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Design and Analysis of D STATCOM and DVR for Power System Stability with Fuzzy Logic Controller and PI Controller

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Abstract: **The growing scale of the power system and the applications of non linear load increase the complexity of the system and also make it difficult to control and results the instabilities of the systems in terms of voltage and frequency. Although there are various FACT devices available for stability enhancement of the power system such that D STATCOM and DVR, although traditionally these system uses the PI controllers to smoothly suppress the fluctuations but the proper configuration of PI controller parameters is quite difficult. It requires detailed mathematical understanding and modeling. It also suffers from the limitations of continuous system like oscillations and finite gradients and liner controlling only. In this paper it has been developed a fuzzy logic based controller and replaced the PI controller by this fuzzy controller and compared the results for both the systems.**

Keywords: **Power system stability, DSTATCOM, DVR, PI Controller, Fuzzy Logic Controller.**

1. INTRODUCTION

The stability of the power system is always a challenging task for power companies to provide the regulated and smooth power supply to its customers and also to protect the system from tripping or even complete blackouts. Because of the large network of interconnected transmission lines, generators and load with all having time changing dynamic characteristics it is very difficult to stabilize a huge power system.

In present days the FACT devices playing an important role in achieving the required goal because the FACT devices can be operated at relatively very high switching speeds which provides the capability to perform some complex operations (reactive power absorption, short term active power injection and dynamic reactance formation etc.) very quickly. But all these capabilities of the FACT devices depend upon the performance of the internal controller which is designed by using PI controllers. Although the PI controller have been proved their capabilities in past but the recent growth in electronic devices provide a new type of controllers (microprocessors) which can work on different kind of controlling models such as neural network, evolution algorithm and fuzzy logic. In all of them fuzzy is considered as one of the most simple and efficient way of developing the robust control system.

In this paper we are targeting the same fuzzy controllers for the controlling of the FACT devices DSTATCOM and DVR. The rest of the paper arranged as that the second and third section describes the working of the DSTATCOM and DVR respectively followed by the Fuzzy controller in fourth section. The fifth section explains the simulated model with the proposed fuzzy controlling and the sixth section shows the simulated results followed by conclusion.

2. D STATCOM

D STATCOM is a voltage-source inverter (VSI) based shunt device [3] generally used in distribution system to improve power quality.

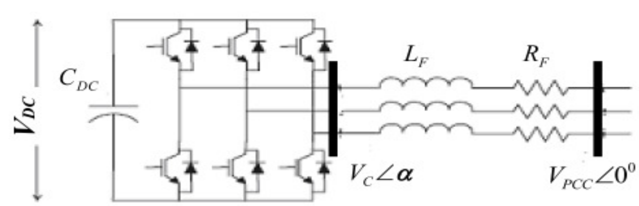


Figure 1: Schematic diagram of a basic DSTATCOM.

The main advantage of DSTATCOM is that, the current injection into the distribution bus can be regulated very efficiently by the sophisticated power electronics based control present in it. Another advantage is that, it has multifarious applications, e.g. it can be used for canceling the effect of poor load power factor, for suppressing the effect of harmonic content in load currents, for regulating the voltage of distribution bus against sag/swell etc. and also for compensating the reactive power requirement of the load and so on [16]. The simplest structure of a DSTATCOM is shown in Fig. 1. The principle of operation of DSTATCOM is based on the fact that the real and reactive power can be varied by the voltage magnitude (V_C) of the inverter and the angle difference between the bus and the inverter output (α).

The control strategy is employed for the MATLAB based simulation. Here, a GTO based square wave voltage source converter (VSC) is used to generate the alternating voltage from the DC bus. In this type of inverters, the fundamental component of the inverter output voltage is proportional to the DC bus voltage. So, the control objective is to regulate V_{dc} as per requirement. Also, the phase angle should be maintained so that the AC generated voltage is in phase with the bus voltage. Here, the PLL synchronizes the GTO pulses to the system voltage and generates a reference angle. This reference angle is used to calculate positive sequence component of the DSTATCOM current using a-b-c to d-q-0 transformation. The voltage regulator block calculates the difference between reference voltage and measured bus voltage and the output is passed through a PI controller to generate the reactive current reference Iq_ref. This Iq_ref is then passed through a current regulator block to generate the angle α. This current regulator block also consists of a PI controller to keep the angle α close to zero.

