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Fuzzy Logic Control of D-STATCOM for Improving Power Quality and Dynamic Performance

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Abstract: Distribution power system has poor power quality and dynamic performance due to insufficient reactive power support during disturbances. Distribution Static Compensator (DSTATCOM) can improve the power quality and dynamic performance of distribution power system. Proportional and Integral (PI) controllers are often used to control the operation of the DSTATCOM for the distribution power system. However, since the power system is highly nonlinear and subject to various disturbances, the PI controlled DSTATCOM cannot provide optimal performance for different operating points. More robust controllers such as the one based on fuzzy logic approach are required for the DSTATCOM to provide adequate dynamic voltage control and to improve power quality and stability of the distribution power system. This paper presents the design of a fuzzy logic based controller of a 3MVA DSTATCOM for improving the power quality and stability of a distribution power system. Comparison study of PI controlled and fuzzy logic controlled DSTATCOM for improving the power quality and dynamic performance of a distribution power system is simulated using Sim Power System in MATLAB/Simulink environment. The performances of the DSTATCOM controllers are evaluated during grid side voltage sag and load variation. The simulation results in MATLAB/Sim Power Systems show that the fuzzy logic controlled DSTATCOM controller provides better system dynamic response and hence improves power quality and stability for the distribution power system.

Keywords: Fuzzy Logic, Power Quality, D-STATCOM.

I. INTRODUCTION

Low voltage poor power quality can be caused by the demand in reactive power as it loads up the supply system unnecessarily. This can also be due to harmonic pollution and load imbalance as these cause extra stress on the networks and excessive voltage imbalance causing stress on other loads connected to the same network. Flexible AC Transmission Systems (FACTS) devices such as Static Synchronous Compensator (STATCOM) can address the power quality issues related to transmission lines while DSTATCOM can improve the power quality and dynamic performance in a distribution network. A DSTATCOM is a shunt connected bidirectional converter based device which can provide adequate level of reactive power to improve the quality of electrical power featured as the voltage at the point of common coupling (PCC) in distribution network. Various control structure and algorithms for DSTATCOM converter such as phase shift control with PI controller, carrier based PWM control with PI controller, and carrier less hysteresis control with PI controller have been proposed to address the power quality issues. In this paper, carrier-based PWM control with fuzzy controllers are designed for controlling the DC voltage, AC voltage, and current regulators. A Mamdani type of fuzzy controller was employed. In addition, it is more convenient in mathematical analysis and in system analysis for a DSTATCOM equipped with amamdani type fuzzy controller as the membership functions for the output are singletons. After designing the fuzzy controller, fine tuning can be made in order to improve the performance of the controller.

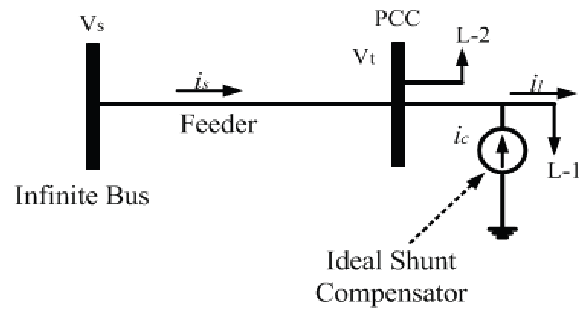

Fig.1. Schematic diagram of load compensation.

Tuning can be made either to the membership functions or to the scaling factors. This paper presents the design of fuzzy logic based controller of a 3MVA DSTATCOM for improving the power quality and stability of a distribution network. A comparative study of the PI controlled and the fuzzy logic controlled DSTATCOM for improving the power quality and dynamic performance of a distribution power system is simulated using Sim Power System in MATLAB/Simulink environment. The performances of the DSTATCOM controllers are evaluated during grid side voltage sag and large load variations.

