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A New Approach Based on Genetic Algorithm for Optimal Reactive Power Flow Solution in Multi-terminal AC-DC Systems

***Abstract**. This paper presents a new approach based on Genetic Algorithm (GA) for the solution of Optimal Reactive Power Flow (ORPF) in multi-terminal ac-dc systems. Active power loss optimization is implemented through GA considering the constraints of entire multi-terminal ac-dc system. Ac-dc power flow is solved by sequential method. So, any ac and dc power flow algorithm can be used effectively in the proposed approach. Unlike the similar studies, active powers of all converters except at least one are selected as control variables for ORPF in this study to achieve most suitable converter active powers and converter types that improve active power loss minimization.This paper presents the first study that utilizes GA for the solution of optimal reactive power flow in multi-terminal ac-dc systems in the literature. The proposed approach is tested on the modified IEEE 14-bus ac-dc test system. The obtained results by this study and another alternative study are also given. Comparative results showed that the proposed approach is more efficient and reliable in reaching to a global optimum while satisfying entire system constraints.*

***Streszczenie.** W artykule przedstawiono propozycję metody zarządzania rozpływem mocy biernej w sieci AC-DC, opartej na algorytmie genetycznym. Optymalizacja strat mocy czynnej została dokonana przez uwzględnienie w algorytmie ograniczeń w całym systemie AC-DC. Proponowane rozwiązanie jest pierwszym tego typu podejściem do optymalizacji rozpływu mocy biernej w wieloterminalowej sieci. Testy wykonane zostały na zmodyfikowanym 14-szynowym systemie w standardzie IEEE. Analiza porównawcza z innymi rozwiązaniami wskazuje, na większą skuteczność i niezawodność przedstawionej metody. (**Optymalizacja rozpływu mocy biernej w wieloterminalowym systemie AC-DC w oparciu o algorytm genetyczny**).*

Keywords: Optimal Reactive Power Flow, AC-DC System, Genetic Algorithm
Słowa kluczowe: Optymalny rozpływ mocy biernej, system AC-DC, algorytm genetyczny.

Introduction

In electrical power systems, system over-loading related to constantly increasing demand is extremely important for both the supply of existing and future demand and the reliability of power system. Due to high costs and inconvenient terrain circumstances economically, there are difficulties for allocating new energy transmission lines. Hence, the existing power systems must be used efficiently. Therefore, active power loss minimization in power systems is vastly important for system efficiency and reliability. Active power loss minimization is provided by Optimal Reactive Power Flow (ORPF). Dynamic and static reactive power compensators, shunt capacitors and reactors, generators' voltage amplitude values and tap changers in power systems are the main factors of ORPF because of having the ability of changing reactive power flow [1].

Even though the investment costs related to High Voltage Direct Current (HVDC) systems are high, they are more economic than ac transmission lines for very long distances. Additionally; efficient conductor intersection, flexible control, system reliability and consistency, efficient implementation, not having reactive power problem, and continuously increasing development in semiconductor technology are the advantageous characteristics for HVDC systems [2]. For these reasons, researchers have been working on integrated ac-dc systems for a long time. Many methods have been proposed for ac-dc power flow. These methods in the literature can be separated into two main part: sequential method and simultaneous method. In sequential method, ac and dc power flow are implemented separately and convergence can be provided by getting back and forward [3-4]. In simultaneous method, all equations regarding to ac-dc system are one within other and the equations are solved together [5-6].

Although there are many significant studies about ac-dc power flow in this area, there are not enough substantial studies on optimal power flow of two or multi-terminal ac-dc systems. Existing optimal power flow studies in ac-dc systems have been implemented successfully by using quadratic programming, linear programming, mixed-integer nonlinear programming, gradient-restoration algorithm and steepest descent algorithm [7-14]. However, there are convergence and dropping to local minimum problems in these methods [15].

