PSO Based Reactive Power Coordination of Multiple Dispatchable Distributed Generations & Voltage Controlled Devices

Mogaligunta Sankaraiah, S Suresh Reddy, M Vijaya Kumar

Abstract*: The presence of multiple distributed generations on radial distribution system increases switching operations of voltage controlled devices (VCDs). Reduction of switching operations (SOs) of VCDs in the presence of multiple dispatchable distributed generations (MDDGs) is a demanding research area now a days. This paper proposes a novel method for the reduction of SOs of VCDs together with system power loss, in which we estimated the load one day in advance which makes MDDGs to dispatch the reactive power cooperatively with VCDs and particle swarm optimization (PSO) method used for solving multiple objective function. Multiple objective function (MOF) is formulated with cost of power loss and cost of SOs. The proposed method is tested on 16 nodes practical system under different operating output patterns and locations considering under load tap changers (ULTCs) and shunt capacitors (SCs) as VCDs. Simulation results clearly depicts that this method is effectively achieved the goals compared with existing conventional optimization techniques..

Index Terms*: Particle swarm optimization (PSO), Under load tap changers (ULTCs), Shunt capacitors (SCs); Voltage Controlled Devices (VCDs), Dispatchable distributed generation (DDG).

I. INTRODUCTION

Distributed generations (DGs) becoming popular due to their advantages in enhancing voltage stability index and possibility of placing at any location in the radial distribution system [1]. In [2-3], two different procedures for optimal allocation and optimal sizing proposed for DGs and authors focused mainly on distributed generations sizing and placement. The presence of DGs affects the performance of radial distribution system as well as voltage controlled devices, that means, which increases the voltage fluctuations and switching operations (SOs) of voltage controlled devices (VCDs) like shunt capacitors (SCs) and under load tap changers (ULTCs) [4-6]. In [7], it is reported that the SOs ULTC and SCs increased by three times when they coordinated with automatic voltage regulator (AVR) in the presence of DG. In [8], SCADA system proposed for coordination of ULTC and SCs in the presence of DG, in this case SOs of VCDs increased more than two times. In [9], dynamic programming method proposed and in [10] combined voltage-controlled method proposed for VCDs coordination. In theses papers the reactive power of DGs not included at the time of VCDs coordination. In [11-12], the reactive power of DGs included in the coordination process among VCDs. In [11], synchronous machine preferred as DG and in [12] coordination applied on an autonomous system. In [13], optimal power flow method proposed for coordination of VCDs together with DG. In [14-17], many methods proposed like TRSQP, Adaptive voltage controlled, dynamic programming and improved search harmony for reactive power coordination among VCDs and DG. In [18], PSO method proposed for dispatchable DG reactive power coordination with VCDs. In [19], GWO method proposed for DFIG reactive power coordination with ULTC and SCs. From the literature it is noticed that much importance given for single DG reactive power coordination with VCDs and there is no importance given for multiple dispatchable distribution generation (MDDG) reactive power coordination with VCDs. Therefore, in this paper two DDGs reactive power coordinated with ULTC and SCs using particle swarm optimization (PSO) algorithm by estimating the load one day in advance in order to reduce the switching the operations of VCDs and system power loss..

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II. PROBLEM FORMULATION

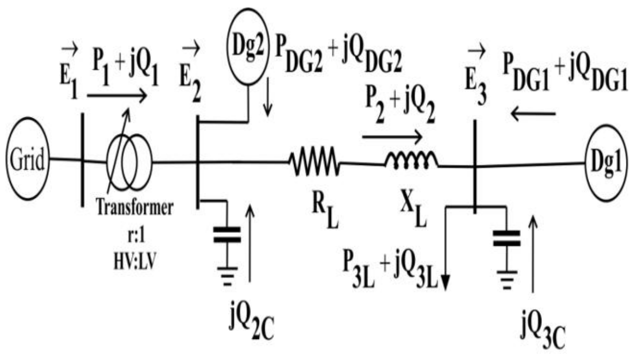

Fig.1 Single Line Diagram of Grid Connected System with DDGs

Where

E_1, E_2 and E_3 represents grid voltage, sending bus voltage, receiving bus voltages respectively; P_1 and Q_1 represents grid real and reactive powers respectively; P_{DG1}, Q_{DG1}, P_{DG2} and Q_{DG2} represents DG1 and DG2 real and reactive powers respectively; P_2 and Q_2 represents distribution line real and reactive powers respectively; P_{3L} and Q_{3L} represents load real and reactive powers respectively. Q_{2C} and Q_{3C} represents capacitor reactive power at sending bus and receiving bus respectively. R_L and X_L represents distribution line resistance and reactance respectively.