II. OPERATING PRINCIPLEOF LOAD COMPENSATION DSTATCOMAND SYSTEM CONFIGURATION

Fig1 shows a schematic diagram for load compensation using an ideal shunt compensator like a DSTATCOM by inject

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current icat the PCC to cancel the reactive, nonlinear and unbalanced load currentil. Fig.2 shows a configuration of a network where DSTATCOM is used to regulate the voltage on a 25 kV distribution power system. 21 km and 2 km feeders are used to transmit power to loads at buses B2 and B3. A variable load producing continuously changing currents and voltage flicker is connected to bus B3 through a 25kV/600V transformer. The DSTATCOM uses Voltage Source Converter (VSC) to regulate voltage at PCC by absorbing or generating reactive power using power electronics to regulate three phase sinusoidal voltage at its terminal. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesise the voltage on the secondary side of the coupling transformer from a DC voltage source. A DSTATCOM with VSC using IGBT-based PWM inverters has been used in this study. Fig.3 depicts a single-line diagram of the DSTATCOM and the control system block diagram of DSTATCOM. In Fig.3, PLL represents the phase-locked loop used to synchronize on the positive sequence component of the three phase (3Φ) primary voltage V1. The output of the PLL is θ =ωt and it is used to compute the direct-axis and quadrature axis components of the AC (3Φ) voltage (V_d and V_q) and currents (Id and Iq).

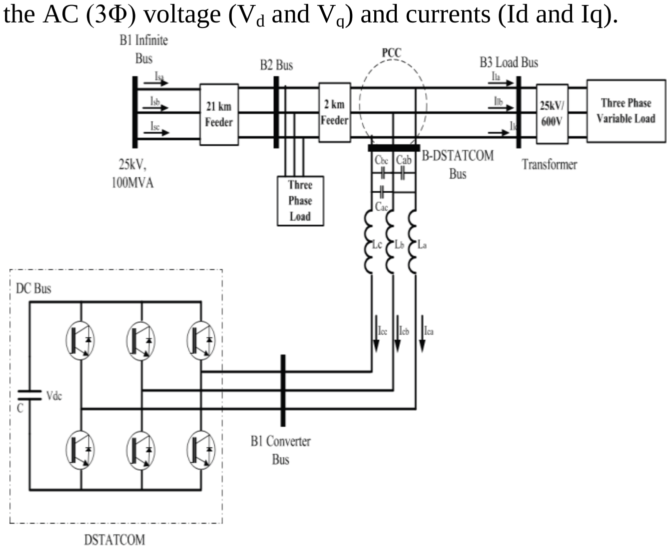

Fig.2. System configuration of a distribution network.

The DC measurement system in Fig.3 provides the measurement of the DC voltage V_{dc}. The AC voltage measurement and current measurement systems in Fig.3 measure the d and q components of AC positive-sequence voltage and currents to be controlled, respectively. The AC voltage regulator and DC voltage regulator form the outer regulation loop of the DSTATCOM control system. The current regulators form the inner current regulation loop. The output of the AC voltage regulator is the reference current I_{qref} for the current regulator where I_q is the current in quadrature with voltage which controls the reactive power flow. The output of the DC voltage regulator is the reference current I_{dref} for the current regulator where Id is the current in phase with voltage which controls the active power flow. The current regulator produces V_{2d} and V_{2q} based on the current difference in (I_{dref}–I_d) and (I_{qref}–I_q). In addition, a feed forward type regulator which predicts V_{2d} and V_{2q} from V_{1d} and V_{1q} and the transformer leakage reactance is used to assist the current regulator. The PWM modulator generates pulses to control the IGBT in the VSC based on V_{2d} and V_{2q} in synchronization with the output of the PLL.

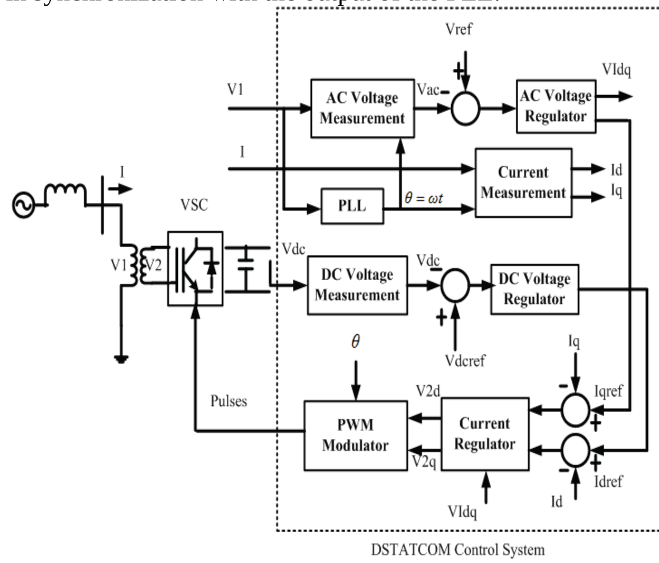

Fig.3. DSTATCOM control system block diagram.

