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VOLTAGE SAG AND SWELL MITIGATION USING PI & FUZZY BASED DSTATCOM

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ABSTRACT: DSTATCOM is a Distribution static compensator which is used to compensate reactive power and improve power quality issues. A Power quality problem is occurring when any unexpected change in voltage, current or frequency which causes in failure of end user equipments. Example of power quality issues are transient, sag, swell, harmonic, notch and so on. DSTATCOM is absorbing or generating controllable reactive power. D-STATCOM (Distribution Static Compensator) is a one type of shunt device. DSTATCOM has mainly three part, DC link which provide DC source, VSC is a heart of the DSTATCOM, is convert DC source into AC source and third is filter which eliminate harmonic. Now a day's PWM based lasted technology is also used. For the operation of the DSTATCOM PI controller and Fuzzy logic controller is tune. A PI controller is a controller that produces proportional plus integral control action. And Fuzzy logic controller is based on fuzzy logic. Further DSTATCOM improve efficiency of the distribution system, also achieved unity power factor, and maintain constant distribution voltage and remove harmonics in a distribution network.
Key word: DSTATCOM, Voltage Sag, Voltage Swell, PI controller, Fuzzy logic controller

I. INTRODUCTION

In a complex interconnected electric transmission network, power can be transfer by many ways from generating station to load. For a system contain number of sources and multiples loads. So load flow study must be studied to check levels active power and reactive power flow on all line. To control active power and reactive power within limit, line impedance may be change by adding inductor and/or capacitor in series and/or parallel with the transmission line. Now a day, consumers use most sensitive load, so they require high quality power supply. In modern industries, power electronic based load are used, which are sensitive to poor voltage quality and if there is any issue according to power quality than these device will shut down and/or mal-operation occurs. So, FACTs devices are used in distribution systems to overcome from the power quality problems. A FACTs device can be series connected, shunt connected or both simultaneously across transmission line system. Distribution Static Compensator (DSTATCOM), Dynamic Voltage Regulator (DVR), Unified Power Quality Conditioner (UPQC), BESS are some of the FACTs devices are used at distribution system. The usage of FACTs device is mostly to control and/or power quality in distribution system at low or medium voltage. Power quality problem means any mismatch in voltage, current or power frequency that result into mis-operation and/or failure in customer equipment. Apart from Voltage Sag and Voltage Swell is major issue in power system. Voltage Sag is decrease in the value of voltage and current in between 0.1 and 0.9 pu in rms, at the power frequency for time period from 0.5 cycle to 1 min. Further voltage swell is defined as an increase in the value of voltage and current in between to between 1.1 and 1.8 pu in at the power frequency for time durations from 0.5 cycle to 1 min. In this paper DSTATCOM is used for the improvement of power quality. A structure of D-STATCOM is shown in Fig 1.1. It is clear that the parts of DSTATCOM are Voltage Source Converter (VSC), a DC energy storage device, a capacitor, and a filter. D-STATCOM is connected to the distribution system in shunt with the filter.

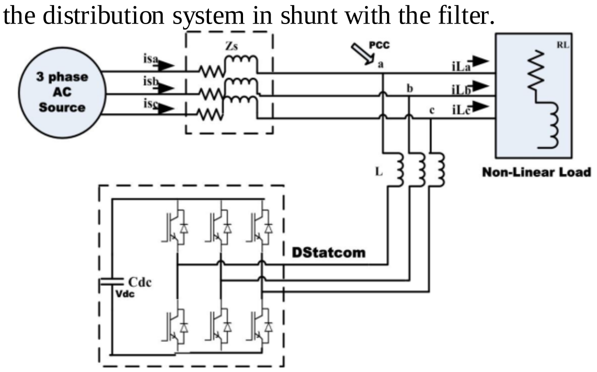

Fig 1.1 Basic structure of Distribution Static Compensator (DSTATCOM)

