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Optimal Placement of Dynamic Voltage Restorer in Distribution Systems for Voltage Improvement Using Particle Swarm Optimization

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ABSTRACT

This paper deals with Dynamic Voltage Restorer (DVR) allocation in radial distribution systems by injecting series voltage. The DVR is used to inject both real and reactive powers into the system for voltage profile improvement and active and reactive power loss minimization. The objective of this paper is to identify the optimal location and series voltage of DVR using Particle Swarm Optimization (PSO) algorithm. The proposed method is tested on standard IEEE 33-bus system and the results are presented.

Keywords: Distribution system, DVR, Particle Swarm Optimization, series voltage, voltage profiles.

I. INTRODUCTION

In distribution systems the major concern is a power quality problem. Due to the radial nature of the distribution system, the voltage regulation at load end becomes poor. Voltage regulation is done by series voltage regulators and shunt capacitors. The various methods available for voltage regulation are shunt capacitor placement [1-2], integration of distributed generation (DG) [3], the latest advancement is distribution FACTS (DFACTS) also called as Custom Power Devices (CPD). Traditionally, DFACTS devices are used in the power quality improvement.

In [4], the optimal allocation of distribution static compensator (DSTATCOM) is carried out to mitigate network power loss and to improve node voltage magnitude. In [5], the modeling of DVR for voltage correction and the performance of the device under different voltage sags condition is presented. Voltage quality improvement by using Dynamic Voltage Restorer (DVR) and Distribution Static Synchronous Compensator (D-STATCOM) are reported in [6]. Modeling of Series Static Voltage Restorer (SSVR) in load flow calculations for steady state voltage improvement is explained in [7]**.** Network reconfiguration technique [8] is also used to reduce the losses in radial distribution systems. Many load flow methods developed for radial distribution system [9-12].

Almost all of the models reported till now for DVR have been utilized for two bus system consisting of sensitive load and the source. Effects of DVR modeling on compensation of power quality problems of sensitive loads have been considered. However the effects of DVR on a large distribution system and other loads have not been considered. In this paper, the effect of DVR on large distribution system is considered for voltage improvement and loss reduction. The effect of the DVR is analyzed in the steady state condition. Suitable modifications are made to the load flow program in order to improve the voltage of desired node to 1 p.u in steady state condition. The optimization technique known as PSO [13-14], proposed by Dr. Eberhart and Dr. Kennedy is used to obtain optimum series voltage.

II. RADIAL DISTRIBUTION SYSTEM LOAD FLOW

Load flow analysis is essential for the analysis of the distribution system in steady state, to investigate the issues related to planning, design and the operation and control. There are many load flow methods available in the literature. In this paper, a load flow method based on BIBC and BCBV method [11] is used. Most of the distribution systems are radial systems fed at a single point and system has radial nature as shown in Fig.1.

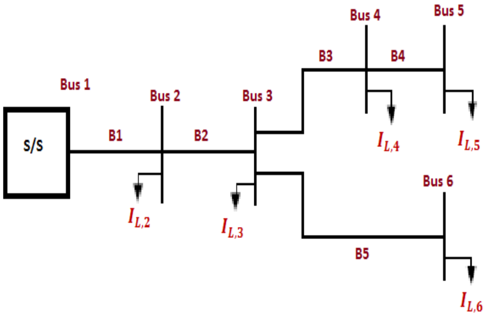

Fig.1. Simple 6 bus radial distribution system

The proposed load flow algorithm requires formation of Bus Injection to Branch Current (BIBC) matrix and Branch Current to Bus Voltage (BCBV) matrix.

At bus i the complex power at load S_{Li} is given by

$$S_{Li} = (P_{Li} + j\,Q_{Li})$$

Where i = 2 ….. N

And the corresponding load current is given by

$$I_L = \left(\frac{P_{Li} + jQ_{Li}}{V_i^k}\right)^* \qquad (1)$$

Where Si, is the complex power at ith bus,

P_{Li} is the real power at ith bus

Q_{Li}, is the reactive power at ith bus

$V_{ik}^{\cdot}$ is the bus voltage at kth iteration for ith bus;

N =number of buses; I_L -load current.