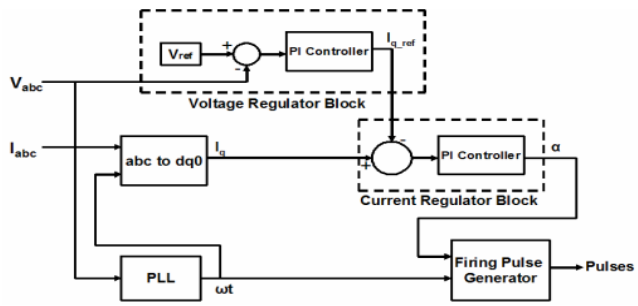


Figure 2: DSTATCOM and Its Control System Block Diagram (from MATLAB) [16].

3. DVR

The basic operation principle is detecting the voltage sag and injecting the missing voltage in series to the bus as shown in Fig.3. DVR has become a cost effective solution for the protection of sensitive loads from voltage sags. Unlike UPS, the DVR is specifically designed for large loads ranging from a few MVA up to 50MVA or higher. The DVR is fast, flexible and efficient solution to voltage sag problems. DVR consists of energy storage unit, PWM inverter, filter and injection transformer as shown in Fig.3 [16].

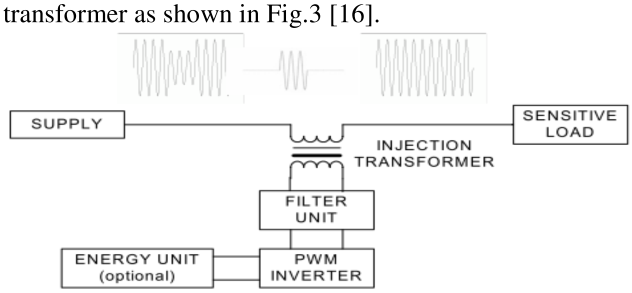


Figure 3: Basic DVR Block Diagram

The detail model of DVR consists of self-commutating IGBT (or MOSFET) switches with parallel diodes. The sinusoidal pulse width modulation technique (SPWM) forms the control strategy. The control block generates the firing signals for each switch with controllable amplitude, phase and frequency whenever sag is detected. The inverter side filtering is applied to the system because it is closer to harmonic source. The main operation principles of DVR can be summarized as shown in Fig. 4

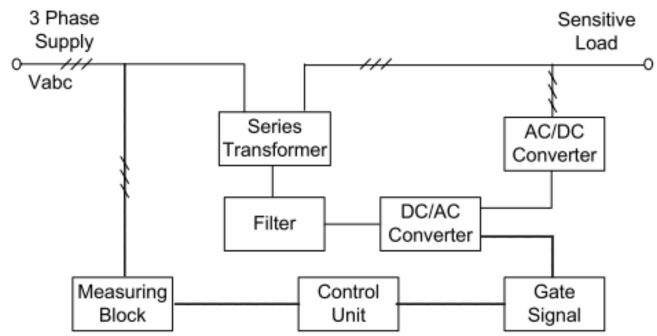


Figure 4: functional diagram of DVR [16]

Direct feed forward type control model is used to minimize the response time and maximize the dynamic performance. Voltage regulation, low harmonic distortions and no interruptions are realized with this type of control architecture [16].

4. FUZZY CONTROLLER

Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as "computing with words rather than numbers"; fuzzy control can be described simply as "control with sentences rather than equations". A fuzzy controller can include empirical rules, and that is especially useful in operator controlled plants. A fuzzy IF-THEN rule-based system consists of the following modules [2]:

Fuzzification: Converting crisp facts into fuzzy sets described by linguistic expressions. Membership functions can be flat on the top, piece-wise linear and triangle shaped, rectangular, or ramps with horizontal shoulders.

Inference: The fuzzy IF-THEN rule expresses a fuzzy implication relation between the fuzzy sets of the premise and the fuzzy sets of the conclusion. The following steps describe this process:

1. Matching of the facts with the rule premises (determination of the degree of firing DOF of the facts to the rule premises).
2. If the rule contains logic connections between several premises by fuzzy AND or fuzzy OR the evaluation is performed by t-norms or t-conorms (the result gives then the DOF of the facts to the complete premise).

3. Implication: The next step is the determination of the individual rule output. The DOF of a rule interacts with its consequent to provide the output of the rule. It will be a fuzzy subset over the output universe.

Aggregation: This process aggregates the individual rule outputs to obtain the overall system output. It will be also a fuzzy subset over the output universe (a union operation yields a global fuzzy set of the output).

Defuzzification: To obtain crisp output (various defuzzification methods can be used, as, e.g., center of gravity, bisector of area, and mean of maximum, to obtain a crisp numerical output value).

