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Evaluation and analysis of loss-reduction methods in all parts of an actual power distribution network: a case study

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Abstract. Using various loss-reduction methods, the loss values are reduced and determined for any part of the power distribution network. Effects of various methods on the voltage profile, total harmonic distortion and voltage unbalance are evaluated. A typical network of the Yazd Electrical Distribution Company (YEDC) Iran, is studied. The transformer and line data are gathered from a catalogue and the load power and network harmonics are recorded using a data logger. Using a MATLAB software, a comprehensive program is produced for the harmonic load flow and asymmetric three-phase systems for a 24-hour interval to calculate the losses in each part of the studied network. The loss values of low- and medium-voltage lines and transformers are calculated. Approaches such as balanced and unbalanced capacitor placement, network reconfiguration, transformers and conductors capacity amendment and load balancing are applied to reduce the losses using a genetic optimization algorithm and an asymmetric harmonic load flow. The explained parameters are measured. The obtained results indicate that the losses in the low-voltage part are higher than those in other parts of the network, and that any kind of loss reduction is highly important.

Keywords: Distribution network, Loss reduction, Asymmetrical harmonic load flow, Genetic algorithm, Component loss value.

Evalvacija in analiza metod za zmanjšanje izgub v elektroenergetskem omrežju: študija primera

V prispevku smo predstavili metode za zmanjšanje izgub v elektroenergetskem omrežju. Analizirali smo vzorčno elektroenergetsko omrežje. Podatke o gradnikih omrežja smo dobili od izdelovalcev, podatke o obremenitvah in harmonskih komponentah pa z meritvami omrežja v intervalu 24 ur. Izračunali smo izgube za posamezne dele omrežja. Izgube v omrežju smo zmanjšali s postavitvijo kondenzatorjev, rekonfiguracijo omrežja, spreminjanjem zmogljivosti transformatorjev in vodnikov in bremensko prilagoditvijo z uporabo genetskih optimizacijskih algoritmov. Dobljeni rezultati potrjujejo, da so izgube, povezane z nizko napetostjo, večje kot v drugih delih omrežja.

1 INTRODUCTION

The need for the electric energy irrespective of its types of use either domestic, commercial, industrial or agricultural is constantly increasing and has led to a 7% increase in the average annual energy consumption. One of the major goals of power utilities is to reduce losses in power generation, transmission and distribution by providing practical and effective solutions. By taking a serious effort in this regard, promising results have been achieved, the so far used employ an amorphous transformer core. These methods either significantly reduce losses in the distribution network [1], or reconfigure it to reduce the losses and thus improve the network voltage profile [2]. Other methods, balance the domestic and commercial load by reducing the phase losses [3]. Using the distributed generation sources reduces the losses and improves the voltage profile [4]. Choosing an appropriate conductor or capacitor type reduces the network losses [5].

The first step towards optimization and reduction of the distribution network losses is their accurate measurement and assessment.

Using a harmonic asymmetric load flow and a genetic algorithm, the shares of different losses in the studied distribution network as well as other magnitudes such as the total harmonic distortion, unbalanced voltage and voltage profile, are determined and estimated.

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In Section 2, scientific bases are laid. In Section 3, the studied network is described. Sections 4 to 7 introduce various loss-reducing methods enabling balancing and placement of unbalanced capacitors, reconfiguration of the distribution network, transformer capacity optimization, load balancing and changing the size of the neutral wire. The loss values for each part of the distribution network are presented in Section 8, Section 9 shows conclusions.

2 SCIENTIFIC BASES

The methods used to determine the distribution network losses, are:

- The unbalanced load-flow method to calculate the network power losses by using the available software [6];
- The method using the load and loss factor to calculate the power and energy losses [7, 8];
- The method to calculate the energy losses based on the difference between the energies recorded by an input and output measuring device [7];

In this paper, the first method is used to determine the losses in the studied network.

The method uses the Backward-Forward Sweep Power Flow for the radial distribution networks [9]. Which are often unbalanced, thus increasing the losses and unbalancing the network voltage and current. The distribution system is therefore assumed to be in its unbalance state and the system load-flow equations are calculated for the three-phase network.