Recently, heuristic methods like differential evolution [16], artificial bee colony algorithm [17], particle swarm optimization [18], and artificial ant colony [19] have been developed for the solution of global optimization problems and they have been implemented to those problems successfully. These methods are more efficient with respect to accurate and faster convergence and not dropping to local minimum than conventional calculation techniques mentioned above.

Genetic Algorithm (GA) is also one of the heuristic methods. It has been successfully applied to the solution of optimal active, reactive and active-reactive power flow in ac power systems as well as in other fields [20-21].

In this study, the newest approach is presented for solution of optimal reactive power flow problem in multi-terminal ac-dc systems by using GA. Sequential method is used for ac-dc power flow problem and GA is used for optimal reactive power flow problem. Furthermore, the constraints of control and state variables vectors are also included into the ORPF solution. Finally, the proposed approach's accuracy and consistency are tested on the modified IEEE 14-bus ac-dc test system.

The Illustration of the Proposed Sequential AC-DC Power Flow

Power flow problem in multi-terminal ac-dc system is solved by using the sequential method as mentioned above. Dc power flow is performed by Gauss iteration method and ac power flow is performed by Newton method throughout ORPF solution. Because the variables belonging to dc system are not taken into account of calculating Jacobian matrix, less dimension is required and fast convergence rate is achieved. Active and reactive powers of converters are taken into account constant load for ac power flow in terms of the sequential method.

The converter model for dc system is shown in Fig. 1. In this model; main harmonic components for ac system and average values without ripples for dc system are taken as base values. This study is based on per-unit system.

Dc terminal voltage of the i^{th} converter is

(1) $v_{di} = t_{di}.v_i.\cos\phi_i - r_{ci}.i_{di}$

where t_{di}, v_i, ϕ_i, r_{ci} and i_{di} represent tap value of the tap changer connected to the i^{th} converter, ac line voltage

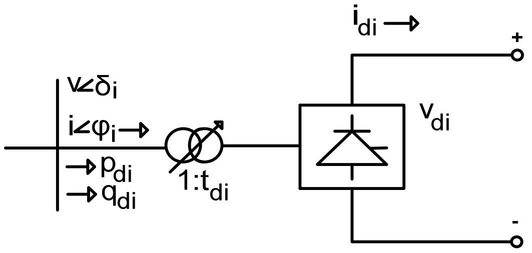


Fig.1. Equivalent representation of a mono-polar converter station

of the bus connected to the i^{th} converter, α firing angle for rectifier mode or γ extinction angle for inverter mode, commutation resistance and dc current, respectively.

Dc terminal voltage can be defined also as follows:

(2) $v_{di} = t_{di}.v_i.\cos\theta_i \quad (\theta_i = \delta_i - \varphi_i)$

where angle θ_i represents difference between ac voltage angle of bus connected to the i^{th} converter (δ_i) and current angle of the i^{th} converter's tap changer (φ_i).

Active power for the i^{th} converter, either in or out, is

(3) $p_{di} = v_{di}.i_{di}$

Reactive power for the i^{th} converter is

(4) $q_{di} = \left| p_{di}.\tan\theta_i \right|$

If the dc terminal connected to the 1st converter in dc system is chosen as reference node, the open circuit voltages of the i^{th} converter are determined as follows:

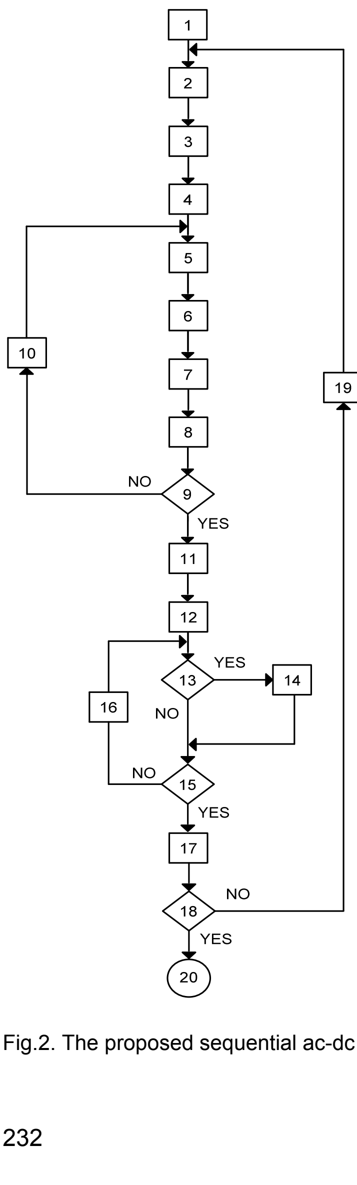
(5) $e_i = e_1 - r_{c1}.i_{d1} + r_{ci}.i_{di} + \sum_{j=2}^{n_c} r_{ij}.i_{dj} \quad (i = 2 \dots n_c)$

where e_1, r_{ij} and n_c represent referenced dc terminal open circuit voltage, bus resistance matrix components obtained from 1st dc terminal and converter number of dc system, respectively.

The algebraic sum of the dc currents flowing to the dc system must be zero:

(6) $\sum_{i=1}^{n_c} i_{di} = 0$

The least square method and based current-balancing mode are used in order to balance the dc currents of converters regarding the multi-terminal dc system to Eq. (6) [22]. Active powers of all converters except at least one are selected as control variables for ORPF in the study to achieve most suitable converter active powers and converter types that improve active power loss minimization. The details of sequential ac-dc power flow algorithm used for ORPF solution are shown in Fig. 2.



1. Input the control variables calculated in optimization algorithm.

2. Estimate reactive powers for all converters and active powers for converters which operate only in non-constant active power mode and then apply ac power flow algorithm.

3. Estimate dc terminal voltages, $v_{di} = t_{di}.v_i.\cos\phi_{i\min} \quad (i = 1 \dots n_c)$

4. Input the active and reactive powers of converters obtained in step 1 and step 2 to dc power flow.

5. Calculate the dc currents of all the converters by current-balancing mode.

6. Find the sign of commutation resistances using, $r_{ci} = \frac{|r_{ci}.i_{di}|}{i_{di}} \quad (i = 1 \dots n_c)$

7. Calculate the open circuit voltages using dc terminal voltages estimated in step 3.

$e_1 = v_{d1} - r_{c1}.i_{d1}$

$e_i = e_1 - r_{c1}.i_{d1} + r_{ci}.i_{di} + \sum_{j=2}^{n_c} r_{ij}.i_{dj} \quad (i = 2 \dots n_c)$

8. Calculate the dc terminal voltages, $v_{di} = e_i - r_{ci}.i_{di} \quad (i = 2 \dots n_c)$

9. Is the difference between dc terminal voltages estimated in step 3 and in step 8 smaller than the predeterminated tolerance?

10. Assign the dc terminal voltages obtained in step 9 as new values.

11. Determine firing or extinction angles of converters.

α_i or $\gamma_i = \arccos\left(\frac{e_i}{v_i.t_{di}}\right) \quad (i = 1 \dots n_c)$

12. Assign as $i = 1$.

13. Control (α_i or γ_i) angles whether imaginer or (α_i or γ_i) < ($\alpha_{i\min}$ or $\gamma_{i\min}$).

14. If the α_i or γ_i angles at step 11 imaginer or they have less than the minimum limit values being indicated in data folder, update the α_i or γ_i angles and tap changers' tap values of the converters.

α_i or $\gamma_i = \alpha_{i\min}$ or $\gamma_{i\min}$

$t_{di} = \frac{e_i}{v_i.\phi_{i\min}}$

15. Is i equal to n_c ?

16. Assign that, $i = i + 1$.

17. Calculate the active and reactive powers of converters.

$p_{di} = v_{di}.i_{di}$

$\theta_i = \arccos\left(\frac{v_{di}}{t_{di}.v_i}\right)$

$q_{di} = \left| p_{di}.\tan\theta_i \right|$

18. Is the difference between active and reactive powers of the converters in step 2 and in step 17 smaller than the predeterminated tolerance?

