Hybrid PI-Fuzzy Controller Based Static Var Compensator for Voltage Regulation under Uncertain Load Conditions

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***Abstract*—This paper presents the voltage regulation strategy under uncertain load condition, using Hybrid PI-Fuzzy controller based Static Var Compensator. The Static Var Compensator could obtain the appropriate value of injected susceptance by triggering the thyristor of the SVC with proper firing angle. This proper firing angle could be acquired by Hybrid PI-Fuzzy control strategy. A series of connected simple PI controller and Fuzzy logic controller formed the Hybrid PI-Fuzzy controller. The simulations showed that this control strategy is capable to regulate the voltage under uncertain load. The proposed controller resulted in an average settling time of 0.1346 seconds for the first case and 0.1469 seconds for the second case. The conventional PI controller resulted in an average settling time of 0.188 seconds for the first case and 0.1702 seconds for the second case.**

***Index Terms*—Hybrid PI-Fuzzy Controller; Static Var Compensator; Voltage Regulation; Uncertain Load.**

I. INTRODUCTION

Voltage fluctuation is one of the most important things that needs to be noticed as the effect of industrialized world [1]. Voltage regulation could be defined as the capability of the system to maintain the system voltage at constant value. The voltage regulation strategies and control methods have been discussed in the previous research. First of all, energy conversion system had been modeled and simulated [2]. Voltage control could be carried out by on-load tap changer (OLTC) transformer [3,4]. This method controls the voltage based on a local voltage measurement. The simulated annealing method also could be used as the control strategy of voltage regulation [5]. The performance of the power system also could be achieved by network reconfiguration method. In order to optimize the network reconfiguration, extended fuzzy multi-objective algorithm had been implemented [6]. Besides functioning as a reactive power compensator, the Static Var Compensator could be operated as a voltage regulation device [7,8,9].

The problem of voltage regulation under uncertainty of loads could be solved by using mixed-integer nonlinear programming (MINLP) [10].

This paper proposed another voltage control algorithms, called the Hybrid PI-Fuzzy based Static Var Compensator as a voltage regulator. The basic concept of Hybrid PI-Fuzzy controller is the combination of a conventional PI controller and Fuzzy Logic controller, which is connected in cascade connection [11]. The objective of this control algorithm is to maintain the Point of Common Coupling's (PCC) voltage at voltage reference. Its ability to maintain could be obtained by selecting appropriate injected susceptance value at PCC due to loads variation. In this case, the static var compensator (SVC) acts as variable susceptance, in which its value could vary from a minimum designed value to maximum designed value. Hybrid PI-Fuzzy controller then drives the SVC with proper firing angle (α); hence, the SVC will generate the proper susceptance. The simulation showed that the proposed control strategy is capable of regulating the voltage at PCC under uncertain load conditions.

II. HYBRID PI – FUZZY CONTROLLER BASED SVC FOR VOLTAGE REGULATION

One of the objectives of Static Var Compensator (SVC) is for voltage regulation. The main concept of this objective is the implementation of Kirchoff's current law. Assuming that SVC is a variable susceptance, a proper value could be selected as needed. Figure 1 represents the general concept of voltage regulation by SVC. Power generation system is represented by an equivalent voltage source, V_s, while X_s represents the equivalent impedance of the systems. The equivalent impedance of the load is represented by Z_L, while B_{SVC} represents the susceptance of the SVC. The voltage bus at point common coupling is represented by V_{PCC} [12].

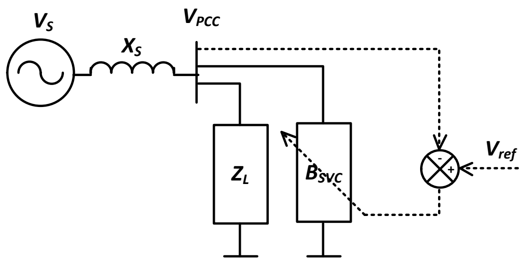

Figure 1: General Concept of Voltage Regulation by SVC

According to Figure 1, the PCC bus voltage is given by:

$$V_s = V_{PCC} + I_S X_S \quad (1)$$

while:

$$V_{PCC} = I_L X_L + \frac{I_{SVC}}{B_{SVC}} \quad (2)$$

where I_{SVC} is the current drown by SVC, I_L is load current and I_S is the system's current. From Equation (2), it could be noticed that the load changing will affect the V_{PCC}. In order to maintain the PCC voltage, the SVC's susceptance should be changed in appropriate value by controlling the firing angle of the SVC. The control strategy used in this paper is the Hybrid PI-Fuzzy controller.

