FUZZY LOGIC BASED OPTIMAL LOCATION AND SIZING OF DSTATCOM IN RADIAL DISTRIBUTION SYSTEMS

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ABSRACT

This paper illustrates a study on voltage profile improvement of a Radial Distribution System (RDS), using Distribution Static Compensator (D-STATCOM). D-STATCOM is a shunt device which is generally used to solve power quality problems in distribution systems and is used in correcting power factor, maintaining constant distribution voltage and mitigating harmonics in a distribution network. The D-STATCOM injects a current into the system to mitigate the voltage sags. In this paper planning and operation of RDS, with respect to placement of DSTATCOM are discussed with the help of load flow studies (LFS) and Fuzzy Logic. A detailed performance analysis was carried out on IEEE 33-bus RDS in MATLAB code.

Keywords: Radial Distribution Systems, D-STATCOM, Fuzzy Logic, Optimal Location, Optimal Size, Objective Function.

I. INTRODUCTION

In the early days of power transmission problems like voltage deviation during load changes and power transfer limitation were observed due to reactive power unbalances. Today these Problems have even higher impact on reliable and secure power supply in the world of Globalization and Privatization of electrical systems and energy transfer. The development in fast and reliable semiconductors devices (GTO and IGBT) allowed new power electronic Configurations to be introduced to the tasks of power Transmission and load flow control. The FACTS devices offer a fast and reliable control over the transmission parameters, i.e. Voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage. On the other hand the custom power is for low voltage distribution, and improving the poor quality and reliability of supply affecting sensitive loads. Custom power devices are very similar to the FACTS. Most widely known custom power devices are DSTATCOM, UPQC, DVR among them DSTATCOM [2] is very well known and can provide cost effective solution for the compensation of reactive power and unbalance loading in distribution system [4].

In this paper an effective methodology to identify the optimum location for DSTATCOM placement for minimizing the losses and voltage profile improvement in radial distribution system is proposed. The optimal size of DSTATCOM is calculated by modeling it, to maintain the voltage magnitude as 1 p.u. and to supply the required reactive power for compensation at the node where DSTATCOM is placed. The cost of DSTATCOM and other associated benefits have not been considered while solving the location and sizing problem. The proposed methodology is suitable for allocation of DSTATCOM in a given distribution system. Section 2 presents brief introduction to Distribution Static compensator (DSTATCOM). Section 3 presents the mathematical modeling of DSTATCOM which is the optimum size of DSTATCOM at each bus. A novel methodology for determining the optimum location of DSTATCOM is presented in Section 4. In Section 5presents the Fuzzy implementation [1]. In Section 6theproposed methodology is tested with a 33 bus radial distribution system and the results are discussed in this section. Finally conclusions of the paper are summarized in section7.

II. DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator (similar in many respects to the DVR) that is used for the correction of bus voltage sags. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations. The major components of a DSTATCOM are shown in Figure 1. It consists of a dc capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage, and a PWM control strategy. In this DSTATCOM implementation, a voltage-source inverter converts a dc voltage into a three-phase ac voltage that is synchronized with, and connected to the ac line through a small tie reactor and capacitor (ac filter).

Components of DSTATCOM:

DSTATCOM involves mainly three parts as described below;

I. IGBT or GTO based dc-to-ac inverters: These inverters are used which create an output voltage wave, controlled in magnitude and phase angle to produce either leading or lagging reactive current, depending on the compensation required.

L-C Filter**:** The LC filter is used which reduces harmonics and matches inverter output impedance to enable multiple parallel inverters to share current. The LC filter is chosen in accordance with the type of the system and the harmonics present at the output of the inverter.

II. Control Block**:** Control block is used to switch Pure Wave by DSTATCOM modules as required. They can control external devices such as mechanically switched capacitor banks too. These control blocks are designed based on the various control theories and algorithms like instantaneous PQ theory, synchronous frame theory etc.

III. CONTROL STRATEGIES

The main objective of any compensation scheme is that it should have a fast response, flexible and easy to implement [5]. The control algorithms of a DSTATCOM are mainly implemented in the following steps:

a. Measurements of system voltages and current and Signal conditioning.

b. Calculation of compensating signals

c. Generation of firing angles of switching devices

d. Generation of proper PWM firing is the most important part of DSTATCOM control and has a great impact on the compensation objectives, transient as well as steady state performance. Since a DSTATCOM shares many concepts to that of a STATCOM at transmission level, a few control algorithms were incorporating Pulse Width Modulation (PWM) switching [9], rather than Fundamental Frequency switching (FFS) methods.

