Optimal placement of D-STATCOM and PV solar in distribution system using probabilistic load models

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Abstract- This paper proposes a hybrid analytical and metaheuristic optimization technique to find the proper locations and sizes for the distributed generator (DG) and Distribution Static Synchronous Compensator (D-STATCOM) in distribution networks to minimize the total losses and improve the voltage profile. The D-STATCOM and DGs are arranged in order to reduce line losses and improve the voltage profile of the system. For this goal, the important parameters of a bus are optimized by Particle Swarm Optimization (PSO) algorithm. probabilistic load model also is calculated using Monte Carlo Simulation (MCS) method. Effectiveness of modified method is tested in a real distribution system of south Kerman (DSSK).

Keywords: D-STATCOM, Distributed Generation, Distribution System, Particle Swarm Optimization, Probabilistic Load, Monte Carlo

Introduction

High R/X ratio and significant voltage drop causes substantial power losses along the distribution network. According to the estimations, around 13% of the total generated power is wasted as line losses on distribution side [1]. There are several approaches for reducing losses like DG allocation, capacitor placement, load management, network reconfiguration, etc. [2]. Series voltage regulator and shunt capacitors are the two conventional ways of maintaining voltages of the distribution system at an acceptable range. But these devices have some disadvantages that are conventional series voltage regulators cannot generate reactive power and have quite slow response because of their step-by-step operations. The disadvantage with the shunt capacitors is that they cannot generate continuously variable reactive power. To overcome these problems, power electronic based FACTS (Flexible AC Transmission System) devices are added to the distribution systems at strategic locations to improve the system performance [3]. Distribution Static Synchronous Compensator (DSSC) or D-STATCOM is one of the popular FACTs in distribution systems that can inject reactive power to grid. D-STATCOM can provide economic solution for the compensation of reactive power [4]. It also provides fast response to improve the voltage profile, reduce line losses, improves voltage stability margin (VSM), release feeder capacity which in turn saves energy as well as environment. Most of the loads are reactive loads, such as motors, fans, pumps etc, which increases the reactive power demand in distribution system. Since, these loads draw lagging currents the burden of reactive power increases in the distribution system. The reactive power demand increases more in the presence of unbalanced loads [5].

Several approaches have been incorporated using optimization techniques for allocation of DG and D-STATCOM in distribution systems using evolutionary based bat algorithm as in [6]. In [7] authors have considered the placement of DG with load variation. A multi objective simultaneous DG & D-STATCOM allocation in radial distribution system using Cuckoo search algorithm have proposed in [8]. The network reconfiguration of unbalanced distribution system using GA have been proposed in [9]. In [10] authors have employed a fuzzy-lightning search algorithm. Impact of DG & D-STATCOM on reactive loading capability is proposed in [11]. Due to various restrictions of classical optimization algorithms, evolutionary algorithms are used as an optimization tool in current work. Artificial neural networks are used to plan, operate, and analyze energy systems. In [12] authors have a meta heuristic technique known as Atom Search Optimization (ASO) is used to solve the optimal allocation of DG and D-STATCOM in distribution systems considering load growth of 2.5% for the next 1 year. The power factor for DG and D-STATCOM are considered unity and zero p.f lag, respectively.

As shown in Fig. 1 the main circuit of D-STATCOM is composed of a voltage-bridge circuit, and its structure is composed of the following parts: voltage support capacitor, which is used to provide a voltage support for the device; The voltage source inverter (VSI) is composed of high-power electronic switching devices [13].

A new stochastic framework based on the probabilistic load flow to consider the uncertainty effects in the D-STATCOM placement and sizing problem is described in [14]. M. Manohara et al. presented modeling of D-STATCOM in radial distribution system (RDS) for the steady state voltage compensation in [15]. The probabilistic nature of distribution networks can be affect the optimal allocation of D-STATCOMs. The correlation between uncertain variables makes this problem more complicated. However, the Monte Carlo simulation (MCS) method can be used easily, but it is incredibly time-consuming, and it is impossible to be used in evolutionary-based algorithms. To deal with such complexity, probabilistic evaluation methods, which are capable of managing correlation with adequate accuracy and convergence speed, are always important [16].

S. Ayazi al. optimized a part of distribution system from south of Kerman (DSSK), Iran and a new approach is introduced to efficiently solve feeder routing problem for a relatively large real distribution network [17]. In [18] presented two comprehensive distribution test systems to address these issues. The notable features of the systems and the different values for the adjacent feeders show that the proposed cases have significant potential to be considered as test cases.

