Optimizing Reactive Power Dispatch considering TCSC allocation by Modified Differential Evolution Algorithm

Conference Paper · December 2015

3 authors, including:

Ragab A. El Sehiemy
Kafrelsheikh University

Ahmed Mohamed Azmy
Tanta University

MEPCON 2015

17th International Middle-East Power System Conference (MEPCON'15) Mansoura University, Egypt, December 15-17, 2015

Optimizing Reactive Power Dispatch considering TCSC allocation by Modified Differential Evolution Algorithm

W. S. Sakr   Ragab A.EL-Sehiemy
Electrical Engineering Department
Faculty of Engineering,
Kafrelsheikh University, Kafrelsheikh, Egypt
lolosakr95@yahoo.com   elsehiemy@eng.kfs.edu.eg

Ahmed M. Azmy
Elec. Power and Machines Eng. Depart.,
Faculty of Eng., Tanta University,
Tanta, Egypt
azmy@f-eng.tanta.edu.eg

***Abstract* - Increasing electrical load demand and transition from regulated to deregulated power systems caused many challenges, such as: high transmission line losses and low voltage levels. An effective control of reactive power improves voltage profile, reduces power losses and improves overall system performance. In case of abnormal operations of power systems, the transmission lines become over loaded and the voltage at buses is decreased. To solve these problems, Flexible Alternating Current Transmission Systems (FACTS) represent a promising solution. One of the important FACTS devices is Thyristor Controlled Series Compensator (TCSC). Differential Evolution (DE) algorithm is one of the recent Meta heuristic optimization algorithms. Two modifications are applied to DE algorithm to enhance its convergence characteristic. In this paper, solving the Optimal Reactive Power Dispatch (ORPD) problem considering TCSC is introduced based on Modified Differential Evolution Algorithm (MDEA). The multi objective function is considered to minimize the summation of power losses, voltage deviation, reactive power losses, cost of TCSC and number of units. Two systems are considered: IEEE 57-bus system and Western Delta Network (WDN).**

Index Terms* - *ORPD problem, Differential evolution, TCSC.

I. INTRODUCTION

Modern power systems face serious problems, due to increasing demand and marketing, such as voltage instability and uncontrolled power flow in transmission lines. ORPD is very important for economic and secure operation of power systems. Effective reactive power compensation improves voltage profile and minimizes active and reactive power losses in transmission lines [1]-[3]. Under abnormal operation of power systems, such as increasing load demand, the transmission lines become over loaded and voltage at buses are decreased. This situation represents a contingency operation and the Independent System Operator (ISO) must take an action to restore safe operation of power systems.

To solve these problems, installing FACTS devises represents a promising solution [4]-[5]. FACTS devices represent one of new technologies which improves the performance of power system. They control voltage magnitude, impedance of transmission line and power flow through transmission lines [6]. TCSC is one of series FACTS devices, which is characterized by fast response. The optimization techniques that were implemented to solve ORPD problem can be classified to two main categories. The first category is the classical optimization methods [7]-[9] such as linear programming, interior point method and gradient method. These methods suffer from the incapability of handling nonlinear objective functions. On the other hand, the second category, i.e. meta heuristic algorithms, [10]-[14] include Particle Swarm Optimization algorithm (PSO), Genetic Algorithm (GA), DE algorithm, seeker optimization algorithm and so on.

Many researches addressed the problem of selecting optimal location and optimal setting of FACTS devices, especially TCSC, in case of normal operation. In [15], PSO technique is applied to find the optimal location of TCSC for static security enhancement. Also in [16], a comparison between GA and DE algorithms is addressed for optimal location of TCSC to maximize loadability. In [17], the authors introduced also two methods for implementation of GA for optimal location and optimal setting of TCSC to increase loadability of transmission lines for IEEE 30-bus system. Many literatures investigated the determination of optimal locations of FACTS devices under abnormal conditions. In [18], TCSC and SVC are used under abnormal conditions to improve the performance of the IEEE 30-bus system based on DE algorithm. Although the optimal reactive power planning is very vital for power systems, especially in contingency situations, few researches discussed this problem.

Moreover, very few papers addressed the ORPD considering FACTS devices under abnormal operation. In [19], a new method is introduced for var planning under multiple operating scenarios to enhance voltage profile. In [20], a model is introduced for long term reactive power planning under load uncertainties and line outage. In [21], reactive power optimization to improve voltage stability limit incorporating TCSC device through DE/PSO was considered under contingency condition.