The operating principle of the basic VSC based D-STATCOM is to control quality of power such as unbalance active and reactive power, voltage variation and so on. So the D-STATCOM is known as a voltage-controlled source. DC storage store DC voltage and VSC convert DC voltage into AC voltage. This AC voltage is synchronized with the grid and it is connected with the grid system via the reactance of the coupling transformer, as shown in Fig 1.2. Vd is the voltage at the point of common coupling and Vs is the source voltage. If the load is not connected than the Vd and Vs are equal, requirement of reactive power is zero, so D-STATCOM does not generate or adsorb any reactive power. If the value of Vd is a greater than the Vs D-STATCOM shows the system as an inductive reactance connected at its terminal and the current Ic flows from the DSTATCOM to the AC system, and the device generates capacitive reactive power. If Vs is greater than Vd, the DSTATCOM shows the system as a capacitive reactance, and the current flows from the AC system to the DSTATCOM, resulting in the device, inductive reactive power is adsorbed. [1][2]

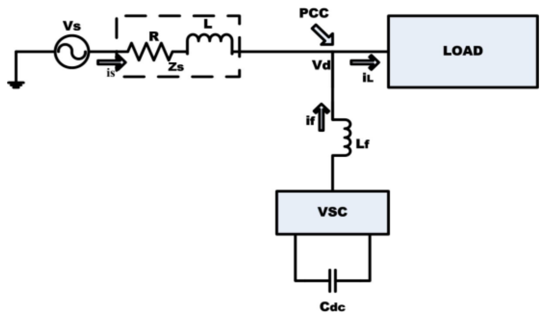

Fig 1.2 Basic single line diagram of D-STATCOM device

II. CONTROLLER

2.1 PI controller

For the operation of DSTATCOM PI controller is used. To control the gate pulse signal of IGBT controller are used. Overall bloke diagram of controller is shown in below Fig 2.1. Controller required input signal Vabc, Iabc, and DC voltage across capacitor Vdc. Output signal Va, Vb, Vc is fed to PWM. Here both three signals are compared with the reference signal. If there is any mismatch then error generates and controller has to produce desire new output. [3] P-I controller is mainly used to eliminate the steady state error resulting from P controller.However in terms of the speed of the response and overall stability of the system,it has a negative impact.This controller is mostly used in areas where speed of the system is not an issue.Since P-I controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations.[4]Here, measurement unit require input signal from PCC. It covert the signal abc to dq from with the help of park's tranformation. Further voltage signal in dq from is transfer to ac voltage regulator. Here this signal is compare with the ac voltage referance signal. Error generated from ac regulator is in term of current in q from. Than dc voltage across the strorage device of DSTATCOM is compare with the dc voltage referance signal in DC voltage regulator. After comparing dc voltage generated error is in terms of current d from. After this two error are compare in current regulator. Further this error generated in current regulator is fed to inverce park's trasformation blok. Here again the dq signal is converted in to abc from and Va, Vb, Vc generated. Further sychonisim of all the voltage Va, Vb, Vc is check with the help of the signal of wt. If there is any mismatch in sychronism then error generated.[5]

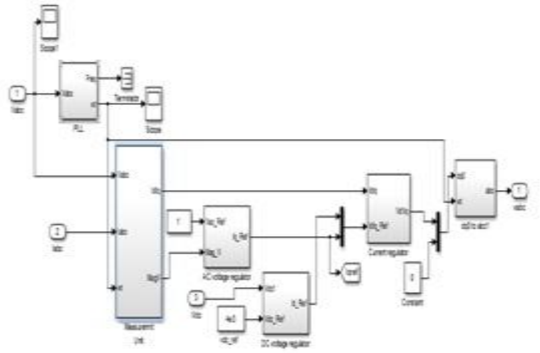

Fig 2.1 Block diagram of PI controller

PI controller is mainly divided into five parts and step by step briefly discussion of all five parts is as below.