III. FUZZY LOGIC CONTROLLER DESIGN FOR THED-STATCOM.

A fuzzy logic controller (FLC) consists of four elements. These are a fuzzification interface, a rule base, an inference mechanism, and a defuzzification interface. A FLC has to be designed for the DC voltage regulator, AC voltage regulator, and the current regulator. The design of the FLC for DC voltage regulator is described in detail first. The design of the fuzzy controllers for the AC and current regulators follows similar procedure. The PI-like FLC designed for DC voltage regulator has two inputs and one output. The error e(t)(e = V_{dcref}– V_{dc}) and the rate of change of errore(t)are the inputs and the output of the FLC is Δ_{Id}. In fact, Δ_{Id} is integrated to produce I_{dref}. Fig.4 shows the block diagram of the DC voltage regulator where GE, GCE, and GCU are the scaling factors for the inputs and output, respectively. The linguistic variables for error e(t), the rate of change of error e(t) and the controller output Δ_{Id} will take on the following linguistic values

NL = Negative Large
NM = Negative Medium
NS = Negative Small
ZO = Zero
PS = Positive Small
PM= Positive Medium
PL = Positive Large.

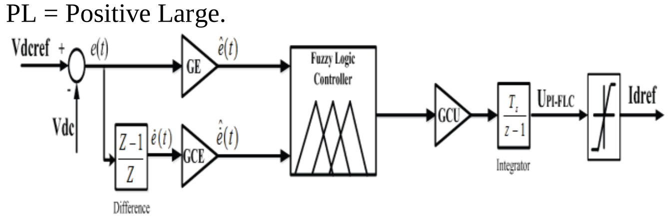

Fig.4. DSTATCOM control system block diagram.

The above linguistic quantification has been used in this paper to specify a set of rules or a rule-base. The rules are formulated from practical experience. For the FLC with two inputs and seven linguistic values for each input, there are 72 = 49 possible rules with all combination for the inputs. The tabular representation of the FLC rule base (with 49 rules) of the fuzzy control based DC voltage regulator is shown in Table I.

TABLE I: 7 × 7 FLC Rule-Base In Tabular Form

e'(t) / e'(t)	NL	NM	NS	ZO	PS	PM	PL
PL	ZO	PS	PM	PL	PL	PL	PL
PM	NS	ZO	PS	PM	PL	PL	PL
PS	NM	NS	ZO	PS	PM	PL	PL
ZO	NL	NM	NS	ZO	PS	PM	PL
NS	NL	NL	NM	NS	ZO	PS	PM

The membership functions to be employed for the inputs are of the triangular type where the membership functions for the output are singletons. The membership functions for the inputs and the output of the fuzzy controller for the DC voltage regulator are shown in Figs. 5, 6, 7.

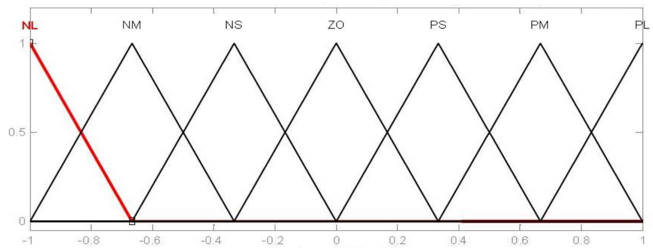

Fig.5. Membership functions of the input error e(t).

