A NOVEL TRANSMISSION LOSS ALLOCATION METHOD USING DIFFERENTIAL EVOLUTION ALGORITHM

Mohsen Golnaraghi*
Department of Electrical Engineering, South Tehran branch, Islamic Azad University, +989124275497,
Corresponding Author's email: Mohsen.gholnaraghi@gmail.com

ABSTRACT*-This paper presents a new transmission loss allocation method for power system of which it is implemented at the optimal operating point of the system. In this method, firstly, the differential evolutionary algorithm is used to find a global optimum operating point of the system. Indeed, in this step, all controllable variables such as a tap of transformers, capacitors, and the voltage of generators must be calculated in order to reduce the active power losses. Then, in the case of optimal active power loss, a current-based loss allocation scheme is applied to the system to allot the active power losses to loads. The proposed method, is a fair approach with low computational cost, and high accuracy in comparison with previous methods such as graph theory. The proposed method is applied to IEEE-6 bus and IEEE-24 bus standard power systems to analyze the effect of system size on the loss allocation methods.*

1- INTRODUCTION

Nowadays, in many countries, the power industry is going to a restructuring power system by which many challenges can be occurred [1-2]. Transmission loss allocation is an expectable challenge of power system restructuring. As loads and generators connect to the grid, any action, which participants take part in system, affects on other participants. Analyzing and detection of these effects are really controversial and difficult. So, the suggestion of a loss allocation scheme, which could adapt to various market structure, is one of the most important problems in power system restructuring [3-4].

One of the main problems in transmission loss allocation is bilateral agreements between participants which causes in the same extents of despotism. The loss allocations should be fairly as possible as it can. Recently, different methods are proposed to allocate the transmission losses to loads and generators as follows [5-10]:

1. Prorata method implements the loss allocation based on proportional to the power delivered by each generator and each load.
2. In a marginal approach, incremental transmission coefficients are used for allocation of transmission losses to demands and generators. A normalization is employed after the implementation of loss allocation which results a high time-consuming algorithm [11].
3. The trading method tries to identify the power flow through lines using system topology. The graph theory based method is the most popular method of this group.
4. Circuit base method uses the Z bus matrix of power system to allocate the active power losses.

Recently, in [12] an advanced approach is suggested based on power flow tracing. In this method, according to grid topology, the proportion of loads and generators participation could be obtained. In [13], authors have divided the transmission system losses into three categories. An analytical investigation is proposed for the categorization of active power losses.

A new method based on the participating composition of game theory and circuit theory is proposed in [14]. It is a two-stage loss allocation method to allot the losses to loads and generators. The Aumamnn Shapley method is a method by which each real and imaginary components could be calculated.

In [15], a novel approach for the transmission loss allocation is submitted of which is based on trade strategy. Another method is suggested in [16] that is based on the usage of the transmission lines. This method calculates the participating proportion of generators and loads subjecting to contract's constraints which are considered between loads and generation companies.

According to existing problems in the transmission loss allocation strategies, it is necessary to propose a method which has a fair vision, with low computational process, and high accuracy. In this paper, a current based method on the optimal operating point of the system is presented for transmission loss allocation. In the proposed method, firstly, the controllable variables in the system, such as transformer tap changers, steps of capacitors, and voltage of generators, are adjusted to achieve a global optimum operating point. Then, in accordance with operating point of system, the current based transmission loss allocation is applied to the power system.

This paper consists of five sections: in section 2, the current based transmission loss allocation is introduced. In section 3, the principal of differential evolutionary (DE) is explained. Then, the proposed method is applied to IEEE-6 bus and IEEE-24 bus standard power system.

2- MATERIAL AND METHODS

2-1- Current based loss allocation method

The proposed method allocates transmission losses to loads based on how the conductor area is occupied by each current. In this method, the line can be divided to sub-lines by which one load current could be carried. The power loss in each sub-line is the power loss caused by the load it carries. There are two assumptions which the proposed method is based on them. Firstly, if two or more currents share a conductor a conductor, they will have equal chances to occupy the conductor's area. This does not mean that the conductor area will be divided equally between the currents. So, based on the current magnitude, the effective area each conductor could be occupied [16].

Let us consider an AC line which is fed to loads shown in Fig.1. In this case, current are defined by its magnitude and its phase. So, the net flow current in the line is the vector sum of the two currents. The line impedance includes the reactance in addition to resistance [16].

