OPTIMIZED PLACEMENT OF DISTRIBUTED GENERATION RESOURCES (DG) AND D-STATCOM IN DISTRIBUTION NETWORKS AIMED AT REDUCING LOSSES AND IMPROVE THE VOLTAGE PROFILE BY IMPERIALIST COMPETITIVE ALGORITHM (ICA)

Mohamad Javad Alinezhad[1,2,3], Masoud Radmehr[4*], Mahmood Ghanbari[3]
[1] Golestan Electric Power Distribution. Co, Gorgan, Iran.
[2.] Department of Electrical Engineering, Golestan Scince and Research Branch, Islamic Azad University, Gorgan, Iran.
[3.] Department of Electrical Engineering, Gorgan Branch, Islamic Azad University, Gorgan, Iran.
[4.] Department of Electrical Engineering, Ali Abad Katoul Branch, Islamic Azad University, Ali Abad Katoul, Iran.
[*]Corresponding author: Masoud Radmehr

ABSTRACT: *In this paper, we will use imperialist competitive algorithm for optimal placement and sizing of distributed generation sources DG and D-statcom in radial distribution networks with the purpose of reducing losses and improvement of network voltage profile. Sensitivity of losses analysis has been used in order to find optimized location in imperialist competitive algorithm. In order to assess the performance of proposed algorithm in a 12-bus test network in five different modes. The results show that using the use of imperialist competitive algorithm and sensitivity analysis to find place and optimal size of auxiliary tools greatly helps to solve the optimization problem and in this case, most reduced losses and improved voltage profile will be achieved.*

Keywords: Sensitivity analysis of casualties or losses, Imperialist competitive algorithm, Static compensator of distribution network, radial distribution networks, distributed generation sources

1. INTRODUCTION

Nowadays by moving from traditional structure of power systems towards restructured power systems and also electrical energy consumers' willingness to receive energy in their residence, has made small production units more important [1]. Distributed generations (DG) refer to small manufacturing units at strategic points of system installed near the load centers including gas turbine, micro turbine, fuel cell, solar energy and etc. DG can help to supply for certain customer or totally to provide loads for desired consumers separately [2]. Distributed generation, provides electricity in the open or closed position for load centers and as connected to distribution network [3]. These products have numerous advantages and disadvantages [4] including standby power, peak shaving, network support and etc. The use of DG in system architecture to produce and utilize economic energy is expanding [5].Some conducted studies indicate that until 2010, the share of these productions in energy production will exceed 25% of total energy production. [4].

On the other hand, reactive power compensation in distribution network plays a determining role in improving power quality, power factor correction and maintaining constant voltage distribution. Among various available adjustment tools, voltage based controllers on source converter (VSC) provide immediate response to the demand for reactive power, thus, in order to they are used to correct the power factor and voltage regulation. A type of these VSC-based controllers called distribution static compensator (D-STATCOM) has been proved to be suitable alternative for SVC [6]. D-STATCOM is used to compensate for power quality problems such as unbalanced load, voltage drop, voltage fluctuations and voltage imbalance that occur in short time within milliseconds. Within this short time, the D-STATCOM injects active and reactive power to the system to compensate for sensitive loads, and active power injection should be done by the energy storage system. Modeling effects of D-STATCOM on compensation for power quality of sensitive loads problems are considered and dynamic effects of D-STATCOM will be studied in a short time and cannot be checked for a long time. Because of limited capacity, the energy storage system cannot inject active power into the system for a long time [6, 7].

2. The distribution static compensator (D-STATCOM)

Static compensator of distribution network is a device parallel to network which injects or absorbs the reactive and active current into the Load connection point to (PCC) network. At steady state and heavy load conditions or the occurrence of a short circuit, usually DSTATCOM injects appropriate compensation current to the point of load connection to network. as a result of which bus voltage of load is regulated and placed in the allowed range. Usually DSTATCOM has an ability to exchange active and reactive power in the network simultaneously and the amount of exchanged active power depends on energy storage capacity. In this article the only task of DSTATCOM is to exchange task of reactive power and active power exchanging with network has been skipped. Figure (1) shows an example of DSTATCOM connected to the i-th bus.

