Load Balancing of Modern Distribution Networks by Genetic Algorithm

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Abstract-- **The main purpose of this paper is to establish a multi-object function for the optimal load balancing in modern distribution networks. The proposed approach can reduce the three-phase voltage unbalance ratio and system power loss; furthermore, the system operation performance will be improved. The genetic algorithm and three-phase power flow algorithm are coded in Matlab. Finally, the IEEE 37-Bus test system is used as the sample system to verify the accuracy of the proposed approach. The simulation results demonstrate that the proposed approach is systematic and efficient for solving the load balancing problem in active distribution networks.**

Index Terms**—Load Balancing, Genetic Algorithm, Three-Phase Power Flow, Voltage Unbalance Ratio, System Power Loss.**

I. INTRODUCTION

Distribution networks are located in the end of power systems; their major function is to distribute electric power to all kinds of users. Therefore, the diverse characteristics of loads, symmetrical and unsymmetrical feeder structures, and vast distribution resulted in complicated operations; additionally, the highly penetration of distribution energy resources (DERs) will cause the operations of distribution networks more complicated. Nevertheless, the unbalanced problem still exists; therefore, the related researches, such as modeling of three-phase distribution transformers and their applications in unbalanced power flow analysis [1-4], and unbalanced improving strategies [5-8], have been applied for increasing operation efficiency. N.Gupta et al. [9] proposed the new winding connections in the ordinary two-winding transformer to reduce the phase unbalance and the magnitude of neutral current without switching operations in the three-phase four wire distribution networks. This approach is efficient and promising for phase balancing in distribution networks. Besides, M. J. E. Alam et al. [10] proposed a three-phase power flow approach for distribution networks to estimate the rooftop PV impacts on different phases and neutrals. In additional to, M. W. Siti et al. [11] presented a heuristic reconfiguration technique for the phase balancing and loss minimization in a distribution network at the low-voltage and medium-voltage levels simultaneously. In this paper, a multi objective optimal function for load balancing is proposed in distribution networks with DERs and loads.

II. SOLUTION TECHNIQUE AND PROCEDURE

A. Objective Function

Because lots of three-phase and single-phase loads are connected in distribution networks, this unbalanced load will cause three-phase voltage and current unbalanced; additionally, extra power loss and neutral current; furthermore, it will result in unfavorable system performance. Consequently, a multi objective function, which considering zero and negative -sequence voltage unbalance ratios, and power loss, is proposed to solve for the optimal load balancing problem. This objective function is expressed as (1).

Minimize

$$FIT = w_1 \cdot TD_{o,\mathrm{norm}} + w_2 \cdot TD_{2,\mathrm{norm}} + w_3 \cdot P_{loss,\mathrm{norm}} \tag{1}$$

Subject to

$$w_1 + w_2 + w_3 = 1 \tag{2}$$

Satisfy

$$D_{o,k} \le D_{o,k}^{max.}; k = 1, 2, ..., n \tag{3}$$

$$D_{2,k} \le D_{2,k}^{max.}; k = 1, 2, ..., n \tag{4}$$

$$I_j \le I_j^{max}; j = 1, 2, ..., m \tag{5}$$

In (1),

$$TD_{o,\mathrm{norm}} = \frac{TD_o - TD_o^{min}}{TD_o^{max} - TD_o^{min}}, \tag{6}$$

$$TD_{2,\mathrm{norm}} = \frac{TD_2 - TD_2^{min}}{TD_2^{max} - TD_2^{min}}, \tag{7}$$

$$P_{loss,\mathrm{norm}} = \frac{P_{loss} - P_{loss}^{min}}{P_{loss}^{max} - P_{loss}^{min}}. \tag{8}$$

In which, $TD_{o,\mathrm{norm}}$ and $TD_{2,\mathrm{norm}}$ represent the normalized total zero and negative-sequence voltage unbalance ratios, respectively. Besides, $P_{loss,\mathrm{norm}}$ denotes the normalized total real power loss. In (2), w_i is the weighting factor. In (3) and (4),

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$D_{o,k}^{max.}$ and $D_{2,k}^{max.}$ are the upper limit of zero and negative-sequence voltage unbalance ratios at bus k, respectively. In (5), I_j^{max} denotes the ampere capacity of the conductor in j^{th} line section.