In this paper solving the ORPD problem considering TCSC is introduced based on modified differential evolution algoeithm (MDEA). A multi objective function is considered to minimize the summation of power losses, voltage deviation, reactive power losses, cost of TCSC and number of units. The control variables include voltages magnitudes of voltage-control bus, location of TCSC units and their settings. Two systems are considered here: IEEE 57-bus test system and Western Delta Network (WDN). IEEE-57 bus system is investigated only under normal operation, while WDN is investigated under normal and outage of three lines.

II. THYRISTOR CONTROLLED SERIES COMPENSATOR

TCSC is the most popular series FACTS device that has many merits such as fast response and low cost. Conventionally, TCSC has two modes of operation, i.e. capacitive and inductive modes. Figure 1 shows the modeling of TCSC in transmission lines. The value of reactance of TCSC (X_{TCSC}) is a function of reactance of transmission line (X_L). To avoid over compensation and resonance of transmission line, the value can be taken as follows [22]-[24]:

$$-0.8\,X_L \le X_{TCSC} \le 0.2\,X_L \tag{1}$$

$$-0.7\,X_L \le X_{TCSC} \le 0.3\,X_L \tag{2}$$

$$-0.5\,X_L \le X_{TCSC} \le 0.5\,X_L \tag{3}$$

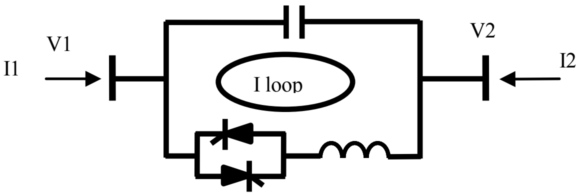

Fig. 1 Modeling of TCSC in transmission line

III. PROBLEM FORMULATION

A) Objectives

The objective function of the ORPD considering existence of TCSC devices is introduced as follows:

$$min(\mathrm{obj}) = w_1 P_1 + w_2 V_D + w_3\, cos\,t + w_4 Q_L + w_5 N_F \tag{4}$$

where w$_1$, w$_2$, w$_3$, w$_4$ and w$_5$ are weights coefficients and N_F is the number of TCSC units. The terms of the objective function will be explained in the following sections:

1. Active and reactive power losses

Real and reactive power losses are calculating as following:

$$P_L = \sum_{k=1}^{nl} g_k (V_i^2 + V_j^2 - 2 V_i V_j cos(\delta_{ij})) \tag{5}$$

$$Q_L = \sum_{k=1}^{nl} b_k (V_i^2 + V_j^2 - 2 V_i V_j sin(\delta_{1j})) \tag{6}$$

where, P_L is real active power losses through transmission lines, g_k is conductance of transmission line, nl is the number of lines, V_i and V_j are voltage magnitudes at buses i and j, respectively, δ_i and δ_j are angles of bus voltages, i, j, Q_L is the reactive power losses through transmission lines and b_k is the sucpetance of transmission lines.

2. Voltage deviation

The voltage deviation at load buses is calculated as following:

$$V_D = \sum_{i=1}^{NL} (V_{Li} - V_{ref}) \tag{7}$$

where V_D is the voltage deviation, NL is the number of load buses, V_L is voltage of load bus and V_{ref} is the reference voltage, i.e. 1.0 pu.

3. Cost of TCSC

Due to the high cost of FACTS devices, it is important to include this cost in the objective function. The cost is calculated as following [25]:

$$C_{TCSC} = 0.0015 S_{TCSC}^2 - 0.713 S_{TCSC} + 153.75 \tag{8}$$

$$cos\,t = \sum_{m=1}^{nl} S_{TCSCm} \times C_{TCSC} \tag{9}$$

where “cost” is the total investment cost of TCSC, S_{TCSC} is the capacity of TCSC in Mvar and C_{TCSC} is investment cost of TCSC per kvar. The capacity of TCSC is calculated as follows:

- $$S_{TCSC} = I_{L\max}^2 \times X_{TCSC} \tag{10}$$
- where $I_{L max}$ is the transmission line current where FACTS device is installed.

