Reactive power compensation in distribution Network with D-STATCOM by Fuzzy logic Controller

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Abstract--- This paper present aims to about the performance of D-STATCOM, to mitigate voltage sag, hence improve the power quality of the power system. Various loads like Starting of induction motor, Transient fault & Arc furnace will create voltage sag in the power system; the fuzzy logic controller is use as a substitute for the conventional PI compensator. Using fuzzy logic has received increased attention in recent years because of its usefulness in reducing the need for intricate mathematical models in problem solving.

As the power electronics advances these conventional approaches are absolute from practices due to slow response.

II. EXCURSION TO FACTS

Now on the contrary with the rapid development in power electronics based devices, popularly known as FACTS controllers, which provides promising pattern of future power system. FACTS are define by the IEEE as “a power electronic based system & other static equipment that provide control over one or more transmission system parameters to enhance controllability & increase power transfer capability”. [B].

Power flow in lossless power system can be given as:

\[
\text{POWER TRANSFER FROM BUS-i TO BUS-k given by}
\]

\[
P_{ik} = \frac{V_i V_k \sin(\delta_{ik} - \delta_k)}{x_{ik}}
\]

\[
Q_{ik} = \frac{V_i^2 - V_k^2 \cos(\delta_{ik} - \delta_k)}{x_{ik}}
\]

Fig. 1:

where Vi and Vk are the voltage magnitudes of buses i and k, Xik is the reactance and \(\delta_{ik} - \delta_k\) is the difference angle between phasors Vi and Vk . In normal power system operation, \(\delta_k\) is small and the voltage magnitudes are typically 1.0 p.u. We can therefore easily decouple the active and reactive power controls from each other. While the active power flow is influenced by \(\delta_{ik}\) and Xik, the reactive power flow is related to the magnitude of (Vi -Vk) and Xik. Fig. 2 shows the active power flow equation between two buses i and k and it is the variables that can be controlled by each FACTS device. By providing midpoint compensation we can double the active power transfer capability at half the Value of \(\delta_{ik}\) and Xik. The type of connection between FACTS controllers and system bus they are classified as

1. Shunt controllers such as SVC and STATCOM
2. Series controllers such as TCSC and SSSC
3. Combined shunt-series controllers such as UPFC
4. Series –Series Controllers Such as IPFC

Basically Series & shunt VAR compensator are used to natural electrical characteristics of electrical power systems. The series compensation modifies the transmission or distribution system parameters, while shunt compensation changes equivalent impedance of the load, mainly series...
controller will inject voltages, while shunt controller injects current in the system. [B]

![Diagram of reactive power compensation in distribution network with D-STATCOM](image)

**Fig. 2:**

### III. POWER QUALITY

Power Quality simply define in IEEE 1100 as, “The concept of powering & grounding sensitive electronics equipment in a manner suitable to the equipment” it also defines as, “set of electrical boundaries that allows a piece of equipment to function in intended manner without any significant loss of performance or life expectancy.” Power quality simply means if equipment operates correctly & reliably without being damaged or stressed, we would say the electrical power is of good quality, on other hand, if electrical equipment malfunction or operate un reliably & damaged, we would suspect that power quality is poor. Thus power quality broadly refers to maintaining sinusoidal waveform of voltage & current at rated magnitude & frequency. The power quality issues are Power frequency variation, Supply voltage distortion, Unbalanced load, DC offset on load voltages, Notching in load voltages, Harmonics contain in load, Poor load power factors Waveform Distortions, Transients, Short duration voltage variation, Long duration voltage variation.

**A. Power quality prime issues**
- Due to reactive power following effects arises
- Voltage Sag
- Voltage Swell
- Voltage outage ( Interruption)
- Transient
- Notches
- Harmonics

### IV. VOLTAGE SAG

As Per IEEE standards 1159-1995, recommended practices for power quality is “Decrease in RMS value of voltage or current at power frequency for duration from half cycle to one minute, reported variation between 1 P.U. to 0.9 P.U. Longer period of low or high voltage are referred as “Under voltage” or “over voltage”.[A]

The Voltage sag or Dip is caused by abrupt increase in reactive loading such as switch on the motors, switch on the transformer, severe short circuit fault Fig 1.2