Hybrid PI-Fuzzy Controller consists of two controllers, namely the conventional PI controller and Fuzzy Logic Controller, which are combined in cascade configuration[11]. The configuration has many advantages, such as obtaining the best gain parameters of the PI controller and the best membership function designed in the form of fuzzy controller; thus, providing a controller which has better response than either PI or fuzzy controller itself[13,14,15]. The block diagram of the Hybrid PI-Fuzzy Logic controller is depicted in Figure 2.

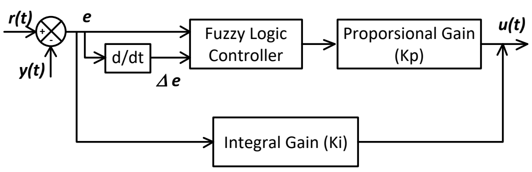

Figure 2: Hybrid PI-Fuzzy Logic Controller

III. SIMULATIONS

The simulations of the proposed control strategy have been conducted to verify the effectiveness of the method. Figure 3 shows the general configuration of the system. The system comprises power source with 16 kV of capacity, transmission line with 6000 MVA, distribution transformer, proposed voltage control strategy and load. The voltage control strategy could be obtained by controlling the reactive power of the system. The appropriate SVC's susceptance could be achieved by triggering the SVC with proper firing angle (α), carried out by Hybrid PI-Fuzzy Controller.

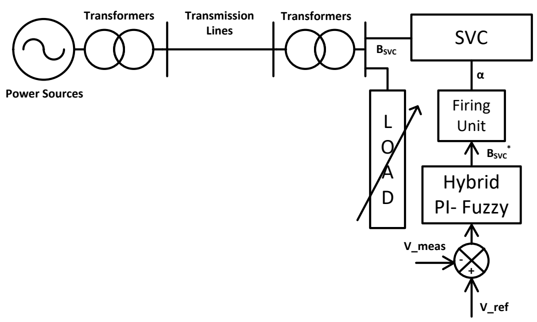

Figure 3: General Configuration of the Proposed Control Strategy

The two cases were simulated to determine the robustness and reliability of the control strategy. The first case represents uncertain load fluctuation with the apparent power S = 193.7 + j67.72 MVA at 0s – 0.5s; S = 379.7 + j90.15 MVA at 0.5s – 1.0s and S = 571.7 + j42.88 MVA at 1.0s – 1.5s. The second case represents load fluctuation with the apparent power S = 193.7 + j67.72 MVA at 0s – 0.5s; S = 396.5 – j29.72 at 0.5s – 1.0s and S = 581.6 – j4.83 MVA at 1.0s – 1.5s. The details of the uncertain load fluctuations are described in Table 1.

The Static Var Compensator, in this case is configured with one 100 MVar Thyristor-Controlled Reactor (TCR) and three 100 MVar Thyristor-Switched Capacitors (TSCs) which result in -100 MVar reactive power to +300 MVar. The proportional gain parameter (Kp) was set to 30 and the Integral gain parameter (Ki) was set to 2500. The Fuzzy Logic controller was designed with triangle membership functions for input and output function. Error and error change of the voltage was the input parameter of the Fuzzy Logic Controller and the susceptance of the SVC was the output parameter. Considering the use of 5-ruled input variables, there were 25 rules for the rule base of the Fuzzy Logic Controller. These 25-rule base will be described in Table 2. Figure 4 shows the Fuzzy Logic's membership function.

