared with, and the output of the current regulator is the angle phase shift of the inverter voltage with regard to the system voltage. The limiter is the limit imposed on the value of control while considering the maximum reactive power capability of the STATCOM.

### 3. Fuzzy Logic Controller

In conventional techniques the gain value of the controller is fixed, hence the response is poor under dynamic condition. Fuzzy logic is a form of many-valued logic which deals with reasoning that is approximate rather than fixed and exact. It can apply to control systems and other applications in order to improve the efficiency and simplicity of the design process. Fuzzy logic controller is used to tune PI controller which provides gate signal to the voltage source converter. The block diagram of fuzzy logic control scheme is shown in Figure 2.

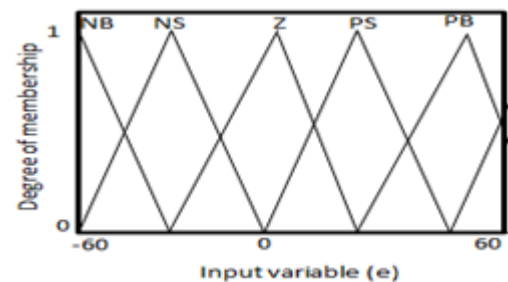


**Figure 2:** FLC control scheme

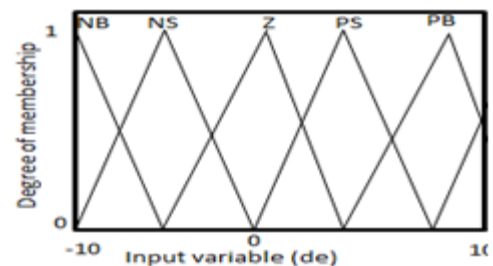
Fuzzy logic controller is composed of three parts: fuzzification, inference engine and defuzzification.

#### 1.2 Fuzzification

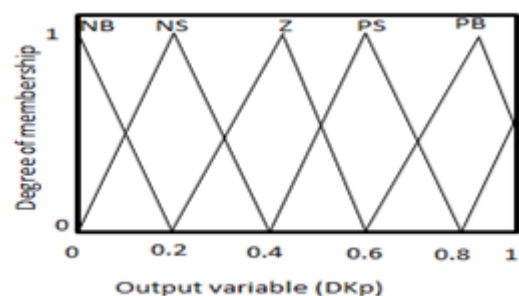
The values of membership function are assigned to the linguistic variables using five fuzzy subsets called negative big (NB), negative small (NS), zero (Z), positive small (PS), positive big (PB). Variables  $e$  and  $de$  are selected as input variables, where  $e$  is the error between the reference voltage ( $V_{ref}$ ) and the actual voltage ( $V_{act}$ ) of system;  $de$  is the change in error in the sampling interval. The output variable is the change in  $K_p$  and  $K_i$  values. Triangular membership functions (trimf) are selected for all these singletons. The membership functions of the variables error, change in error and change in  $K_p$  and  $K_i$  values are shown in Figure 3, 4 and Figure 5,6 respectively. The range of Error is limited between -60 and 60 volt. Change in error is limited between -10 to 10 Volt and change in  $K_p$  and  $K_i$  values between 0 to 1.



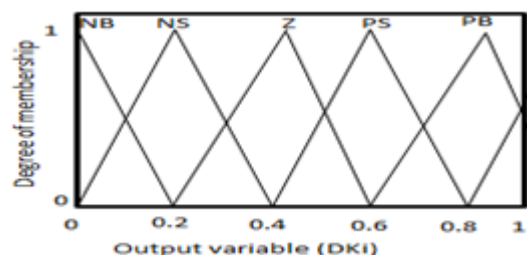
**Figure 3:** Membership function plots  $e$



**Figure 4:** Membership function of  $De$



**Figure 5:** Membership function plots  $DK_p$



**Figure 6:** Membership function plots  $DK_i$

### 1.3 Inference Engine

Inference engine mainly consists of two sub blocks namely, fuzzy rule base and fuzzy implication. The inputs which are now fuzzified are fed to the inference engine and the rule base is then applied. The rule base operates based on IF THEN RULES. For example, if error is NB and change in error is PB then change in Kp value output is NB. If error is NB and change in error value NS then output obtained as NS.