It is clear from the literature review that the optimal placement and sizing of DG and D-STATCOM reduces the total power loss along with voltage profile improvement. In this paper, the optimal location and parameter setting (the reference set point) of the D-STATCOM is searched as well as the location of the RESs with PSO algorithm. The objectives are expected active power losses reduction, expected voltage deviation index (VDI) improvement, and D-STATCOM expected installation cost minimizing considering probabilistic demand of the DSSK.

The paper is organized as follows: Section 2 describes problem formulation. Section 3 describes System test. The simulation result is obtained and analyzed in Section 4. Finally, Section 5 contains the conclusion.

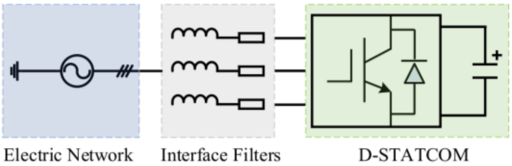

Figure 1. schematic diagram of D-STATCOM device.

Problem Formulation

Distributed Generation is considered as a solar PV that generated real power. Real power generation PV solar is given by:

$$P_{pv}(t)=\left[P_{pv,stc}\cdot\frac{G_T(t)}{1000}.\left[1-\gamma(T_j-25)\right]\right].N_{pv_s}.N_{pv_p} \qquad (1)$$

Where $P_{pv}(t)$ is the power generation of PV module, $P_{pv,stc}$ is maximum power generation in standard situation, $G_t(t)$ is the value of standard irradiance, γ is temperature factor in maximum power generation, T_j is PV cell temperature and $N_{pv\ s}$, $N_{pv\ p}$ are number of series and parallel module. T_j becomes as follows:

$$T_j=T_{amp}+\frac{G_T}{G_{T,stc}}.(NOTC-20) \qquad (2)$$

Here T_{amp} is atmosphere temperature and NOTC is nominal cell temperature.

Optimal location of D-STATCOM is found by calculating the reactive power stability at all the buses. The bus with maximum value of reactive power stability is selected as candidate bus. Fig.2 shows single line diagram of two bus radial distribution system.

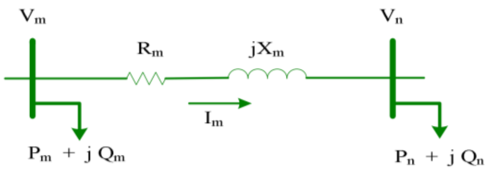

Figure 2. Single line diagram of radial distribution system

The expression for reactive power stability is derived as follows. From Fig.2 the current in branch is given by:

$$I_m=\frac{V_m\angle\theta_m-V_n\angle\theta_n}{R_m+jX_m} \qquad (3)$$

$$V_n\angle\theta_n=V_m\angle\theta_m-I_m(R_m+jX_m) \qquad (4)$$

Here θ_m and θ_n are the phase angles of sending end voltage V_m and receiving end voltage V_n respectively. The complex power is expressed as:

$$I_m=\frac{P_n-jQ_n}{V_n^*}=\frac{P_n-jQ_n}{V_n\angle-\theta_n} \qquad (5)$$

After D-STATCOM placement and reactive power injection

$$I_m=\frac{P_n-j(Q_n-Q_{statcom})}{V_n^*}=\frac{P_n-j(Q_n-Q_{statcom})}{V_n\angle-\theta_n} \qquad (6)$$

Here $Q_{statcom}$ is the reactive power supplied by D-STATCOM.

Uncertainty power demand modeling:

In probabilistic voltage dependent load model, load is allowed to fluctuate at any instant of time and possible load demand is generated using Monte-Carlo Simulation (MCS). Load varies continually with a high degree of uncertainty and depends on customer behavior and temporal factors such as season of the year, day of the week or time of the day. In probability theory, load uncertainty can be adjusted by probabilistic density function (PDF), which fit its behavior. MCS is used to pick random values of input variable from their distribution functions, and for solving a deterministic radial load flow with these values [19]. The probabilistic solution is reconstructed from deterministic data obtained for each simulation after a certain number of simulations. The number of simulations needed to achieve a precise result with the MCS is independent of system size and estimated as sufficient for this type of problem is 1500. Power load consumption is assumed as a normal distribution, characterized by mean value and standard deviation of active and reactive power consumed. In equation (7) calculated Mean and variance of both active and reactive power load demand.

$$f(x)=\frac{1}{(\sigma[x])\sqrt{2\pi}}.e^{-\frac{(x-E[x])^2}{2\sigma[x]^2}} \qquad (7)$$

where σ[] and E[] are the standard deviation and expected value operator, respectively.