Measurement unit

To simplify the solution park's transformation is used. It converts the abc parameter into dq0 parameter. V_{abc}, I_{abc} is an input signal and it transform into V_{dq0} and I_{dq0}. Here zero sequence parameter is eliminating for the easy calculation.

Regulator

Here three type of voltage regulator are used

AC voltage regulator

Mag V is an output of the measurement unit. It is compare with the AC reference voltage. Further calculation generates the Iq_ref reference signal.

$$I_{q\_ref} = (V_{ac\_Ref} - Mag\_V)\times(K_p + \int K_i)$$

DC voltage regulator

Here V_{dc1} is a voltage across the storage capacitor of DSTATCOM. It is compare with the DC reference voltage V_{dc_Ref}. Further calculation generates the I_{d_Ref} reference signal.

$$I_{d\_ref} = (V_{dc\_Ref} - V_{dc1})\times(K_p + \int K_i)$$

Current Regulator

Current I_{dq0} is compare with the reference current I_{dq0_ref}. Both signals are in dq from so it will be separated by the demux, for calculation of the V_d and V_q. Equation for the calculation of V_d and V_q are shown as below.

$$V_d = (I_d - I_{d\_Ref}) \times(K_p + \int K_i)$$
$$V_q = (I_q - I_{q\_Ref}) \times(K_p + \int K_i)$$

Further Voltage in dq form is converted into abc form by using inverse park's transformation.

abc-dq and dq-abc transformation (Synchronous reference frame theory)

The proposed control strategy is aimed to compute mainly the three phase reference voltage at the load terminal. The series active filter based on SRF method can be used to solve the voltage related power quality problems such as, voltage sag, voltage swell and voltage harmonics. The SRF method is used in series active filter for generating reference voltage signal. The supply voltages Vabc are transforming into d-q-0 which is given in equation below.

Abc-dq transformation

$$V_d = \frac{2}{3}(V_a\cos(\omega t) + V_b\cos(\omega t - \frac{2\pi}{3}) + V_c\cos(\omega t + \frac{2\pi}{3}))$$
$$V_q = \frac{2}{3}(V_a\sin(\omega t) + V_b\sin(\omega t - \frac{2\pi}{3}) + V_c\sin(\omega t + \frac{2\pi}{3}))$$
$$V_0 = \frac{1}{3}(V_a + V_b + V_c)$$

Where ωt is the phase angle and V denotes voltages. In the

SRF wt is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltage. Synchronous Reference Frame method (SRF) is one of the most common and probably it is the best method. To implement the SRF method and for reference voltage calculation the phase locked loop (PLL) is used to generate the phase angle (wt) which presents the angular position of the reference frame. This transformation is known as park transformation.

dq-abc transformation:
To convert the function of dq to abc Inverve Park's transformation used. Equation for this is mention below. [6][7][8]

$V_{abc} = Kp^{-1}V_{dq0}$
Where $V_{dq0} = [V_d, V_q, V_0]$
$V_{abc} = [V_a, V_b, V_c]$

$$K_p^{-1} = \begin{bmatrix} cos\,(\omega t) & -\sin\,(\omega t) & 1 \\ \cos\,(\omega t - \frac{2\pi}{3}) & -\sin\,(\omega t - \frac{2\pi}{3}) & 1 \\ \cos\,(\omega t + \frac{2\pi}{3}) & -\sin\,(\omega t + \frac{2\pi}{3}) & 1 \end{bmatrix}$$

2.2 Fuzzy Logic
A fuzzy control system is a control system based on fuzzy logic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively).
Overview
Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true". Although alternative approaches such as genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases, fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans.
Fuzzy sets
The input variables in a fuzzy control system are in general mapped by sets of membership functions similar to this, known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value is called "fuzzification".
A control system may also have various types of switch, or "ON-OFF", inputs along with its analog inputs, and such switch inputs of course will always have a truth value equal to either 1 or 0, but the scheme can deal with them as simplified fuzzy functions that happen to be either one value or another.
Given "mappings" of input variables into membership functions and truth values, the microcontroller then makes decisions for what action to take, based on a set of "rules", each of the form:

IF break temperature is warm and speed is not very fast
Than brake pressure is slightly decreased
Here one example is discussed. When break temperature is warm and speed is low than condition is satisfy otherwise controller check second condition weather brake pressure is decrease or not.
In this example, the two input variables are "brake temperature" and "speed" that have values defined as fuzzy sets. The output variable, "brake pressure" is also defined by a fuzzy set that can have values like "static" or "slightly increased" or "slightly decreased" etc.
This rule by itself is very puzzling since it looks like it could be used without bothering with fuzzy logic, but remembers that the decision is based on a set of rules:

- All the rules that apply are invoked, using the membership functions and truth values obtained from the inputs, to determine the result of the rule.
- This result in turn will be mapped into a membership function and truth value controlling the output variable.
- These results are combined to give a specific ("crisp") answer, the actual brake pressure, a procedure known as "defuzzification."

Fuzzy control in detail
Linear PI controllers are well established in classical control system and it is often used as a benchmark against the other types of controllers. Since this controller is linear, they are not usually suitable for strongly nonlinear systems. Fuzzy Logic Controllers (FLC) is alternative to classical PI controllers in such cases. FLC has been widely used in systems with complex structure because it doesn't need mathematical model of controlled system. Figure 4 shows schematic representation of FLC. As shown in Figure 4, FLC consists of five main parts. These are fuzzification, knowledge base, rule base, inference and defuzzification.

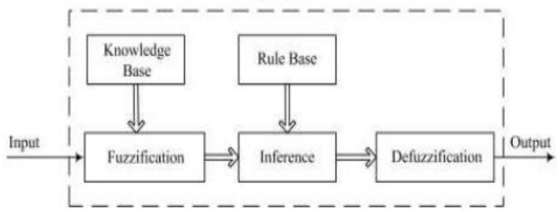

Fig 2.2 Schematic representation of Fuzzy logic controller

In fuzzification part, crisp values of input are converted into fuzzy values, so that these values are compatible with the fuzzy set representation in the rule base. The choice of fuzzification strategy is dependent on the interference engine. The knowledge base consists of a database of the plant. It provides all the necessary definitions for the fuzzification process. Rule base is essentially the control strategy of the system. It is usually obtained from expert knowledge or heuristic as a set of IF-THEN rules. The rules are based on the fuzzy inference. Inference called fuzzy model applies fuzzy reason to rule base to obtain a proper output. Mamdani and Takagi-Sugeno fuzzy systems are the most commonly used fuzzy inference mechanisms. Mamdani is suitable for the systems with slow-changing dynamic while Takagi-Sugeno is suitable for the systems with fast

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changing dynamic. Results obtained from fuzzy process are converted into crisp values by using any defuzzification method such as maxima methods and centre of area.
The structure of the Fuzzy-PI controller is shown Figure 2.3. It has two inputs and one output.

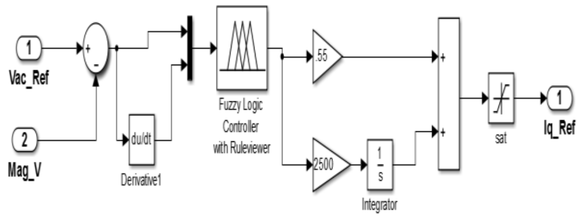

Fig 2.3 Structure of Fuzzy-PI controller

In this study, normalized triangular membership functions are preferred for input variables and output variable as shown in Fig 2.3. Rule base for Fuzzy-PI controller consists of 25 rules and shown in Table 2.1.