The branch currents can be written as

$$[I_B] = [BIBC] \quad [I_L] \qquad (2)$$

The relation between branch current and bus voltages is given by

$$[\Delta V] = [BCBV] \quad [I_B] \qquad (3)$$

The receiving end voltages can be premeditated by forward sweeping across the line by subtracting the line section drop from the sending end voltages of the line section.

$$V_r(i) = V_s(i) - I_B(i) * Z_s(i) \qquad (4)$$

Thus, we obtain the voltage magnitude and phase angle, which completes the load flow. The total real and reactive power losses in a distribution system can be written as

$$P_{Loss} = \sum_{p=1}^{b} I_{Bp}^2 R_p \qquad (5)$$

$$Q_{Loss} = \sum_{p=1}^{b} I_{Bp}^2 X_p \qquad (6)$$

Where b is the number of branches; R_p is the resistance and I_{Bp} is the branch current of pth branch of original network.

III. DYNAMIC VOLTAGE RESTORER

Dynamic Voltage Restorer (DVR) is a series device which is used to inject a series voltage to the network to improve the voltage profile. The Single Line Diagram of two buses of a radial distribution System with consideration of the DVR is as shown in Fig.2.

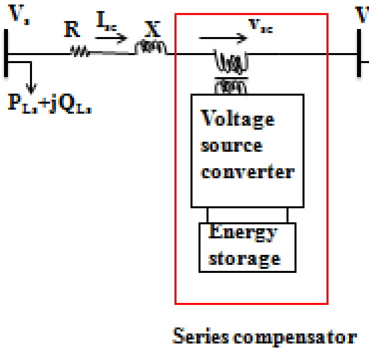

Fig.2. Single Line Diagram of Two Buses of a Distribution System with Consideration of DVR

The voltage source converter of DVR injects the series voltage (V_{se}) in the branch to improve the voltage at the receiving end bus in such a way that the receiving end voltage (V_r or V_L) is maintained at a desired value (1p.u.) From fig 1, if the DVR is placed in the branch B2, then the receiving end bus 3 is maintained at 1 p.u. The phasor diagram in Fig.3

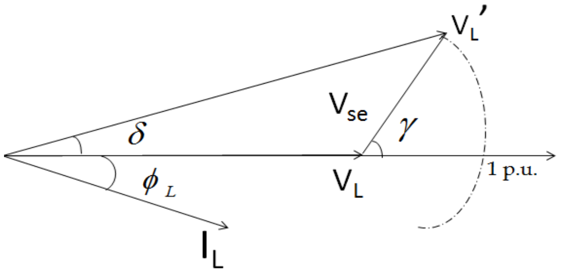

Fig3. Phasor diagram after including Vse

From the above phasor diagram given in Fig.3 the new load bus voltage given in generalized form is

$$V_r^{/}\angle\delta = V_r + V_{se}\angle\gamma \qquad (7)$$

Where $V_r^{/}$ □ magnitude of receiving end bus voltage

V_{se} □ Series injected voltage

δ □ Displacement angle between V_r and $V_r^{/}$

γ □ Series injected voltage angle with respect to receiving end load voltage (V_r) angle.

Since DVR injects both active and reactive power into the system, the series power is given as follows:

$$S_{DVR} = V_{se}.(I_B)^* \qquad (8)$$

Where S_{DVR} □ complex power rating of DVR

V_{se} □ Series voltage injected by DVR

I_B □ Branch current in which DVR injects the series voltage

IV. PARTICLE SWARM OPTIMIZATION METHOD

Particle swarm optimization (PSO) method is a population based evolutionary computation technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. The particle swarm concept originated as a simulation of a simplified social system, and has been found to be robust in solving continuous linear and nonlinear optimization problems. The PSO technique can generate high-quality solutions within shorter calculation time and have more stable convergence characteristic than other stochastic methods.

Algorithm to find optimum values of series injected voltage using PSO technique

Step 1: Initialize the number of particles, maximum iterations, dimension, minimum and maximum series voltage limits and minimum and maximum velocity of the particles within the limits.

Step 2: Generate the particles and velocities randomly within the limits.

Step 3: Run the load flow by adding the series voltage in the branch as given in the equation (7). The voltage constraint imposed is the voltage at the optimal location should not exceed 1 p.u.

Find the fitness function using equation (5)

Step 4: pbest values for all the particles are obtained from the fitness values and the best value among all the particle best values (gbest*)* is identified.

Step 5: gbest and average fitness values are calculated.

Step 6: Iteration count is set to one.