Besides, the harmonics effects are taken into account. The transformers are assumed to be in their linear state at different harmonics. The transformer impedance in the h*th* harmonic is obtained from $Z_T^h = R_T + jhX_T$. Similarly, the h*th* line harmonic impedance is determined from $Z_L^h = R_L + jhX_L$. The capacitor modeling at various harmonic frequencies is obtained from $1/2\pi hC_f$. The load model at harmonic frequencies is considered as a constant-current model and harmonic current sources are injected to nodes or buses. Since the line harmonic current is always constant, the harmonic voltage of the distribution network can be obtained using a backward-forward sweep.

Besides, a genetic algorithm is used to optimize calculations for each step [10].

3 DESCRIPTION OF THE STUDIED NETWORK

The studied distribution network is an actual feeder operating of the Yazd Electrical Distribution Company in Iran. In Fig.1 it is shown as a DigSilent file. The system includes 59 transformers (buses) feeding residential, industrial and greenhouse loads through standard lines (Dog, Mink, Hyena, Fox). For the different load behaviors (residential, industrial and greenhouse), a 24-hour load curve of three different transformers is provided using a TDL112 data logger shown in Fig. 2. Using the load curve of the three transformers with different loads and the percentage of the feeder transformer loading for all the phases, the load curve of each transformer is determined for each phase separately. It is used as an input data for a 24-hour load-flow.

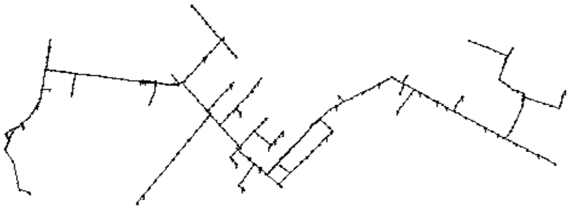

Figure 1. The Yazd (Iran) feeder.

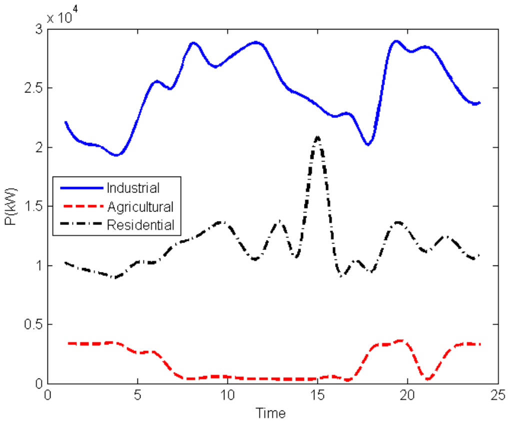

Figure 2. Residential, industrial and greenhouse load curves for phase T.

4 OPTIMAL LOCATION AND SIZE OF CAPACITORS

Shunt capacitors are installed in primary feeders of the distribution network to both improve the voltage profile and reduce the losses by correcting the power factor and also releasing the line capacity. To reduce the losses and improve the voltage profile, taking into account the capacitors the installation cost and relevant constraints, the capacitor location and capacitance are determined. The component of the objective function presented in equation (1) include the cost of the energy and power losses, and cost of the capacitor placement in the network. The optimal solution is to determine the sum of the total costs minimized in [11].

$$\min F = \sum_{i=1}^{n} T_i \, P_i \, K_e + K_p \, P_0 + \sum_{j=1}^{n} K_c \, C_j \qquad (1)$$

where K_e is the cost per unit of the energy loss ($/kWh), K_p is the cost per unit of the peak loss ($/kW), K_c is the cost per unit of the injected reactive power ($/kVAR), T_i is the duration of the i*th* load level, P_i is the power loss of the i*th* load level, P_0 is the peak power loss, C_j is the reactive power injected in the j*th* bus (kVAR) and n is the number of total buses.

The values include $K_e = 168$, $K_p = 4.9$ and $K_c = 0.06$, [11].