The formulation of multi objective function (MOF) consists of two terms, first one is the power loss and second one is switching operations.

Equation 1 represents the power loss calculation for radial distribution system shown in figure.1.

$$Powerloss^{hour} = I_{dl}^2 \times R_L \tag{1}$$

Equation 2 represents the second objective, equations 3 and 4 represents power loss and switching operations in terms of cost functions.

$$SOs^{hour} = f(tap, SCs) \tag{2}$$

$$OBF_1^{hour} = pc \times Powerloss^{hour} \tag{3}$$

$$OBF_2^{hour} = cultc \times \left(tap^{hour} - tap^{hour-1}\right) + cs \times \left(k_{sbc}^{hour} - k_{sbc}^{hour-1}\right) + cf \times \left(k_{cf}^{hour} - k_{cf}^{hour-1}\right) \tag{4}$$

Where tap Stands for tapping position of ULTC; pc, $cultc$, cs and cf represents cost weighting factors of power loss, ULTC, substation capacitors and feeder capacitors respectively; $hour$, k indicates time in hours and number of capacitors at substation and feeders respectively.
Equation 5 represents multi objective function (MOF) and constraints taken in this paper listed in equations 6 to 13.

$$MOF = OBF_1^{hour} + OBF_2^{hour} \tag{5}$$

$$P_{DG1} + P_{DG2} - P_L = P_{Loss} \tag{6}$$

$$Q_{DG1} + Q_{DG2} - Q_L = Q_{Loss} \tag{7}$$

$$Q_{DG1}^{\min} \le Q_{DG1} \le Q_{DG1}^{\max} \tag{8}$$

$$Q_{DG2}^{\min} \le Q_{DG2} \le Q_{DG2}^{\max} \tag{9}$$

$$E^{\min} \le E \le E^{\max} \tag{10}$$

$$tap^{\min} \le tap \le tap^{\max} \tag{11}$$

$$K_{sbc}^{\min} \le K_{sbc} \le K_{sbc}^{\max} \tag{12}$$

$$K_{cf}^{\min} \le K_{cf} \le K_{cf}^{\max} \tag{13}$$

III. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) algorithm is very popular for optimizing the objective function. This algorithm has favorable performance as compared with other heuristic algorithms [19]-[20]. In this paper, we preferred PSO for minimizing the multi-objective function.

Particle swarm optimization method works on particle movements. Initially all the particles are starting from a random position and moves randomly with relative velocities, then updating their positions based best particle position decided in the previous iteration. The description of PSO can be mathematically modeled as:

$$Y_i^{k+1} = round\left(w.Y_i^k\right) + round\begin{pmatrix} c_1.rn(0,1). \\ \left(P_i^k - X_i^k\right) \end{pmatrix} + round\left(c_2.rn(0,1).\left(G^k - X_i^k\right)\right) \tag{14}$$

$$w = w_{\max} - \left(w_{\max} - w_{\min}\right) * k / k_{\max} \tag{15}$$

$$X_i^{k+1} = X_i^k + Y_i^k \tag{16}$$

P_i^k and G^k responsible for movement of particles towards optimal value. ULTC, SCs and DGs inertia weights were taken as 3,2 and 0.040. The round functions just for the operation of ULTC and Schs not for the DG voltage variations. In this work there are four optimizing parameters, first one is power loss reduction and the remaining three are switching operations of ULTC and Schs. The proposed algorithm is written in the following steps.

Step:1 Assume all node voltages 1p.u

Step:2 Read Distribution system data and initialize PSO parameters

Step:3 Calculate power losses in Distribution network by applying Backward/Forward algorithm

Step:4 Based on load flow estimate the approximate initial positions of ULTC & Schs

Step:5 DG is located at specified bus

Step:6 Repeat step 3 and evaluate the fitness function with initial positions of ULTC and Schs

Step:7 Minimize the fitness function with minimum switching operations of ULTC and Schs

Step:8 If all the constraints are satisfied, then display results. Otherwise, go to step 6.