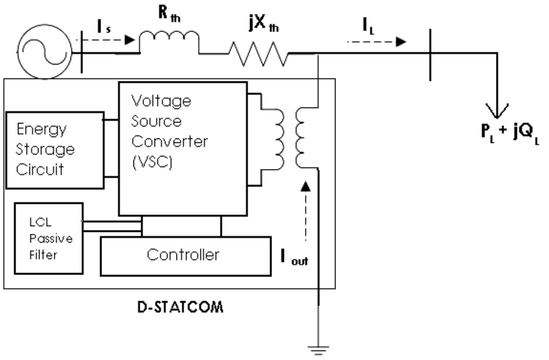


Fig: 1 Block Diagram of DSTATCOM

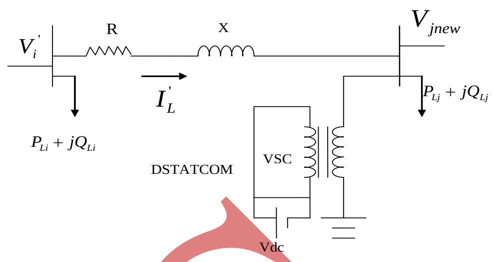


Fig: 2 Line diagram of RDS

III. DSTATCOM MATHEMATICAL MODELING

The schematic diagram of buses i and j of a distribution system, when DSTATCOM is installed for voltage profile improvement in bus j, as shown in figure 2. Voltage of bus j changes from V_j to V_{jnew} when dstatcom is used.

$$V_j\angle\alpha = V_i\angle\delta - ZI_L\angle\theta \quad (1)$$

Where $V_i\angle\alpha$ is the source voltage, $V_j\angle\beta$ is the voltage at DSTATCOM placed.

Z is the branch impedance, and I_L is the line current.

$$\angle I_{DSTATCOM} = \frac{\pi}{2} + \alpha_{new} \;, \alpha_{new} < 0$$

Where $I_{DSTATCOM}$ is the current injected by DSTATCOM.

$$V_{jnew}\angle\alpha_{new} = V_i'\angle\delta' - (R+jX)I_L'\angle\theta' - (R+jX)I_{DSTATCOM}\angle\left(\alpha_{new}+\frac{\pi}{2}\right) \quad (2)$$

$V_{jnew}\angle\alpha_{new}$ is the voltage of the bus after compensation by DSTATCOM.

Equating real and imaginary parts of equation 2, we obtain

$$V_{j\,new}\cos\alpha_{new} = \mathrm{Re}\left(V_i'\angle\delta\right) + XI_{D-STATCOM} * \sin\left(\alpha_{new}+\frac{\pi}{2}\right) - \mathrm{Re}\left(ZI'_L\angle\theta'\right) - RI_{D-STATCOM} * \cos\left(\alpha_{new}+\frac{\pi}{2}\right) \quad (3)$$

$$V_{j\,new}\sin\alpha_{new} = \mathrm{Im}\left(V_i'\angle\delta\right) - XI_{D-STATCOM} * \cos\left(\alpha_{new}+\frac{\pi}{2}\right) - \mathrm{Im}\left(ZI'_L\angle\theta'\right) - RI_{D-STATCOM} * \sin\left(\alpha_{new}+\frac{\pi}{2}\right) \quad (4)$$

Using the following notations

$$a_1 = \mathrm{Re}\left(V_i'\angle\delta\right) - \mathrm{Re}\left(ZI'_L\angle\theta'\right)$$

$$a_2 = \mathrm{Im}\left(V_i'\angle\delta\right) - \mathrm{Im}\left(ZI'_L\angle\theta'\right)$$

$$b = V_{j\,new} \;, c_1 = -R \;,\; c_2 = -X \;,\; x_1 = I_{D-STATCOM} \;,\; x_2 = \alpha_{new}$$

Equating the above notations in Equations 3 & 4,

$b\cos x_2 = a_1 - c_1 x_1 \sin x_2 - c_2 x_1 \cos x_2$ (5)