4. Number of TCSC units

The number of TCSC units has to be reduced since it is preferred to enhance the performance of power system by few umbers of FACTS devices to facilitate control processes

B) Constraints

Equation (4) is subjected to equality and inequality constraints. Equations (11) and (12) represent the power flow equations as equality constraints, while equations (13)-(18) represent the system inequality constraints.

$$P_{gi} - P_{di} - \sum_{j=1}^{NB} V_i V_j Y_{ij} \cos\left(\delta_{ij} + \gamma_{ij}\right) = 0 \tag{11}$$

$$Q_{gi} - Q_{di} - \sum_{j=1}^{NB} V_i V_j Y_{ij} \sin\left(\delta_{ij} + \gamma_{ij}\right) = 0 \tag{12}$$

$$Qg_i^{min} \le Qg_i \le Qg_i^{max} \tag{13}$$

$$Pg_i^{min} \le Pg_i \le Pg_i^{max} \tag{14}$$

$$Vg_i^{min} \le Vg_i \le Vg_i^{max} \tag{15}$$

$$S_i \le S_i^{max}; i \in \mathrm{nl} \tag{16}$$

$$V_{Li}^{min} \le V_{Li} \le V_{Li}^{max}; i \in \text{load bus} \tag{17}$$

$$-0.5 X_L \le X_{TCSC} \le 0.5 X_L \tag{18}$$

where P_{gi} , P_{di} are active power generation and load demand at bus i, respectively, Q_{gi} , Q_{di} are reactive power generation and load demand at bus i, respectively, V_i , V_j are voltage magnitudes at bus i and j, Y_{ij} is the admittance between bus i and j, γ_{ij} is the admittance angle of transmission line connected between buses i and j.

IV. MODIFIED DIFFERENTIAL EVOLUTION ALGORITHM

A) basic differential evolution algorithm

Differential evolution algorithm (DE) is an effective evolutionary computation methodology due to its fast convergence characteristic, few control parameters and small computation time. It was introduced by R. Storn and K. Price and its process can be summarized as following [26]:

- Initial population and parameter selections
  The first step of DE is to create initial population of candidate solutions. The parameter values of each vector in the population must be within certain limits according to:
  $$U_i = U_i^{\min} + rand \times (U_i^{\max} - U_i^{\min}) \qquad (19)$$
  where: $U_i^{\min}, U_i^{\max}$ are the minimum and maximum values of decision variables, respectively, rand is uniformly distributed number between [0 and 1], i=1, 2,..., N_P. N_P is the number of population.
- Mutation process
  The mutation process depends on perturbing the selected vector U_3 randomly using the difference between two other randomly-selected vectors (U_2, U_1). The mutation process is applied according to:
  $$U_4 = U_3 + F \times (U_1 - U_2) \qquad (20)$$
  where: U_1, U_2, U_3 and U_4 are randomly selected vectors with $U_4 \neq U_3 \neq U_2 \neq U_1$ and F is the scaling factor, whose value is ($0 \leq F \leq 1.2$).
- Crossover process
  To increase the population diversity, a crossover operator is applied. The crossover operation produces a trial vector, which is used in the selection process. The trial vector is the combination of parent vector (U_i) and mutant vector, (U_4). The crossover process is performed as following:
  $$U_t = \begin{cases} U_4 & \text{if } r(0,1) \leq CR \quad \text{or } j = q \\ U_i & \text{if } r(0,1) > CR \quad \text{and } j \neq q \end{cases} \qquad (21)$$
  where, j=1, 2,…, D and q is a randomly chosen index $\in$ [1, 2,…, D]. The value of CR is chosen in the range of [0, 1]. D is the number of control variables.
- Selection process
  In this process, the vectors that compose the next generation will be selected. The fitness of parent vector is compared with the fitness of trial vectors and the vectors of better fitness are selected according to:
  $$U_{t+1} = \begin{cases} U_t & \text{if } f(U_t) < f(U_i) \\ U_i & \text{otherwise} \end{cases} \qquad (22)$$

B) Proposed Modifications

In this work, two modifications are applied to DE algorithm to enhance the characteristic of convergence and performance as explained in the next section:

1) Modifying the mutation factor

In this section, a modified mutation factor for DE is applied to improve the performance of traditional DE. The scaling factor (F) is modified in each generation according to the following relation:

$$F = S\sqrt{r(0,1)^2 d} - b \qquad (23)$$

where: d is a linear decreasing factor in the range between [0.2 and 1.2], r is a random variable, S is an acceleration factor and b is a deceleration factor. The Factor “d” increases the capacity to explore the search space.

On the other hand, when combining the random variable “r” in the optimization process, the value of scaling factor “F” will fluctuate. The acceleration factor (S) balances between global exploration and local exploitation. When improved fitness function reduces the value of F, the speed of convergence increases. The importance of deceleration factor appears when the fitness function is not improved. In this case, the value of “F” will be increased to prevent dropping in local optimum [27].