B. *Power Flow Solution Technique*

In this paper, the implicit Z_{BUS} Gauss approach [12] is used for solving the optimal load balancing problem. This method is based on the principle of superposition applied to the bus voltages along the feeders. The voltage on each bus can be considered to be contributed from two different types of sources: the specified incoming bus voltage of distribution substation and current injection which is generated by the loads and DERs. For simplified the solution procedure, a distribution transformer with its loads and DERs can be integrated represented by its equivalent loads and generations as shown in Fig. 1. The equivalent individual complex power is functions of the connection and loads and generations of the distribution transformer. The solution steps of this power flow algorithm are described as follows.

Step 1: initialize bus voltage estimates and build the Z_{BUS}.

Step 2: compute the bus injection current by (9) for loads and DERs

$$I_{i_{abc}}^{(k)} = \left(\frac{S_{i_{abc}}}{V_{i_{abc}}^{(k)}}\right)^{*} = \left(\frac{P_{i_{abc}} + jQ_{i_{abc}}}{V_{i_{abc}}^{(k)}}\right)^{*} \tag{9}$$

Step 3: calculate the voltage deviations due to the current injections by (10).

$$\left[\Delta V_{Bus}^{(k)}\right] = \left[Z_{Bus}\right] \cdot \left[I_{Bus}^{(k)}\right] \tag{10}$$

Step 4: apply voltage superposition principle by (11) and update each bus voltage.

$$\left[V_{Bus}^{(k+1)}\right] = \left[V_{NL}\right] + \left[\Delta V_{Bus}^{(k)}\right] \tag{11}$$

Where V_{NL} is the no load voltage.

Step 5: check for convergence. If not converged go to step 3.

Step 6: compute the three-phase line flows.

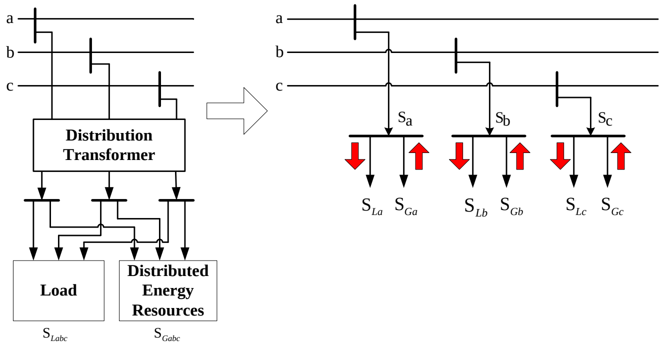

Fig. 1 Schematic diagram of the simplified models.

C. *Solution Procedure*

As mentioned above, the load balancing is a combinatorial mathematic problem, it can be solved by artificial intelligent algorithms, and the genetic algorithm was used in this paper. The solution flow chart of the proposed genetic algorithm based approach was shown in Fig. 2.