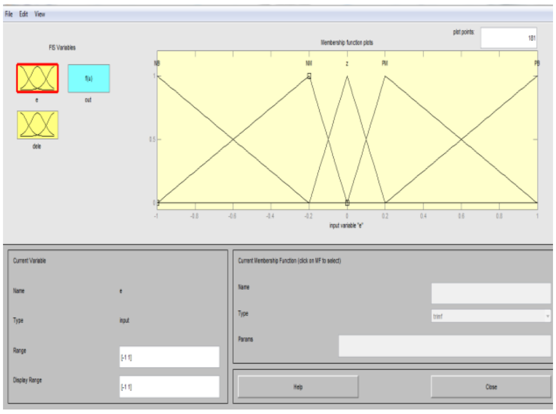

Fig 2.4 Membership function for input 1 for fuzzy logic

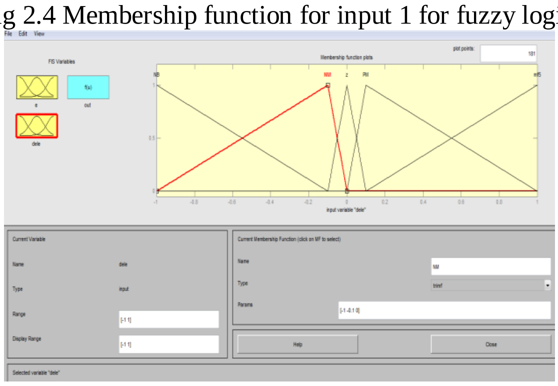

Fig 2.5 Membership function for input 2 for fuzzy logic

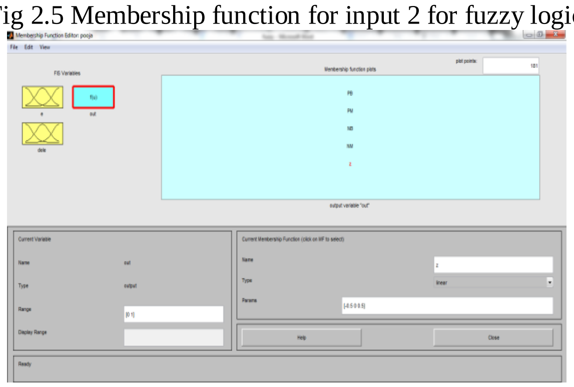

Fig 2.6 Membership function for output for fuzzy logic

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

Table 2.1 Rule base for Fuzzy PI controller

III. VOLTAGE SAG

Sag is a decrease the value of voltage and current in between 0.1 and 0.9 pu in rms, at the power frequency for time period from 0.5 cycle to 1 min. Sag is mostly used to describe the short-duration voltage decrease. Fig 3.1 shows typical voltage sag that can be associated with line-to-ground (LG) fault on another feeder from the same substation. [10]

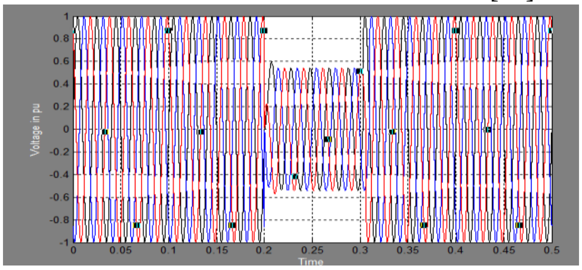

Fig 3.1 Voltage Sag (linear load)

Further Fault timing is 0.2 s to 0.3 s. So fault start at 0.2 s and then it will be healthy system after the 0.3 sec. Further to mitigate this issue DSTATCOM is used as shown in Fig 3.2. Output of PI and Fuzzy based DSTATCOM is shown in Fig 3.3 and Fig 3.4. Here output is approximately one pu so DSTATCOM can be used for mitigation of voltage sag.