IV. TEST SYSTEM & RESULTS

10KV test system and output patterns of dispatchable distribution generation (DDG) have shown in figures 2 and 3 respectively. Test system consists of 40MVA, 70/10KV transformer with 32 steps on primary side; four capacitor banks with different ratings and numbers; three feeders with different distances. Grids connected to bus 1 through a line of 10km, feeder one consists of 4 buses, feeder 2 consists of 5 buses and feeder 3 consists of 4 buses. Forecasted load at all the buses of the test system taken from reference [18].

In this paper, two 3MW DDGs with 0.9 power factor lead/lag connected at bus 5 and 8. The results tabulated in 9 cases depending upon DDG output patterns.

Case 1: DDGs at buses 5 and 8 will have an output pattern of profile 1.

Case 2: DDG at bus 5 will have an output pattern of profile 1 and DDG at bus 8 will have an output pattern of profile 2.

Case 3: DDG at bus 5 will have an output pattern of profile 1 and DDG at bus 8 will have an output pattern of profile 3.

Case 4: DDG at bus 5 will have an output pattern of profile 2 and DDG at bus 8 will have an output pattern of profile 1.

Case 5: DDGs at buses 5 and 8 will have an output pattern of profile 2.

Case 6: DDG at bus 5 will have an output pattern of profile 2 and DDG at bus 8 will have an output pattern of profile 3.

Case 7: DDG at bus 5 will have an output pattern of profile 3 and DDG at bus 8 will have an output pattern of profile 1.

Case 8: DDG at bus 5 will have an output pattern of profile 3 and DDG at bus 8 will have an output pattern of profile 2.

Case 9: DDGs at buses 5 and 8 will have an output pattern of profile 3.

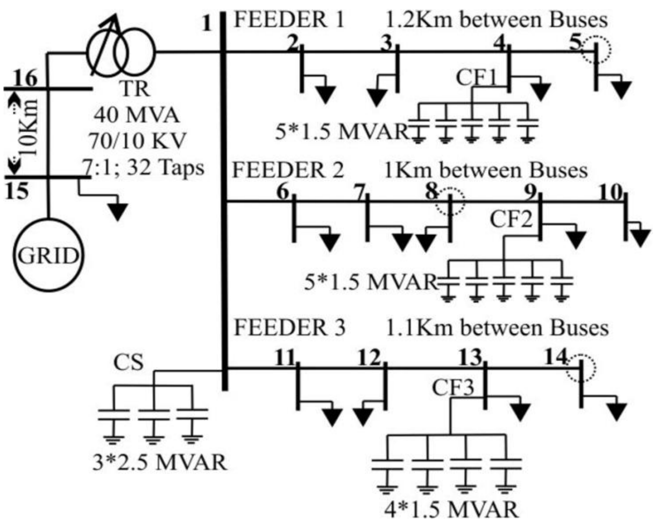

Fig.2 10kv Test System

Figures 4 and 5 illustrates how ULTC tap variations and capacitors variations at substation in case 8 with conventional method (CON) and particle swarm optimization (PSO) methods. The switching operations reduction is possible with PSO with proper reactive power coordination. In tables 1 to 9 power loss, switching loss and total loss calculated using 17 to 19 equations.

From fig.4, the conventional method changes ULTC taps by 7 times, source capacitors changing their values by 12 times.

From table.1 it is clear that with conventional method ULTC changes 3 times, Schs changes 16 times and with proposed method ULTC changes 2 times , Schs changes 15 times. Therefore, the proposed method reduces ULTC and Schs switching's by one time.

From table.2 it is clear that with conventional method ULTC changes 3 times, Schs changes 16 times and with proposed method ULTC changes 2 times , Schs changes 14 times. Therefore, the proposed method reduces ULTC and Schs switching's by 1 and 2 times respectively.

From table.3 it is clear that with conventional method ULTC changes 3 times, Schs changes 16 times and with proposed method ULTC changes 2 times , Schs changes 14 times. Therefore, the proposed method reduces ULTC and Schs switching's by 1 and 2 times respectively.