Step 7: For all the particles, calculate the new velocities using equation (9)

$$V^{t+1}_{(m,n)} = k * (w * V^{t}_{(m,n)} + c_1 rand_1 (\mathrm{pbest}^{t}_{(m,n)} - \mathrm{X}^{t}_{(m,n)}) + c_2 rand_2 (\mathrm{gbest}^{t}_{(1,n)} - \mathrm{X}^{t}_{(m,n)})) \tag{9}$$

Where $K = -0.7298$ is the constriction factor[13]; ω is the inertia weight given by

$$w = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{T} \right) * t \tag{10}$$

$C_1 = C_2 = 2.05$ are acceleration constants.

rand$_1$, rand$_2$ are the random numbers

V^{iter}_{mn} is velocity of mth particle in nth dimension; X^{iter}_{mn} is the position of mth particle in nth dimension; $\mathrm{pbest}^{iter}_{mn}$ is the pbest particle m, n; $\mathrm{gbest}^{iter}_{mn}$ is the gbest particle m, n.

w is an adjustable parameter between $w_{\max} = 0.9$ *and* $w_{\min} = 0.4$

t = current iteration number

T = maximum number of iterations

Step 8: Update the position of each particle as given in equation (11)

$$\mathrm{X}^{t+1}_{(m,n)} = \mathrm{X}^{t}_{(m,n)} + V^{t+1}_{(m,n)} \tag{11}$$

Step 9: New fitness functions are calculated for the new positions of all the particles. Update the pbest from equation (12):

$$P^{t+1}_{best,t} = \begin{cases} P^{t}_{best,t} & if\ f(x_i^{t+1}) > P^{t}_{best,i} \\ x_i^{t+1} & if\ f(x_i^{t+1}) \le P^{t}_{best,i} \end{cases} \tag{12}$$

Update the gbest from the latest pbest

Step 10: The iteration count is incremented and if the iteration count is not reached to max then go to step 7.

Step 11: gbest particle gives the optimal series voltage values and the results are printed.

V. RESULTS

The standard IEEE 33-bus radial distribution system is used to examine the applicability of DVR and illustrate the proposed approach.

Results of 33-bus system

The proposed algorithm is applied to 33-bus system [9]. The system has real load of 3715 kW and and reactive load of 2300 kVAr. Table 1 shows the voltage profiles. Table 2 shows the results for 33-bus system. Table 3 shows the results for DVR Location, Series injected voltage, Real power injected, Reactive power injected, Power loss, Loss reduction and No. of nodes with under voltage problem for a 33 bus distribution system.

Table 1: Voltage profiles of 33 bus system without and with DVR

Bus no	Voltage in p.u		Bus no	Voltage in p.u	
	Without DVR	With DVR		Without DVR	With DVR
1	1.0000	1	18	0.9131	0.9654
2	0.9970	0.9971	19	0.9965	0.9966
3	0.9829	0.9834	20	0.9929	0.9930
4	0.9755	0.9763	21	0.9922	0.9923
5	0.9681	0.9692	22	0.9916	0.9917
6	0.9497	1	23	0.9794	0.9799
7	0.9462	0.9967	24	0.9727	0.9732
8	0.9413	0.9921	25	0.9694	0.9699
9	0.9351	0.9862	26	0.9477	0.9982
10	0.9292	0.9807	27	0.9452	0.9957
11	0.9284	0.9799	28	0.9337	0.9849
12	0.9269	0.9784	29	0.9255	0.9771
13	0.9208	0.9727	30	0.9220	0.9738
14	0.9185	0.9705	31	0.9178	0.9698
15	0.9171	0.9692	32	0.9169	0.9690
16	0.9157	0.9679	33	0.9166	0.9687
17	0.9137	0.9660			

Table 2: Results of 33 bus system

Description	**Real power loss (kW)**	**Reactive power loss (kVAr)**	**Minimum voltage (p.u.)**	**No. of Buses with Under voltage**	**Rating of DVR**
Before DVR installation	202.6771	135.1410	0.9131 @bus18	21	0
After DVR installation	185.2856	123.2805	0.9654 @bus18	0	124.47 kVA

Table 3: DVR Location, Series injected voltage, Real power injected, Reactive power injected, Power loss, Loss reduction and No. of nodes with under voltage problem for standard IEEE 33-bus distribution system

