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Power Quality Improvement Using D-STATCOM with PI & Fuzzy Logic Controller

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Abstract:

It was observed from the literature Survey that, the field of power quality and custom power devices plays an important role in power system. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments .The major problems dealt here is the voltage sag and swell.

To solve this problem, custom power devices are used. One of those devices is the D-STATCOM, which is the most efficient and effective modern custom power device used in power distribution networks. DSTATCOM injects a current in to the system to correct the voltage sag and swell. A IGBT based VSC is used. A PWM method is used to generate pulses for IGBT. VSC with pulse-width modulation (PWM) offers fast and reliable control for voltage dips mitigation. The proposed D-STATCOM is modeled and simulated using MATLAB/SIMULINK software. The DSTATCOM is controlled using Synchronous Reference Frame Theory (SRF) using the PI controller.

KEYWORDS:

Distribution Static Compensator (D-STATCOM), Fuzzy Inference Systems (FIS), Proportional Integral (PI), Synchronous Reference Frame Theory (SRF), Voltage Sag, Voltage swell, MATLAB
.

1. INTRODUCTION:

Power quality is one of major concern in the present era. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. The power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end user equipments [1]. Power quality problems comprise a wide range of disturbances such as voltage sags/swells, flicker, harmonics, distortion, impulse, transient and interruptions. Among this problem, voltage sag is the most commonly occurring problems in terms of power quality problems. The IEC electro technical vocabulary, IEC 60050- 604, 1998 defines a voltage sag as any "sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds". Likewise, in more explicitly, A sag, as defined by IEEE Standard 1159, IEEE Recommended Practice for Monitoring Electric Power Quality, is "a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage". Typical values are between 0.1 p.u. and0. 9 p.u. Typical fault clearing times range from three to thirty cycles depending on the fault current magnitude and the type of over current detection and interruption. Actually, Voltage sags are appearing due to faults, motor starting , and transformer energizing. D-STATCOM includes lower cost, smaller size, and its fast dynamic response to the disturbance. [2]. The importance of this paper is to resolve voltage sag and swell problem manifested in voltage deviations that result in failure of customer equipment and to present the model of the custom power device, namely, D-STATCOM and its control application to mitigate voltage sag/swell.

2. BASIC THEORY

D-STATCOM

A distribution static compensator (D-STATCOM) is the most efficient and effective modern custom power device used in power distribution system.

Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. D-STATCOM consists of a voltage source converter (VSC), a DC energy storage device (ESD), a coupling transformer connected in shunt to the distribution system through a coupling transformer. The VSC converts the DC voltage across the storage device into a set of three phase AC output voltages. These voltages are in phase and coupled with the AC system through the reluctance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the AC system. Such configuration allows the device to absorb or generate controllable active and reactive power. As shown in figure 1[3].

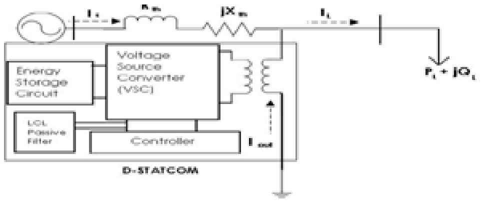

Figure 1 Schematic Representation of D-STATCOM [3].

Control of VSC D-STATCOM(SRF method):

There are many control schemes for control of shunt active compensators such as instantaneous reactive power theory, power balance theory, synchronous reference frame theory, symmetrical components based etc. [4] and the synchronous reference frame theory is used for the control of proposed DSTATCOM.

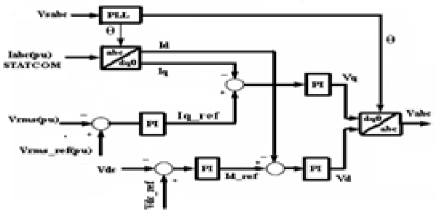

Figure 2 D-STATCOM Controller for voltage regulations

A block diagram of the control scheme is shown in Fig.2 The load currents (i_a, i_b, i_c), the PCC voltages (V_a, V_b, V_c) and dc bus voltage (V_dc) of DSTATCOM are sensed as feedback signals. The load currents from the a-b-c frame are first converted to the α-β-0 frame and then to the d-q-0 frame as,