**Fig. 3:**

Voltage sags are most common power disturbances; It contributes more than 80% of power quality problems. Voltage sags are not tolerated by sensitive equipment used in used in industrial plants such as process controllers, programmable logic controllers [PLC], Adjustable speed drives [ASD] and robotics. It has been reported that high intensity discharge lamps used for industrial illumination get extinguished at voltage sag of 20%, the other equipment’s like PLC & ASD are adversely affected by 10% of voltage sag.[9]

The voltage sag is more severe at rural areas, where voltage profile is always very low & almost all the agriculture pumps used induction motor, which is started by Direct on line starter, which leads to high starting inrush current & that results in burning of induction motor due to low voltage & it imposed additional financial burden to poor people.

### V. D-STATCOM

**A. Definition:**

When Static Var compensator is used in low voltage distribution line either to generate or absorb the reactive power is known as DSTATCOM

**Fig. 4:** Single line diagram

The STATCOM is an promising device to mitigate voltage sag & elimination of harmonics from the complex power system. Thus it can control the reactive power by either absorbing or injecting reactive power

**B. Basic configuration**

Mainly it is shunt connected compensator. It has three parts
- [A]Charged D.C. Capacitor
- [B] Voltage source inverter (IGBT based)
- [C] Filters
- [D] inductive coupling

As figure 2.2 indicates charged capacitor will behave as D.C. source That will supply power to three phase line through Voltage Source Inverter.[B] By voltage source inverter this D.C. supply is converted into three phase supply by supplying
pulses to Insulated gate bi junction transistor[IGBTs] [C]Filters are used to avoid switching ripples , which are produces due to switching of IGBTs.

Fig. 5: Voltage source Converter

VI. OPERATION OF STATCOM
The D.C. Capacitor is used as an energy source, This D.C. voltage is converted into three phase through voltage source inverter. The switching of IGBT is done by PWM technique. Switching ripples can be damped by providing filters When STATCOM voltage [Vi] is higher than [Vs] system voltage, Then it will feed the reactive power to the system & When Vi<Vs. , then system will supply reactive power to charge the capacitor. When Vs is equal to Vi, then STATCOM is in floating state

Fig. 6: Operation of DSTATCOM

VII. VARIOUS CONTROLLERS
After deriving transfer function of cited system, it’s behaviour is checked using various controllers First I have started with PI Controller , Step Input[1/S] at 0.5second is given to themsystem&behaviour is observed , for C.R.O. is connected, which shows the waveformsof input signal , error signal & output signal.

VIII. FUZZY CONTROLLER
A. Introductions
Fuzzy set theory is mathematical concept proposed by Prof.L.A.Zadeh in 1965 this concept helps a lot to improve the relationship between human and computers. This control method can be regard as an adaptive control based on a linguistic process, which is in turn base on the prior experience, and heuristic rules used by human operators. The implementation of such control consists of translating the input variables to a language, like: positive big, zero, negative medium, etc. and to establish control rules so that the decision process can produce the appropriate outputs. If necessary, these linguistic outputs are transformed to numeric values.

Fuzzy logic control is one of the best and most successful techniques among expert control strategies, and is well known as an important tool to control non-linear, complex, vague, and ill-defined systems. The use of fuzzy set theory in providing effectiveness control based on the knowledge and technical experience of operators and the establishment of intelligent control have found favour in industry.[11]

B. Fuzzy logic algorithm
Fuzzy logic is a mathematical theory and introduced by Zadeh in 1965. Since its introduction, it has been use to solve many different problems in electrical engineering fields. Fuzzy logic is an effective approach in dealing with electric power engineering problems such as stability studies, load frequency control, unit commitment, and reactive compensation in distribution networks. Fuzzy logic is base on linguistic variables. The first step in designing fuzzy inference mechanism is to identify effective input variables and output decision variables, and then qualify them with membership functions. Membership functions determine that how variables belong to a fuzzy set. This process is call fuzzification. After fuzzification, we should define rules based on linguistic variables and the physical dynamic of the system. Then fuzzy inference mechanism determines effective rules and based on these rules, decision variables are produce. Finally, the fuzzy decision variables are convert to real numbers through the process of defuzzification.[8]

C. Fuzzy logic controller methodology
Fuzzy logic control essentially involves the derivation of a control law from heuristic and imprecise (fuzzy) rules. The configuration of the Fuzzy logic control system that is employed for designing the Fuzzy supplementary controller is shown in fig 3.1.