The maximum THD constraint is that the voltage harmonic distortion of any bus should be less than 5% and the harmonic distortion for the jth bus is calculated using equation (2).

$$THD_v^j = \frac{\sqrt{\sum_{h=2}^{hmax}(V_j^h)^2}}{V_j^1} \tag{2}$$

where V_j^h is the voltage of the jth bus in harmonic h, and V_j^1 is the voltage of the same bus in the first harmonic. In general, by considering the effect of the nonlinear loads on the capacitor placement the economic evaluation of the system is more accurate and the harmonic losses are evaluated. Using the genetic algorithm, capacitor placement is conducted in both states, i.e. at a balanced and unbalanced three-phase capacitor.

The results of the capacitor placement are illustrated in Table 1, based on GA.

Table 1: Results at a balanced and unbalanced capacitor

	Network primary mode	**Network with a balanced capacitor**	**Network with an unbalanced capacitor**
System loss (MW)	4.1619	4.0801	4.0634
Cost function($)	42018	38743	38290
THD %	1.6193	0.8457	0.760
Max. voltage	0.9958	0.9975	0.9977
Min. voltage	0.9527	0.9742	0.9792
Voltage imbalance	2.535	2.288	1.498

The results show that the capacitor minimizes all the constraints and improves the objective function. Besides, the capacitor unbalance is more suitable. Since the capacitor unbalance leads to a phase balance and further reduces the unbalanced voltage, the resulting unbalanced voltage reduction a further reduces the losses. The results show that the difference between the maximum and the minimum voltage is the optimal state of the unbalanced capacitors, compared to other states, and improves the voltage profile.

5 CORRECTION OF THE LINE AND TRANSFORMER CAPACITY

The size and type of the conductor and the transformer capacity in radial feeders are one of the most important issues in designing a distribution network. By optimizing them and minimizing the losses due to considering some constraints, including voltage drops and the conductor and transformer current limitations, the system reliability increases and the power supply reaches a suitable voltage level.

To improve the 20 kV line capacity, the objective function given in equation (3) is used. The components of this function include the cost of the energy and peak-power losses and cost of all network lines. The optimal solution is to minimize the total costs.

$$min\, F = \sum_{i=1}^{n} T_i\, P_i\, K_e + K_p\, P_0 + \sum_{j=1}^{n} K_l\, L_j \tag{3}$$

where K_l is the conversion factor of the aluminum cost ($/kg), and L_i is the quantity of the used aluminum (kg).

In order to improve the network transformer capacity, the objective function given in equation (4) is used. The components of this function include the cost of the energy and peak-power losses and the cost of all network transformers. The optimal solution is to minimize the total costs.

$$min\;\; F = \sum_{i=1}^{n} T_i\, P_i\, K_e + K_p\, P_0 + \sum_{j=1}^{n} K_t\, T_j \tag{4}$$

where K_t is the conversion factor of the transformer cost ($/kVA) and L_i is the initial transformer cost ($).

Table 2 shows a corrected line and transformer capacity based on GA.

Table 2: Results of the line and transformer capacity correction.

	Network primary mode	**Transformers capacity correction**	**Lines capacity correction**
System loss (MW)	4.1619	4.1365	4.1293
Cost function($)	42018	41679	41479
THD %	1.6193	1.6193	1.5904
Max. voltage	0.9958	0.9958	0.9958
Min. voltage	0.9527	0.9527	0.9550
Voltage imbalance	2.535	2.534	2.515

As seen from the table above, correction of the line and transformer capacity does not significantly reduce the losses, since the difference between the losses of the replaced transformers and the losses due to conductor replacement is negligible.

Also, the difference between the maximum and the minimum voltage shows that the optimal 20 kV line capacity correction compared to other states insignificantly improves the voltage profile as there is no important loss in the medium-voltage section. So the loss reduction in this part has no significant effect on voltage variations. The voltage profile in the optimization state of the transformer capacity correction is the same as in the normal network, since the transformer capacity variation caused by the low load rates do not affect the voltage variations.

6 RECONFIGURATION OF THE POWER DISTRIBUTION NETWORK

Reconfiguration of the power distribution network is a method of reducing losses in electric systems by using an objective function to reduce the active and reactive losses (5):

$$F_{obj} = \sum_{l=1}^{NL} R_l \times |I_l|^2 + \sum_{l=1}^{NL} X_l \times |I_l|^2 \tag{5}$$

where R_l is the line resistance, X_l is the line reactance, I_l is the current of line l, and N_l is the total number of lines. The network reconfiguration should meet the radial and electrical constraints, including no line overloading and no over voltages on the buses from 1± 0.05.