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

Where, cosθ , sinθ are obtained using a three-phase PLL.The d-axis and q-axis currents consist of fundamental and harmonic components as,

$$i_{Ld} = i_{d\,dc +} i_{d\,ac}$$
$$i_{Lq} = i_{q\,dc} + i_{q\,ac}$$

Instantaneous reactive power theory (p–q theory), synchronous reference frame theory, power balance theory, etc. The synchronous reference frame theory-based method is used for the control of DSTATCOM. A block diagram of the control scheme is shown in Fig. 4.8. The load currents, the source voltages, and dc bus voltage of DSTATCOM are sensed as feedback signals. The loads currents (i_L), the source voltages (V_s), and dc bus voltage V_dc of DSTATCOM are sensed as feedback signals. The loads currents in the three phases are converted into the d-q-0 frame using the Park's transformation as in (2)

A three-phase phase-locked loop (PLL) is used to synchronize these signals with the source voltage. The d-q components are then passed through lowpass filters to extract the dc components of i_d and i_q. The error between the reference dc capacitor voltage and the sensed dc bus voltage of DSTATCOM is given to a proportional-integral (PI) controller whose output is considered the loss component of the current and is added to the dc component of Similarly, a second PI controller is used to regulate the load terminal voltage. The amplitude of the load terminal voltage and its reference value are fed to a PI controller and the output of the PI controller is added with the dc component of.

The control strategy is to regulate the terminal voltage and the elimination of harmonics in the load current and load unbalance. The resulting currents are again converted into the reference source currents using the reverse Park's transformation. The reference source currents and the sensed source currents are used in the PWM current controller to generate gating pulses for the switches. For the power factor correction, only the dc bus voltage PI controller is used in the control algorithm.

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3. PROPORTIONAL INTEGRAL (PI) CONTROLLER:

The aim of the control A PI scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favored in flexible alternating Current transmission systems (FACTS) applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses. The controller input is an error signal obtained from the reference voltage and the value r.m.s of the terminal voltage measured. Such error is processed by a PI controller the output is the angle δ, which is provided to the PWM signal generator. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the r.m.s voltage measured at the load point. The PI controller process the error signal generates the required angle to drive the error to zero, i.e., the load r.m.s voltage is brought back to the reference voltage. As shown in figure 3. PI Controller (proportional-integral controller) is a close loop controller which drives the plant to be controlled with a weighted sum of error and integral that value. PI Controller has the benefit of Steady-state error to be zero for a step input.

Output of comparator = Vdc_ref – Vdc….. (1)

Where,

V dc_ref: Equal 1 per unit voltage reference.

V dc : Voltage in 1 per unit at the load terminals.

PI controller input is an actuating signal which is the difference between the V dc_ref and Vdc Output of the controller block the angles. The angle provides to PWM signal generator to obtain desired firing sequence. Fig. 3 is shown model of PI controller block diagram.

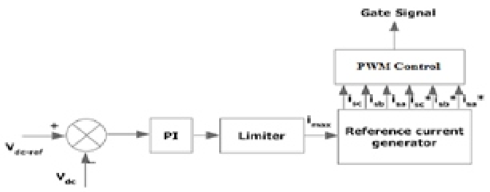


Figure-3 Simulink Model of PI Controller.

4. FUZZY INFERENCE SYSTEM (FIS):

Fuzzy inference systems (FIS) are one of the most famous applications of fuzzy logic and fuzzy set theory. They can be helpful to achieve classification tasks, offline process simulation and diagnosis, online decision support tools and process control. The strength of FIS relies on their two fold identity. On the one hand, they are able to handle linguistic concepts. On the other hand, they are universal approximates able to perform nonlinear mappings between inputs and outputs. These two characteristics have been used to design two kinds of FIS. The first kind of FIS to appear focused on the ability of fuzzy logic to model natural language. These FIS contain fuzzy rules built from expert knowledge and they are called fuzzy expert systems or fuzzy controllers, depending on their final use. Prior to FIS, expert knowledge was already used to build expert systems for simulation purposes.