2) Modified penalty factor

The proposed MDEA is enhanced with an adaptive penalty factor which is multiplied by the violated dependent variables. This penalty term is added to the fitness function which aims to enhance the system convergence. The penalty factor is updated according to the following expression:

$$\alpha_{n+1} = \alpha_n + \Delta\alpha \qquad (24)$$

where, α_{n+1} is a new penalty factor at iteration (n+1), α_n is the previous penalty factor at iteration (n) and $\Delta\alpha$ is the updating formula of the penalty factor.

The updating formula of penalty factor is calculated as follows:

$$\Delta\alpha = \frac{|\,fit_n - fit_{n+1} + \beta\,|}{Dep_{n+1} - Dep_n + \mu\,|} \qquad (25)$$

where, fit_n, fit_{n+1} are the old and new fitness functions, Dep_{n+1}, Dep_n are the new and old dependent variables, respectively, and β, μ are constants, whose value are obtained empirically. In this work, updating penalty factors is applied only for load voltages and reactive power generation, while penalty factors for thermal limit violation, active power generation for slack bus and equality constraints are maintained constants.

V. PROPOSED METHODOLOGY

Figure 2 shows the flowchart of the proposed methodology. For solving ORPD problem considering FACTS devices (TCSC), many aspects are considered as following:

- The lines with low power losses are excluded from the candidate ones
- Lines, which are connected between two generation buses, are excluded to avoid conflict between control of FACTS and generators.
- Lines, which contain on-load tap changer, are excluded to avoid conflict between control of FACTS and control of on-load tap changer.

VI. CASE STUDIES

A) *Test systems*

IEEE 57-bus test system and WDN are used to implement the proposed technique for ORPD using MDEA in normal and abnormal operation. The IEEE 57-bus test system has 7 generators allocated at buses 1, 2, 3, 6, 8, 9 and 12. Bus 1 is the slack bus, while other generator buses are voltage control buses. There are 80 lines and 17 on-load tap-changer transformers. The second system is WDN, as a part of the unified Egyptian network system, which has 8 generators at buses 1, 2, 3, 4, 5, 6, 7 and 8. Bus 1 is the slack bus, while other generation buses are voltage control buses [28].