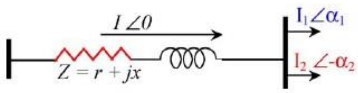

Fig. 1. The model of an AC transmission line with its loads

Also, the vector diagram of AC transmission line with two current loads could be depicted in Fig. 2. According to the vector diagram, the following equations can be resulted [16]:

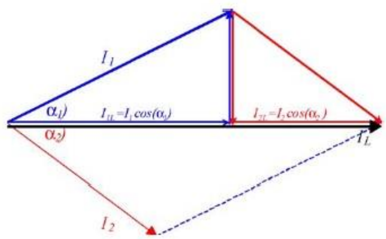

Fig. 2. The vector diagram of transmission line and its currents

$$I_L = I_{1L} + I_{2L} \tag{1}$$

In equation (1):

$$I_{1L} = \frac{I_1.I_L}{I_L}, \quad I_{2L} = \frac{I_2.I_L}{I_L} \tag{2}$$

It is worth to say that (.) shows an internal product of two vectors in (1).

$$\begin{aligned} P_{Loss1} &= rI_{1L}I_L = r(I_1.I_L) \\ P_{Loss2} &= rI_{2L}I_L = r(I_2.I_L) \end{aligned} \tag{3}$$

Now, by considering the voltage vector as a reference point:

$$\begin{aligned} I_1 &= \frac{P_1 - jQ_1}{V}, I_2 = \frac{P_2 - jQ_2}{V}, \\ I_L &= \frac{P_L - jQ_L}{V} \end{aligned} \tag{4}$$

The active power loss can be calculated from:

$$\begin{aligned} P_{Loss1} &= \frac{(P_1P_L + Q_1Q_L)r}{P_L^2 + Q_L^2} P_{LossL} \\ P_{Loss2} &= \frac{(P_2P_L + Q_2Q_L)r}{P_L^2 + Q_L^2} P_{LossL} \end{aligned} \tag{5}$$

The equation (5) can be extended to n-bus power system as follows:

$$P_{Loss_i} = \frac{S_i.S_L}{|S_L|^2} P_{LossL} \tag{6}$$

Where S_i is the complex power and P_{lossL} is the total active power loss. For n-bus power system, the F matrix could be defined as a load currents of the system:

$$F = [f_{i,j}] \tag{7}$$

Where $f_{i,j}$ is a current which is made by i-load through the j -branch. So, the loss allocated to load can be obtained from (5).

$$[P_{Loss_i}] = [f_{i,j}].[G_j] \tag{8}$$

Where $[G_j]$ is the NB×1 dimension matrix. The N_B is the number of branches. Also,

$$G_j = \frac{S_j.P_{L_j}}{|S_j|^2} \tag{9}$$

Where P_{Lj} is the active power loss of the j-branch and the S_j is the total current flow of the j-branch.

Finally, the loss allocated to loads can be calculated by (10).

$$[P_{Loss_i}] = \Re([f_{i,j}].[G*_j]) \tag{10}$$

2-2- Differential Evolution Algorithm

Differential Evolution Algorithm (DEA) is a stark population- based, heuristic search evolutionary algorithm for the global optimization process. This algorithm is capable of minimizing non-differential, non-linear, and multi-modal objective functions. The initial population is uniformly distributed in the search space, as follows [17]:

$$x_{i,k}^G = x_{k_{\min}} + rand[0,1] \times (x_{k_{\max}} - x_{k_{\min}})\; i \in [1, N_p] \tag{10}$$

Each variable k in an individual i in the generation G is initialized within its boundaries. In mutation process, for each individual, $x_i^G, i = 1,\ldots,N_p$, at generation G, a mutant vector, $V_i^{G+1} = (v_{i1}^{G+1}, v_{i2}^{G+1}, \ldots, v_{iD}^{G+1})$ could be calculated as follows [17]:

$$V_i^{G+1} = X_{r_1}^G + s(X_{r_2}^G - X_{r_3}^G) \tag{11}$$

Where s>0 is a real parameter, called mutation constant, which controls the amplification of the difference between two individuals. Also, r_1, r_2, and r_3 are randomly selected numbers from the set {1,2,…, N_p}.

Following the mutation phase, the crossover operator is used for each population. For each mutant vector, a trial vector is generated as follows [17]:

$$U_{j,i}^{G+1} = \begin{cases} V_{j,i}^{G+1} \; if \; (rand_j \le CR) \; or \; (j = I_{rand}) \\ X_{j,i}^G \; if \; (rand_j > CR) \; or \; (j \ne I_{rand}) \end{cases} \tag{12}$$

Where $rand_j$ is a number between 0 and 1, is chosen randomly from the interval 1 to D, once for each vector to ensure that at least one vector component comes from the mutated vector. Also, CR is the DE control parameter that is called the crossover rate and is a user defined parameter within the range 0 and 1.