These expert systems were based on classical Boolean logic and were not well suited to managing the progressiveness in the underlying process phenomena. Fuzzy logic allows grading rules to be introduced into expert knowledge based simulators. It also points out the limitations of human knowledge, particularly the difficulties in formalizing interactions in complex processes. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping, then provides a basis from which decisions can be made, or patterns discerned.. The fuzzy inference system is shown in Figure 3.

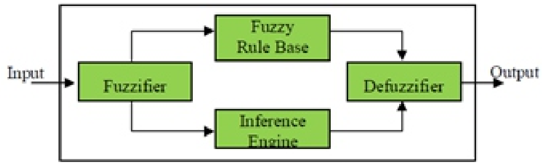


Fig: Fuzzy interface system

Error Calculation The error is calculated from the difference between supply voltage data and the reference voltage data. The error rate is the rate of change of error. The error and error rate are defined as:

Error = V_{ref} – VS……….. (2)
Error rate = error (n) – error (n-1)…… (3)
Where is:
V_{ref} is voltage References.
VSis voltage Source.
Error is Error supply.
Error rate is Error rate supply.

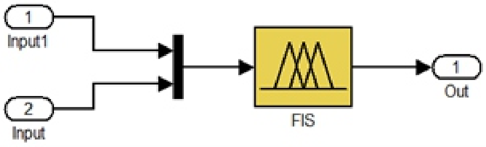


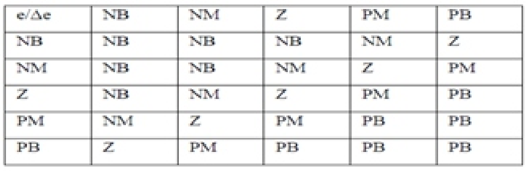
Figure 4(FLC) Scheme

4.1 . METHODS:

The aim of the control system is to maintain voltage magnitude at the point where a sensitive load is connected under system disturbances. Voltage sags is created at the load terminals via a three-phase fault. The above voltage problems are sensed separately and passed through the sequence Analyzer. The control system of the general configuration typically consists of a voltage correction method which determines the reference voltage injected by D STATCOM. FIS has two inputs and one output, the input consisting of 5 members and output fuzzy consists of 5 members. Where the input variables in the range [-5 5], while the output variable in the range [-10 10]. A process for constructing a FIS can be summarized as follows:

I. Choose a specific type of FIS (Mamdani or Sugeno)
II. Select relevant input-output variables
III. Determine the number of linguisticTerms associated with each input-output variable
IV. Design a collection of fuzzy if-then rules
V. Choose thedefuzzification method.

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy. Thus Fuzzification process may involve assigning membership values for the given crisp quantities. This unit transforms the non-fuzzy (numeric) input variable measurements into the fuzzy set (linguistic) variable that is a clearly defined boundary, without a crisp (answer). In this simulation study, the error and error rate are defined by linguistic variables such as negative big (NB), negative medium (NM), zero (Z), positive medium (PM) and positive big (PB) characterized by membership functions given in this Figure.



e/Δe	NB	NM	Z	PM	PB
NB	NB	NB	NB	NM	Z
NM	NB	NB	NM	Z	PM
Z	NB	NM	Z	PM	PB
PM	NM	Z	PM	PB	PB
PB	Z	PM	PB	PB	PB

Figure 5 Rule base for fuzzy-pi controller.

5. MODELLING SIMULATION AND IT'S RESULTS:

5.1 Introduction:

In this section, the model is developed in MATLAB / SIMULINKS. Results of test system without and with D-STATCOM, modelling of andvoltage sag and voltage swell are measure.

5.2.1 Test system for PI controller based system :

The modeled system has been tested on fault condition and under dynamic load condition with two linear RL load. The system is employed with three phase generation source with configuration of 220KV, 50 Hz. The source is feeding two transmission lines through a three phase, three windings transformer with power rating 100MVA, 50 Hz.