$b\sin x_2 = a_2 - c_2 x_1 \sin x_2 + c_1 x_1 \cos x_2$ (6)

From equations 5 and 6

$$x_1 = \frac{b\cos x_2 - a_1}{-c_1 \sin x_2 - c_2 \cos x_2} \quad (7)$$

$$x_1 = \frac{b\sin x_2 - a_2}{-c_2 \sin x_2 + c_1 \cos x_2} \quad (8)$$

Equating7 and 8 we obtain

$(a_1c_2 - a_2c_1)\sin x_2 + (-a_1c_1 - a_2c_2)\cos x_2 + bc_1 = 0$ (9)

From 9 and squaring on both sides

$(k_1^2 + k_2^2)x^2 + (2k_1bc_1)x + (b^2c_1^2 - k_2^2) = 0$ (10)

Where

$k_1 = a_1c_2 - a_2c_1$, $k_2 = a_1c_1 + a_2c_2, x = \sin x_2$

From10

$x = \frac{-B \pm \sqrt{\Delta}}{2A}$, $\Delta = B^2 - 4AC$, $A = k_1^2 + k_2^2$, $B = 2k_1bc_1$, $C = b^2c_1^2 - k_2^2$

By finding the Roots find α_{new} and from 7 find $I_{D-STATCOM}$.

$\alpha_{new} = sin^{-1} x$ (11)

$jQ_{D-STATCOM} = V_{j\ new} I^*_{D-STATCOM}$ (12)

$V_{j\ new} = V_{j\ new} \angle \alpha_{new}$ (13)

$I_{D-STATCOM} = I_{D-STATCOM} \angle \left(\alpha_{new} + \frac{\pi}{2}\right)$ (14)

IV. DSTATCOMALLOCATION IN A RDS

A new method is introduced to allocate the DSTATCOM in RDS. The algorithm of DSTATCOM allocation is in 4.1. Optimum location of a DSTATCOM is described by the Rate of Nodes whose voltages are within limits (NVIL) i.e. 0.95 p.u to 1.05 p.u power loss and cost of the DSTATCOM. NVIL is the ratio of the difference of the number of buses whose voltage magnitudes are within limits (before and after compensation) to that of total number of buses multiplied with 100. More the S value, more is the chances of DSTATCOM placement for that bus. A new relation is introduced between NVIL, power losses and cost of the DSTATCOM.

$$S(max) = k1 * NVIL + \frac{k2}{Ploss} + \frac{k3}{C} \quad (15)$$

S is the selection criteria.

NVIL is the percentage number of voltages within limits before and after compensation.

Ploss is the total power losses after compensation.

C is the cost of DSTATCOM depends on its size and reactive power losses [11].

k1, k2, k3 are the weights depends upon the importance of indices.

ALGORITHM FOR DSTATCOM ALLOCATION

Step 1: Read the distribution system branch impedance values and the bus real and reactive power data.

Step 2: Run the Load Flow of Distribution System to find out voltage magnitudes at the buses using forward - Backward method.

Step 3: Select the weak bus

Step 4: Assume the voltage profile of the candidate bus to be 1 p.u.

Step 5: Obtain the reactive power of the DSTATCOM and phase angle of the compensated bus by using equations 11 &12.

Step 6: Update the reactive power and voltage phase angle at candidate bus.

Step 7: Run the Load Flow of Distribution System with updated reactive power at the candidate bus.

Step 8: Calculate the NVIL for that bus and total power loss.

Step 9: Similarly attach DSTATCOM in all the buses one by one and perform Step1 to Step 8 in each case.

Step 9: By using Fuzzy logic optimize dstatcom location with the selection criteria in equation 15.

Step10: end.