Table 1
Uncertain Load Configurations

First Case		Second Case	
Time (s)	Load (MVA)	Time (s)	Load (MVA)
0.0 – 0.5	193.7 + j67.72	0.0 – 0.5	193.7 + j67.72
0.5 – 1.0	379.7 + j90.15	0.5 – 1.0	396.5 – j29.72
1.0 – 1.5	571.7 + j42.88	1.0 – 1.5	581.6 – j4.833

Table 2
Rule Base of the Fuzzy Logic Controller

		error				
		NB	NS	ZZ	PS	PB
Δ error	NB	NB	NB	NS	NS	ZZ
	NS	NB	NS	NS	ZZ	PS
	ZZ	NS	NS	ZZ	PS	PS
	PS	NS	ZZ	PS	PS	PB
	PB	ZZ	PS	PS	PB	PB

Where NB is Negative Big, NS is Negative Small, ZZ is Zero, PS is Positive Small and PB is Positive Big.

The robustness and the reliability of the proposed control strategy was verified by comparing it with the conventional PI Controller which was set to 30 for the proportional gain parameter (K_p) and 2500 for the integral gain parameter (K_i). In this case, the performance was verified by checking its settling time.

IV. RESULTS AND DISCUSSIONS

This section discusses the simulation results of the proposed control strategy, which had been simulated in two cases, as described in the previous section.

A. First Case

The uncertain load condition affects the voltage at Point of Common Coupling (PCC). As described in Table 1, the load changed at 0.5s and 1.0s. The voltage variations affected by the uncertain load conditions is shown in Figure 5a). As the load changes at 0.5s, the voltage drops from 0.9835 p.u to 0.9741 p.u. The voltage rises from 0.9741 p.u to 0.9761 p.u as the load changes that occurred at 1.0s.

Figure 5(b) depicts the SVC's susceptance (BSVC), which was obtained by the Hybrid PI-Fuzzy Controller as the voltage changes the PCC. This BSVC was processed in the Firing Unit block, which then produced the appropriate firing angle (α) for triggering the SVC. The SVC absorbed or produced the reactive power according to the load condition. Figure 5(c) depicts the reactive power at PCC.

Figure 5(d) represents the voltage regulation capability of the control strategy. The voltage was regulated by Hybrid PI-Fuzzy control strategy for the first load condition, which had the settling time ts_1 = 0.1603s. The settling time for the second load condition was ts_2 = 0.1296s and for third load condition was ts_3 = 0.114s. Therefore, the average settling time for this control strategy was ts_{avg} = 0.1346s, while the conventional PI Control strategy had ts_1 = 0.1930s, ts_2 = 0.1881s and ts_3 = 0.183s. Therefore, the average settling time was ts_{avg} = 0.188s. The result showed that the proposed control strategy has better performance compare with the conventional PI control strategy.