From table.4 it is clear that with conventional method ULTC changes 3 times, Schs changes 16 times and with proposed method ULTC changes 2 times , Schs changes 13 times. Therefore, the proposed method reduces ULTC and Schs switching's by 1 and 3 times respectively.

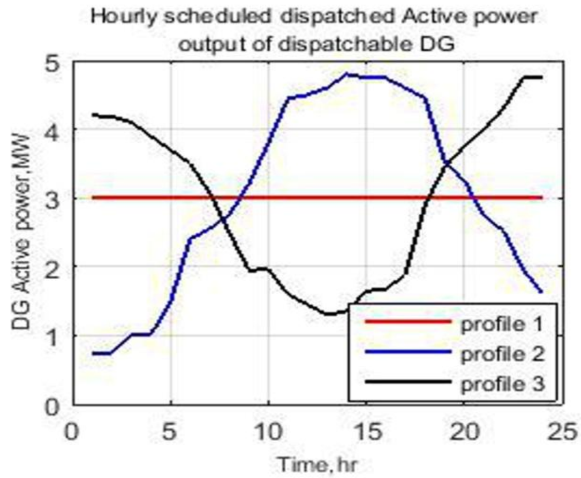

Fig.3 Output Patterns for 3MW DDGs

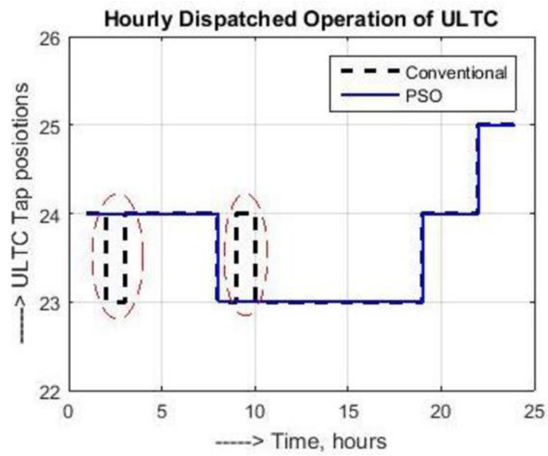

Fig.4 Hourly Dispatched operation of ULTC with Conventional & PSO Methods

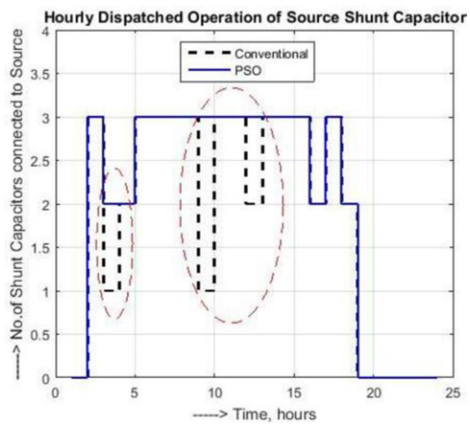

Fig.5 Hourly Dispatched operation of Source Capacitor with Conventional & PSO Methods

$$Lineloss(\$) = 80 * Loss(MWh) \quad (17)$$

$$SOC(\$) = (80 * ULTC) + (60 * SC) + 40 * (F1C + F2C + F3C) \quad (18)$$

$$Total\ cost(\$) = Lineloss(\$) + SOC(\$) \quad (19)$$

In similarly DDGs at buses 8 & 14; at buses 14 & 5 are simulated for all the cases.

In Tables CON & POS represents Conventional and Particle Swarm Optimization methods respectively.

TABLE 1

CASE 1 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		8.459	7.980
NUMBER OF SWITCHING OPERATIONS	ULTC	3	2
	SC	3	3
	F1C	5	5
	F2C	5	5
	F3C	3	2
LINE LOSS($)		676.7	638.4
SOC($)		940	820
TOTAL COST($)		1616.7	1458.4

TABLE 2

CASE 2 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		9.556	8.759
NUMBER OF SWITCHING OPERATIONS	ULTC	3	2
	SC	3	3
	F1C	5	4
	F2C	5	4
	F3C	3	3
LINE LOSS($)		764.5	700.7
SOC($)		940	780
TOTAL COST($)		1704.5	1480.7

From table.5 it is clear that with conventional method ULTC changes 2 times, Schs changes 16 times and with proposed method ULTC changes 2 times , Schs changes 13 times. Therefore, the proposed method reduces Schs switching's by 3 times.