Finally, to decide whether the vector U_i^{G+1} should be a member of the population comprising the next generation, it is compared to the specific vector X_i^G [17].

$$X_i^{G+1} = \begin{cases} U_i^{G+1} \; if \; f(U_i^{G+1}) < f(X_i^G) \\ X_i^G \quad \text{otherwise} \end{cases} \tag{13}$$

All solutions in the population have the equal chance of being chosen as parents independents of their objective value. If the parent is still better, it is maintained in the population.

The iterative procedure can be terminated when any of the following criteria is met. Indeed, a permissible solution has been reached, a state with no further improvement in solution is reached, control variables has converged to a stable state or a predefined number of iterations have been ended [17].

3- RESULTS

To assess the efficiency of the DE-based transmission loss allocation method, the proposed approach is applied to IEEE-6 bus power system and IEEE-14 bus power system, respectively. So, each power system is evaluated regarding to the loss allocation in two sections, separately.

1. The loss allocation in the IEEE-6 bus standard power system

In the 6-bus power system, there are three controllable variables which are voltage of generator type. The topology of IEEE-6 bus power system is shown in Fig. 3. Firstly, the DE method is employed to find the global optimum of controllable variables regarding to active power loss reduction. To verify the obtained results, the particle swarm optimization algorithm is also applied to IEEE-6 bus standard power system. The optimal values of parameters are shown in Table. 1. The calculated controllable variable values could result in minimum active power losses. The voltage profile of the system is shown in Fig. 4 on the condition of minimum active power losses. The convergence of the DE algorithm is illustrated in Fig. 5 when it tries to decrease active power losses. The powerful performance of the DE algorithm can be found from simulation results. Also, the PSO method is also has a behavior as same as the DE algorithm regarding to the active power loss reduction.

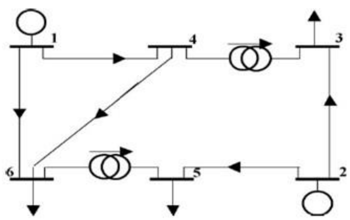

Fig. 3. The single diagram of IEEE-6 bus power system

TABLE. 1. The obtained controllable variable values using the DEA and PSO to optimize the objective function

Method	Controllable variable	Value (p.u)	Active power loss (MW)
DE	V1	0.95	7.452
	V2	0.95	
	V3	0.95	
PSO	V1	0.95	7.452
	V2	0.95	
	V3	0.95	

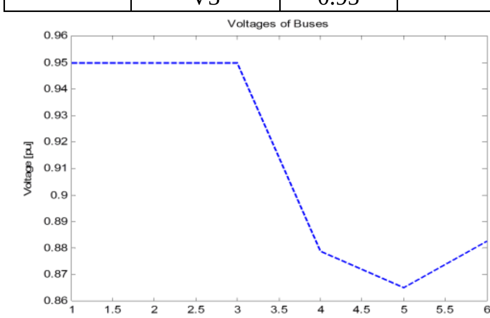

Fig. 4. The voltage profile of IEEE 6 bus power system in optimal active power loss condition

After finding of optimal operating point of the power system, the current-based loss allocation method is applied to IEEE-6 bus power system. Also, to show the accuracy of current-based method, it is compared with graph theory method in this case study. As it is seen, there is less error in the power loss allocated using current-based method than graph theory method. It attributes from principal of current-based method which considers diagram of the system. The results of the loss allocation obtained from two different methods are shown in Table. 2. Also, the active power loss of each branch is shown in Fig. 6 in the optimal operating point of the grid.