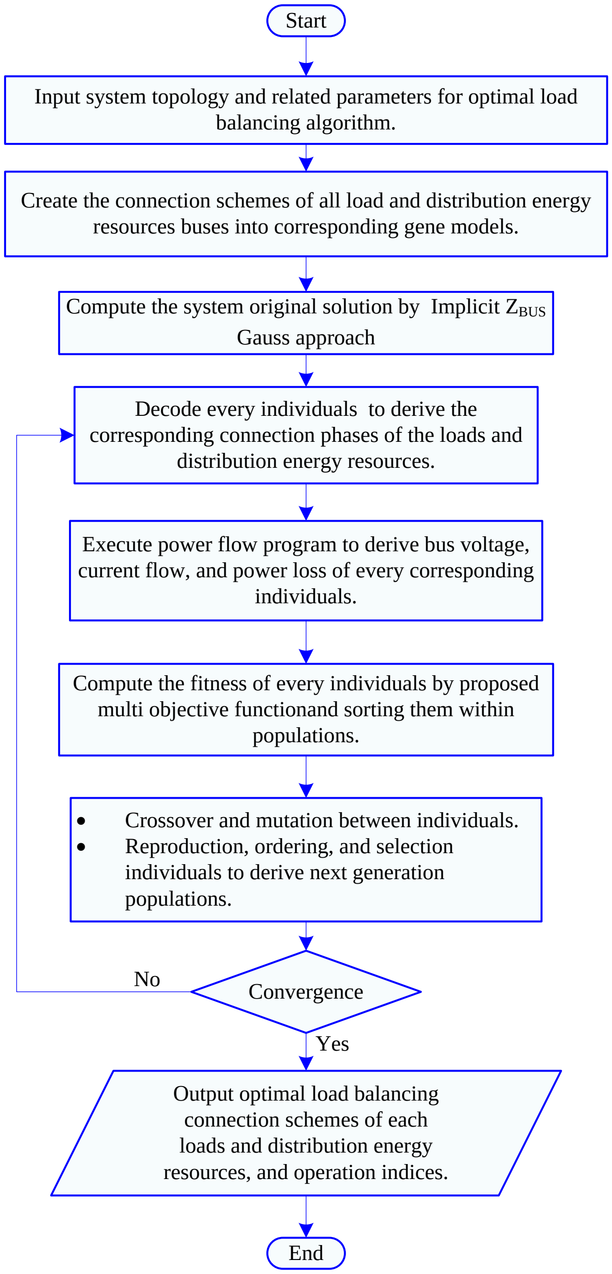

Fig. 2. The flow chart for optimal load balancing by genetic algorithm.

III. NUMERICAL RESULTS AND DISCUSSION

The IEEE 37-Bus [13] test system was used as sample system to verify the feasibility of the proposed approach, as shown in Fig. 3. Table I showed the connection bus and capacity of each DER. Generally, the traditional passive distribution networks connected with DERs became active networks. In this sample system, there are 24 asymmetrical loads and 2 unbalanced DERs excluded symmetrical components for rearranging. According to genetic algorithm, each load bus or DER connected bus has its connection scheme, which is corresponding to its gene code, and the chromosome is composed of a set of gene codes. Fig. 4 and Fig. 5 showed the three-phase and two-phase connection schemes corresponding to their gene codes, and each code represented the individual phase arrangements at each bus. It is expected that the interconnected of DERs will helpful for improving voltage profile and reducing power loss. In this paper, the proposed genetic algorithm was applied to search for the optimal connection schemes of every loads and DERs by the proposed multi objective function. The simulation results are discussed as follows.