Rule base table formed based on human knowledge. Table I shows the rule base of fuzzy logic controller, where all the entries of the matrix are fuzzy sets of error (e), change in error (De) and output change in Kp values. In Table 2 also formed using e and De and output is Change in Ki. These rules are formulated in the membership function editor. The output fuzzy sets are then identified using fuzzy implication method.

**Table 1:** Rule base matrix for Kp

e/De	NB	NS	Z	PS	PB
NB	PB	NS	NB	NS	NB
NS	NB	PB	Z	NB	Z
Z	NB	Z	NB	PS	PB
PS	NS	NB	NB	PB	PB
PB	NB	Z	PB	NS	PB

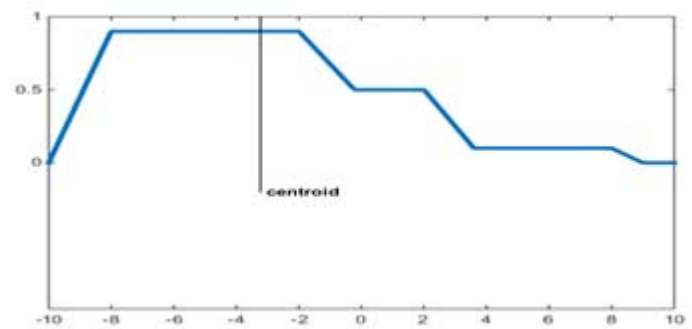
**Table 2:** Rule base matrix for Ki

e/De	NB	NS	Z	PS	PB
NB	NB	NS	NB	NS	PB
NS	NS	NB	Z	PB	Z
Z	NB	Z	NB	PS	Z
PS	NS	PB	NS	NB	PS
PB	PB	Z	NB	PS	NB

### 1.4 Defuzzification

After fuzzy implication, output fuzzy region is located. As the final desired output is a non-fuzzy value of control, a defuzzification stage is needed. Fuzzy values are again converted into crisp data process is known as defuzzification process.

Defuzzification has many techniques to convert fuzzy values to again crisp data. In adaptive Pi controller Centroid method is used for defuzzification in the proposed scheme. This is the most commonly used technique. The centroid defuzzification technique can be represented by using below Figure 7. After defuzzification tuned Kp and Ki values are fed to abc to dq0 transformation Iq value obtained. PLL (Phase locked loop) used for synchronization purpose. Finally firing angle value obtained.

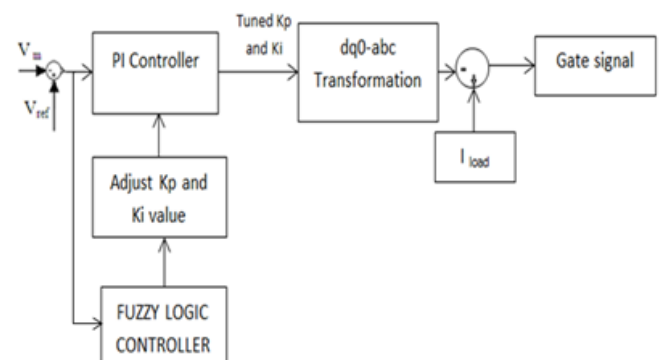


**Figure 7:** Centroid method

Advantages of FLC system are very robust, easily can be modified, use with multiple input and output sources and very easy and cost less to implement.

## 4. PI Controller with Fuzzy Technique

The STATCOM with fixed PI control parameters may not reach the desired and acceptable response in the power system when the power system operating condition (e.g., loads or transmissions) changes. In this project proposed with PI and fuzzy control method to achieve desirable response during dynamic condition. For this adaptive technology Fuzzy logic controller is used. PI and Fuzzy controller block diagram shown in Figure 8.



**Figure 8:** Block diagram of PI and Fuzzy controller

The process of the adaptive voltage-control method for STATCOM is described as follows.