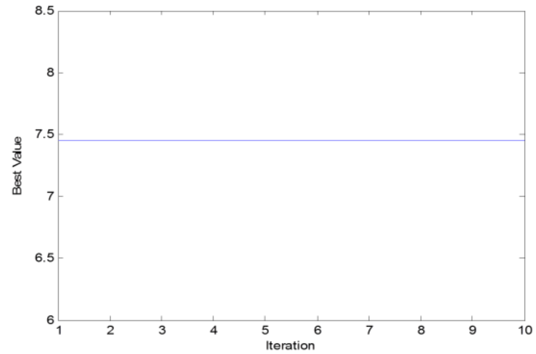

Fig. 5. The convergence of the differential evolutionary algorithm to minimize the active power loss of IEEE-6 bus power system

TABLE. 2. The obtained results of two different loss allocation methods

Algorithm	Active power loss obtained by optimal power flow	Active power loss allocated to loads
Current-based	7.452	7.542
Graph theory	7.452	6.951

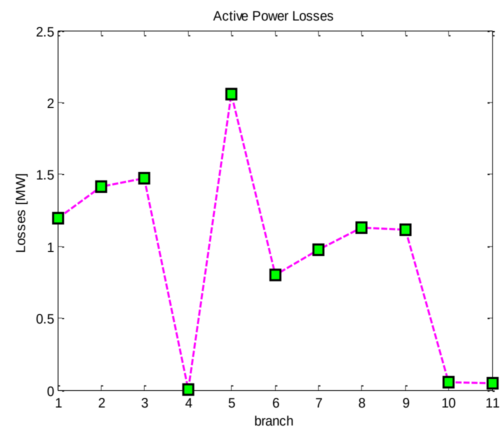

Fig. 6. The active power loss for each branch of IEEE-6 bus standard power system

2. The loss allocation of IEEE-14 bus standard power system

The single diagram of IEEE-14 bus standard power system is illustrated in Fig. 7. In this case, the effect of power system topology on proposed method is analyzed. The results of controllable variable values to decrease the active power loss of the system are shown in Table. 3. Also, the active power loss curve in operating point of IEEE-14 bus standard power system is shown in Fig. 8. Then, the result of loss allocated to loads of systems is shown in Table. 4 by two different methods.

According to information shown in TABLE.4, one can find out when the system gets bigger, the loss allocation can be done with error more than in a smaller network. So it is necessary to implement the loss allocation scheme locally. Also, the powerful performance of current-based loss allocation algorithm is identified based on less computational error.

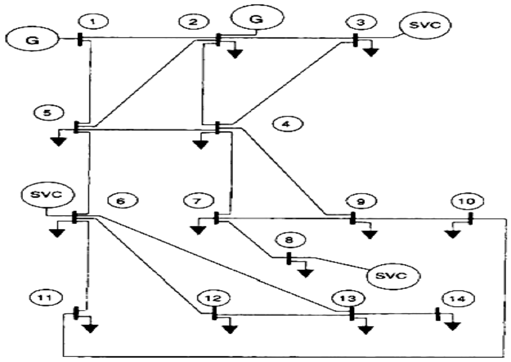

Fig. 7. The single diagram of IEEE-14 bus standard power system

TABLE. 3. The optimized values of controllable variables for IEEE-24 bus standard power system, using PSO and DE

Variable	PSO	DE
V1	1.0468	1.0452
V2	1.0174	1.0203
V3	1.0487	1.0251
V4	1.1	1.0802
TAP1	0	0
TAP2	0	9
TAP3	10	9
C1	2	1
C2	2	2

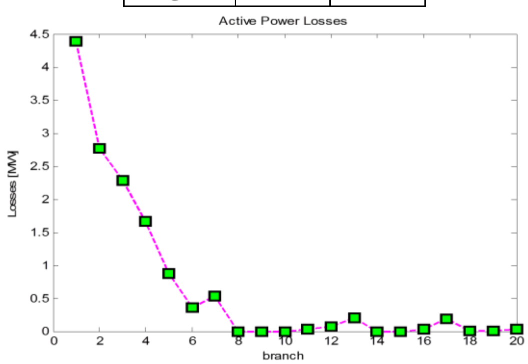

Fig. 8. The active power loss diagram for the system

TABLE. 4. The comparison of different methods of loss allocation in IEEE-14 bus power system

Method	Active power loss obtained by optimal power flow	Loss allocated
Current-based	11.747	9.984
Graph theory	11.747	11.485

CONCLUSION

This paper presents a novel approach to allocate the active power losses of the transmission system to the participants of this area. In this method, a differential evolution heuristic method is applied to find the global operating point of the system. Then, a current-based method is employed to allot the losses to loads of the system. By comparing the results it can be obtained that the proposed method has a powerful performance to allocate the losses to loads of the system with less computational error. The loss allocated to loads is fair because of the circuit based method which is used. Also, the differential evolutionary method has a reliable performance to optimize the active power loss objective function. Finally, the proposed method gains better results than previous methods such as graph theory.

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