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A Review on Controlling the Voltage and Reactive Power of Multimachine System using Fuzzy Logic Controller based STATCOM

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Abstract- Fuzzy logic based controllers have been designed for controlling a STATCOM in a multi-machine power system. Such controllers do not need any prior knowledge of the plant to be controlled and can efficiently control a STATCOM during different disturbances in the network. Two different approaches for the controller are mainly used: one is conventional controller using PI design and other one is fuzzy logic design based on membership functions. Review is based on simulation results, along with a comparison of the conventional PI controller performance with that of the fuzzy logic controller will be presented. Thus the several advantages of FLC based intelligence controlled STATCOM serves as the most reliable system for our future power transmission.

Keywords- Fuzzy logic, voltage and reactive power control, intelligence control, multi-machine power system.

I. INTRODUCTION

Static Compensators (STATCOMs) are power electronic based shunt Flexible AC Transmission System (FACTS) devices which can control the line voltage at the point of connection to the electric power network. Regulating the reactive power injected to the network and the active power drawn from it by this device provides control over the ac line voltage and the DC bus voltage inside the device respectively. A power system containing generators and FACTS devices is a nonlinear system. It is also a non-stationary system since the power network configuration changes continuously as lines and loads are switched on and off [1].

In recent years most of the researchers have suggested methods for designing STATCOM controllers using linear control techniques, in which the system equations are linearized at a specific operating point and based on the linearized model, PI controllers, are tuned at that point in order to have the best possible performance.

The drawback of such PI controllers is that their parameters are mostly tuned based on a trial and error approach. Moreover, their performance degrades as the system operating conditions change. Nonlinear adaptive controllers on the other hand can give good control capability over a wide range of operating conditions, but they have a more sophisticated structure and are more difficult to implement compared to linear controllers. In addition, they need a mathematical model of the system to be controlled.

Fuzzy logic controllers offer solutions to this problem. They are nonlinear controllers and need no prior plant information. Moreover, they can provide efficient control over a wide range of system operating conditions. Conventional fuzzy logic controllers have been widely applied in power systems. This paper designs a conventional PI based controller and a modified fuzzy logic based controllers for a STATCOM connected to a multi-machine power system, using Membership Functions. Simulation results are provided to compare the performance of both the modified fuzzy controllers with that of the conventional PI controller [7].

II. STATCOM IN A MULTIMACHINE POWER SYSTEM

Figure 1 shows a STATCOM connected to a multi-machine power system. The STATCOM is first controlled using a conventional PI controller. D axis and Q-axis voltage deviations are derived from the difference between actual and reference values of the power network line voltage and the DC bus voltage (inside the STATCOM) respectively, and are then passed through two PI controllers (Fig. 2). Those values in turn determine the modulation index and inverter output phase shift applied to the PWM module. Controlling the voltage V at the point of connection to the network is the main objective of the STATCOM considered in this paper.

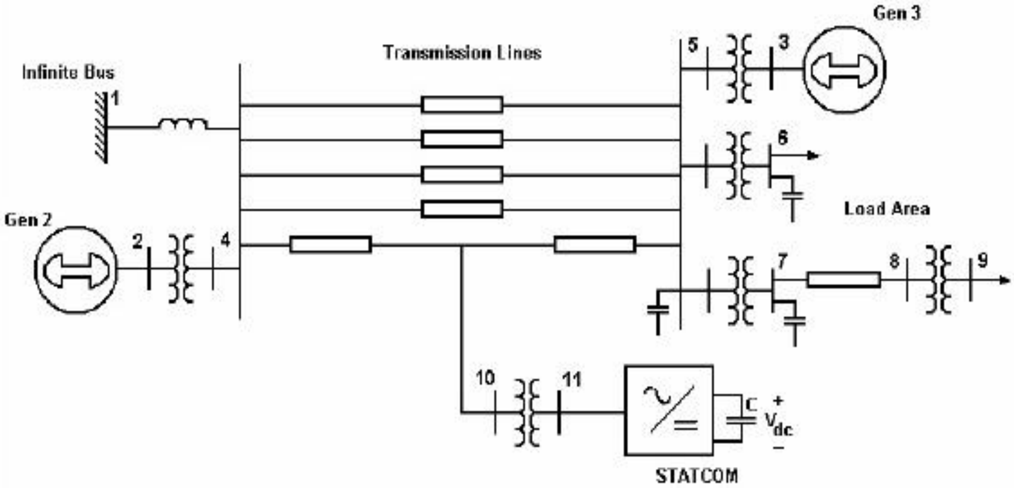

Fig 1. STATCOM in the multi-machine system

Parameters of the STATCOM PI controllers are tuned at one specific operating point, so that the controller provides satisfactory and stable performance when the system is exposed to small changes in reference values as well as large disturbances such as a three phase short circuit on the power network [1].