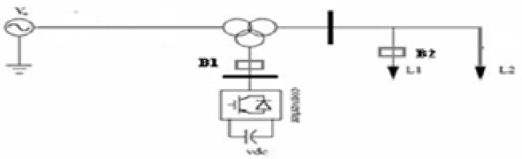


Figure 6 Circuit model for DSTATCOM Test system (11KV system)

5.2.2 Simulation model for without D-STATCOM for voltage sag:

Fig 7 shows the test system implemented in MATLAB. The test system comprises a 220kV, 50Hz transmission system, feeding into the primary side of a 3-winding transformer connected in D/Y, 220/11 kVA varying load is connected to the 11 kV, secondary side of the transformer. A two-level DSTATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the DSTATCOM energy storage capabilities. To show the effectiveness of this controller in providing continuous voltage regulation, simulations were carried out with and with no DSTATCOM connected to the system.

For the simulation study a three source is treated as primary distribution substation and the distribution line is treated as the lumped inductance in series with the resistance. Let us consider a fixed load is connected to the distribution line and a heavy inductive and capacitive load is connected at required instants to study the performance the D-STATCOM for the case of voltage sag conditions.

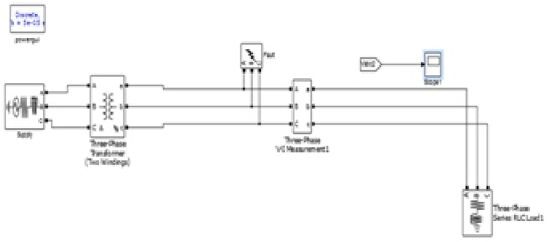


Figure.7 Simulation model for test system for voltage sag

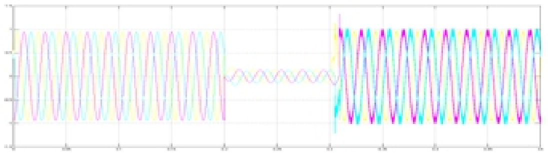


Figure: 8 Voltage sag in phase A,B&C under fault condition

5.2.3 Simulation model without D-STATCOM for voltage swell:

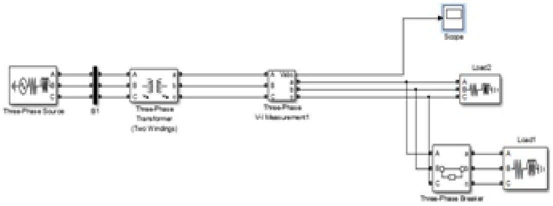


Figure.9 Simulation model for test system for voltage swell

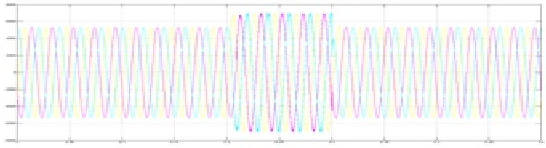


Figure: 10 Voltage swell in phase A,B&C under light load condition