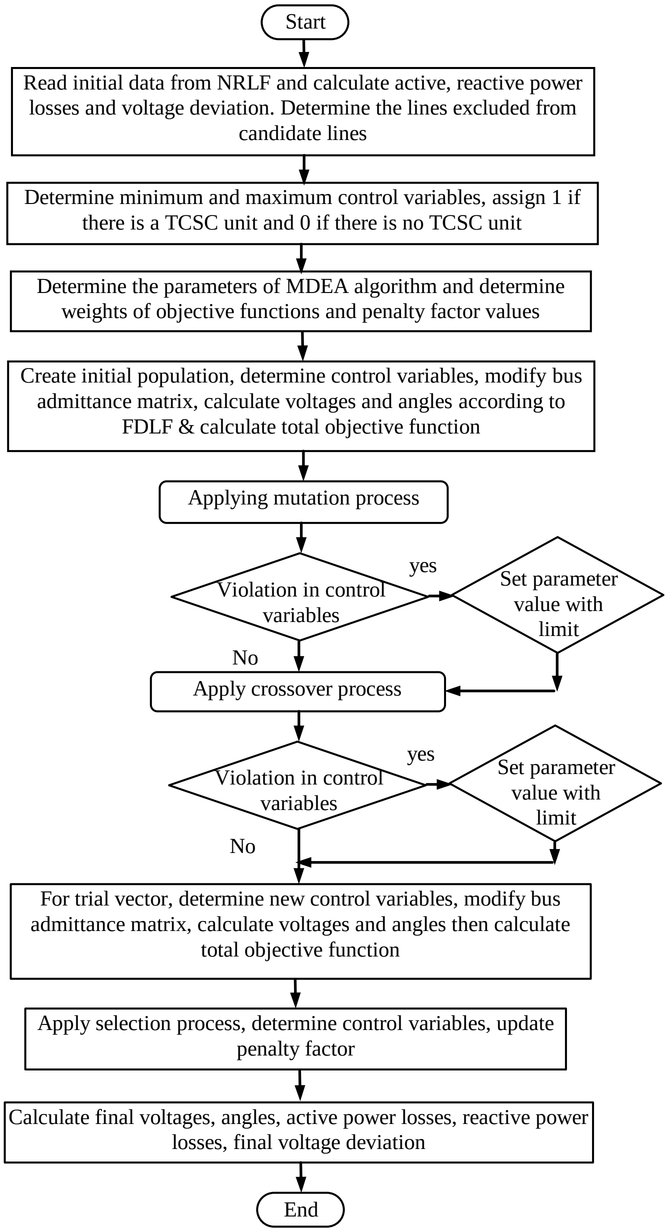

Fig. 2 The flow chart of the proposed methodology

B) *Results and comments*

1. IEEE 57-bus system

This system is investigated only under normal operation. The initial active and reactive power losses of this system are 0.2786 pu and 1.21 pu, respectively. The average voltage deviation is 0.0246 pu. There is a violation in voltage at bus 31 since it is 0.936 pu, i.e. lower than minimum value. The ORPD is solved by MDEA considering only voltages of voltage control buses as control variables. The number of voltage control bus is six and the total number of control variables is six. Table I illustrates the results of solving ORPD problem with MDEA, where there is a high reduction in active and reactive power generation after solving ORPD problem. The reduction in reactive power generation after applying ORPD with MDEA is about 0.12 pu. Also it is found that after applying ORPD with MDEA, the violation at bus 31 is eliminated, where the voltage is increased to 0.9518 pu. From the table it is obvious that active and reactive power losses are reduced after applying ORPD. In addition, the voltage profile is improved with higher reserve power.

Table I: ORPD solution for IEEE 57-bus using MDEA

Variables	Limits		Initial case	ORPD with MDEA
	Min.	Max.		
Pg1 (pu)	0.50	5.75	4.7866	4.767
Qg1 (pu)	-2.00	3.50	1.2885	0.5786
Qg2 (pu)	-1.50	2.00	-0.0075	0.5787
Qg3 (pu)	-1.50	1.50	-0.0090	0.3995
Qg6 (pu)	-1.25	1.25	0.0087	0.0278
Qg8 (pu)	-2.00	2.00	0.6210	0.4595
Qg9 (pu)	-3.00	1.10	0.0229	0.5747
Qg12 (pu)	-2.00	1.55	1.2863	0.4808
V_1 (pu)	0.94	1.06	1.0400	1.0400
V_2 (pu)	0.94	1.06	1.0100	1.0289
V_3 (pu)	0.94	1.06	0.9850	1.0120
V_6 (pu)	0.94	1.06	0.9800	1.0022
V_8 (pu)	0.94	1.06	1.0050	1.0214
V_9 (pu)	0.94	1.06	0.9800	1.0015
V_{12} (pu)	0.94	1.06	1.0150	0.9972
V_{31} (pu)	0.94	1.06	0.9360	0.9518
$\sum QG$			3.2109	3.09
Active Power loss (pu)			0.2786	0.259
Reactive power loss (pu)			1.21	1.137
voltage deviation (pu)			0.0246	0.0214
Reduction in power flow in transmission lines (pu)			-	0.7691
Reserve in reactive power generation (pu)			-	0.12

Table II compares between the proposed technique and other algorithms for IEEE 57-bus power systems. From this table, it is found that for the proposed technique, the voltages of only voltage control buses are considered as control variables. Neither FACTS devices nor load tap changer transformers are considered in this system. However, the power losses are reduced to 0.259 pu using MDEA. In case of using DE, Artificial Bee Colony (ABC) and combined DE and ABC, the power losses are reduced to 0.2586 pu, 0.2769 pu and 0.2556 pu, respectively. The control variables used are the voltages at generation bus, on-load tap changers and two shunt capacitors. In case of using Honey Bee and Bacterial Foraging, the active power losses are reduced to 0.27 pu, the number of TCSC is seven units in this case. So, the cost is increased in addition to increasing the number of control actions in case of using DE, PSO, Honey Bee, Bacterial Foraging and ABC.