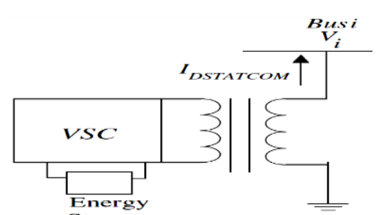

Figure (1) an example of STATCOM connected to the bus i [8]

Many distribution networks have radial structures feeding of which is only one sided. In Fig (2) a section of a typical distribution network has been shown.

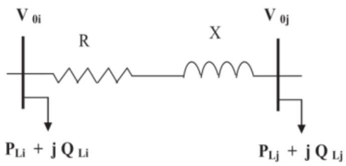

Figure (2) Single-line diagram of two consecutive load buses in distribution network

In this figure it is assumed that three-phase distribution network is in equilibrium state, that is why have modeled network by a single line diagram. We have shown the impedance between buses i and j as $R+jX$, load installed on bus i as P_i+jQ_i and load installed on the bus j as $Pj+jQj\,.V_i$ and V_i are bus voltage of this system. Phasor diagram for Fig (2) has been shown as Fig (3).

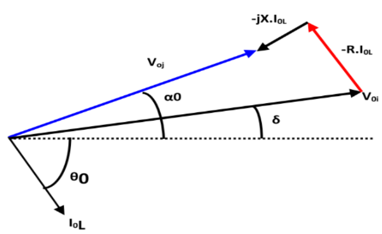

Figure (3) Voltage and current phasor diagram of the system shown in Figure (2) [8]

The KVL equation can be expressed as follows:

$$Voj\angle\alpha_o = V_{oi}\angle\delta_o-(R+jX).I_{oL}\angle\theta_o \qquad (1)$$

Usually in traditional networks, bus voltages are less than 1p.u. where j bus voltage can be assumed less than 1p.u. In this study, a DSTATCOM system is installed on j bus in order to compensate the voltage drop. As mentioned previously, DSTATCOM used in this article in order to adjust the voltage and reduce losses in steady state is only by injecting reactive power. As a result, $I_{Dstatcom}$ according to the system voltage is perpendicular to it. Installing a DSTATCOM device on j bus has been shown in Fig (4) and its phasor diagram in Fig 5.

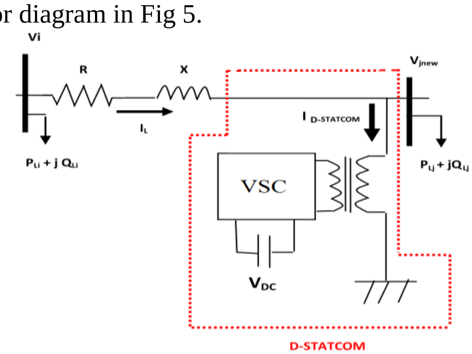

Figure (4) installing STATCOM on J bus in proposed distribution network [8]

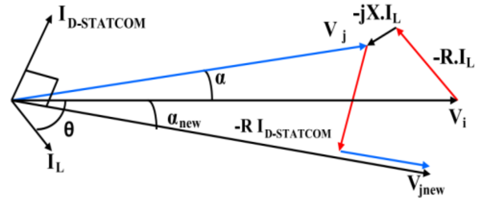

Figure (5) Voltage and current phasor diagram in Figure (4) [8]

While J bus voltage STATCOM is installed on it, change from Vj to the $Vjnew$ and we have:

$$\angle I_{Dstatcom} = \left(\frac{\pi}{2}\right)+\alpha_{new}\ , \quad \alpha_{new}<o \qquad (2)$$

$$V_{jnew} = Vi\angle\delta-(R+jX)(I_L\angle\theta+I_{Dstatcom}\angle(\frac{\pi}{2} +\alpha_{new}) \qquad (3)$$

Which ultimately STATCOM reactive power injected into the network to correct V_{jnew} bus voltage is expressed as equation (4) is as follows:

$$jQ_{Dstatcom} = V_{jnew}.(I_{Dstatcom})^* \qquad (4)$$

3. Modelling the problem

The main purpose of this article, is to find a place and optimum size of distributed generation sources and DSTATCOM in distribution network to reduce network losses, to achieve this objective we define a major objective function and a set of limits and equality and inequality constraints to the problem. The main objective function in order to optimize is expressed as equation (5):

$$\min f = \min(P_{Loss}) \qquad (5)$$

Where: P_{Loss} is total power dissipation in radial distribution network. Desired equality and inequality constraints to solve this optimization problem have been considered based on the following relationships.