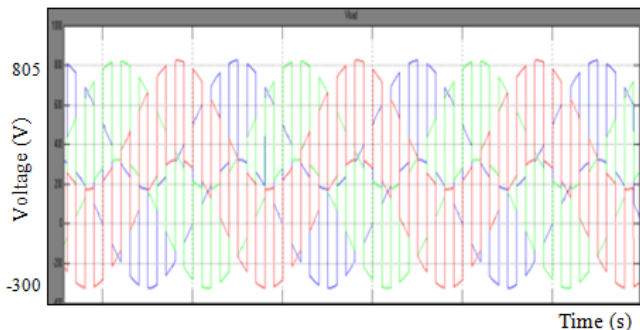
1. The bus voltage is measured in real time.
2. Measured bus voltage is compared with reference voltage, error value is calculated. Based on the desired reference voltage curve, and are dynamically adjusted in order to make the measured voltage match the desired reference voltage, and the axis reference current can be obtained.
3. In the inner loop, axis current is compared with the axis reference current. Using the similar control method like the outer loop, the parameters can be adjusted based on the error. Then, a suitable angle can be found and eventually the dc voltage in STATCOM can be modified such that STATCOM provides the exact amount of reactive power injected into the system to keep the bus voltage at the desired value. If one of the maximum or minimum limits is reached, the maximum capability of the STATCOM to inject reactive power has been reached.

The adaptive PI control process begins at Start. The bus voltage over time  $V_m(t)$  is sampled according to a desired sampling rate. Then,  $V_m(t)$  is compared with  $V_{ss}$ . If  $V_m(t) = V_{ss}$ , then there is no reason to change any of the identified parameters  $K_{p_v}(t)$ ,  $K_{p_i}(t)$ ,  $K_{p_l}(t)$  and  $K_{p_r}(t)$ . The power system is running smoothly. On the other hand, if,  $V_m(t) \neq V_{ss}$  then adaptive PI control begins.

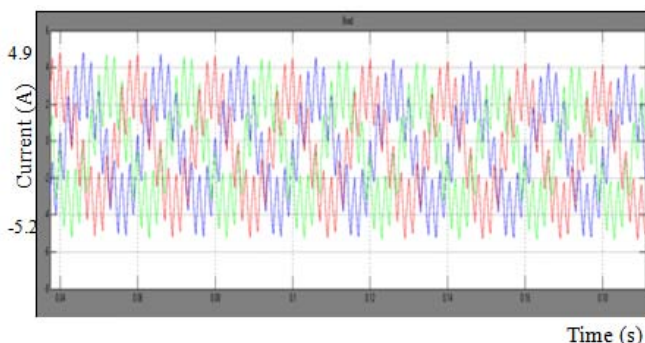
The measured voltage is compared with  $V_{ref}(t)$ , based on the error value  $K_{p_v}(t)$  and  $K_{p_i}(t)$  are adjusted in the voltage regulator block which leads to  $I_m$ . Then measured q- current compared with  $I_{qref}$  control gains  $K_{p_l}(t)$ ,  $K_{i_l}(t)$  are also adjusted. Then the phase angle  $\alpha$  is determined and passed through a limiter for output, which essentially decides the reactive power output from the STATCOM. STATCOM provides reactive power to the transmission line and using PI with fuzzy technique improves voltage regulation and system performance.

## 5. Simulation

Adaptive Pi method operated with fuzzy technique to tune controller parameter values based on dynamic condition. Fuzzy logic controller taken input as present and previous error values and proceeded with rule base table give tuned output of Kp and Ki values which in fed to corresponding PI controller. Tuned value processed in controller and produced tuned current output. This tuned value compared with load current error value obtained. The error output again compared with already injected system current provide gate signal.



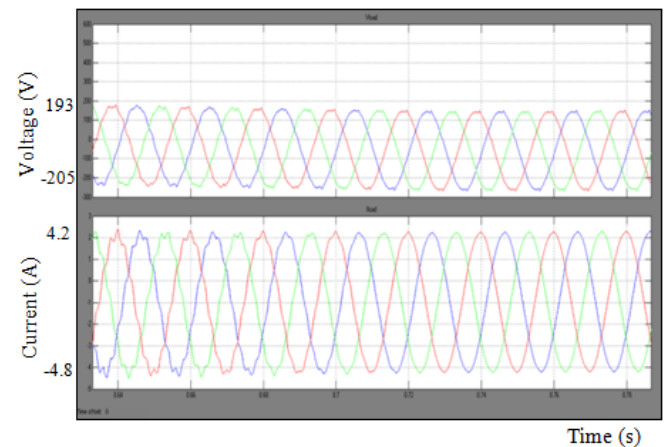
**Figure 9:** Results of Nonlinear load voltage