Table II: Comparison between the proposed technique and other algorithms for IEEE 57-bus power system

Algorithm	Active power losses in (pu)
Proposed Technique	0.259
DE [29]	0.2586
ABC [29]	0.2769
DE and ABC [29]	0.2556
Honey Bee [30]	0.2700
Bacterial Foraging [30]	0.2700

2. Western Delta Network (WDN)

Table III presents the ORPD solution considering two case studies. Case1 represents normal operation, while Case 2 represents outage of three critical lines to simulate an emergency condition. With respect to Case 1, the initial active and reactive power losses in case of normal operation are 0.4046 pu and 1.375 pu, respectively, while the average voltage deviation is 0.0265 pu. Under these conditions, there is no violation related to transmission lines. However, there are voltage violations at buses 15, 18, 20→22. The performance of WDN is not satisfactory and many improvements are needed. Thus, solving the ORPD problem is very important to improve the performance of system. Furthermore, this investigation is vital to eliminate the violation of voltages at different buses. Only the voltage values at voltage-control buses are considered as the control variables and no TCSC units are inserted in this case. The number of voltage control buses is seven and the number of control variables is also seven. After applying ORPD, the violations in voltages at buses are eliminated and also the summation of reactive power generation is reduced. The active and reactive power losses are reduced to 0.3741 pu and 1.2783 pu, respectively.

The outage of the most-critical three lines, lines 2, 9 and 28, is addressed in Case 2. The active and reactive power losses are increased to 0.5584 pu and 1.844 pu, respectively and the average voltage deviation is increased to 0.0288 pu. There are violations in voltages at buses (15, 18, 20→22, 30 and 32). On the other hand, there is a violation in the power flow through line 1, which reaches 1.54 pu, while the maximum limit is 1.2 pu. So, it is important to eliminate the violation, improve voltage profile and improve power quality. After applying ORPD, the voltages at all buses are within limit, there is no violation in line 1, the power flow through line 1 becomes 1.19 pu within limit and also there is high reduction in reactive power generation. The performance of system is improved after solving ORPD problem considering TCSC units. The active and reactive power losses are reduced to 0.4945 pu and 1.659 pu, respectively. There are reductions in power flow through transmission lines by 0.6857 pu. In addition, there is high reserve in reactive power generation by 0.2391 pu. The optimal locations of TCSC units for this case are in lines 1 and 10 that represent the lines with maximum power losses.

Table III: ORPD solution for WDN for cases 1 and 2

Cases	Operating Limits (pu)		Case 1		Case 2	
Variables	Min.	Max.	Initial case	ORPD + MDEA	Initial Case	ORPD +MDEA + TCSC
Pg1 (pu)	0.1	3.75	2.49	2.46	2.6442	2.5805
Qg1(pu)	0	2.0	0.5671	0.3109	0.6089	0.3914
Qg2 (pu)	0	2.0	0.2251	0.3186	0.4559	0.3911
Qg3 (pu)	0	2.0	1.0450	1.0815	1.0450	1.1267
Qg4 (pu)	0	2.0	1.1489	1.1067	1.1489	1.1418
Qg5 (pu)	0	2.0	0.6794	1.2556	0.7728	1.0668
Qg6 (pu)	0	2.0	0.8147	0.6057	0.8924	0.6371
Qg7 (pu)	0	2.5	0.8362	0.8864	0.8357	0.9297
Qg8 (pu)	0	2.5	0.6014	0.2033	0.6324	0.4683
V_{13} (pu)	0.95	1.05	0.9730	0.9984	0.958	0.9927
V_{15} (pu)	0.95	1.05	0.9440	0.9989	0.944	0.9987
V_{18} (pu)	0.95	1.05	0.9190	0.9757	0.919	0.9756
V_{20} (pu)	0.95	1.05	0.9030	0.9612	0.9030	0.9611
V_{21} (pu)	0.95	1.05	0.9080	0.9654	0.9080	0.9652
V_{22} (pu)	0.95	1.05	0.9390	0.9948	0.9390	0.9947
V_{30} (pu)	0.95	1.05	0.957	0.9858	0.944	0.9852
$\sum QG$			5.9178	5.7687	6.392	6.1529
Optimal location of TCSC			-	-	-	Lines 1&10
Total cost of TCSC U$			-	-	-	2.77×10^{6}

Table IV summarizes performance of WDN for normal and emergency operation conditions. According to the obtained results, the proposed methods enhanced the operation of the WDN and release the power flow in transmission lines as well as the reactive power reserve from generating units.

Table IV: Performance of WDN for Cases 1 and 2

Variables	Case 1		Case 2	
	Initial case	ORPD + MDEA	Initial Case	ORPD +MDEA + TCSC
Active power loss (pu)	0.4046	0.3741	0.5584	0.4945
Reactive power loss (pu)	1.375	1.2783	1.8444	1.6590
Average voltage deviation (pu)	0.0265	0.0230	0.0288	0.0182
Reduction in power flow (pu)	-	0.4046	-	0.6857
Reserve in reactive power generation (pu)	-	0.1491	-	0.2391

Table V illustrates the parameter of MDEA for IEEE 57-bus system and WDN. From this table, it is found that the parameters of MDEA are constant.