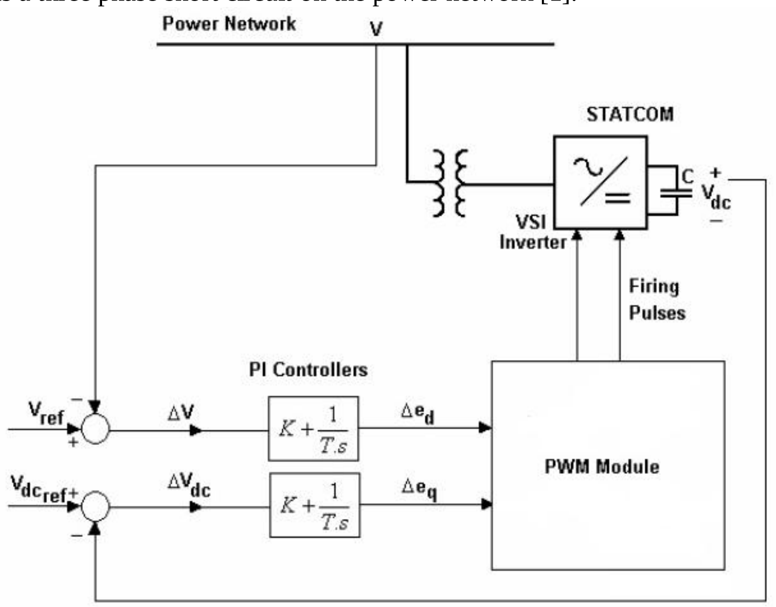

Fig 2. STATCOM internal control structure

III. FUZZY LOGIC CONTROLLERS

Analytical approaches have traditionally been used for modelling and control of power networks. However, these mathematical models/equations are achieved under certain restrictive assumptions, such as linearizing a nonlinear system, or approximating a low order model for a higher order system. Even in such conditions the solution is not necessarily trivial, and sometimes uncertainties associated with real life problems further exacerbate the reliability of such approaches.

Fuzzy logic is a tool that can compensate for the above problems, since it is the only technique that can deal with imprecise, vague or fuzzy information. Fuzzy logic controllers consist of a set of linguistic control rules based on fuzzy implications and the rule of inference. By providing an algorithm, they convert the linguistic control strategy based on expert knowledge into an automatic control strategy.

In contrast to the mathematical models or other expert systems, fuzzy logic controllers allow the representation of imprecise human knowledge in a logical way, with approximate terms and values, rather than forcing the use of precise statements and exact values; thus making them more robust, more compact and simpler. Also, as opposed to most neural network based controllers, in most of the cases fuzzy logic controllers do not need a model of the plant to be controlled.

Fuzzy logic systems provide a nonlinear mapping from a set of crisp inputs to a set of crisp outputs, using both intuition and mathematics. In order to do that, each fuzzy logic system is associated with a set of rules, which heuristically define the dynamics of the plant to be controlled. For instance in a multi-input single output fuzzy system:

Rule *j*: **If** *u1* is *F j* 1 ,..., and **If** *un* is *j*
n F , **Then** *y* is *G j* .

Using different fuzzifiers such as *Singleton*, *Gaussian* and *Triangular* fuzzifiers, any set of crisp inputs is mapped to a fuzzy set. Various rules in the rule base are applied to the fuzzy input data, in order to create a fuzzy output. This output is in turn defuzzified to generate a crisp output value [9].

IV. STATCOM FUZZY LOGIC CONTROLLER

Fuzzy variables are as ΔV, ΔV_{dc} , Δe_d , Δe_q , and fuzzy sets with linguistic characteristics of *negative big*, *negative small*, *zero*, *positive small* and *positive big* are assigned to each variable and equal-span triangular functions have been selected as the fuzzy membership functions (Fig. 3).