DVR Location (branch)	Series injected voltage (p.u)	Real power injected (kW)	Reactive power injected (kVAr)	Power Loss		Loss Reduction		No. of nodes with under voltage problem
				Real (kW)	Reactive (kVAr)	Real (kW)	Reactive (kVAr)	
1	0.0026+j0.0270	11.55	7.179	201.2971	134.2188	1.38	0.9222	19
2	0.0168+j0.0000	56.7967	36.3834	195.1382	130.1075	7.5389	5.0335	14
3	0.0240+j0.0000	56.2369	39.9454	193.358	128.8263	9.3191	6.3147	10
4	0.0310+j0.0000	68.4093	48.7682	190.9854	127.1863	11.6917	7.9547	3
5	0.0480+j0.0000	101.0600	72.6630	185.2856	123.2805	17.3915	11.8605	0
6	0.0433+j0.1321	0.0000	168.0000	191.5033	127.5493	11.1738	7.5917	8
7	0.0455+j0.1501	0.0000	153.8000	192.0447	127.9254	10.6324	7.2156	9
8	0.0473+j0.1769	0.0000	137.8100	192.7451	128.3799	9.932	6.7611	10
9	0.0504+j0.1904	0.0000	135.1200	192.7968	128.4073	9.8803	6.7337	11
10	0.0524+j0.1853	0.0000	119.9300	193.7173	129.0231	8.9598	6.1179	12
11	0.0508+j0.2016	0.0000	118.1900	193.8112	129.0839	8.8659	6.0571	13
12	0.0478+j0.2411	0.0000	122.0100	193.5202	128.8801	9.1569	6.2609	14
13	0.0390+j0.2833	0.0018	121.9300	193.5172	128.8754	9.1599	6.2656	15
14	0.0000+j0.3978	8.3202	113.1700	192.9778	128.4849	9.6993	6.6561	16
15	0.0000+j0.4030	3.3758	90.6530	195.1905	129.9944	7.4866	5.1466	17
16	0.0000+j0.4093	1.8428	66.1198	197.1607	131.3345	5.5164	3.8065	18
17	0.0244+j0.3525	0.0004	34.8009	199.8116	133.1549	2.8655	1.9861	19
18	0.0035+j0.0079	0.0000	3.4196	202.659	135.1281	0.0181	0.0129	21
19	0.0069+j0.0162	0.0000	5.2031	202.6462	135.1183	0.0309	0.0227	21
20	0.0076+j0.0179	0.0000	3.8252	202.6536	135.1233	0.0235	0.0177	21
21	0.0082+j0.0194	0.0000	2.0767	202.6639	135.1309	0.0132	0.0101	21
22	0.0194+j0.0451	0.0000	51.0598	201.3734	134.3725	1.3037	0.7685	21
23	0.0250+j0.0617	0.0000	62.0383	201.0736	134.1913	1.6035	0.9497	21
24	0.0278+j0.0705	0.0000	35.2720	201.7125	134.5614	0.9646	0.5796	21
25	0.0509+j0.0000	48.2397	49.2485	192.6181	128.3644	10.059	6.7766	12
26	0.0533+j0.0000	47.2082	50.1403	192.5075	128.2738	10.1696	6.8672	13
27	0.0638+j0.0000	52.0538	57.7704	191.1046	127.3048	11.5725	7.8362	14
28	0.0713+j0.0000	53.4372	62.6472	190.4022	126.8182	12.2749	8.3228	15
29	0.0748+j0.0000	46.9229	60.3763	191.253	127.3901	11.4241	7.7509	16
30	0.0537+j0.2198	0.0000	106.3300	192.4493	128.1172	10.2278	7.0238	17
31	0.0567+j0.2144	0.0000	67.4496	196.0367	130.5669	6.6404	4.5741	18
32	0.0702+j0.1538	0.0000	12.1930	201.4373	134.2829	1.2398	0.8581	20

When DVR is placed in branch 5 (6th node) the number of nodes with under voltage problem is zero. The real and reactive power losses with DVR in branch 5 are 185.2856 kW and 123.2805 kVAr respectively. DVR placement in the branches 18 to 24 at (19 to 25 nodes) does not result in much significant improvement in voltage & loss reduction.

VI. CONCLUSION

The effect of the DVR is considered by injecting both real and reactive power. The optimal location is the location at which minimum losses are obtained. The optimum series voltage is obtained by using PSO method. The results show that there is considerable improvement in voltage profile and reduction in losses.

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