Table V: Parameter of MDEA for IEEE 57-bus system and WDN

Parameter	IEEE 57-bus system	WDN
Maximum number of generation	500	2000
Number of control variables	6	7- 67
Number of populations	30	335
Crossover factor	0.95	0.95
Acceleration factor	1.8	1.8
Deceleration factor	1	1
Decreasing factor	1	1

VII. CONCLUSION

This paper presents the implementation of a modified differential evolution algorithm for solving the ORPD problem. This is intended to improve the system performance under normal and abnormal operating conditions. Case studies are implemented on IEEE 57-bus test systems, in addition to WDN to prove the capability of the proposed procedure. Numerical results show that the proposed MDEA has significant benefits as good convergence characteristics. Two efficient modifications are proposed to the MDEA on the basis of scaling factor and penalty factor. The results prove the flexibility of synchronous generators as efficient reactive power sources compared to other switchable devices in terms of the power losses reduction as well as the voltage profile at load buses. Another salient advantage is the reduction of the FACTS sizing, the number of switching processes and control action in addition to increasing the life time of equipment. In addition, using generation bus voltages as control variable is more effective in solving ORPD problem. It was proven that the proposed procedure is able to release transmission power flow and reactive power at generation buses. Also, it is able to increase the transfer capability of transmission lines and improve the system performance.

REFERENCES

[1] A.A.Abou El-Ela, A.M.Kinawy, R.A.El-Sehiemy and M.T.Mouwafi, "Optimal reactive power dispatch using ant colony optimization algorithm." Electrical Engineering,Vol.93, Issue. 2, pp.103-116, 2011.

[2] D.Devaraj and J.P.Roselyn, "Genetic algorithm based reactive power dispatch for voltage stability improvement." Inter. Journal of Electrical Power & Energy Systems, Vol.32, Issue.10, pp.1151-1156, 2010.

[3] N.Mancer, B.Madad, K.Sariri and M.Hamed, "Multi objective for optimal reactive flow using modified PSO considering TCSC." Inter. Journal of Energy Engineering, Vol.2, Issue.4, pp.165-170, 2012.

[4] L.Rajalakshmi, M.V.Suganyadevi and S. Parameswari, "Congestion management in deregulated power system by locating series FACTS devices." International Journal of Computer Applications, Vol.13, pp. 0975-8887, 2011.

[5] N.G.Hingorani, L.Gyugyi and M.El-Hawary, "Understanding FACTS." IEEE press, 2000.

[6] N. Yorino, E.E. El Araby, H. Sasaki and S. Harada, "A new formulation for FACTS allocation for security enhancement against voltage collapse" IEEE Trans on Power Systems, Vol. 18, no. 1, pp. 3-10, 2003.

[7] C.Y. David, J.E. Fagan, B. Foote and A.A. Aly, "An optimal load flow study by the generalized reduced gradient approach" Electric Power Systems Research, Vol. 10, Issue 1, pp. 47-53, 1986.

[8] J.Z. Zhu and X.F. Xiong, "Optimal reactive power control using modified interior point method" Electric Power Systems Research, Vol. 66, Issue 2, pp. 187–192, 2003.

[9] N.I. Deeb and S.M. Shahidehpour, "An efficient technique reactive power dispatch using a revised linear programming approach" Electric Power Systems Research, Vol. 15, Issue 2, pp. 121–34, 1988.

[10] P. Subbaraj and P.N. Rajnaryanan, "Optimal reactive power dispatch using self-adaptive real coded genetic algorithm" Electric Power Systems Research, Vol. 79, Issue 2, pp. 374–381, 2009.

[11] W. Yan, S. Lu and D.C. Yu, "A novel optimal reactive power dispatch method based on an improved hybrid evolutionary programming technique" IEEE Trans. on Power Systems, Vol. 19, Issue 2, pp. 913–918, 2004.

[12] D. Chaohua, C. Weirong, Z. Yunfang and Z. Xuexia, "Seeker optimization algorithm for optimal reactive power dispatch" IEEE Trans. on Power Systems, Vol. 24, Issue 3, pp. 1218–1231, 2009.