Both inputs of the fuzzy controllers have the same membership function description as in Fig. 3, however the subintervals *xi*'s are heuristically selected based on the characteristics of each control loop in order to provide the best damping/stabilization performance [11]. A fuzzy rule base is been assigned for each combination of input/output variable. As an example for the line voltage loop:

Rule *1*: **If** ΔV is *negative big*, **Then** Δe_d is f_1 (ΔV),
Rule *2*: **If** ΔV is *negative small*, **Then** Δe_d is f_2 (ΔV),
Rule *3*: **If** ΔV is *zero*, **Then** Δe_d is f_3 (ΔV),
Rule *4*: **If** ΔV is *positive small*, **Then** Δe_d is f_4 (ΔV),
Rule *5*: **If** ΔV is *positive big*, **Then** Δe_d is f_5(ΔV).

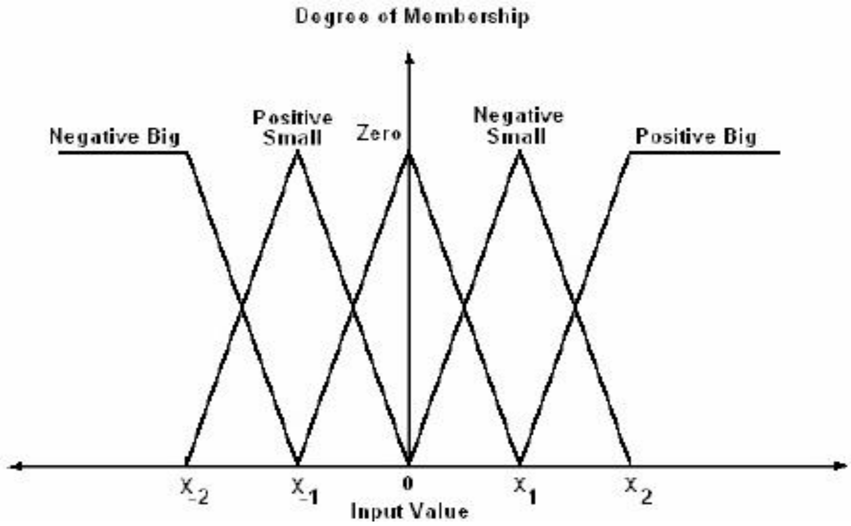

Fig 3. Membership functions of the input fuzzy sets

V. LITERATURE SURVEY

The various advancements that took place in the field of FLC based STATCOM in the past decades is summarized as follows:

In 1998- *Chun Li* et al [12] designed a STATCOM to supply fast voltage control and to enhance the damping of inter-area electromechanical oscillations of the system. By investigating the added synchronizing and damping torque induced by STATCOM, the conflicts between these control objectives were analyzed and the limitations or even invalidity of the fixed-parameters damping controller for certain system parameters and load conditions was discussed. A rule-based controller, which employs bang-bang, fuzzy logic or fixed-parameter PI control strategy according to the operation state of the system, was designed. The advantages of the proposed controller over the fixed-parameter PI controller were demonstrated by nonlinear digital simulations.

The requirements of voltage and damping control of STATCOM were found to be conflicting and rules for compromise were presented in the paper. Simulation results show the advantages of the proposed controller based on those rules over the conventional fixed- parameter PI controller [12].

In 2000- *L.O. Mak* et al [13] designed the fuzzy controller for static synchronous compensator (STATCOM) to enhance interconnected power system stability. The power frequency model for STATCOM with conventional controllers was presented first. Fuzzy controllers were then designed for both main and supplementary controllers of the STATCOM. The fuzzy main control was constant voltage control with voltage regulation which aims at providing voltage support on the tie lines of interconnected power systems to enhance transient stability and increase transfer limit. The fuzzy supplementary control (SC) was designed for damping inter-area power oscillation and enhancing dynamic stability of interconnected power systems. The integrated STATCOM model had been incorporated to the small signal stability and transient stability programs with a novel interface. Computer tests were conducted on a four-generator test system. The results show that STATCOM can enhance system transfer limit and improve system dynamic behaviour significantly. Computer results also show that the performance of fuzzy controllers was fairly well and possesses good robustness.