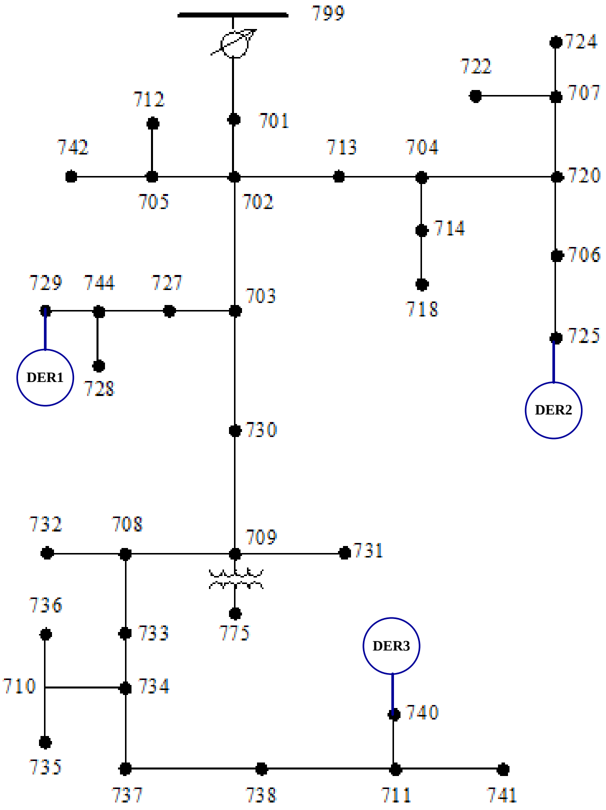

Fig. 3. The IEEE 37-bus test system with DGs.

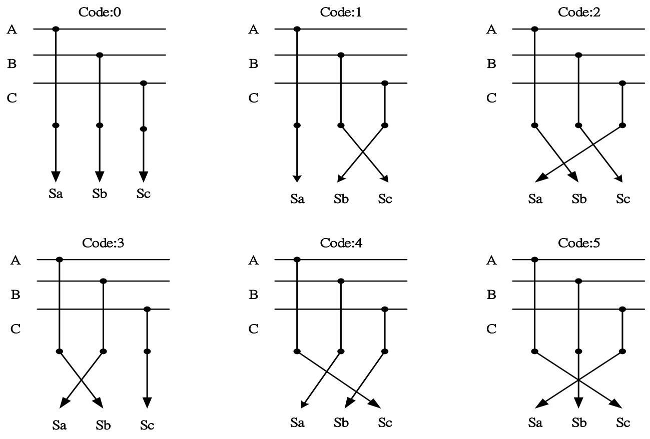

Fig. 4. The three-phase connection schemes corresponding to gene codes.

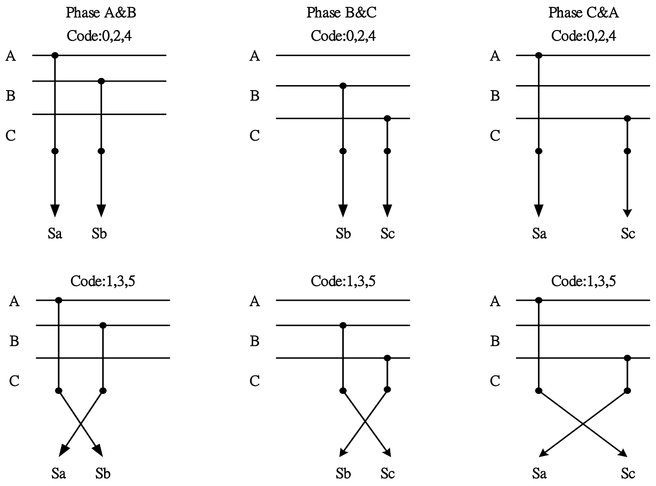

Fig. 5. The two-phase connection schemes corresponding to gene codes.

Table I The connection buses and capacities of DERs.

DER No.	Connection Bus	Capacity(kW)		
		Phase A	Phase B	Phase C
DER1	729	100	0	0
DER2	725	150	150	0
DER3	740	100	100	100

A. *Without DERs Connection*

In this subsection, the simulation results of IEEE 37-Bus test system without DERs are shown in Fig. 6~8. The weightings are set as W_2=0.33, W_3=0.33, and W_4=0.34, respectively. The optimal connection schemes are listed in Table II. Besides, the zero- sequence voltage ratios are reduced slightly, as shown in Fig. 6; however, it is obviously that the negative- sequence voltage ratios are decreased significantly, as shown in Fig. 7. Moreover, the system power loss is reduced from 160.3 kW to 153.9 kW. Consequently, after the proposed optimal algorithm, the system performance is better than that before optimization.