5. SIMULATED MODEL

The testing of the fuzzy controller is performed for D STATCOM and DVR for different scenario and it is also compared with PI controller.

The structure of the proposed fuzzy system involves two inputs E and ΔE and one output as shown below

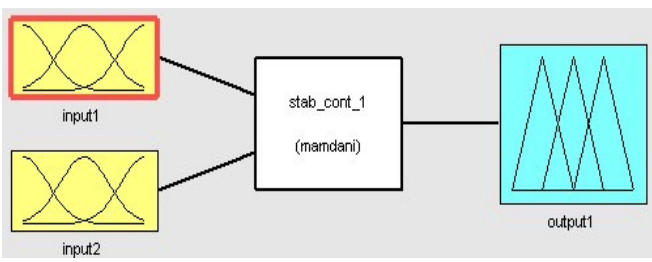


Figure 5: Structure of the Fuzzy Controller

The Fuzzy controller rules are selected as given below:

Table 1: Fuzzy Rule set for the proposed Fuzzy Controller.

E\ΔE	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PM	PS	PS	PS	Z
NM	PM	PM	PS	PS	PS	Z	Z
NS	PS	PS	PS	PS	Z	PS	NM
Z	PS	PS	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NS	NS
PM	PS	Z	PS	NM	NS	NM	NM
PL	A	NS	NM	NL	NL	NL	NL

$Where: E = Error, \Delta E = Change\ in\ Error$
$NL = Negative\ Large$
$NM = Negative\ Medium$
$NS = Negative\ Small$
$Z = Zero$
$PS = Positive\ Small$
$PM = Positive\ Medium$
$PL = Positive\ Large$

And the complete transfer function of the fuzzy controller in graphical form is shown below:

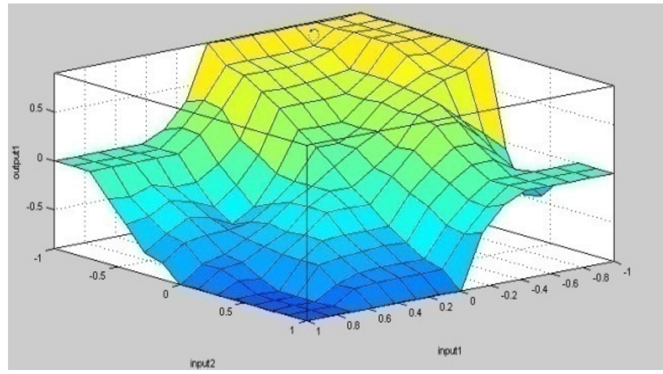


Figure 6: Transfer function of the proposed fuzzy controller the x and y axis showing E and ΔE and the z axis is showing output.

All the membership function is triangular and the output estimation (de-fuzzification) is performed on the basis of centroid.

Finally the PI controller is replaced with designed controller in current regulator block of DSTATCOM (figure 2) and control loop of DVR (Figure 5).

DSTATCOM Simulation: The simulation scenario for the DSTATCOM is as follows:

A power system with 15KV generator and 21 km long transmission line feed a 3 MW and 0.2MVA loads and then after 2km from these loads a DSTATCOM of +/- 3MVAR is attached. Finally a 1 MW load is feeded by a step-down transformer. In the scenario the generator voltage is fluctuated in some intervals and the fluctuations at the load is measured.

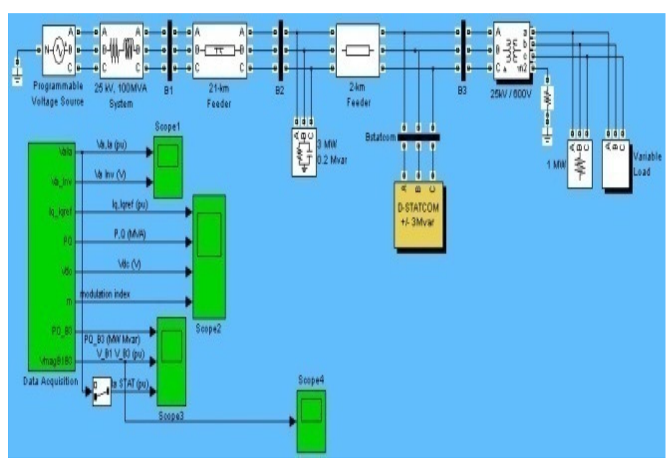


Figure 7: Diagram of the proposed system with DSTATCOM.