Simulation results show that STATCOM with proper control is capable of enhancing system transient stability and increasing transfer limit noticeably. The system dynamic behavior can also be improved by STATCOM. The results support the applications of fuzzy controllers in power systems. In the tests, the fuzzy controller can yield almost the same positive effects on system transients as the well-designed conventional controllers, and has better performance under changed system operation conditions [13].

In 2001- *Pierre Giroux* et al [14] designed the model of a STATCOM (Static Synchronous Compensator) used for reactive power compensation on a distribution network. An "average modelling" approach was proposed to simplify the PWM inverter operation and to accelerate the simulation for control parameters adjusting purpose. Simulation performance obtained with both modelling approaches were presented and compared.

Two modeling approaches (device and average modeling) have been presented and applied to the case of a +3Mvar D-STATCOM connected to a 25-kV distribution network. The obtained simulation results have demonstrated the validity of the developed models. Average modeling allows a faster simulation which is well suited to controller tuning purposes [14].

In 2003- *Stella Morris* et al [15] presented two new variable structure fuzzy control algorithms for controlling the reactive component of the STATCOM current in a power system. The control signal was obtained from a combination of generator speed deviation and STATCOM bus voltage deviation fed to the variable structure fuzzy controller. The parameters of these fuzzy controllers can be varied widely by a suitable choice of membership functions and parameters in the rule base. Simulation results for typical single machine and multi-machine power systems subject to a wide range of operating condition changes confirm the efficiency of the new controllers.

These new fuzzy controllers for STATCOM provide a wide range of gain variations for controlling the electromechanical oscillations of a single-machine infinite-bus and multi-machine power systems [15].

In 2004- *Salman Mohagheghi* et al [16] designed a Takagi-Sugeno (TS) based fuzzy logic controllers for controlling a STATCOM in a multi-machine power system. Such controllers can efficiently control a STATCOM during different disturbances in the network. Two different approaches for the TS fuzzy logic controller were proposed: a conventional TS fuzzy logic design and a modified TS fuzzy logic design based on shrinking span membership functions. Simulation results, along with a comparison of the conventional TS fuzzy logic controller performance with that of the proposed controller were presented.

The first two controllers are simulated and the results show better and faster damping compared to that of the conventional PI controller. Even though both conventional and SSMF fuzzy controllers designed and simulated in this work, tend to rely on the fuzzy inference and reasoning, they still slightly depend on the nature of the plant. In other words, a better knowledge of the dynamics of the STATCOM in this specific power system will lead to a better tuning of the controller, which in turn produces better results at different operating conditions and under various faults applied to the system [16].

In 2006- *A. Ajami* et al [17], investigated application of a role based fuzzy control technique for controlling a STATCOM at steady and transient states. Fuzzy controllers were designed for main and supplementary controllers of STATCOM. The main controller is used for regulating the AC bus voltage and the supplementary controller is designed for controlling of DC capacitor voltage. This study demonstrates that STATCOM considerably improves transient stability of power system after occurring fault and load changing.

The presented control system has two loops. The first loop is named main controller and regulates the AC bus voltage and damps rotor angle oscillations under steady state and transient conditions. The second control loop is named supplementary controller and regulates the DC capacitor voltage. The presented simulation results show that STATCOM with FLC is capable to enhancing the system transient stability. The simulation results support the applications of fuzzy controllers in power systems [17].

In 2007- *S.V Ravi Kumar* and *S. Siva Nagaraju* [18] described the techniques of correcting the supply voltage sag, swell and interruption in a distributed system. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle. A DVR injects a voltage in series with the system voltage and a D-STATCOM injects a current into the system to correct the voltage sag, swell and interruption. Comprehensive results are presented to assess the performance of each device as a potential custom power solution.

A new PWM-based control scheme has been implemented to control the electronic valves in the two-level VSC used in the D-STATCOM and DVR. As opposed to fundamental frequency switching schemes already available in the MATLAB/SIMULINK, this PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications. The simulations carried out showed that the DVR provides relatively better voltage regulation capabilities. It was also observed that the capacity for power compensation and voltage regulation of DVR and D-STATCOM depends on the rating of the dc storage device [18].

VI. CONCLUSION

In this paper a short review on different control strategies including FLC based STATCOM for controlling the voltage and reactive power of multi-machine system is presented. The literature survey on this topic demonstrates that Fuzzy logic based STATCOM improves the controlling ability of the power system in comparison with the conventional controller.

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