3.1 Equality constraints

The angle between V_{jnew} the voltage after compensation and the DSTATCOM, $I_{Dstatcom}$ is equal to 90 degrees. Actually, to improve the power factor, DSTATCOM current angle and voltage after compensation must be maintained 90 degrees. Another equality constraint that must be observed is power restriction. Actually real power of buses must be limited as equation (6):

$$P_{Loss}+\sum P_{Dj} = \sum P_{DGj} \qquad (6)$$

Real power produced in bus j by DG, must be equal with total power consumption of bus j and the real power losses at that bus.

3-2 Inequality constraints

Compensated reactive power must be restricted as equation (7):

$$Q_j^c \le \sum_{j=1}^{n} Q_{Lj} \tag{7}$$

In which Q_j^c and Q_{Lj} are compensated reactive power in bus j and consumed reactive power in bus j, respectively. Actually in order to maintain power quality, Q_j^c must be equal to or less than Q_{Lj} . Also the amplitude voltage in each node and current amplitude in each branch must be placed in defined permitted range in relations (8) and (9):

$$V_{j\min} \ge Vj \ge V_{j\max}\ ,\ j = 1,2,\ldots,N \tag{8}$$

$$\left|I_j\right| \le \left|I_{j\max}\right|\ ,\ j = 1,2,\ldots,N \tag{9}$$

4- Calculating power distribution

Power distribution equations defined by subset of simple equations of power balance are as follows:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1} * \frac{(P_i^2 + Q_i^2)}{\left|V_i^2\right|} \tag{10}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1} * \frac{(P_i^2 + Q_i^2)}{\left|V_i^2\right|} \tag{11}$$

Where: P_i and Q_i are active and reactive power ejected from bus i respectively and P_{Li} and Q_{Li} are active and reactive power consumed in bus i. Resistance and reactance line between bus i and i + 1, are displayed with $R_{i,i+1}$ and $X_{i,i+1}$. The power losses in line between buses i and i + 1 are calculated as relations (12) and (13):

$$P_{Loss}(i,i+1) = R_{i,i+1} * \frac{(P_i^2 + Q_i^2)}{\left|V_i^2\right|} \tag{12}$$

$$Q_{Loss}(i,i+1) = X_{i,i+1} * \frac{(P_i^2 + Q_i^2)}{\left|V_i^2\right|} \tag{13}$$

Eventually, active and reactive power losses and total power dissipation for all the considered network buses are calculated based on equations (14) to (16):

$$P_{T,Loss} = \sum_{i=o}^{n-1} P_{Loss}(i,i+1) \tag{14}$$

$$Q_{T,Loss} = \sum_{i=o}^{n-1} Q_{Loss}(i,i+1) \tag{15}$$

$$P_{Loss} = \sqrt{P_{T,Loss}^2 + Q_{T,Loss}^2} \tag{16}$$

5. Sensitivity analysis of losses

In this study, the best place to install DG and STATCOM is determined by sensitivity factor of losses. Actually this factor causes to reduce the search space in optimization process by imperialist competitive algorithm and also the increased speed of searching optimal solution [9]. According to obtained active and reactive power losses, equations (17) and (18) for K-th bass line between p and q can be written as below:

$$P_{lineloss(q)} = \frac{P_{(eq)}^2(q) + Q_{(eq)}^2(q)}{(V(q))^2} * R(k) \tag{17}$$

$$Q_{lineloss(q)} = \frac{P_{(eq)}^2(q) + Q_{(eq)}^2(q)}{(V(q))^2} * X(k) \tag{18}$$

