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Optimal location and sizing of Distribution Static Synchronous Series Compensator using Particle Swarm Optimization

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ABSTRACT

This paper describes the power quality improvement using Particle Swarm Optimization for optimal placement and sizing of Distribution Static Synchronous Series Compensator in radial distribution networks. In this analysis, enhancement of power quality includes improvement of voltage and reduction of line losses. A complete performance analysis is carried out on 12 and 69 bus radial distribution systems to demonstrate the effectiveness of the proposed work. The results show that the placement of DSSSC in radial distribution systems effectively improves the voltage of a system and reduces the power losses. MATLAB, Version 7.10 software is used for simulation.

Introduction

In the deregulated electricity supply markets, power quality plays an important role because it affects the power consistency of demand particularly for bulk tariff consumers or large management companies. Therefore from the customer side, improving power quality is an important issue [1]. Many literatures have shown that in the distribution side 13% of total generated power is wasted as loss. With the increment in load, the voltage profile has a tendency to drop along the distribution feeder which is less than the tolerable operating limits. Also the power loss increases with the voltage drop. This improves the infrastructure of distribution systems [2].

Also, high reactive power requirement of the distribution systems, addition of load and subsequent augmentation of system losses initiate deviation at the buses voltage magnitudes, which disturb the quality of the supplied electrical energy. Voltage regulators and capacitor banks are installed to control voltage magnitude, reactive power and power factor to guarantee high quality [3]. In highly automated industries and sensitive load centers the power quality has become a serious problem. For customers, voltage quality is the most important part of power quality [4]. Also in industries, voltage sag plays a major role for profitable consequences.

Flexible AC Transmission System (FACTS) is initially developed for transmission networks but at present the same has been applied for distribution systems too. Also for the security of sensitive loads from the voltage sag, FACTS devices are becoming more popular [5]. Basically FACTS have three types. (i) Series (ii) Shunt (iii) combination of series and shunt. In this, series-connected FACTS device enhances the maximum megawatt power transfer [6]. A GA based technique to design a SSSC based controller to improve the transient performance of a power system using multi objective optimization approach is proposed in literature [7]. An optimization problem for sizing of SSSC controllers in transmission network has been proposed in literature [8]. This uses PSO technique to reduce the transmission losses along with the modification in Newton–Raphson load flow algorithm. Using PSO power system stability is improved by a SSSC based damping controller by minimizing a time-domain-based objective function. Also it provides efficient damping to power-system oscillations and greatly improves the system voltage profile [9].

In large distribution systems Static Synchronous Voltage Regulator (SSVR) develops the reliability indices [10]. Maintaining the voltage profile under control is the very important task in large distribution systems. But keeping the voltage within certain limit is not easy because the voltage is directly proportional to the normal fluctuations of load in the system [11]. Therefore recently voltage stability is becoming a tough issue in many power system applications. Also distribution systems are reconfigured with a vision to decrease the system losses and offer an enhanced voltage profile for the consumers. Fuzzy based reconfiguration algorithm,

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to enhance the voltage stability and improves the voltage profile, in addition to loss minimization is proposed in literature [12].

In the case of practical power systems, placement and sizing of FACTS controllers for voltage stability with voltage profile improvement is a major consideration [13]. To improve the quality of supply, a series device namely Dynamic Voltage restorer (DVR) is used to add a voltage to the network which reduces the voltage sag. To reduce the small voltage drop, reactive power injection is sufficient but to eliminate the high voltage drop it is essential to inject active power. Hence energy storage system is used to inject active power to the system. Supply of active power for a long duration is not possible, because of the limited capacity of energy storage systems, for a long term it cannot supply active power to the system. Therefore DC capacitor replaces the energy storage system hence the name Static Synchronous Series Compensator (SSSC) [14].

In this paper Static Synchronous Series Capacitor (SSSC) is used to enhance the voltage profile and to reduce the total loss of the distribution systems. Our previous work was optimal placement and sizing of DG using BFOA and MBFOA [15]. Both BFOA and MBFOA when applied to find the optimal placement and sizing of DSSSC do not provide optimum results. Therefore for analyzing the optimal placement and sizing of DSSSC, we use Particle Swarm Optimization (PSO) algorithm in this work. Also, the results are compared with the results obtained from the analytical method.

Static Synchronous Series Compensator (SSSC)

FACTS technology opens up new opportunities for controlling power and enhancing the usable capacity to the present, as well as the new and upgraded lines. It has the ability to control the interrelated parameters that manage the operation of transmission systems including series impedance (e.g. SSSC), shunt impedance, current, voltage and phase angle. The application of this technology has paved way for an innovative and superior transmission and distribution control [16].