Using the software [12], the network is reconfigured for two feeders (7 and 12), fed from the Modarres substation. The total system losses are thus reduced and the results are presented in Table 3.

Table 3: Distribution network loss-reduction results after network reconfiguration

	Network primary mode	**Reconfigured network**
System loss (MW)	4.1619	4.1199
Cost function($)	42018	-
THD %	1.6193	1.2577
Max. voltage	0.9958	0.9959
Min. voltage	0.9527	0.9606
Voltage imbalance	2.535	2.238

It seen that the reduced network losses due to reconfiguration, do not significantly affect the voltages. The THD is reduced by 0.4%. The difference between the maximum and the minimum voltage shows that reconfiguration the network improves the voltage profile.

7 LOAD BALANCING AND NEUTRAL-WIRE SIZE CORRECTION

In the distribution network, beside the unbalanced load distribution on the phases, the load consumption by individual phases differs, thus leading to an unbalanced network load [13].

The consequences of an unbalanced network load are an increase in the power losses and voltage unbalance. The network phase wires are of the same size. Due to the different current flows throughputs, the wires have different voltage drops, causing a voltage unbalance on the consumer side. In this section, the balancing load and increasing the conductor size in a low-voltage network are studied to reduce the losses, improve the voltage profile and minimize the voltage unbalance. The results presented in Table 4 show that balancing the load reduces the losses, unbalances the voltage and controls voltage variations, yet, it increases the level of harmonic disturbances due to harmonics overlapping resulting from a decrease in the unbalanced phase current.

Table 4: Results of balancing the load and changing the size of the neutral conductor

	Network primary mode	**Load balancing**	**Changed neutral wire size**
System loss (MW)	4.1619	3.0409	3.9251
Cost function($)	42018	-	-
THD %	1.6193	2.857	1.6193
Max. voltage	0.9958	0.9960	0.9958
Min. voltage	0.9527	0.9918	0.9527
Voltage imbalance	2.535	0.119	2.534

Changing the size of the neutral conductor does not significantly affect the studied magnitudes power network. The difference between the maximum and minimum voltage in an optimal load balancing mode improves the voltage profile as load balancing reduces the losses in any part of the feeder and improves the feeder voltage.

8 LOSS SHARES OVER THE POWER DISTRIBUTION NETWORK FOR EACH LOSS-REDUCTION METHOD

Identifying the loss components and separating and determining the contribution of affecting factors have a significant role in managing and planning loss reduction in power distribution companies.

Apart from the results presented for the compared optimization methods, the shares of the low- and high-voltage losses and transformers are calculated separately for each method (Table 5).

Table 5: Equipment losses in the investigated distribution network for different optimization methods

Row	**Optimization methods**	**System losses (MW)**	**Low-voltage losses (MW)**	**Transformer losses (MW)**	**Medium-voltage losses (MW)**
1	Network Primary mode	4.1619	2.6441	1.4114	0.10634
2	Network with a balanced capacitor	4.0801	2.5517	1.3918	0.10512
3	Network with an unbalanced capacitor	4.0634	2.4844	1.3833	0.10405
4	Reconfigured network	4.1199	2.6151	1.4059	0.0988
5	Lines capacity correction	4.1293	2.6348	1.4097	0.08483
6	Transformers capacity correction	4.1365	2.6405	1.3826	0.10621
7	Load balancing	3.0409	1.6406	1.3137	0.09473
8	Changed neutral size	3.9251	2.4073	1.4114	0.10634

As seen from Table 5, the optimization method for load balancing decreases the total system losses down to 3.0409Mw which is the highest loss-reduction rate. In general, the distribution loss shares are some 62%, 34%, and 4% for the low-voltage network, transformer, and medium voltage network, respectively.

It is shown that the loss share in the low-voltage part is higher than in other parts of the network. Therefore, any method that leads to lower losses in this section is of a high significance. Optimization methods reduce losses in different parts of the network. However, the loss-reduction shares differ from one network part to another, depending on the used optimization method.