19. Use the active and reactive powers of the converters obtained from step 17 as new values and return to ac power flow.

20. Ac-dc power flow accomplished. Go to optimization algorithm with ac-dc power flow results.

Fig.2. The proposed sequential ac-dc power flow algorithm for ORPF solution

ORPF Problem

The general optimization formula can be shown below,

$$\begin{aligned} &\text{Minimize} && f(x,u) \\ &\text{Subjected to} && g(x,u), h(x,u) \end{aligned} \tag{7}$$

where, $f(x,u)$, $g(x,u)$, $h(x,u)$, x and u represent objective function, equality constraints inequality constraints, state variables and control variables, respectively.

The total active power loss in ac-dc system can be calculated as follows:

$$p_{loss} = \sum_{i=1}^{n_g} p_{gi} - \sum_{i=1}^{n_b} p_{loadi} - \sum_{i=1}^{n_c} p_{di} \tag{8}$$

where n_g, n_b, p_{gi} and p_{loadi} represent generator number, ac bus number, generator active power output and active powers for ac loads, respectively.

Equality constraints for ac system,

$$p_{gi} - p_{loadi} - p_{di} - p_{linei} = 0 \tag{9}$$

$$q_{gi} + q_{sci} - q_{loadi} - q_{di} - q_{linei} = 0 \tag{10}$$

where q_{gi}, q_{sci}, q_{loadi}, p_{linei} and q_{linei} represent generator reactive power output, synchronous condenser reactive power, reactive powers of ac loads, active power flowing from i^{th} ac bus to the other ac buses and reactive power flowing from i^{th} ac bus to the other ac buses, respectively.

Equality constraints for dc system,

$$\sum_{i=1}^{n_c} i_{di} = 0 \tag{11}$$

Equality constraints in Eq. (9-11) defined as $g(x,u)$ are solved in the ac-dc power flow mentioned in the preceding section.

Inequality constraints for ac system,

$$p_{gi}^{\min} \le p_{gi} \le p_{gi}^{\max} \tag{12}$$

$$q_{gi}^{\min} \le q_{gi} \le q_{gi}^{\max} \tag{13}$$

$$q_{sci}^{\min} \le q_{sci} \le q_{sci}^{\max} \tag{14}$$

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

$$t_i^{\min} \le t_i \le t_i^{\max} \tag{16}$$

where t_i represents tap values of the tap changers between the ac buses.

Inequality constraints for dc system,

$$p_{di}^{\min} \le p_{di} \le p_{di}^{\max} \tag{17}$$

$$v_{di}^{\min} \le v_{di} \le v_{di}^{\max} \tag{18}$$

$$t_{di}^{\min} \le t_{di} \le t_{di}^{\max} \tag{19}$$

where $\min$ and $\max$ superscripts represent lower and upper limits of associated variables, respectively.

State variables of ac-dc system,

$$x = [x_{ac}, x_{dc}] \tag{20}$$

where x_{ac} and x_{dc} represent state variables of ac and dc system, respectively.

$$x_{ac} = [\delta_2, \ldots, \delta_{nb}, v_1, \ldots, v_{nl}] \tag{21}$$

$$x_{dc} = [i_{d1}, \ldots, i_{dnc}, v_{d1}, \ldots, v_{dnc}, t_{d1}, \ldots, t_{dnc}, \phi_1, \ldots, \phi_{nc}] \tag{22}$$

where δ and n_l represent ac bus voltage angle and ac load bus number without synchronous condenser, respectively.