A static synchronous generator is operated without an external electric energy source as a series compensator. But the SSSC consists of transiently rated energy storage or energy absorbing device to improve the dynamic performance of the power system. The overall active voltage drop of the line can be temporarily increased and decreased by adding temporary active power compensation devices [17,18].

Mathematical modeling of DSSSC

DSSSC injects voltage by voltage source converter that must be kept in quadrature with load current and the model of a typical SSSC is shown in Fig. 1. In principle, the inserted series voltage

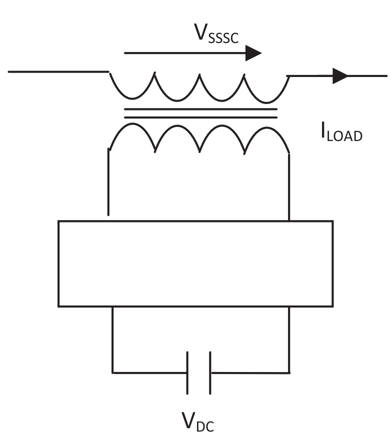

Fig. 1. Typical model of SSSC.

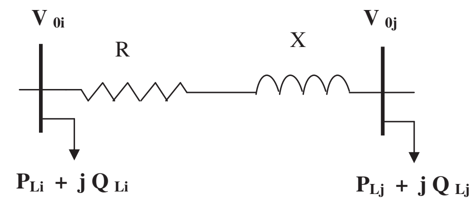

Fig. 2. Single line diagram of two buses of a distribution system.

changes the impedance (i.e, reactance) of the transmission line. Therefore the real and reactive power flow of transmission line can be controlled.

Consider a system with two buses ‘i’ and ‘j’ as shown in Fig. 2. By installing DSSSC in distribution system, in the steady state condition all node voltages, particularly the nearby nodes of DSSSC position and branch currents of the network changes. Schematic diagram of buses ‘i’ and ‘j’ of a distribution system when DSSSC is installed for voltage regulation in bus ‘j’ is shown in Fig. 3. Fig. 4 shows the phasor diagram of voltages and current of the system shown in Fig. 1.

Using DSSSC, voltage of bus ‘j’ changes from V_j to $V_{j\,new}$ as shown in the phasor diagram of Fig. 5. For the sake of simplicity, the angle of voltage V_i, i.e., δ is assumed to be zero in phasor diagram. Eq. (1) is developed from Figs. 3 and 5.

$$V_{SSSC}\angle\beta = V_{jnew}\angle\alpha_{new} + (R + jX)I_L\angle\theta - V_i\angle\delta \quad (1)$$

also

$$\beta = \frac{\pi}{2} + \theta, \quad \theta < 0 \quad (2)$$

where $V_{SSSC}\angle\beta$ is the injected voltage by SSSC and $V_{jnew}\angle\alpha_{new}$ is the voltage of bus ‘j’ after compensation.

DSSSC consists of a voltage source inverter connected in series through a coupling transformer to the distribution line. An energy source is required to provide and retain the DC voltage across the DC capacitor and compensation of DSSSC losses. Fig. 6 shows the equivalent circuit of two buses of a distribution system with DSSSC. From Fig. 6,

$$V_i\angle\delta + V_{SSSC}\angle\beta = V_{jnew}\angle\alpha_{new} + (R + jX)I_L\angle\theta \quad (3)$$

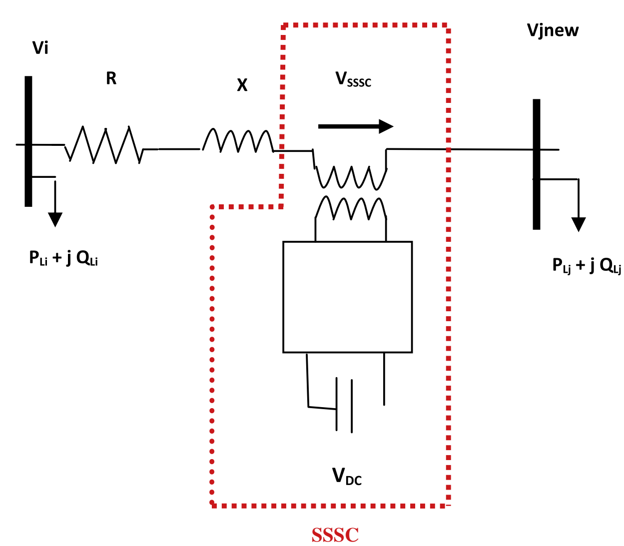

Fig. 3. Single line diagram of two buses of a distribution system with consideration of DSSSC.