The following steps are involved in the designing fuzzy logic controller.
1) Choose the inputs to FLC (INPUT-CRISP):
   - The inputs to FLC used in this study are generator terminal voltage deviation (\(\Delta V_t\)) which are given by
   - \(\Delta V_t\)pu = Vref – Vt(\(\Delta V_t\))
   - Where
   - Vt= Transmission line voltage (pu)
   - Vref=Reference voltage per unit (constant 1)
2) Choose membership functions to represent the inputs and outputs in fuzzy set notation (FUZZIFICATION):

Triangular membership functions were selected for this study as shown in Fig. with six linguistic variables chosen as negative (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), positive big (PB) for both inputs and outputs. The values of the axes are given in Fig 4.2.

Choose membership functions to represent the inputs and outputs in fuzzy set notation (FUZZIFICATION):

D. Develop fuzzy rules (FUZZY RULE BASE):

A set of decision rules relating the inputs to the controller with the output are compiled and stored in the memory in the form of decision table. Forty-nine rules for the present study are developing as follows.

<table>
<thead>
<tr>
<th>Error</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>ZE</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NM</td>
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<td>NS</td>
<td>ZE</td>
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<tr>
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<td>NM</td>
<td>NS</td>
<td>NS</td>
<td>ZE</td>
<td>PS</td>
<td>PM</td>
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<tr>
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<td>NM</td>
<td>NS</td>
<td>NS</td>
<td>ZE</td>
<td>PS</td>
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<td>PM</td>
<td>PB</td>
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<td>PB</td>
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<tr>
<td>PB</td>
<td>ZE</td>
<td>PS</td>
<td>PM</td>
<td>PB</td>
<td>PB</td>
<td>PB</td>
<td>PB</td>
</tr>
</tbody>
</table>

TABLE 3

E. FUZZY INFEERENCE ENGINE:

Since there are N (seven) membership functions for each input, there are $N^2$ (forty-nine) possible combinations resulting in M (seven) values for the decision variable $u$. All the possible combinations of inputs, called states, and the resulting control are arranged in a $(N^2 \times M)$ fuzzy relationship matrix. The membership values for the output characterized by the M linguistic variables are then obtained from the intersection of N2 values of membership function $\mu(x)$ with the corresponding values of each decision variables in the fuzzy relationship matrix.

F. Defuzzy to obtain crisp output (DEFUZZIFICATION):

The output FLC is converted to crisp value by Centre or Gravity (COG) method in this study. The crisp value of FLC in COG is express as,

$$\text{crisp output } (u) = \frac{\sum_{i=1}^{n} b_i \mu(i)}{\sum_{i=1}^{n} \mu(i)}$$

Where, $b_i$ is the center of the membership function.

$\mu(i)$ is the membership of member $i$ of output fuzzy set.

n is the number of discrete value $i$ on the universal of discourse.

Test system

The test system shown in figure 4.2 comprises a 230kv, 50 Hz transmission system, represented by a thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 KV. A varying load is connecting 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 750μF capacitor on the dc side provide the DSTATCOM energy storage capabilities. Capacitor value calculated equation (4) using; dc voltage find equation (5).

The percentage of sag for the system is calculated using the following equation.

$$sag(\%) = \frac{v_{pre-sag}(p,u) - v_{sag}(p,u)}{v_{pre-sag}(p,u)} \times 100$$
G. Fuzzy Controller

In basic applications, the FL controller is used as a substitute for the conventional PI compensator. The voltage error and its derivative are the FL controller input crisp values. The reference voltages for the PWM generator are the FL controller crisp output commands.

When a FL controller is used, the tracking error and transient overshoots of PWM can be considerably reduced. This is because in contrast to the conventional PI compensator-the control surface of the FL controller can be shaped to define appropriate sensitivity for each operating point. The FL controller can easily be implemented as an off-line pre-calculated three-dimensional lookup table consisting of the control surface.