Control variables of ac-dc system,

$$u = [u_{ac}, u_{dc}] \tag{23}$$

where u_{ac} and u_{dc} represent control variables of ac and dc system, respectively.

$$u_{ac} = [p_{g2}, \ldots, p_{gng}, v_1, \ldots, v_{ng}, v_1, \ldots, v_{nsc}, t_1, \ldots, t_{nt}] \tag{24}$$

$$u_{dc} = [p_{d1}, \ldots, p_{dnc^{set}}] \tag{25}$$

where n_t and n_{sc} represent number of tap changers between ac buses and number of synchronous condensers in ac system, respectively.

Optimal reactive power flow in multi-terminal ac-dc system tries to minimize active power loss defined in Eq. (8) while providing system constraints in Eq. (12-19) defined as $h(x,u)$. Thus, the objective function that is optimized can be defined as,

$$\begin{aligned} f(x,u) &= c_1.p_{loss} + c_2.\sum_{i=1}^{n_g}\left|p_{gi} - p_{gi}^{\lim}\right| + c_3.\sum_{i=1}^{n_g}\left|q_{gi} - q_{gi}^{\lim}\right| \\ &+ c_4.\sum_{i=1}^{n_{sc}}\left|q_{sci} - q_{sci}^{\lim}\right| + c_5.\sum_{i=1}^{n_b}\left|v_i - v_i^{\lim}\right| + c_6.\sum_{i=1}^{n_t}\left|t_i - t_i^{\lim}\right| \\ &+ c_7.\sum_{i=1}^{n_c}\left|p_{di} - p_{di}^{\lim}\right| + c_8.\sum_{i=1}^{n_c}\left|v_{di} - v_{di}^{\lim}\right| + c_9.\sum_{i=1}^{n_c}\left|t_{di} - t_{di}^{\lim}\right| \end{aligned} \tag{26}$$

where c represents penalty coefficients of the objective function. The variables having $\lim$ superscript can be defined as,

$$(x,u)^{\lim} = \begin{cases} (x,u), & (x,u)_{\min} \le (x,u) \le (x,u)_{\max} \\ (x,u)_{\min}, & (x,u) < (x,u)_{\min} \\ (x,u)_{\max}, & (x,u) > (x,u)_{\max} \end{cases} \tag{27}$$

GA and Its Application for ORPF Problem

GA is a heuristic method for searching and optimizing based on evolutionary process. GA is proposed and used for solving optimization problems by Holland for the first time in 1975 [23]. The algorithm is based on natural selection. Main stages of natural selection are separated into three parts: human is born, human grows and human dies. Parameters which produce objective function that will be optimized by GA are defined as gens in the algorithm. For ORPF solution these parameters are the control variables defined in Eq. (23). Set of the gens is defined as individual in the algorithm. According to natural selection, individual represents human. All of the individuals create population. The flow chart of ORPF solution in multi-terminal ac-dc system by GA is given in Fig. 3. Main stages of GA can be defined as follows; initial population, fitness scaling, selection, crossover, mutation and optimization criterion [24].

Initial population of the algorithm is determined as,

$$\begin{gathered} w_{ij} = w_{\min,j} + rand(0,1) \times \left(w_{\max,j} - w_{\min,j}\right) \\ (i = 1 \ldots n_{ind}) \quad (j = 1 \ldots n_p) \end{gathered} \tag{28}$$

where n_{ind}, n_p, $w_{\min,j}$ and $w_{\max,j}$ represent number of the individuals within the population, number of the parameters of the individuals, minimum and maximum values of the parameters, respectively.

In fitness scaling stage, the individuals that will be used in selection stage are determined.

$$fit_{ave} = \frac{\sum_{i=1}^{n_{ind}} fit_i}{n_{ind}} \quad (29)$$

where fit_{ave} and fit_i represent average fitness value of the population and fitness value of the i^{th} individual that equals to objective function defined in Eq. (26), respectively. The individuals whose fitness values are better (smaller) than the average fitness value are used in selection stage.