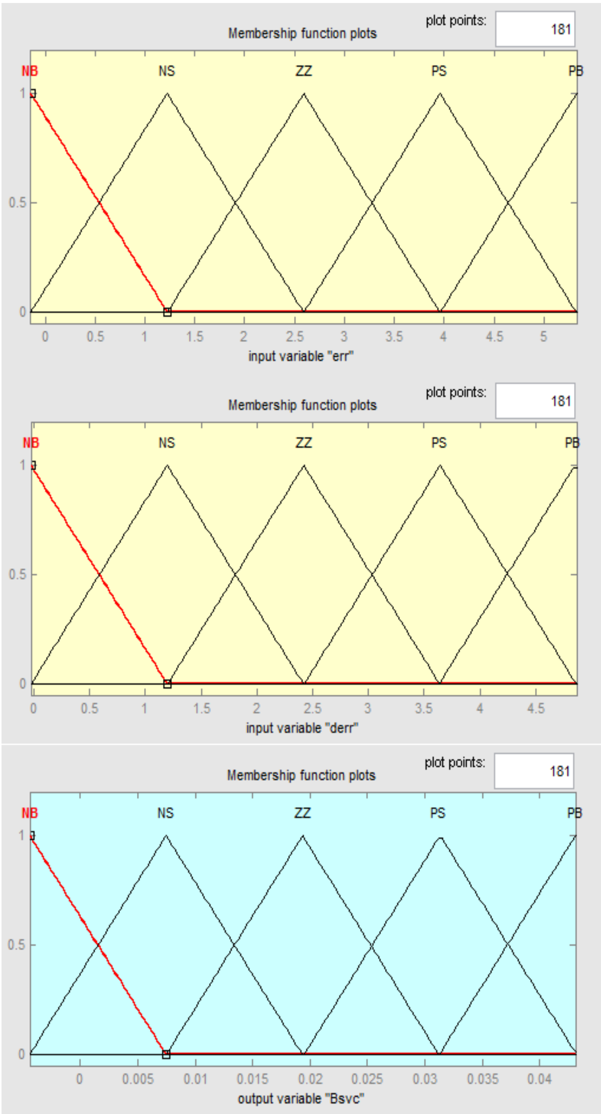

Figure 4: Fuzzy Logic's membership function

B. Second Case

Figure 6(a) shows the voltage variation as a result of the uncertain load conditions.

The voltage rised up from 0.9835 p.u to 0.9955 p.u at 0.5s and dropped down from 0.9955 p.u to 0.9845 p.u at 1.0s. Figure 6(b) represents the SVC's susceptance (BSVC) and Figure 6(c) represents the reactive power at PCC.

The comparison of two control strategies could be seen in Figure 6(d). The voltage regulation by Hybrid PI-Fuzzy control strategy for first load condition had a settling time ts_1 = 0.1736s. The settling time for second load condition was ts_2 = 0.1271s and for third load condition was ts_3 = 0.14s. Therefore, the average settling time for this control strategy was ts_{avg} = 0.1469s, while the conventional PI Control strategy had ts_1 = 0.2021s, ts_2 = 0.1545s and for the third load condition ts_3 = 0.154s. Therefore, the average settling time was ts_{avg} = 0.1702s. The result showed that the proposed control strategy has better performance compare with the conventional PI control strategy.

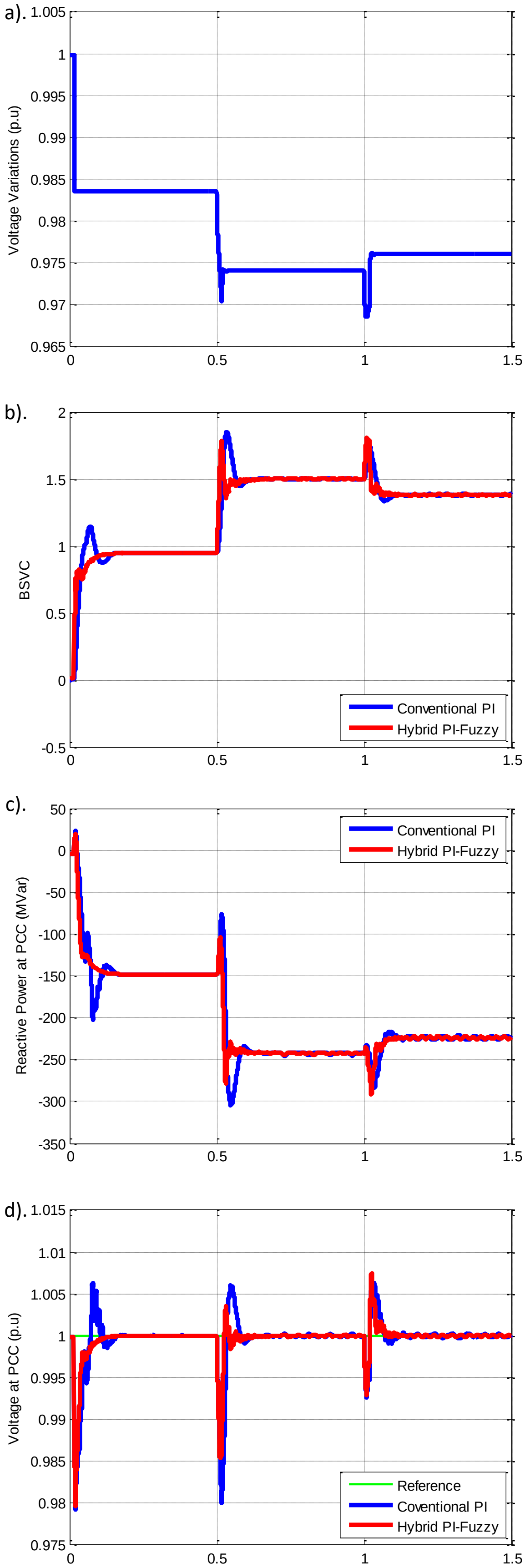

Figure 5: Simulation results for first case: a). Voltage variations under uncertain load conditions; b). SVC susceptance (BSVC); c). Reactive Power at PCC; d). Voltage at PCC.