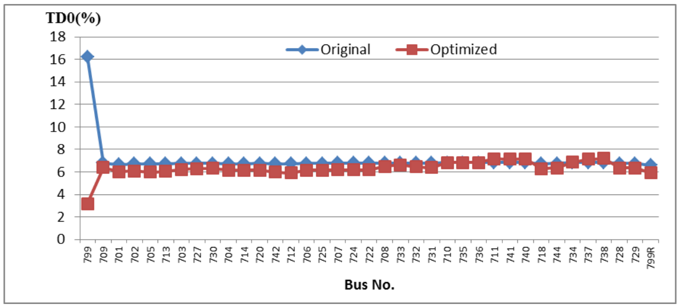

Fig. 6. Simulation result of zero- sequence voltage ratios without DERs.

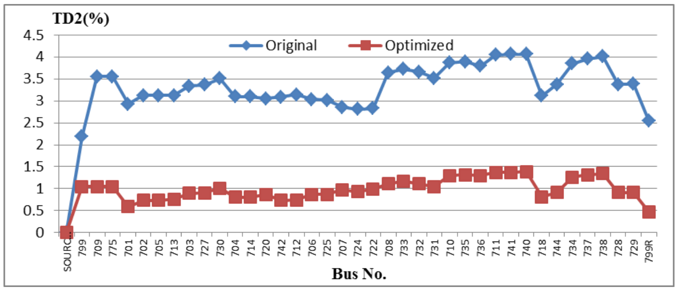

Fig. 7. Simulation result of negative- sequence voltage ratios without DERs.

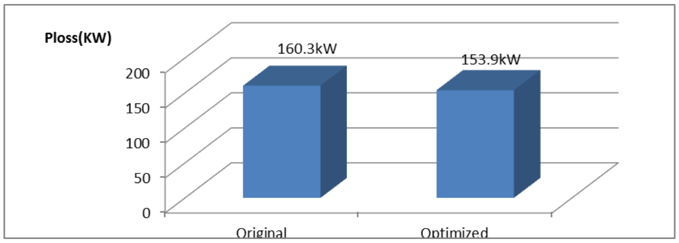

Fig. 8. Simulation result of system power loss without DERs.

B. *With DERs Connection*

Similarly to the previous subsection, the simulation results of IEEE 37-Bus test system with DERs are shown in Fig. 9~11. The weightings are also set as W_2=0.33, W_3=0.33, and W_4=0.34, respectively. After the optimization, the connection schemes are listed in Table III. In addition to, the zero- sequence voltage ratios are reduced, as shown in Fig. 9, and the negative-sequence voltage ratios are decreased significantly, as shown in Fig. 10. Furthermore, the system power loss is reduced from 160.3 kW to 84.7 kW. Therefore, the system performance is better than that before optimization, and it is the best compared with the system without DERs connection.

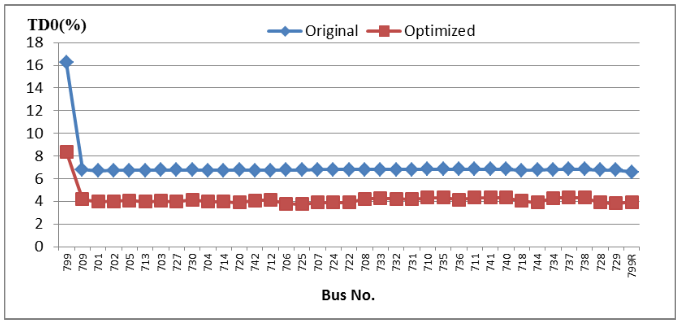

Fig. 9. Simulation result of zero- sequence voltage ratios with DERs.