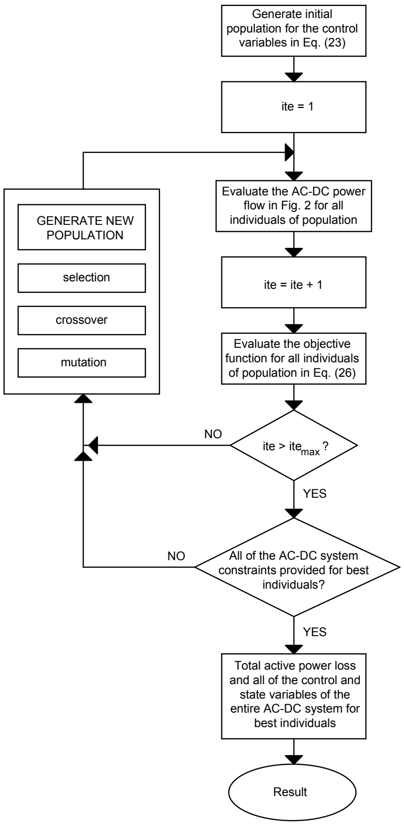


Fig.3. The proposed flow chart for ORPF in multi-terminal ac-dc system by GA

In selection stage, the parents to be crossed for producing children are selected within the determined individuals. For selection of the parents within these determined individuals, tournament method is performed and can be formulated as,

$$g_i = \frac{fit_i}{\sum_{j=1}^{n_{ind}} fit_j} \quad (30)$$

where g_i is the weight of the i^{th} individual. The weight of an individual defines the elective probability in this stage and the sum of the weights within population is 1.

$$\sum_{i=1}^{n_{ind}} g_i = 1 \quad (31)$$

The number of the individuals for selection of the parents within the population is twice of the children number determined in the beginning of the algorithm. The parents in the same number of the children are selected within these selected individuals.

In crossover stage, the children are produced as new individuals by parents determined in selection stage. These new individuals in the same number of the children are produced through the crossing method. 0 and 1 values in the same number of individual's gen number for crossing are randomly produced. If the value is 0, then gen is taken from father, if the value is 1, then gen is taken from mother and thus the child is produced. Crossing process can be illustrated as follows:

Cross: 0 1 1 0 1
Mother: a b c d e
Father: u w x y z
Child: u b c y e

In mutation stage, new individuals are produced to be changed all or some gens of the selected individuals that undergo mutation within the population. The number of the selected individuals is determined in the beginning of the algorithm. These individuals are reproduced to be formed all the gens of the selected individuals within algorithm. Thus, new individuals in the same number of the selected individuals that undergo mutation are randomly produced by Eq. (28). Mutation process increases diversity of the population and prevents losing the individuals that provide good solutions.

There are many criterions for optimization that is performed by GA and similar heuristic methods in the literature. In this study, iteration number is selected for stopping the optimization by GA. The algorithm stops when it reaches the determined maximum iteration number. Additionally in this study, system constraints are included in the optimization stopping criterion so that all of the system constraints are provided at the end of the algorithm.

Results

The proposed approach's accuracy and efficiency are tested on the modified IEEE 14-bus ac-dc test system shown in Fig. 4.