Particle Swam Optimization (PSO):

PSO is a population-based optimization method. Taking inspiration from the social behavior of bird, Kennedy and Eberhart proposed PSO in 1995. The PSO is an optimization tool which provides a population-based search procedure in which individuals, called particles, change their position or state with time. In Particle Swam Optimization (PSO) system, particles fly around in a multidimensional search space. During flight, each particle will adjust its position according to its own experience (P_{best}), and according to the experience of a neighboring particle (G_{best}), making use of the best position encountered by itself and its neighbor. The standard PSO is quite simple. It is ineffective in finding the global optimal for most of the complex problems. The velocity update rule can be mathematically represented as follows:

$$V_{id}^{k} = C_1 rand * (Pbest_{id} - S_{id}^{k}) + C_2 rand * (Gbest_{id} - S_{id}^{k}) \quad (8)$$

Objective Function:

The optimal allocation of the D-STATCOM problem at the presence of RESs can be performed as an optimization problem with discrete and continuous variables.

$$OF = P_{loss}\{\sum_{i=1}^{NL} r_i |I_i|^2\} + VDI\{\sum_{i=1}^{Nb} (|V_{ref}| - |V_i|)^2\} + C_{statcom}\{\sum_{i=1}^{Ns} \mathrm{Cos}\, t_{statcom}\} \quad (9)$$

Here P_{loss} is total loss in distribution system, r_i and I_i are line resistance and line current, VDI is voltage deviation index and $C_{statcom}$ is total D-STATCOM cost.

Constraints:

1.Voltage limit: Magnitude of bus voltage must be between a minimum and maximum value:

$$V_{\min} \langle V_i \langle V_{\max} \quad (10)$$

2. Power limit: Real power (DG) and reactive power (D-STATCOM) delivered must lie within certain limits.

$$P_{DG}^{\min} \langle P_{DG} \langle P_{DG}^{\max} \quad (11)$$

$$Q_{statcom}^{\min} \langle Q_{statcom} \langle Q_{statcom}^{\max} \quad (12)$$

3.Current constraints: Current constraint are so made that temperature of the conductor should not exceed beyond defined limit.

$$I_i \langle I_{\max} \quad (13)$$

Test System

The proposed test cases are depicted in Figs. 3 and this system is a part of distribution system from south of Kerman (DSSK), Iran. The voltage level is changed from 132 kV, high voltage (HV), to 20 kV through the substation transformers, where the winding connections of Yn/d are opted for the HV/MV sides. The MV power lines are primarily implemented as overhead lines (OHL), including different types of bare aluminum conductor steel-reinforced (ACSR) conductors and aerial bundled cables (ABC) [18]. Fig. 4 depicts the share of different load sectors, viz. residential, commercial, industrial, agricultural, public, and lighting, of total demand for the two systems.

Results and Discussions

The effectiveness of PSO algorithm is applied in DSSK to find the optimal place of DG and D-STATCOM and Load flow analysis is with deterministic and probabilistic MCS load model.