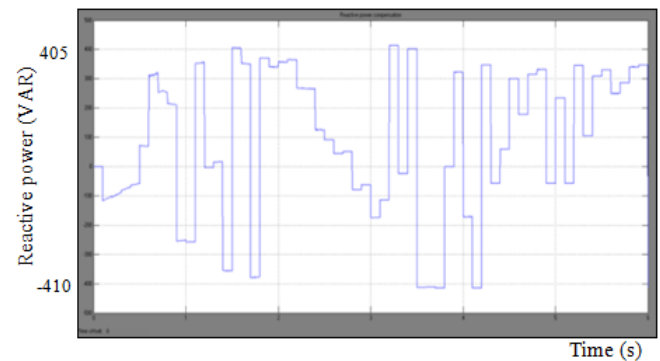
**Figure 10:** Results of Nonlinear load current

Based on gate signal given to thyristor decides amount of reactive power inject into bus. Simulation studies of the PI controller with Fuzzy Logic Controller have been carried out using MATLAB. In the original model, the compensating reactive power injection and the regulation

speed are mainly affected by PI controller parameters in the voltage regulator and the current regulator. When the original control will be compared with the proposed adaptive PI control model the initial gain settings are not affected.



**Figure 11:** Results of Nonlinear load with adaptive PI controller



**Figure 12:** Reactive power compensation waveform

For simulation universal bridge used as non linear load with 2200 micro farad capacitance, 100KΩ resistances. Line resistance and inductance values are 0.01Ω and 2 mille Henry. Load operates with 60Ω resistance and 0.1 mille Henry. At nonlinear load condition output waveform produced with some distortion. While using nonlinear load with Fuzzy PI controller, gain values are tuned based on disturbance and distortion to be compensate by providing proper reactive power using STATCOM. Nonlinear load voltage and current waveform shown in Figure 9 and 10 produced with some distortion. So Fuzzy PI controller used with non linear load and the corresponding waveform shown in Figure 11. Fuzzy PI controller provides Reactive power compensation waveform shown in Figure 12 and power factor correction. So the voltage regulation improved. Magnitude values are also shown in waveform.

Power factor improvement is very important consideration in power sectors. Because power factors below unity require a utility to generate more than the minimum volt-amperes necessary to supply the real power. Low power factor increases generation and transmission costs. By improving power factor and providing reactive power improves system performance. Power factor improvement shown in Table.3. Power factor correction also achieved using PI and Fuzzy controller. Using linear load, power



factor value achieved nearer to unity. But when load acts as nonlinear load leads to poor power factor (0.5118), by providing compensation power factor to be improved as 0.8355.

**Table 3: Power factor improvement**

<i>Load</i>		<i>Power Factor</i>
Linear load		0.9999
Non linear load	Without Fuzzy controller	0.5118
	With Fuzzy controller	0.8355

Using STACOM with PI and fuzzy controller can improve power factor to unity or closed to unity value. Load compensation consists of reactive power compensation, power factor correction and voltage regulation. So by achieve power factor correction and reactive power compensation voltage to be regulated. Overall system performance also increased.

## 6. Conclusion

Fuzzy controllers self-adjust the controller gain values dynamically during disturbances so that the performance always matches a desired response, regardless of the change of operating condition. Fuzzy logic technique used in PI controller which tune gain values. Simulation output shows that PI and Fuzzy control method gives power factor correction, reactive power compensation and voltage regulation. Fuzzy controller with fixed gain values not reach desired response when operating condition changes. So the output response is also poor. To address the challenge, this paper proposes a new control model based on fuzzy technique improves performance provide reactive power compensation and power factor correction achieved. By achieving these two factors voltage profile improved and overall system performance improved.

Future studies in Harmonic mitigation performed using STATCOM with PI control method and performance can be improved by ICOS algorithm.