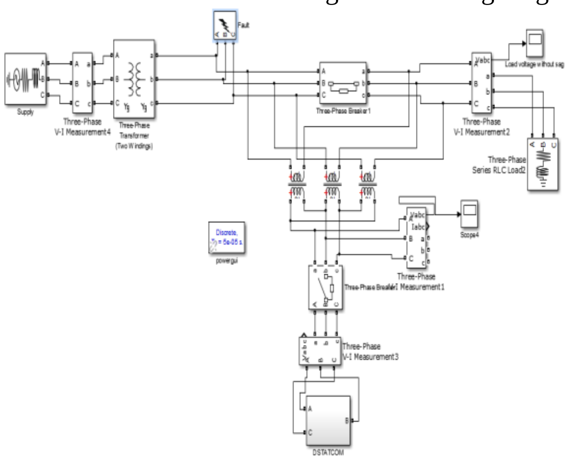

Fig 3.2 Sag mitigation using PI based DSTATCOM

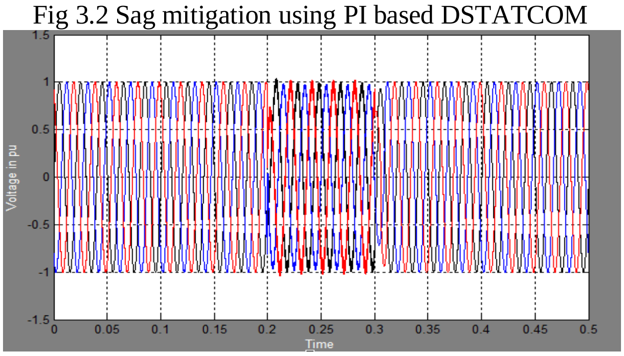

Fig 3.3 PI based DSTATCOM output for voltage sag

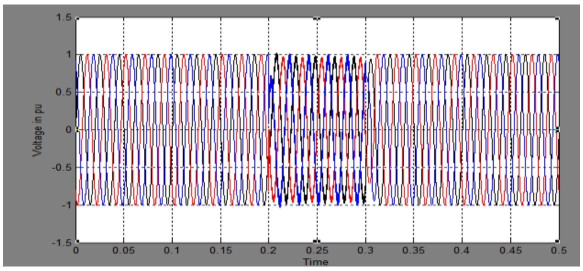

Fig 3.4 Fuzzy based DSTATCOM output for voltage sag

IV. VOLTAGE SWELLS

Swell is defined as an increase in the value of voltage and current in between to between 1.1 and 1.8 pu in at the power frequency for time durations from 0.5 cycle to 1 min. Sags, swells are mostly associated with system fault conditions, but both are different phenomena If there is a temporary voltage rise on the healthy phases during an SLG fault at that time swell can be occur. Fig 4.1 shows a voltage swell occur during an SLG fault. [11]

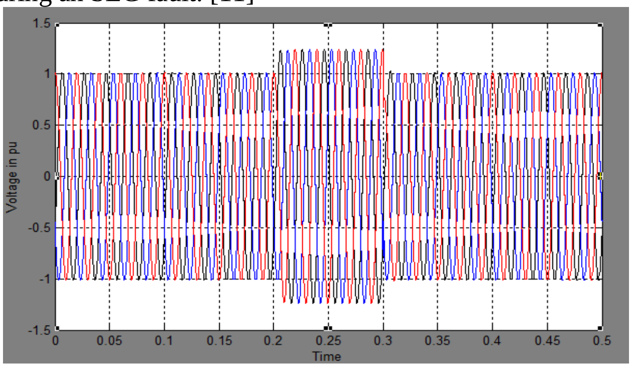

Fig 4.1 Voltage Swell Issue

To mitigate this issue DSTATCOM is used. How DSTATCOM is connected to mitigate this issue is shown in Fig 4.2.