TABLE 3

CASE 3 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		8.330	7.561
NUMBER OF SWITCHING OPERATIONS	ULTC	3	2
	SC	3	3
	F1C	5	4
	F2C	5	4
	F3C	3	3
LINE LOSS($)		666.4	604.9
SOC($)		940	780
TOTAL COST($)		1606.4	1384.9

TABLE 4

CASE 4 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		9.629	8.025
NUMBER OF SWITCHING OPERATIONS	ULTC	3	2
	SC	3	2
	F1C	5	4
	F2C	5	4
	F3C	3	3
LINE LOSS($)		770.3	642.0
SOC($)		940	720
TOTAL COST($)		1710.3	1362.0

From table.6 it is clear that with conventional method ULTC changes 3 times, Schs changes 16 times and with proposed method ULTC changes 2 times, Schs changes 14 times. Therefore, the proposed method reduces ULTC and Schs switching's by 1 and 2 times respectively.

From table.7 it is clear that with conventional method ULTC changes 7 times, Schs changes 20 times and with proposed method ULTC changes 5 times , Schs changes 16 times. Therefore, the proposed method reduces ULTC and Schs switching's by 2 and 4 times respectively.

From table.8 it is clear that with conventional method ULTC changes 7 times, Schs changes 23 times and with proposed method ULTC changes 3 times , Schs changes 18 times. Therefore, the proposed method reduces ULTC and Schs switching's by 4 and 5 times respectively.

TABLE 5

CASE 5 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		11.36	10.01
NUMBER OF SWITCHING OPERATIONS	ULTC	2	2
	SC	3	3
	F1C	5	4
	F2C	5	4
	F3C	3	2
LINE LOSS($)		909.5	801.0
SOC($)		860	740
TOTAL COST($)		1769.5	1541.0

TABLE 6

CASE 6 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		9.154	8.556
NUMBER OF SWITCHING OPERATIONS	ULTC	3	2
	SC	3	3
	F1C	5	4
	F2C	5	4
	F3C	3	3
LINE LOSS($)		732.3	684.4
SOC($)		940	780
TOTAL COST($)		1672.3	1464.4

TABLE 7

CASE 7 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		7.950	7.870
NUMBER OF SWITCHING OPERATIONS	ULTC	7	5
	SC	11	7
	F1C	5	5
	F2C	2	2
	F3C	2	2
LINE LOSS($)		636.0	629.6
SOC($)		1580	1180
TOTAL COST($)		2216.0	1809.6

TABLE 8

CASE 8 RESULTS

CONTROL METHODS		CON	POS
LOSS(MWh)		8.310	7.895
NUMBER OF SWITCHING OPERATIONS	ULTC	7	3
	SC	12	7
	F1C	5	5
	F2C	4	4
	F3C	2	2
LINE LOSS($)		664.8	631.6
SOC($)		1720	1100
TOTAL COST($)		2384.8	1731.6

From table.9 it is clear that with conventional method ULTC changes 7 times, Schs changes 20 times and with proposed method ULTC changes 5 times , Schs changes 13 times. Therefore, the proposed method reduces ULTC and Schs switching's by 3 and 7 times respectively.

In similarly, from tables 1 to 9 it is clear that the power loss also reduced by the proposed method.

TABLE 9			
CASE 9 RESULTS			
CONTROL METHODS		CON	POS
LOSS(MWh)		8.768	8.459
NUMBER OF SWITCHING OPERATIONS	ULTC	7	5
	SC	11	7
	F1C	5	4
	F2C	2	2
	F3C	2	2
LINE LOSS($)		701.4	676.7
SOC($)		1580	1140
TOTAL COST($)		2281.4	1816.7

V. CONCLUSIONS

In this paper two 3MW DDG reactive powers coordinated together with ULTC and SCs with different output patterns. PSO algorithm proposed for coordination and the effectiveness of this method compared with conventional method. The following are the conclusions:

1. Reduction in power loss: minimum of 1.005% and maximum of 16.65% compared with conventional respectively.
2. Reduction in switching losses: minimum of 12.76% and maximum of 36.04% compared with conventional respectively.
3. Reduction of total loss: minimum of 9.79% and maximum of 27.39% compared with conventional respectively.

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