V. IDENTIFICATION OF OPTIMAL DSTATCOM LOCATION – FUZZY APPROACH

This study presents a fuzzy approach to determine the suitable locations for DSTATCOM placement. Three objectives are considered while designing a fuzzy logic for identifying the optimal DSTATCOM locations. They are (i) to minimize the power loss (ii) to maintain voltage within permissible limits and (iii) Cost of the dstatcom. Voltage limits, cost and power loss indices of distribution systems are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing set of rules is then used to determine suitable placement of DSTATCOM on the nodes in a distribution system. The DSTATCOM can be placed on the nodes with highest suitability index. A set of fuzzy rules has been used to determine suitable locations in a distribution system. Three input and one-output variables are selected. Input variable-1 is NVIL (rate of number of voltages within limits), Input variable-2 is the Power Loss and Input variable-3 is the cost of DSTATCOM. Output variable is DSTATCOM suitability index (DSSI). Five membership functions are selected for NVIL, PLOSS and COST. They are L, LN, N, HN and H. These membership functions are trapezoidal as shown in figure3. Five membership functions are selected for Power Loss. They are L, LM, M, HM and H. All the five membership functions are triangular as shown in figure 4. Five membership functions are selected for COST. They are L, LM, M, HM and H. All the five membership functions are triangular as shown in figure5. Five membership functions are selected for DSSI. They are L, LM, M, HM and H. These functions are also triangular as shown in figure 6. For the DSTATCOM allocation problem, rules are defined to determine the suitability of a node for DSTATCOM installation. Such rules are expressed in the following manner: IF premise (antecedent), THEN conclusion (consequent). For determining the suitability of DSTATCOM placement at a particular node, a set of multiple antecedent fuzzy rules have been established. The inputs to the rules are the voltage, cost and Loss indices and the output is the suitability of DSTATCOM placement. FIS editor receives inputs from the load flow program. Several rules may fire with some degree of memberships. FIS is based on Mamdani max-min and max-prod implication methods of inference. These methods determine the aggregated output from the set of triggered rules. The max-min method involves truncating the consequent membership function of each fired rule at the minimum membership value of all the antecedents. A final aggregated membership function is achieved by taking the union of all truncated consequent membership functions of the fired rules. After calculating the suitability membership function, it is to be defuzzified using the centroid method in order to determine the optimal DSTATCOM location.

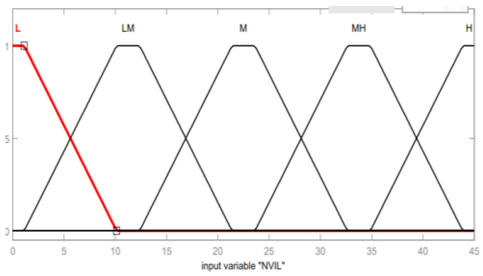


Fig 3: Membership function plot for Rate of Nodes Whose voltages are within limits.

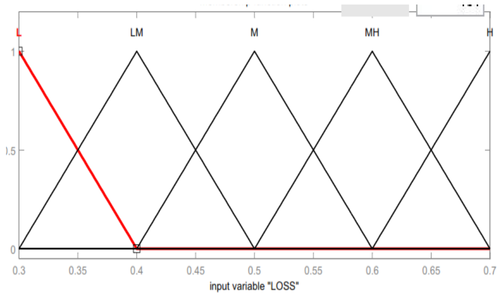


Fig 4: Membership function plot for Power loss

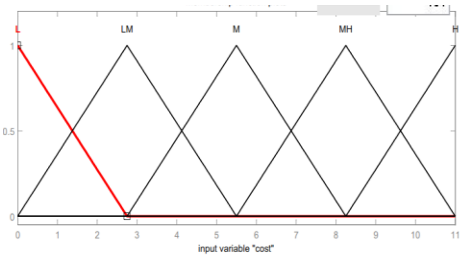


Fig 5: Membership function plot for Cost

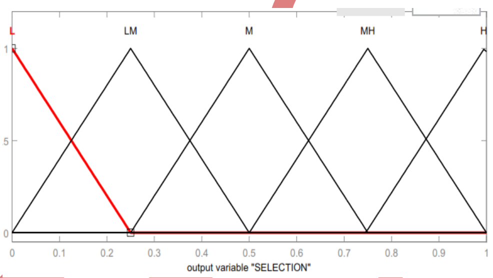


Fig 6: Membership function plot for Selection of DSTATCOM optimal location

VI. RESULTS AND DISCUSSION

The proposed methodology is tested on IEEE 33bus test systems with different sizes, to show that it can be implemented in distribution systems of various configuration and sizes. By using section-3 size of the DSTATCOM size is found out. By using section-5 optimal location of dstatcom is found out. The proposed methodology is tested on a 11 kV, 33 bus radial distribution system (RDS). A computer program has been written in MATLAB to calculate the optimum sizes of DSTATCOM at various buses and based on proposed objective function identity of the best location is found out by using fuzzy logic. A backward forward sweep load flow program is used to solve the load flow problem.