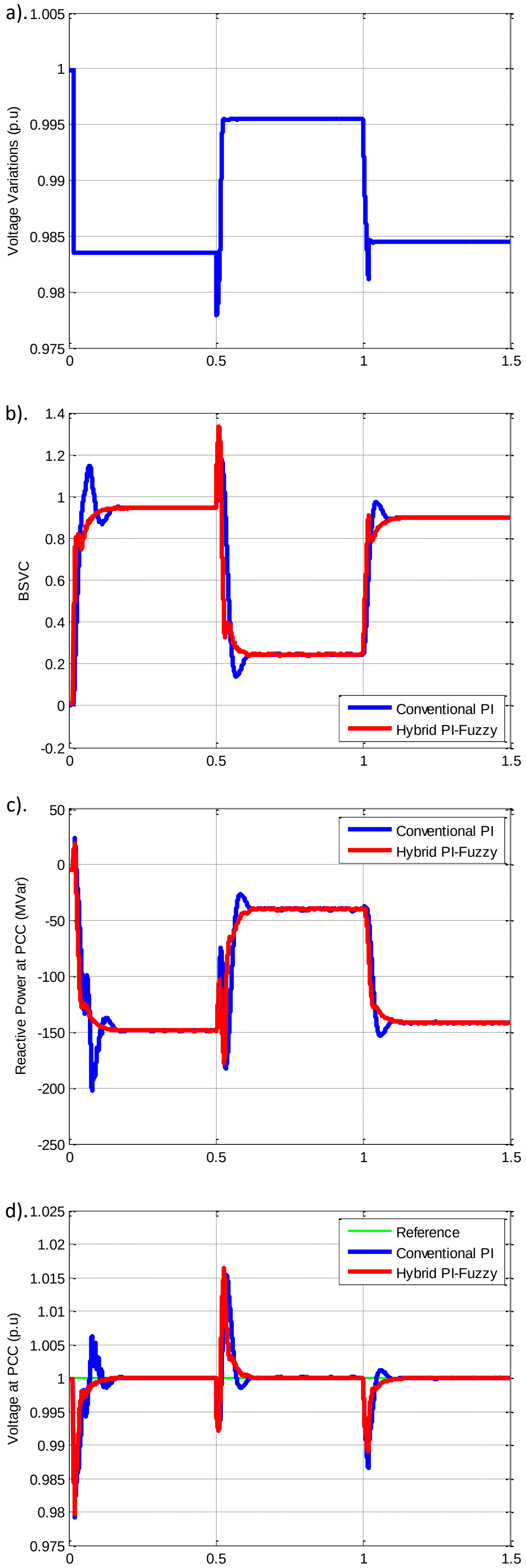

Figure 6: Simulation results for second case: a). Voltage variations under uncertain load conditions; b). SVC susceptance (BSVC); c). Reactive Power at PCC; d). Voltage at PCC.

V. CONCLUSION

This paper proposed a voltage regulation strategy using Static Var Compensator based on Hybrid PI-Fuzzy Control algorithm under the uncertain load conditions. The performance of this control algorithm was evaluated in two cases, which represent the uncertain load conditions and verified by comparing it with the conventional PI control algorithm. The first case resulted in the average time settling ts_{avg}=0.1346 seconds for the proposed algorithm and ts_{avg}=0.188 seconds for conventional PI controller. The second case resulted in the average settling time ts_{avg}=0.1469 seconds for Hybrid PI-Fuzzy controller and ts_{avg}=0.1702 seconds for conventional PI controller. Obviously, it can be concluded that the Hybrid PI-Fuzzy controller based SVC could be used as the control strategy for voltage regulation under uncertain load conditions.

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