Where: $P_{eq}(q)$ and $Q_{eq}(q)$ are active and reactive total power released before node q, respectively. In this study, we will use matrix BIBC (matrix of injected bus current into the current's branch) to calculate $P_{eq}(q)$ and $Q_{eq}(q)$ as follows:

$$P_{eq}(q) = BIBC * P_{RLPM} \tag{19}$$

$$Q_{eq}(q) = BIBC * Q_{REPM} \tag{20}$$

Where $P_{eq}(q)$ and $Q_{eq}(q)$ are matrix of active and reactive power from considered network power losses. This will make calsulation easier and faster. In this study, active power is provided by distributed generation sources (DG) and network reactive power by DSTATCOM. Now both obtained active and reactive power sensitivity coefficients can be represented as follows: sensitivity coefficient for placement of distributed generation (DG) and DSTATCOM are obtained of the relations (21) and (22), respectively:

$$\frac{\partial P_{lineloss}}{\partial P_{eq}} = \frac{2 * P_{eq}(q) * R(k)}{(V(q))^2} \tag{21}$$

$$\frac{\partial P_{lineloss}}{\partial Q_{eq}} = \frac{2 * Q_{eq}(q) * X(k)}{(V(q))^2} \tag{22}$$

After calculating the sensitivity coefficient for all buses, we rank obtained values downward. We save this sequence of obtained numbers in a separate matrix called B (i). Then we save buses which have voltage less than 0.95 pu. Actually considering listed V (i), it is decided that which of the buses stored in matrix B (i) requires the DG or DSTATCOM. In fact, with this method, optimum location of DG or DSTATCOM is determined. To calculate optimum size in this study, we will benefit from imperialist competitive algorithm (ICA) which is an evolutionary optimization algorithm too.

6- Imperialist competitive algorithm (ICA)

Imperialist competitive algorithm is a new algorithm in evolutionary computations that has been established based on the socio-political evolution of human. Similar to other evolutionary algorithms, this algorithm, also begins with some random initial population each called a country. Some of the best elements are selected as a colonizer or colonist or imperialist and the rest of the population are considered as colony. In an optimization problem the next N_{var} of a country, is one $1\times N_{\text{var}}$ array. This array is defined as (23).

$$Country=\left[p_1,p_2,p_3,\ldots,p_{N\,\text{var}}\right] \tag{23}$$

The cost of a country, evaluating f function per the variables in it $(p_1,p_2,p_3,\ldots,p_{N\,\text{var}})$ will be as equation (24).

$$Cost_i=f(country_i)=f(p_{i1},p_{i2},p_{i3},\ldots,p_{iN\,\text{var}}) \tag{24}$$

To start the algorithm, the $N_{country}$ primary countries are created and N_{im} of the best known members of this population are elected as the imperialists. The remaining N_{col} countries, constitute colonials that each of them belong to an empire [10]. Colonizer countries absorb the colonies to their sides by applying recruitment policy for various aspects of optimization. Colonialists considering to their power, draw absorb colonies with equation (25). Total power of every empire, is determined by calculating the power of both parts of its constituent namely power of colonizer country, plus percentage of average strength of it colonies.

$$T.C._n=Cost(imperialist_n)+\xi mean\left\{\ Cost(colonies\ of\ empire_n)\ \right\} \tag{25}$$

Colony country, moves the X unit size in direction of filed line from colony to colonist, and is drawn to new situation. In Fig 6, the distance between colonialist and colonized has been shown by d and X is random number with uniform distribution. In equation (26) for X, we have:

$$x\sim \mathrm{U}(0,\beta\times d) \tag{26}$$

Where, β is greater than one and is close to 2. A suitable choice could be β = 2. Also angle of motion has been considered as uniform distribution (27).

$$\theta\sim \mathrm{U}(-\gamma,\gamma) \tag{27}$$

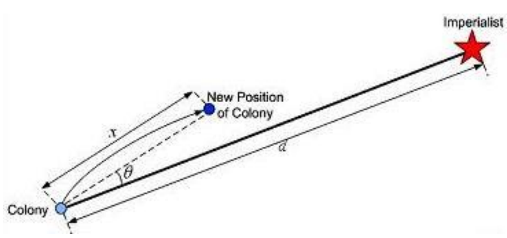

Figure (6) Movement of the colonies toward Colonialist [10]

In algorithm ICA, with a possible deviation, colony goes in the course of colonialist absorption. This deviation has been shown as rhe angle θ which is selected randomly and even distribution. While moving colonies toward colonialist country, some colonies may reach a better position than colonialist in this case, colonialist and colonized countries change their places with each other [10].