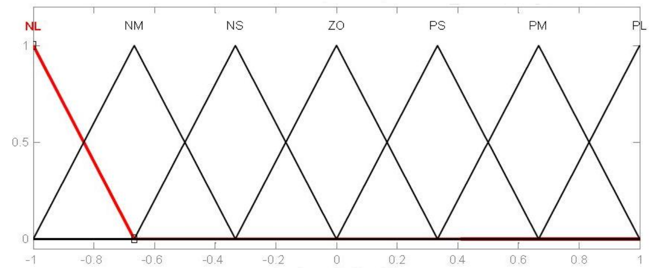

Fig.6. Membership functions of the input change of error e(t).

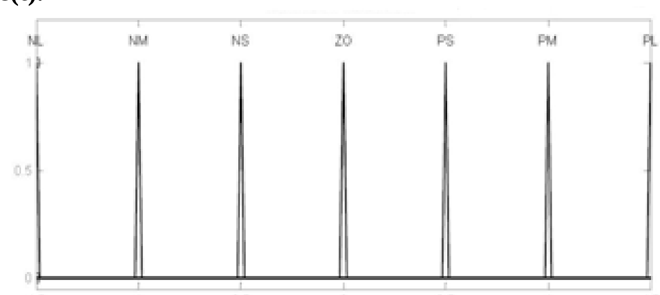

Fig.7. Membership functions of the output of fuzzy logic controller.

IV. COMPARATIVE STUDY OF THE PERFORMANCE OF THE PI AND OPTIMAL FUZZY LOGIC CONTROLLERS FOR THE D-STATCOM

The power system used in the simulation study is shown in Fig. 2 in Section II. System parameters are shown in Table II. The control parameters of the DSTATCOM such as the PI DC and AC voltage regulators gains, and the PI current regulator gains as well as the fuzzy controllers of the DSTATCOM are provided in Table II. Note that the parameters of the PI controllers are provided in the examples in MATLAB/Sim Power Systems. The dynamic response of a DSTATCOM corresponding to initial system transient, step changes in source voltage at the infinite bus, and load variation is observed without the DSTATCOM, with the conventional PI controlled DSTATCOM, and with the fuzzy controlled DSTATCOM. Fig. 9 shows the voltage at B3 when the source voltage has been changed by successively increasing the source voltage by 6%, decreasing it by 6% and bringing it back to its initial value at 0.2s, 0.3s, and 0.4s. Fig. 8 also shows the dynamic response of the system. In addition, the fuzzy controlled DSTATCOM has improved the voltage dynamic response more at PCC by providing less overshoot and faster settling time in comparison with the response with the PI controlled DSTATCOM. It is observed that the voltage at the PCC has improved dramatically when the distribution system is equipped with the DSTATCOM. The fuzzy controlled DSTATCOM has the lowest overshoot and fastest dynamic response during the initial system transient period as show in fig.9.

TABLE II: System Parameters

Parameter	numerical value
Source Voltage	25KV
Distribution Line Voltage	25KV
Frequency	60HZ
Feeder resistance R	0.1153Ω/Km
Feeder inductance L	1.048mH/Km
Feeder capacitance C	11.33nF/Km
Fixed load	1MVA with power factor = 1
DC link capacitor	10mF
DC voltage set point	2.4KV
DSTATCOM DC Voltage RegulatorGains	Kp= 0.001; Ki = 0.15
DSTATCOM AC Voltage RegulatorGains	Kp= 0.55; Ki = 2500
DSTATCOM Current Regulator Gains	Kp= 0.8; Ki = 200

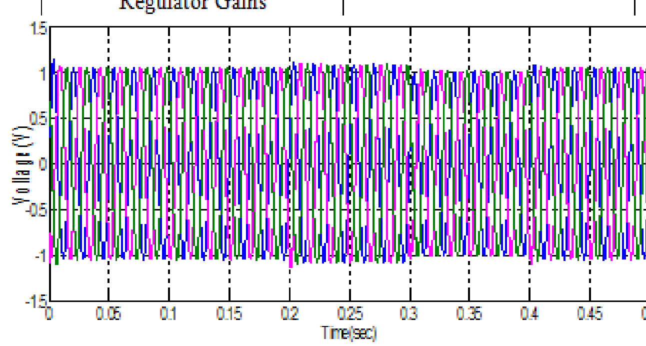

Fig.8(a). voltage at B3 without D-STATCOM.