5.2.4 Simulation model with D-STATCOM(PI control) for voltage sag:

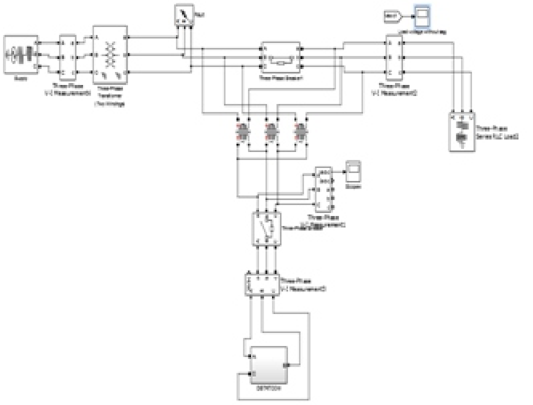


Figure.11 Simulation model with D-STATCOM for voltage sag

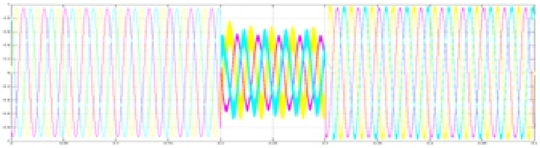


Figure.12 Load Voltage(PI control) Waveform for voltage sag

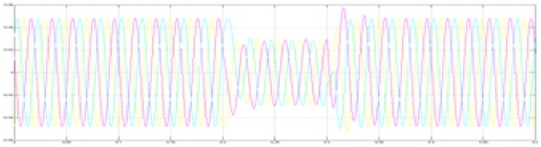


Figure.13 Load Voltage(FUZZY logic control) Waveform for voltage sag

5.2.5 Simulation model with D-STATCOM(Using PI control) for voltage swell:

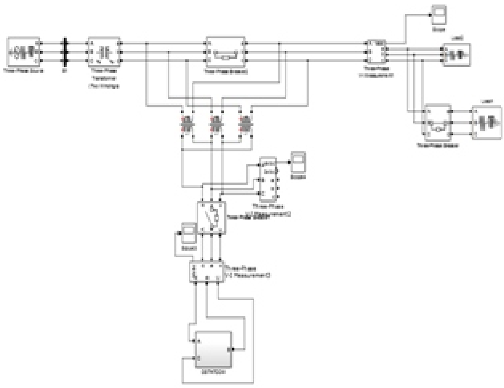


Figure.14 Simulation model with D-STATCOM for voltage swell

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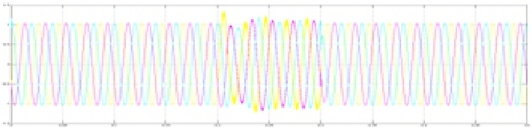

Figure.15 Load Voltage(PI control) Waveform for voltage swell

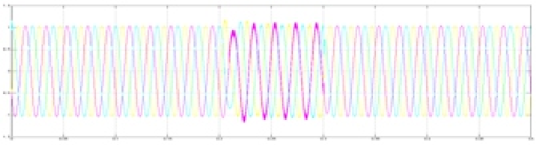

Figure.16 Load Voltage(FUZZY logic control) Waveform for voltage swell

Inverter Model (VSC)

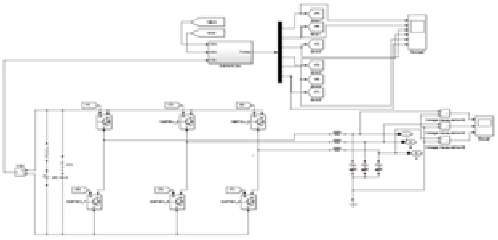

Figure.17 Inverter Model(VSC)

Input & Output

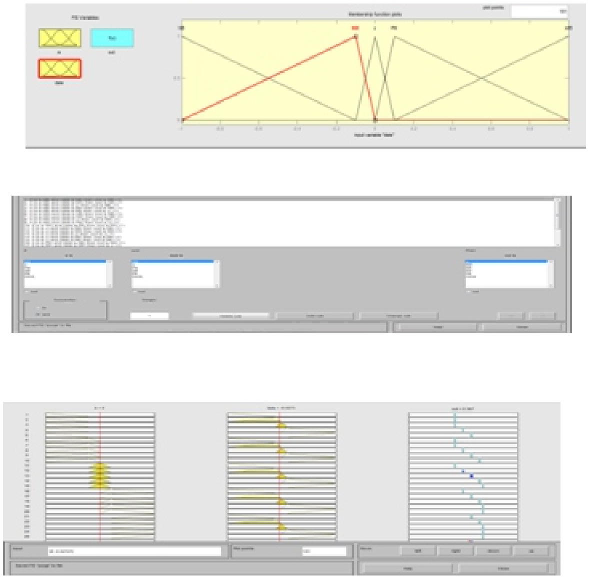

Figure.18 Input output

CONCLUSION:

The modelling of test system for voltage sag without D-STATCOM gives the output 15% and 85% loss. The modelling of test system for voltage sag with D-STATCOM(PI control) gives the 91% output and 9% loss. The modelling of test system for voltage sag with D-STATCOM(fuzzy control) gives the 95% output and 5% loss. The modelling of test system for voltage swell without D-STATCOM gives the output 80% and 20% loss. The modelling of test system for voltage swell with D-STATCOM(PI control) gives the 97% output and 3% loss.

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