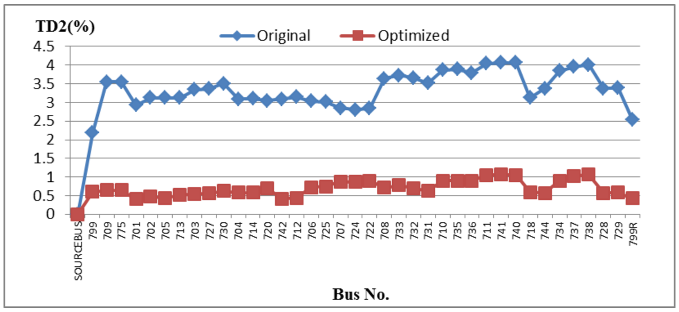

Fig. 10. Simulation result of negative- sequence voltage ratios with DERs.

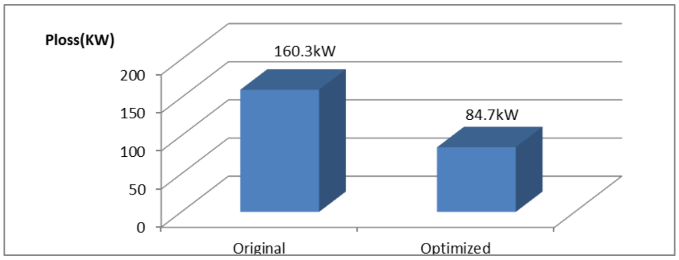

Fig. 11. Simulation result of system power loss with DERs.

IV. CONCLUSIONS

In this paper, a multi objective function for load balancing was proposed to improve three-phase unbalance condition in passive and active distribution networks. This problem was solved by genetic algorithm, which the program was coded in Matlab. The IEEE 37-Bus test system was used as sample system to verify the proposed approach, and the simulation results demonstrated that this method is feasible and it is capable of improving system performance. The outcomes of this paper also helpful for distribution engineer for planning and operating the modern active distribution networks.

APPENDIX

Table II Optimal connection schemes of IEEE 37-bus test system without DERs.

Bus No. Connection	701	712	713	714	718
Gene Code	3	1	1	3	1
Bus Side↔Load Side	ABC↔bac	AC↔ca	AC↔ca	ABC↔bac	AB↔ba
	720	722	724	725	727
Gene Code	0	2	0	1	0
Bus Side↔Load Side	AC↔ac	ABC↔bca	BC↔cb	BC↔cb	AC↔ac
	729	730	731	732	733
Gene Code	1	1	1	1	0
Bus Side↔Load Side	AB↔ba	AC↔ca	BC↔cb	AC↔ca	AB↔ab
	734	735	736	737	738
Gene Code	0	0	1	1	1
Bus Side↔Load Side	AC↔ac	AC↔ac	BC↔cb	AB↔ba	AB↔ba
	740	741	742	744	
Gene Code	0	1	1	1	
Bus Side↔Load Side	AC↔ac	AC↔ca	ABC↔acb	AB↔ba	

Table III Optimal connection schemes of IEEE 37-bus test system with DERs.

Bus No. Connection	701	712	713	714	718
Gene Code	2	1	4	1	3
Bus Side↔Load Side	ABC↔bca	AC↔ca	AC↔ac	ABC↔acb	AB↔ba
	720	722	724	725	727
Gene Code	3	2	4	5	3
Bus Side↔Load Side	AC↔ca	ABC↔bca	BC↔bc	BC↔cb	AC↔ca
	729	730	731	732	733
Gene Code	2	5	4	2	5
Bus Side↔Load Side	AB↔ab	AC↔ca	BC↔bc	AC↔ac	AB↔ba
	734	735	736	737	738
Gene Code	0	1	3	0	0
Bus Side↔Load Side	AC↔ac	AC↔ca	BC↔cb	AB↔ab	AB↔ab
	740	741	742	744	**DER1**
Gene Code	0	2	4	2	3
Bus Side↔Load Side	AC↔ac	AC↔ac	ABC↔cab	AB↔ab	ABC↔abc
	DER2				
Gene Code	4				
Bus Side↔Load Side	ABC↔acb				

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