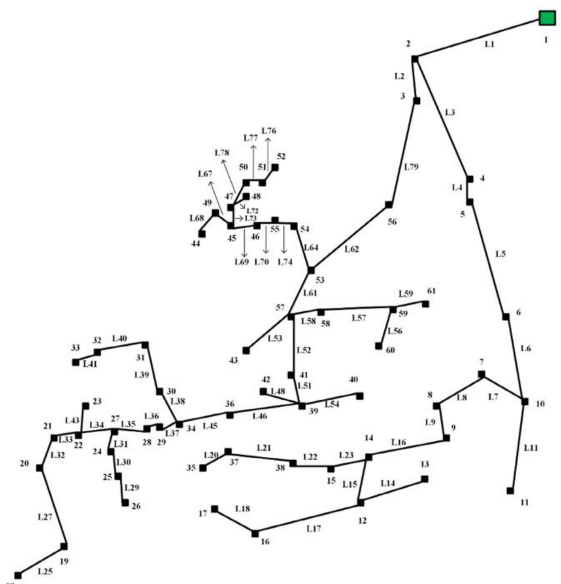

Figure 3. DSSK Single line diagram

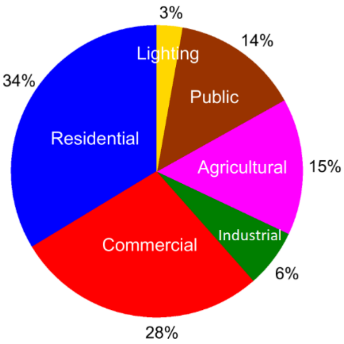

Figure 4. Different load types of DSSK

Results obtained from the PSO algorithm are shown in table .1 that shows the DG and D-STATCOM size obtained for different iterations during the program execution. figure .5 shows the best capacity of PV with the value of the PDF. Load flow analysis with D-STATCOM and PV placement with deterministic and probabilistic MCS load model and the results obtained are given in figure .6 and figure .7 that show active and reactive power before and after placement PV and D-STATCOM in DSSK.

Figure .6 shows VDI before and after placement that means in simulation by MCS with high iteration, the best VDI is 0.24.

Table 1. The relevant parameters and placement of PV and D-STATCOM

Parameter	Value
PV size	2.909 MW
PV location	Bus 24
D-STATCOM size	1.122 MVAR
D-STATCOM location	Bus 22

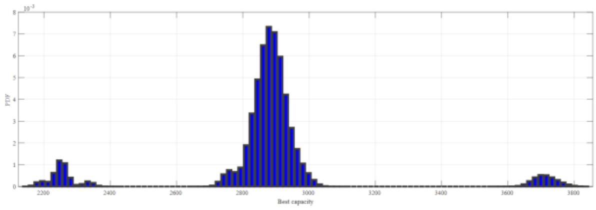
Figure 5. The best probabilistic capacity of PV

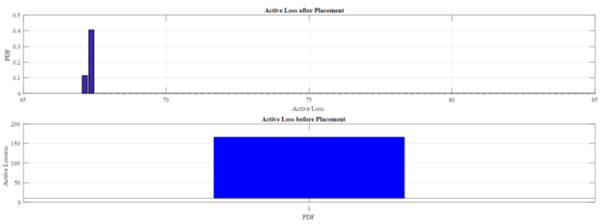
Figure 6. Probabilistic Active Loss

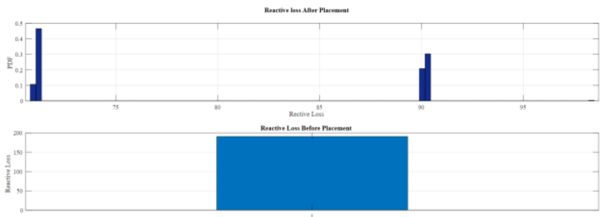
Figure 7. Probabilistic Reactive Loss

Voltage profile without D-STATCOM and PV with D-STATCOM and PV considering probabilistic load model is shown in Fig. 8. After D-STATCOM and PV placement, all 61 busses voltage DSSK are between $0.95^{p.u}$ and $1.05^{p.u}$. Figure .9 shows the voltage angle base DSSK and with D-STATCOM and PV DSSK.

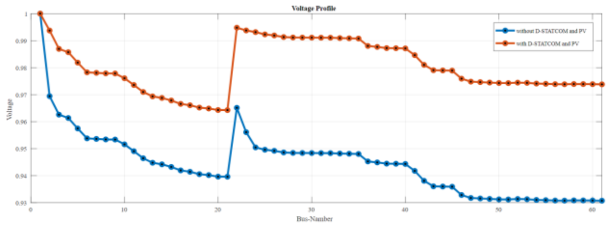
Figure 8. DSSK Voltage Profile

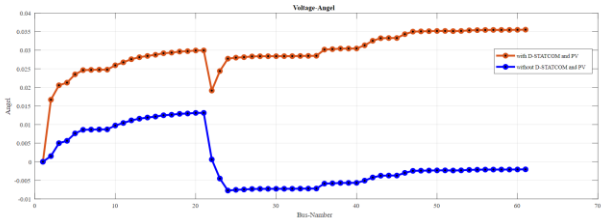
Figure 9. DSSK Voltage Angel

Conclusions

Optimal allocation of D-STATCOMs and PV solar has been taken into account in a probabilistic environment using the PSO algorithm and Monte Carlo simulation in the radial distribution networks. Simulations have been carried out on a real distribution system from south of Kerman (DSSK). The result shows the improvement in voltage profile and reduction in losses with D-STATCOM and PV placement. This paper can help the planning engineers to plan the distribution system with D-STATCOM for getting better voltage profile at reduced loss which in turns saves the energy as well as environment.

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