Fuzzy Logic Based Control of Static Var Compensator

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Abstract: The Static Var Compensator (SVC) has been designed to compensate reactive power, increase voltage stability and to reduce voltage oscillation. The application of control algorithms based on fuzzy sets theory, proposed by Zadeh, has grown in recent years. This control method can be regarded as an adaptive control based on a linguistic process which is in turn based on the prior experience and heuristic rules used by human operators. The TSK (Takagi-Sugeno-Kang) and mamdani type fuzzy controllers is two types of fuzzy controllers. This paper compare these fuzzy controller types for reactive power compensation and power factor correction with SVC. Input signals for the FLC are chosen as load reactive power and initial firing angle of thyristors. The control signal is thyristors firing angles. Effectiveness of the proposed technique is demonstrated by simulation studies on a single machine infinite bus system. Results obtained show improvement in the overall system characteristics using the proposed adaptive fuzzy logic SVC controller.

Key words: Reactive power, Fuzzy, SVC.

INTRODUCTION

Var compensation is defined as the management of reactive power to improve the performance of ac power systems. The concept of Var compensation embraces a wide field of both system and customer problems, especially related with power quality issues, since most power quality problems can be solved with an proper control of reactive power (Dixon et al, 2005), (Miller, 1982). In general, the problem of reactive power compensation is viewed from two parts: load compensation and voltage support. In load compensation the purposes are to increase the value of the system power factor, to balance the real power drawn from the ac supply, to compensate voltage regulation, and to eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads (Wannet et al, 1983), (Bonnard, 1985).

The Static Var Compensator (SVC) has been designed to compensate reactive power, increase voltage stability and to reduce voltage oscillation (Dixon et al, 2005). The SVC consists of shunt reactors which current can be continuously controlled by thyristor valves thus the inductive power of reactors can be controlled. These reactors are called Thyristor Controlled reactors (TCR). In the parallel of the TCR’s there are number of the filter capacitor banks. The Filter Circuits (FC) are providing needed amount of capacitive power and absorbing harmonic current generated by load and TCR. The difference between inductive power of TCR and capacitive power of filter circuits is the output power of SVC (Hedayati, 2004). However, in recent years, static Var compensators (SVCs) employing thyristor-switched capacitors (TSCs) and thyristor-controlled reactors (TCRs) to provide or absorb the required reactive power have been developed (Dixon et al, 2005). The application of control algorithms based on fuzzy sets theory, proposed by Zadeh (Martins, 2000) has grown in recent years (Suiton & Towlil, 1995), (Graham and Newell, 1989). This control method can be regarded as an adaptive control based on a linguistic process which is in turn based on the prior experience and heuristic rules used by human operators. The implementation of such control consists of translating the input variables to a language, like: positive big, zero, negative medium, etc. and to establish control rules so that the decision process can produce the appropriate outputs. If necessary, these linguistic outputs are transformed to numeric values.

Fuzzy logic control is one of the best and most successful techniques among expert control strategies, and is well known as an important tool to control non-linear, complex, vague, and ill-defined systems. The use of fuzzy set theory in providing effectiveness control based on the knowledge and technical experience of operators and the establishment of intelligent control have found favor in industry.

The SVC system model based on the intelligent controller was given in the paper. This paper proposed a two input one-output fuzzy logic controller (FLC) for SVC. Also the effectiveness and feasibility of the TSK (Takagi-Sugeno-Kang) and mamdani methods for TCR thyristors firing control is compared.

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Shunt Compensation:

Fig. 1 shows the principles and theoretical effects of shunt reactive power compensation in a basic ac system, which comprises a source, a power line, and a typical inductive load. Fig. 1(a) shows the system without compensation and its associated phasor diagram. In the phasor diagram, the phase angle of the current has been related to the load side, which means that the active current is in phase with the load voltage. Since the load is assumed inductive, it requires reactive power for proper operation and hence, the source must supply it, increasing the current from the generator and through power lines. If reactive power is supplied near the load, the line current can be reduced or minimized, reducing power losses and improving voltage regulation at the load terminals (Dixon et al., 2005). This can be done in three ways: 1) with a capacitor; 2) with a voltage source; or 3) with a current source. In Fig. 1(b), a capacitor device is being used to compensate the reactive component of the load current. As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated. If the load needs leading compensation, then an inductor would be required. Also, a current source or a voltage source can be used for inductive shunt compensation. The main advantage of using voltage- or current-source Var generators (instead of inductors or capacitors) is that the reactive power generated is independent of the voltage at the point of connection.

TCR (Thyristor Controlled Reactor) Branch:

The TCR branch makes use of the TSC overcompensation to fine-tune the SVC VARs supplied to the load. This fine-tuning is completed by varying the firing delay angle of the thyristors.