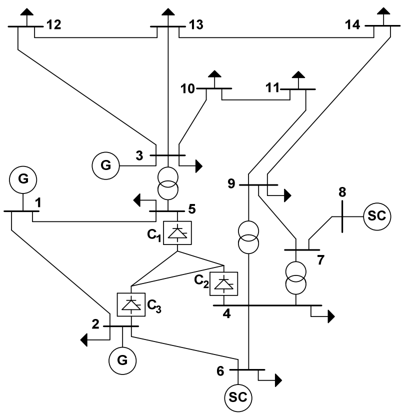


Fig.4. The modified IEEE 14-bus ac-dc test system

Total active power loss variation throughout the algorithm is shown graphically in Fig. 5. Total active power loss gained with proposed approach and another method, steepest descent algorithm (SDA), are compared in the same test system. In the literature, generally, 100 iterations are performed for GA. GA approximately reached to global optimum at 45th iteration for this study. For GA; 20 population sizes, 0.5 crossover rate and 0.1 mutation rate are used. These values used for GA are found at trials. The values used beyond current values didn't change the global optimum for GA. The situation, using more sizes than the above values, decreased the number of iteration but increased optimization time in order to reach the global optimum. Penalty coefficient values c used in Eq. (26) are found after several trials. 30 different optimization trials are done for GA method. The worst and the best total active power loss values for GA are 0.0697 per unit and 0.0664 per unit, respectively. Error deviation for GA is 4.96%. At the end of the optimization, it is observed that all control and state variables are in their limit values.

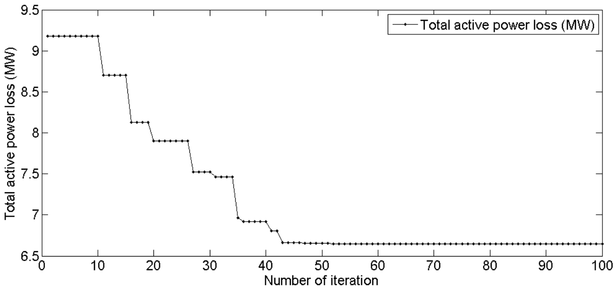


Fig.5. Variation of total active power loss against iteration for proposed approach $(P_{base} = 100MW)$

The proposed approach is better and more reliable than SDA [25] shown in Table 1 for reaching global optimum.

Table 1. Comparison of the results for the test system

	GA	SDA [25]
$p_{loss}(MW)$	6.640	8.532

Conclusion

In this article, a new approach is proposed for optimal reactive power flow in multi-terminal ac-dc systems. This approach is one of the rare ones in optimal reactive power flow studies in multi-terminal ac-dc systems. GA is utilized for the first time in multi-terminal ac-dc system for ORPF solution in this study. Because of using sequential method in ac-dc power flow, any ac and dc power flow method can be utilized without any change in optimization algorithm. Unlike the other studies in the literature, converter active powers are used as control variables for optimization in the entire dc system in this study. So, both the most suitable converter active powers $\left(p_{di}^{\min} \leq p_{di} \leq p_{di}^{\max}\right)$ and converter types (rectifier or inverter) are achieved at determined system conditions. Therefore, efficiency of the active power loss optimization is enhanced. The obtained results demonstrated that the proposed approach is better and more reliable for reaching global optimum than similar approaches not to drop to local minimum points. The proposed approach utilizes optimization technique to prevent the violation of system constraints.