The PI controller requires precise linear mathematical models, which are difficult to obtain and fails to perform satisfactorily under parameter variation, nonlinearity, load disturbance. FLC are that they do not need an accurate mathematical model. They can work with imprecise input, can handle none-linearity and they are more robust than conventional controller. [2]

H. Control strategy for voltage sag mitigation

To mitigate voltage sag, the following figure will indicate the control strategy. At start though positive sequence analyses. The positive sequence comparator will give out put in P.U. The comparator compares. The value with the reference [1P.U], then the error is fed to fuzzy controller. His fuzzy controller will generate actuating signal, which is multiply by pi/180, thus we can convert the sag into angel [radians,ø]. Now one clock signal created & added. Now it is [Wt+ø]. As with the addition & subtraction of 2π/3, it can be converted into [Wt + ø - 2π/3] & [Wt + ø + 2π/3]. Then sin function is taken & that will pass through triangular wave, which create pulse for IGBTs of VSC.

Table 4 shows the overall result of voltage sags in P.U for different types of fault. From the table, it can
observe that when the value of fault resistance is increase, the voltage sag will also increase for different types of fault. 

Three phase to ground fault with 0.66 \(\Omega\) 0.6600 P.U scope output

Fig. 16: Double line ground fault with 0.66\(\Omega\), 0.7060 P.U scope output

Fig. 17: Line to line fault with 0.66\(\Omega\), 0.7580 P.U scope output

Fig. 18: Single line to ground fault with 0.66\(\Omega\), 0.8245 P.U scope output

X. SIMULATION OF VOLTAGE SAG MITIGATION BY D-STATCOM

Fig. 20: Result of voltage sags for different types of fault with insertion of DSTATCOM

<table>
<thead>
<tr>
<th>Types of fault</th>
<th>Without D-STATCOM (P.U)</th>
<th>With D-STATCOM (P.U)</th>
<th>Percentage of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPG</td>
<td>0.6600</td>
<td>0.9428</td>
<td>28.28</td>
</tr>
<tr>
<td>DPG</td>
<td>0.7070</td>
<td>0.9825</td>
<td>27.55</td>
</tr>
<tr>
<td>LL</td>
<td>0.7580</td>
<td>1.0195</td>
<td>26.08</td>
</tr>
<tr>
<td>SPG</td>
<td>0.8245</td>
<td>0.9865</td>
<td>16.20</td>
</tr>
</tbody>
</table>

Table 5

Figure 5.6 show the simulation result of the test system for different types of fault. The fault occurs during (0.4s 0.6s) when the fault resistance is 0.66\(\Omega\).

Three phase to ground fault with 0.66 \(\Omega\) 0.9428 P.U scope output

Fig. 21: Double line to ground fault with 0.66 \(\Omega\) 0.9825 P.U scope output

Fig. 22: Line to line fault with 0.66 \(\Omega\), 1.0195 P.U scope output
XI. CONCLUSION

The simulation result show that the voltage sags can be mitigating by inserting D-STATCOM to the distribution system.

A fuzzy logic controlled D-STATCOM has been simulated compensating reactive power in distribution networks and compared result of simulation with the PI conventional controller, we can see fuzzy logic controller with linguistic variable is very simple and in the fuzzy controller we does not require a mathematical model of the system.

<table>
<thead>
<tr>
<th>Types of fault (Rf=0.66Ω)</th>
<th>D-STATCOM with PI controller (P.U)</th>
<th>D-STATCOM with fuzzy logic controller (P.U)</th>
<th>Percentage of improvement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPG</td>
<td>0.9367</td>
<td>0.9428</td>
<td>0.60</td>
</tr>
<tr>
<td>DLG</td>
<td>0.9800</td>
<td>0.9825</td>
<td>0.25</td>
</tr>
<tr>
<td>LL</td>
<td>1.0168</td>
<td>1.0195</td>
<td>0.27</td>
</tr>
<tr>
<td>SLG</td>
<td>0.9837</td>
<td>0.9865</td>
<td>0.28</td>
</tr>
</tbody>
</table>

REFERENCE


[4] Harish suryanarayana and Mahesh k. Mishra “fuzzy logic based supervision of DC link PI controller”