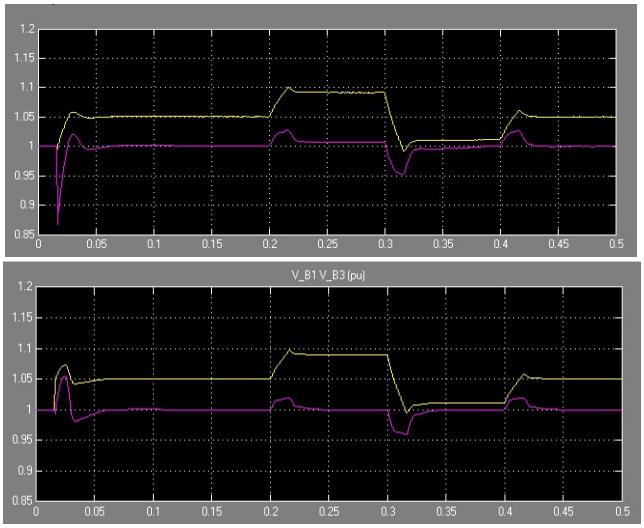


Figure 8: The Performance if DSTATCOM with Fuzzy Controller (above) and PI (Below). Green color showing the voltage variations of generator and blue color shows voltage variations across load.

DVR Simulation: The simulation scenario for the DVR is as follows:

A power system with 13KV generator followed by the three winding stepup transformer which transform 13KV to 115KV into two branches one is fed to fixed load through a stepdown transformer the second branch feds the another load but in between path it contains a fault generator (phase to ground) which is switched for a particular duration.

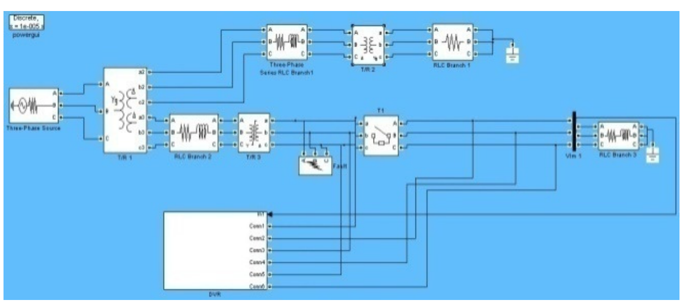
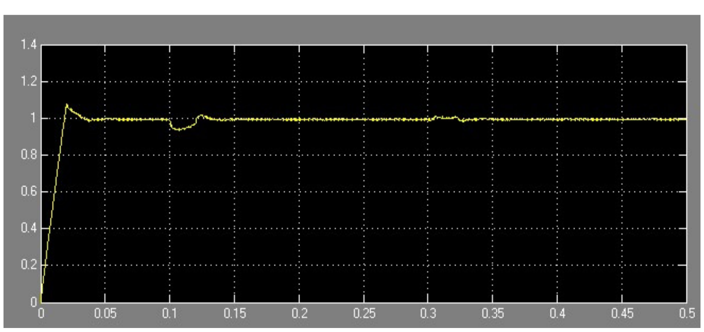


Figure 9: Diagram of the proposed system with DVR.



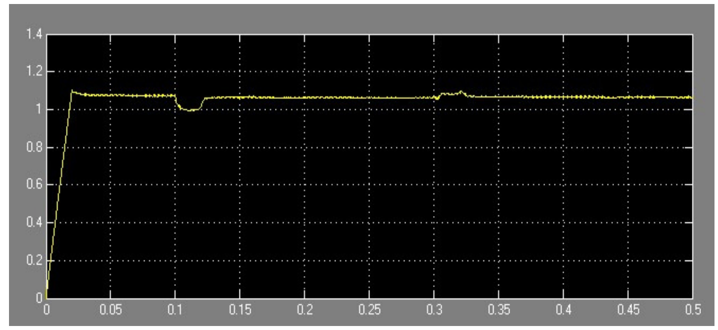


Figure 10: The Performance if DVR with Fuzzy Controller (above) and PI (Below). Green color showing the voltage variations across load.

6. CONCLUSION

In this study, the modeling, simulation and comparison of DSTATCOM and DVR with PI and Fuzzy controller have been developed by using Matlab/Simulink. The simulation results show that the fuzzy logic performs equally well for DSTATCOM as PI but for DVR the fuzzy controller compensates the sag quickly and provides excellent voltage regulation. The simulation also shows that the fuzzy controller is relatively easy to design and tune for regular and critical conditions for excellent performance.

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