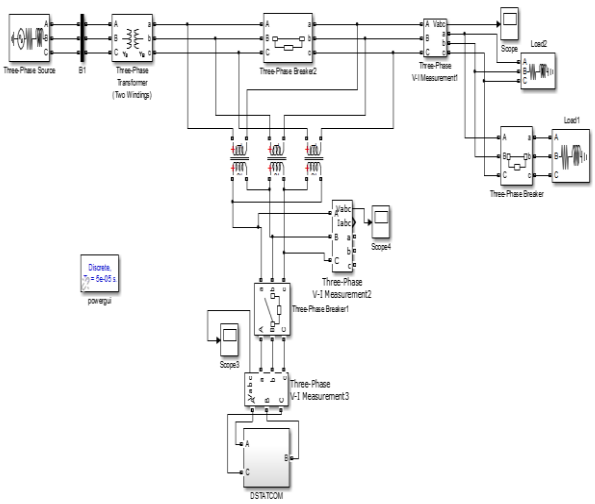

Fig 4.2 Swell mitigation using PI based DSTATCOM

When voltage swell occur at that time DSTATCOM should adsorb current to make system stable. Output of this system is shown in Fig 4.3 and Fig 4.4. Here voltage is approximately one pu so voltage swell is mitigated by DSTATCOM

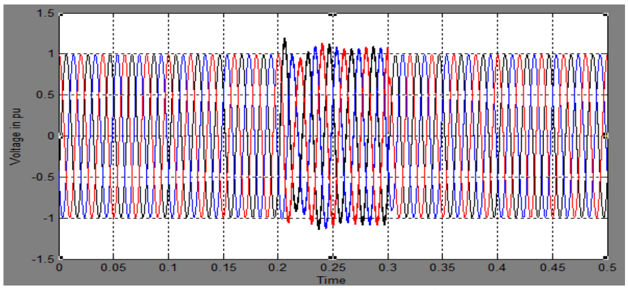

Fig 4.3 PI based DSTATCOM output for voltage swell

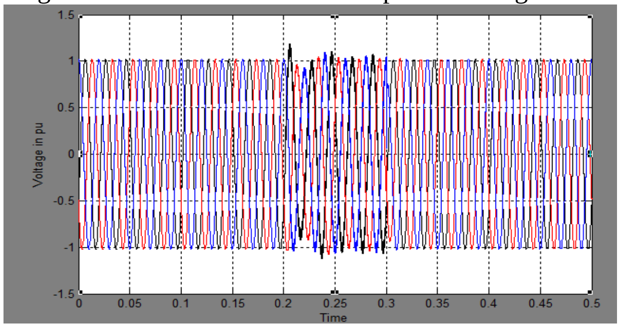

Fig 4.4 Fuzzy based DSTATCOM output for voltage swell

V. COMPERISION

A PI controller is a controller that produces proportional plus integral control action. The PI controller has only one input and one output. The output value increases when the input value increases. A fuzzy-PI controller is a generalization of the conventional PI controller that uses an error signal and its derivative as input signals. Fuzzy-PI controllers have two inputs and one output. Multiple inputs allow for greater control diversity for a fuzzy-PI controller over a conventional PI controller. The benefit of the fuzzy-PI controller is that it does not have a special operating point. The rules evaluate the difference between the measured value and the set value, which is the error signal. The rules also evaluate the tendency of the error signal to determine whether to increase or decrease the control variable. The absolute value of the command variable has no influence. Another advantage of a fuzzy-PI controller over a conventional PI controller is that it can implement nonlinear control strategies and that it uses linguistic rules. With fuzzy-PI controllers, you can consider the error tendency by itself when the error becomes small.

VI. CONCLUSION

DSTATCOM is used as a power quality improvement device. To generate output voltage of DSTATCOM PI and fuzzy logic controller are tuned. This controller generates the gate pulse for the VSC. DSTATCOM is also compensating reactive power. Here operation of DSTATCOM is capacitive when voltage sag is mitigated and inductive operation when voltage swell is mitigated. PI based DSTATCOM is capable for the remove issue like voltage sag and swell. Further voltage sag and swell is also mitigated by Fuzzy based DSTATCOM. Here fuzzy logic controller has Mainer advantage than PI controller. The advantages are response of fuzzy logic controller is fast.

Operation	Voltage in PU	Improvement PI/Fuzzy
Voltage swell	0.5 pu	1 pu
Voltage swell	1.3 pu	1.04 pu

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