7. Numerical results

In this paper, distributed generation sources and STATCOM are connected to the network at distribution network level and in order to evaluate effectiveness of proposed algorithm to solve the optimization problem, 12 buses will be reviewed and evaluated before installing and after installation of distributed generation sources and DSTATCOM in an IEEE standard test network. In each of the modes defined with respect to the objective function of the problem, network losses and voltage profile will finally be reviewed and compared. Information of testing network has been taken from reference [11]. The total loss of 12 bus network before compensation is equal to 20.7 kW. To evaluate proposed performance, 5ive modes for each network considered as follows:

First case: without the presence of DG and STATCOM .
Second case: only the presence of DG in the network .
Third case: only the presence of DSTATCOM in the network.
Fourth case: the presence of DG and DSTATCOM in similar buses in the network.
Fifth case: the presence of DG and DSTATCOM buses in different buses in the network

In the first case (without the presence of DG and STATCOM) Network total losses are 20.7 kW and network's weakest bus in terms of voltage levels, is the last bus of network i.e. bus number 12 with value of 0.9443 pu. In the second case by sensitivity analysis, bus No. 9 is selected as a candidate for the installation of DG, in this case DG capacity is equal to 236.673 kW. Network losses decrease to 8.012 kW and voltage profile is within the permitted range.

In the third case we use DSTATCOM only in order to reduce network losses. Installing DSTATCOM in bus 9 of network with capacity of 215.632 kW, the network losses decreased to 9.3 kW and voltage profile will be placed within the permitted range. In this case compared to the second case, the end line's voltage profile has declined a little but it is still in defined permitted range and losses in this case, have a slight increase compared to the presence of DG.

In the fourth case, we used both DSTATCOM and DG equipment in a similar bus to reduce network losses. By installing DSTATCOM and DG in bus 9 of the network, with capacities 216.632 kW and 232.45 kW, respectively, network losses is reduced to 2.399 kW and voltage profile will be within the permitted range. In this case, both the voltage profile and network losses reduction have improved compared to the previous modes.

In this scenario, we will use both equipped STATCOM and DG in different buses to reduce network losses. Installing DSTATCOM and DG in bus networks 8 and 9, with capacities 246.1491 kW and 232.913 kW respectively, the Network losses was reduced to 2.399 kW and voltage profile will be within the permitted range. In this case, voltage profile has improved compared to the fourth case and reduction of network losses have not changed significantly compared to the fourth case.

In order to compare and have suitable scenario analysis and various investigated modes in previous section, voltage profile curve has been shown in five states in Fig (7) and also losses reduction curves in five states in 12-bus network in Fig (8).

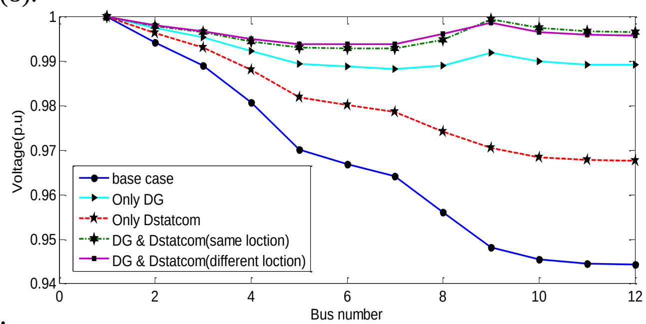

Figure (7) Voltage profile curve in five states in 12-bus network

To evaluate the results numerically in five different states, Table (1) shows numerical results of the voltage profile in five different modes of optimization.