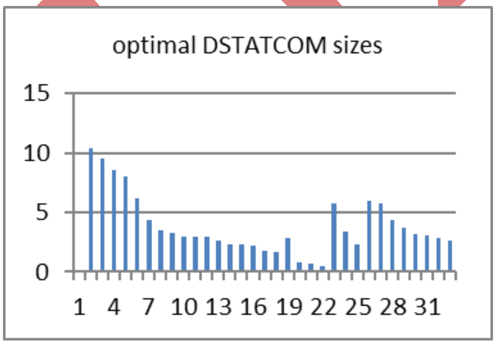


Fig 7: optimum sizes of DSTATCOM

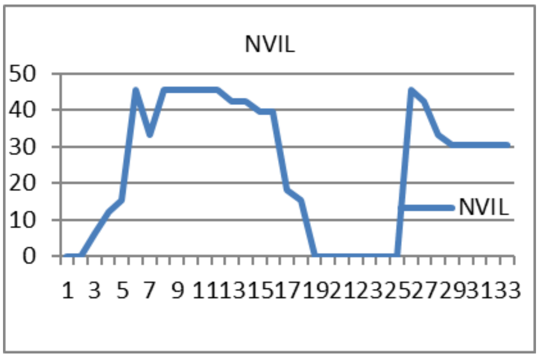
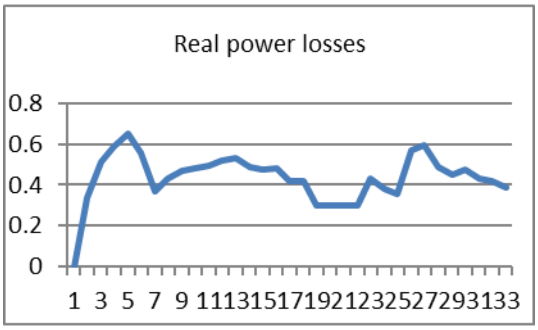


Fig 8: Rate of voltages improved



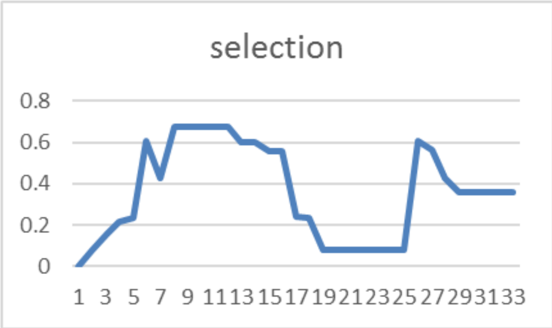


Fig 9: Total real power losses at each node with DSTATCOM Fig 10**:** Optimal selection for placement of DSTATCOM

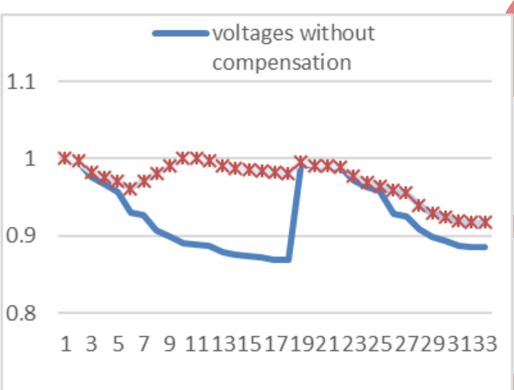


Fig 11**:** voltages before and after compensation at 8thnode.

From the above simulation results Selection criteria by fuzzy logic shows that the 10th node is the optimal location. So by compensating at 10th node, percentage increase in node voltages within limits is 55%, percentage reduction in total real power loss is 23%. From the above results we can conclude that by placing DSTATCOM in optimal size and placement, significant reduction in losses and voltage profile improvement are achieved.

VII. CONCLUSIONS

In this paper fuzzy logic is used for the optimal location of DSTATCOM in radial distribution system. This method utilizes a forward-backward load flow for calculation of power flow and losses in the system. The total system losses, voltage profile and cost of the dstatcom are used as an objective for optimal location of DSTATCOM. And the corresponding optimum size of dstatcom is found out by modeling it to maintain the voltage magnitude as 1p.u. from the simulation results this method is found to be effective, easy to be implemented & faster for the given accuracy.

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