## References

- [1] G. Hingorani and L. Gyugyi, "Understanding FACTS, Concepts, and Technology of Flexible AC Transmission Systems", Piscataway, NJ: IEEE Press, 2000.
- [2] A.A Edris, R Aapa, M H Baker, L Bohman, K Clark, "Proposed terms and definitions for flexible ac transmission system (FACTS)", IEEE Trans. on Power Delivery, Vol. 12, No.4, 1997, pp.1848-1853.
- [3] F. Li, J. D. Kueck, D. T. Rizy, and T. King, "A preliminary analysis of the economics of using distributed energy as a source of reactive power supply," Oak Ridge, TN, USA, First Quart. Rep. Fiscal Year, Apr. 2006, Oak Ridge Nat. Lab.
- [4] A. Jain, K. Joshi, A. Behal, and N. Mohan, "Voltage regulation with STATCOMs: Modeling, control and results," IEEE Trans. Power Del., vol. 21, no. 2, pp. 726–735, Apr. 2006.
- [5] D. Soto and R. Pena, "Nonlinear control strategies for cascaded multilevel STATCOMs," IEEE Trans. Power Del., vol. 19, no. 4, pp. 1919–1927, Oct. 2004.
- [6] F. Liu, S. Mei, Q. Lu, Y. Ni, F. F. Wu, and A. Yokoyama, "The non- linear internal control of STATCOM: Theory and application," Int. J. Elect. Power Energy Syst., vol. 25, no. 6, pp. 421–430, 2003.
- [7] C. Hochgraf and R. H. Lasseter, "STATCOM controls for operation with unbalanced voltage," IEEE Trans. Power Del., vol. 13, no. 2, pp. 538–544, Apr. 1998.
- [8] G. E. Valdarannma, P. Mattavalli, and A. M. Stankonic, "Reactive power and unbalance compensation using STATCOM with dissipativity based control," IEEE Trans. Control Syst. Technol., vol. 19, no. 5, pp. 598–608, Sep. 2001.
- [9] H. F. Wang, "Phillips-Heffron model of power systems installed with STATCOM and applications," Proc. Inst. Elect. Eng., Gen. Transm. Distrib., vol. 146, no. 5, pp. 521–527, Sep. 1999.
- [10] H. F. Wang, "Applications of damping torque analysis to statcom control," Int. J. Elect. Power Energy Syst., vol. 22, pp. 197–204, 2000.
- [11] Y. Han, Y. O. Lee, and C. C. Chung, "Modified non-linear damping of internal dynamics via feedback linearization for static synchronous compensator," IET Gen. Transm. Distrib., vol. 5, no. 9, pp. 930–940, 2011.
- [12] P. Rao, M. L. Crow, and Z. Yang, "STATCOM control for power system voltage control applications," IEEE Trans. Power Del., vol. 15, no. 4, pp. 1311–1317, Oct. 2000.
- [13] W. L. Chen and Y. Y. Hsu, "Controller design for an induction generator driven by a variable speed wind turbine," IEEE Trans. Energy Convers., vol. 21, no. 3, pp. 625–635, Sep. 2006.
- [14] K. Wang and M. L. Crow, "Power system voltage regulation via STATCOM internal nonlinear control," IEEE Trans. Power Syst., vol. 26, no. 3, pp. 1252–1262, Aug. 2011.
- [15] C.-H. Liu and Y.-Y. Hsu, "Design of a self-tuning PI controller for a STATCOM using particle swarm optimization," IEEE Trans. Ind. Electron., vol. 57, no. 2, pp. 702–715, Feb. 2010.
- [16] C. Schauder and H. Mehta, "Vector analysis and control of the advanced static VAR compensators," Proc. Inst. Elect. Eng., Gen., Transm., Distrib., vol. 140, no. 4, pp. 299–306, Jul. 1993.
- [17] K. K. Sen, "Static synchronous compensator— Theory, modeling and applications," presented at the IEEE Power Eng. Soc. Winter Meeting, Edmonton, AB, Canada, Jan. 1999.
- [18] H. Li, F. Li, Y. Xu, D. T. Rizy, and S. Adhikari, "Autonomous and adaptive voltage control using multiple distributed energy resources," IEEE Trans. Power Syst., vol. 28, no. 2, pp. 718–730, May 2013.
- [19] A. Luo, C. Tang, Z. Shuai, J. Tang, X. Y. Xu, and D. Chen, "Fuzzy PI based direct output voltage control strategy for the STATCOM used in utility distribution

systems,” IEEE Trans. Ind. Electron., vol. 56, no. 1, pp. 2401-2411, Jul.2009.

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