The firing delay angle is the time delay from the start of each half-cycle that the TCR is turned on. Firing angles of TCR will be in the range of \( (\pi/2) < \alpha < \pi \) for each half-cycle. Eq. (1) derived from the conduction angle equation in (Dixon et al., 2005), illustrates the relationship between the firing angle and the TCR reactance \( (X_{TCA}) \).
Fig. 2 shows the relationship between the firing angle and the TCR reactance.

\[ X_{\text{TCR}} = \frac{\left[ 2 \left( \pi - \alpha \right) - \sin(2(\pi - \alpha)) \right]}{\left( \pi \times X_L \right)} \]  

(1)

Fig. 2: TCR impedance vs. thyristor firing angle.

Fig. 3 shows the relationship between the firing angle and the SVC impedance. This figure illustrates that the SVC impedance is sensitive in small firing angles.

Fig. 3: SVC impedance vs. thyristor firing angle.

**Simulation Results:**

Several simulink simulations were created to verify the feasibility of the SVC design and the TCR fuzzy controller. For the particular simulink model is shown in Fig. 4. Three reactive loads are switched in different times. Load 2 is switched on at \( t_2 = 0.4s \) and switched off at \( t_2 = 1.2s \) and load 3 is switched on at \( t_3 = 0.8s \). The TSC branch and a TCR branch were modeled with their respective controllers. The TSC branch consists of a single switched capacitor while the TCR branch consists of a reactor that is fed a firing angle determined by the fuzzy controller. The fuzzy controller accepts the phase angle difference of the load and firing angle of thyristors as an input and outputs the optimum firing angle of TCR.
Fig. 4: Analyzed power circuit topology.

Fig. 5 shows the displacement power factor (PF) of the load without the branches compensating. Fig. 6 shows the active and reactive power at load side without compensation. As shown in this figure at \( t_1 \approx 0.4s \) and \( t_2 \approx 0.8s \), reactive power increases and power factor (PF) decreases by inductive load increasing. Also at \( t_3 \approx 1.2s \) one of inductive loads retreat from power system and therefore power factor increases and reactive load decreases.

Fig. 5: Power factor (PF) of the load without the branches compensating.

Fig. 6: Active and reactive power at load side without compensation.
Mamdani Type Fuzzy Controller:

In this section a Mamdani type double input single output (DISO) Fuzzy Linguistic Controller has been designed. The rules are shown in Table I. As shown in figures 10 and 11 with using fuzzy controller we have suitable power factor and reactive power compensation.

Fig. 7: The fuzzy membership function of reactive power at load side (input 1 of fuzzy controller).

Fig. 8: The fuzzy membership function of initial thyristor firing angle (input 2 of fuzzy controller).

Fig. 9: The fuzzy membership function of variation of thyristor firing angle (output of fuzzy controller).
Fig. 10: Power factor (PF) of the load with the branches compensating (Mamdani type fuzzy controller).

Table I: Fuzzy controller rules (Mamdani type fuzzy controller).

<table>
<thead>
<tr>
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<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>NVS</th>
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<td>VB</td>
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Sugeno Type Fuzzy Controller:

In this section a sugeno type double input single output (DISO) Fuzzy Linguistic Controller has been designed which has same memberships at input.

The rules are shown in Table II. As shown in fig. 14 and 15 using sugeno type controller results power factor correction and reactive power compensation similar to section (a). But as shown in fig. 17 using mamdani type fuzzy controller has results better characteristics in reactive power and power factor.

Fig. 11: Active and reactive power at load side with compensation (Mamdani type fuzzy controller).
Table II: Fuzzy controller rules (Sugeno type fuzzy controller).

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Fig. 12: Variation of TCR firing angle (Mamdani type fuzzy controller).

Fig. 13: TCR current at different time.

Conclusion:

The fuzzy logic control strategy of SVC is researched in the paper. The effectiveness and feasibility of the TSK (Takagi-Sugeno-Kang) and mamdani type fuzzy controllers for thyristors firing control in SVC is shown and compared clearly. Simulation results show good performance of fuzzy controller in power factor correction and reactive power compensation. Also in this paper demonstrated that using mamdani type fuzzy controller has results better characteristics in reactive power and power factor.
Fig. 14: Power factor (PF) of the load with the branches compensating (Sugeno type fuzzy controller).

Fig. 15: Active and reactive power at load side with compensation (Sugeno type fuzzy controller).

Fig. 16: Variation of TCR firing angle (Sugeno type fuzzy controller).
Fig. 17: Comparison of “Mamdani” and “Sugeno” type fuzzy controller for power factor correction.

REFERENCES