REFERENCES

[1] Li Z., Li Y., Duan X., Multiobjective optimal reactive power flow using elitist nondominated sorting genetic algorithm, *J. Electr. Eng. Technol.,* 5 (2010), No. 1, 70-78
[2] Mobarak Y. A., Modified load flow analysis for integrated ac/dc power systems, *12th Int. Middle East Power Syst. Conf. MEPCON*, Aswan-Egypt (2008)
[3] Li C., Zhang B., Hou Y., Wu F. F., Liu Y., An improved approach for ac-dc power flow calculation with multi-infeed dc systems, *IEEE Trans. Power Syst.,* 26 (2011), No. 2, 862-869
[4] De Silva J. R., Arnold C. P., A simple improvement to sequential ac/dc power flow algorithms, *Int. J. Elect. Power Energy Syst.,* 12 (1990), No. 3, 219-221
[5] Smed T., Andersson G., Sheble G. B., Grigsby L. L., A new approach to ac/dc power flow, *IEEE Trans. Power Syst.,* 6 (1991), No. 3, 1238-1244
[6] Arifoglu U., Load flow based on newton's method using norton equivalent circuit for ac-dc multiterminal systems, *Eur. Trans. Elect. Power,* 9 (1999), No. 3, 167-174
[7] Thukaram D., Yesuratnam G., Optimal reactive power dispatch in a large power system with ac-dc and FACTs controllers, *IET Gener. Transm. Distrib.,* 2 (2008), No. 1, 71-81
[8] Thukaram D., Yesuratnam G., Vyjayanthi C., Optimal reactive power dispatch based on voltage stability criteria in a large power system with ac/dc and FACTs devices, *IEEE Int. Conf. Power Electro. Drives Energy Syst. PEDES*, New Delhi-India (2006)
[9] Yu J., Yan W., Li W., Wen L., Quadratic models of ac-dc power flow and optimal reactive power flow with HVDC and UPFC controls, *Elect. Power Syst. Res.,* 78 (2008), No. 3, 302-310
[10] Yu J., Yan W., Li W., Chung C. Y., Wong K. P., An unfixed piecewise-optimal reactive power-flow model and its algorithm for ac-dc systems, *IEEE Trans. Power Syst.,* 23 (2008), No. 1, 170-176
[11] De Martinis U., Gagliardi F., Losi A., Mangoni V., Rossi F., Optimal load flow for electrical power systems with multiterminal HVDC links, *IEE Proc. Gener. Transm. Distrib.,* 137 (1990), No. 2, 139-145
[12] Lu C. N., Chen S. S., Ong C. M., The incorporation of HVDC equations in optimal power flow methods using sequential quadratic programming techniques, *IEEE Trans. Power Syst.,* 3 (1988), No. 3, 1005-1011
[13] Ambriz-Perez H., Acha E., Fuerte-Esquivel C. R., High voltage direct current modelling in optimal power flows, *Int. J. Elect. Power Energy Syst.,* 30 (2008), No. 3, 157-168
[14] Arifoglu U., Tarkan N., New sequential ac-dc load-flow approach utilizing optimization techniques, *Eur. Trans. Elect. Power,* 9 (1999), No. 2, 93-100
[15] Ayan K., Kilic U., Artificial bee colony algorithm solution for optimal reactive power flow, *Appl. Soft Comput.,* 12 (2012), No. 5, 1477-1482
[16] Mohamed A. W., Sabry H. Z., Constrained optimization based on modified differential evolution algorithm, *Inf. Sci.,* 194 (2012), No. 1, 171-208
[17] Kashan M. H., Nahavandi N., Kashan A. H., DisABC: A new artificial bee colony algorithm for binary optimization, *Appl. Soft Comput.,* 12 (2012), No. 1, 342-352
[18] Gomez-Gonzalez M., Lopez A., Jurado F., Optimization of distributed generation systems using a new discrete PSO and OPF, *Elect. Power Syst. Res.,* 84 (2012), No. 1, 174-180
[19] Verma O. P., Kumar P., Hanmandlu M., Chhabra S., High dynamic range optimal fuzzy color image enhancement using artificial ant colony system, *Appl. Soft Comput.,* 12 (2012), No. 1, 394-404
[20] Guvenc U., Altun B. E., Duman S., Optimal power flow using genetic algorithm based on similarity, *Energy Educ. Sci. Technol.,* 29 (2012), No. 1, 1-10
[21] Kumari M. S., Maheswarapu S., Enhanced genetic algorithm based computation technique for multi-objective optimal power flow solution, *Int. J. Elect. Power Energy Syst.,* 32 (2010), No. 6, 736-742
[22] Arifoglu U., The power flow algorithm for balanced and unbalanced bipolar multiterminal ac-dc systems, *Elect. Power Syst. Res.,* 64 (2003), No. 3, 239-246
[23] Holland J. H., Adaptation in Natural and Artificial Systems (1975) *University of Michigan Press,* Ann Arbor, Michigan, USA
[24] MATLAB Optimization Toolbox 5 User's Guide (2012) The Math Works, Inc.
[25] Arifoglu U., Optimal power flow using sequential power flow approach for an AC-DC power system, Ph.D. Thesis, Istanbul Technical University (1993)

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