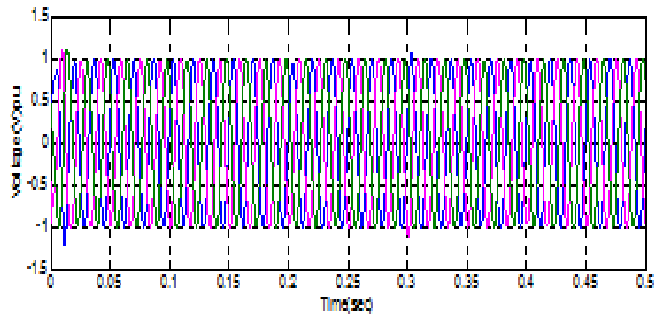

Fig.8(b). voltage at B3 with PI controlled D-STATCOM.

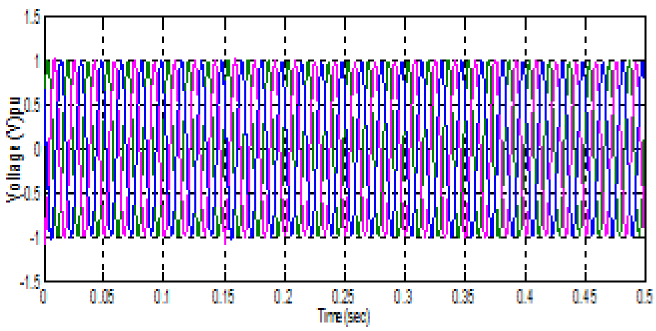

Fig.8(c). voltage at B3 with fuzzy controlled D-STATCOM.

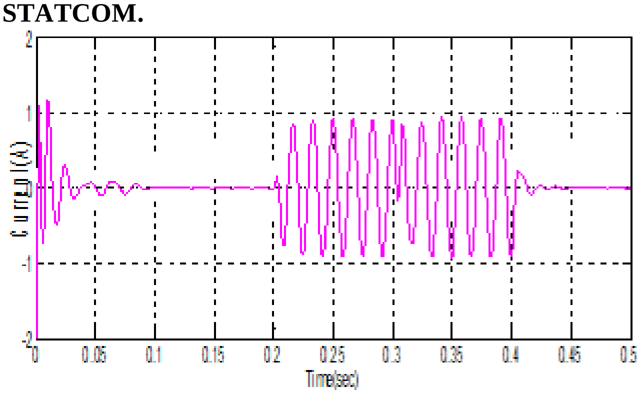

Fig.9(a). Shunt Current of PI Controlled D-STATCOM.

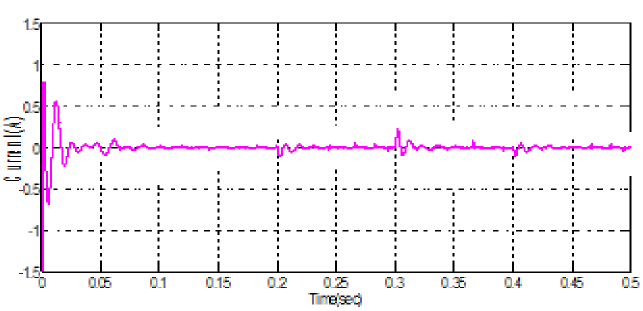

Fig.9(b). Shunt Current of fuzzy Controlled D-STATCOM.

V. CONCLUSION

This paper has presented the design of fuzzy controller for a DSTATCOM to improve power quality and dynamic performance of a distribution power system. Comparison study of the PI controlled and the optimal fuzzy logic controlled DSTATCOM for improving the power quality and dynamic performance of a distribution power system has been simulated using Sim Power System in MATLAB/ Simulink environment.The performances of the DSTATCOM controllers are evaluated during grid side voltage sag and load variations. The simulation results obtained in MATLAB/Sim Power Systems show that the fuzzy logic controlled DSTATCOM provides better system dynamic response and hence improves power quality and stability for the distribution power system.

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