[13] H. Tehzeeb-Ul-Hassan, R. Zafar, S.A. Mohsin and O. Lateef, "Reduction in power transmission loss using fully informed particle swarm optimization" International Journal of Electrical Power & Energy Systems, Vol. 43, Issue 1, pp. 364-368, 2012.

[14] A.Q. Badar, B.S. Umre and A.S. Junghare, "Reactive power control using dynamic Particle Swarm Optimization for real power loss minimization" International Journal of Electrical Power & Energy Systems, Vol. 41, Issue 1, pp. 133–136, 2012.

[15] S.M.R. Slochanal, M. Saravanan and A.C. Devi, "Application of PSO technique to find optimal settings of TCSC for static security enhancement considering installation cost" The 7th IEEE International Conference on Power Engineering, 2005., pp. 1-394, 2005.

[16] G.I. Rashed, Y. Sun and K.P. Liu, "Optimal placement of thyristor controlled series compensation in power system based on differential evolution algorithm" Natural Computation (ICNC), 2011 Seventh International Conference, Vol. 4. IEEE, 2011.

[17] A.Y. Abdelaziz, M.A. El-Sharkawy and M.A. Attia. "Optimal location of thyristor-controlled series compensators in power systems for increasing loadability by genetic algorithm." Electric Power Components and Systems, Vol. 39, Issue 13, pp. 1373-1387, 2011.

[18] L. Jebaraj, C.C. A.Rajan and S. Sakthivel, "Real Power Loss and Voltage Stability Limit Optimization Incorporating TCSC and SVC through DE Algorithm under Different Operating Conditions of a Power System" Journal of Electrical and Electronics Engineering, Vol. 1, Issue 5, pp. 16-25, 2012.

[19] J.C. López, J. Contreras, J.I. Munoz and JJ.R.S. Mantovani, "A multi-stage stochastic non-linear model for reactive power planning under contingencies"Power Systems, IEEE Trans., Vol. 28, Issue 2, pp. 1503-15014, 2013.

[20] R.A. Jabr, N. Martins, B.C. Pal and S. Karaki, "Contingency constrained VAr planning using penalty successive conic programming" Power Systems, IEEE Trans., Vol. 27, Issue 1, pp. 545-553, 2012.

[21] S. Sakthivel and D. Mary, "Reactive power optimization for voltage stability limit improvement incorporating TCSC device through DE/PSO under contingency condition" IU-Journal of Electrical & Electronics Engineering, Vol. 12, Issue 1, pp. 1419-1430, 2012.

[22] S.Gerbex, R.Cherkaoui and A.J.Germond, "Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms." Power Systems, IEEE Trans., Vol.16, Issue.3, pp.537-544, 2001.

[23] M.Saravanan, S.M.R.Slochanal, P.Venkatesh and J.P,S.Abraham, "Application of particle swarm optimization technique for optimal location of FACTS devices considering cost of installation and system loadability." Electric Power Systems Research, Vol.77, Issue.3, pp.276-283, 2007.

[24] G.M.Huang and N.C.Nair, "Incorporating TCSC into the voltage stability constrained OPF formulation." Power Engineering Society Summer Meeting, 2002 IEEE, Vol. 3. IEEE, 2002.

[25] R.S. Wibowo, N. Yorino, M. Eghbal and Y. Saski, "Expected security cost based FACTS device allocation using hybrid PSO" IEEJ Trans. on Elect. and Electronic Engineering, Vol. 6, Issue 4, pp. 331-337, 2011.

[26] R.Storn, and P.Kenneth, "Differential evolution-a simple and efficient adaptive scheme for global optimization over continuous spaces" Berkeley: ICSI, 1995.

[27] C.W.Chien, Z.R.Hsu and W.P.Lee, "Improving the Performance of Differential Evolution Algo rithm with Modified Mutation Factor." Proceedings of International Conference on Machine Learning and Computing (ICMLC 2009), 2009.

[28] Washington University. http://www.ee.washington.edu/research/pstca/.

[29] Y. Li, Y. Wang and B. Li, "A hybrid artificial bee colony assisted differential evolution algorithm for optimal reactive power flow" Inter.Journal of Elect. Power & Energy Syst., vol. 52, pp. 25-33, 2013.

[30] R. Selvarasu and M. Surya Kalavathi, "TCSC placement for loss minimization using self adaptive Firefly algorithm"Journal of Engineering Science and Technology, Vol. 10, Isuue.3, pp. 291-306, 2015.