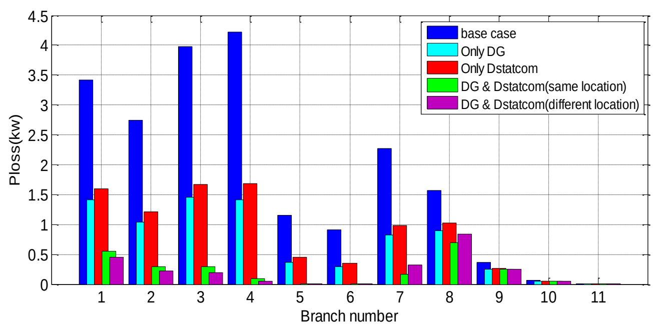

Figure (8) losses reduction curve in five states in 12-bus network

Table (1) Numerical results of Voltage profile In five different modes

Voltage (p.u)	First mood	Second mood	Third mood	Fourth mood	Fifth mood
Bus 1	1	1	1	1	1
Bus 2	0.9943	0.9974	0.9964	0.9980	0.9981
Bus 3	0.9891	0.9954	0.9931	0.9965	0.9967
Bus 4	0.9808	0.9924	0.9880	0.9945	0.9950
Bus 5	0.9702	0.9895	0.9819	0.9931	0.9939
Bus 6	0.9669	0.9888	0.9801	0.9930	0.9938
Bus 7	0.9642	0.9883	0.9787	0.9930	0.9939
Bus 8	0.9560	0.9890	0.9741	0.994	0.9962
Bus 9	0.9481	0.9919	0.9705	0.9995	0.9986
Bus 10	0.9454	0.9899	0.9684	0.9975	0.9966
Bus 11	0.9445	0.9893	0.9677	0.9968	0.9959
Bus 12	0.9443	0.9892	0.9676	0.9967	0.9958

8. CONCLUSION

It can be seen from the voltage profile curve that the modes 4 and 5 are the best modes of the network in terms of improving voltage profile. Also the presence of DG and DSTATCOM in separate cases has caused the improvement of the voltage profile reasonably (within the permitted voltage range). By examining the losses reduction curve, it can be seen that only the presence of STATCOM in the network has had fewer loss reduction compared to other cases (except for the ground state) and then the presence of DG in the network has such result. States 4 and 5 have the same values in total losses of network but reduction in losses in the 5th case at the start of network is greater than the fourth case and the same condition applies conversely, at the end of line for these two cases.

REFERENCES:

[1] B. J. Brooks, "Rural protection policy for long overhead networks" Northern Ireland Electricity, IEE colloquium, pp.4-8, 1988.

[2] Carmen L.T. Borges, Djalma M. Falca˜o ", Optimal distributed generation allocation for reliability, losses and voltage improvement' Electrical Power and Energy Systems, Vol. 28, pp.413-420, 2008.

[3] Mark Rawson, DISTRIBUTED GENERATION COSTS AND BENEFITS ISSUE PAPER, Public Interest Energy Research California Energy Commission, JULY 2004.

[4] Tahir Niknam and Ali Mohammad Ranjbar "Effect of distributed generation to flow asymmetric three-phase power distribution systems", the 17th International Conference on electricity, Iran, 138, page 49-57.

[5] Anshu Bharadwaj and Rahul Tongia ",Distributed power generation: rural India – A case study", Member, IEEE

[6]Deepika, masand.2006,"Control algorithms for distribution static compensator" IEEE isie, july, Canada.pp.1830-1834

[7] Irena. wasiak,Rozmys law mienski,"application of DSTATCOM compenstors for mitigation of power quality disturbances in low voltage grid with distributed generation" electrical power quality and utilization, October, 2007,pp.1-6.

[8] Devi, S., and M. Geethanjali. "Optimal location and sizing determination of distributed generation and DSTATCOM using particle swarm optimization algorithm." International Journal of Electrical Power & Energy Systems 62 (2014): 562-570.

[9] SrinivasasRao R, Narasimham SVL, Ramalingaraju M. Optimal capacitor placement in a radial distribution system using plant growth simulation algorithm. Electr Power Energy Syst 2011; 33:1133–9.

[10]E. Atashpaz-Gargari, C. Lucas, "Imperialist Competitive Algorithm: An algorithm for optimization inspired by imperialistic competition", IEEE Congress on Evolutionary Computation, 2007.

[11] Tuba Gozel, HakanHocaoglu M. An analytical method for the sizing and siting of distributed generators in radial systems. Electr Power Syst Res 2009; 79: 912–8.