9 CONCLUSION

The paper analyzes some of the known loss-reduction methods by using them on an actual feeder operating at the Yazd Electrical Distribution Company in Iran. Loss shares are determined for different network parts, voltage profile and total harmonic distortion. The methods are used for the case of balanced and unbalanced capacitor placement, line-capacity correction, transformer-capacity modification, network reconfiguration, load balancing and changing the neutral-wire size. The results show that each method reduces the network losses, improves the voltage profile and minimizes the harmonic disturbances. Moreover, load balancing provides a maximum loss-reduction rate and a minimum unbalanced voltage, and unbalanced capacitor placement ensures the best voltage profile and the lowest harmonic disturbances. Reviewing the losses by using each of the analyzed optimization methods shows that the losses are the highest in the low-voltage distribution network. The next are the transformer losses and the lowest are the losses in the medium-voltage network. According to the study results, the overall share of the power distribution losses for the low-voltage part is approximately 62% compared to 34% for transformers and 4% for the medium-voltage part.

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REFERENCES

[1] Azuma, D., "Core Loss in Toroidal Cores Based on Fe-Based Amorphous Metglas 2605HB1 Alloy", IEEE Trans. On Magnetics, Vol. 47, No. 10 ,pp. 3460-3467, 2011.

[2] Das, D., "A Fuzzy Multi-Objective Approach for Network Reconfiguration of Distribution Systems", IEEE Trans. Power Delivery, Vol. 21, No. 1 ,pp. 202-209, 2006.

[3] Chen, C., Che and Hsu, Y. Yih, " A Novel Approach to Design of a Shunt Active Filter for an Unbalanced Three-Phase Four–Wire System Under Non-Sinusoidal Conditions", IEEE Transactions on Power Delivery, Vol. 15, No. 4, pp. 1258-1264, 2000.

[4] Algarni, A., and Bhattacharya, K., "Novel Sensitivity Indices Based Siting of Distributed Generation Resources", IEEE PES Annual General Meeting, pp. 1-8, 2008.

[5] Askarzadeh, A.," Capacitor placement in distribution systems for power loss reduction and voltage improvement: a new methodology", IET Generation, Transmission & Distribution Vol. 10, No. 14 , pp. 3631 – 3638, 2016.

[6] Shirmohammadi, D. and Cheng, C., "A Three-Phase Power Flow Method for Real-Time Distribution System Analysis", IEEE Transaction on Power system, Vol. 10, No. 2,pp. 671-679, 1995.

[7] M. R. Haghifam and O. P. Malik, "Genetic algorithm-based approach for fixed and switchable capacitors placement in distribution systems with uncertainty and time varying loads," Generation, Transmission & Distribution, IET, vol. 1, pp. 244-252, 2007.

[8] Izadi, M., Razavi, F., Hosseinian, H., "A cost-effective analysis of the power-loss reduction methods in an actual distribution network ", ELEKTROTEHNIŠKI VESTNIK 81(4): 167-178, 2014.

[9] Shirmohammadi, D. and Cheng, C., " Backward-Forward Sweep Power Flow Simulation for Three-Phase Unbalance Radial Distribution Systems" IEEE Transaction on Power system, Vol. 10, No. 2, 1995.

[10] Falkanauer, E., Genetic Algorithms and Grouping Problems, John Wiley and Sons, Inc., 1998.

[11] Eajal, A.A, El-Hawary, M.E., " Optimal Capacitor Placement and Sizing in Unbalanced Distribution Systems With Harmonics Consideration Using Particle Swarm Optimization, " IEEE Trans. Power Del. , Vol. 25, No. 3, pp. 1734–1741, 2010.

[12] Mirjalili H.R., Sedighi A.R., Haghifam M.R., "Hybridization of ACO and GA with a New Heuristic Method to Speeding up Reconfiguration Problem: a Practical Usage", CIRED Regional - Iran, Tehran, 13-14 Jan 2013.

[13] Che Chen, C., Yih Hsu, Y.," A Novel Approach to Design of a Shunt Active Filter for an Unbalanced Three-Phase Four Wire System Under Non-Sinusoidal Conditions ", IEEE Transactions on Power Delivery, Vol. 15, No. 4, pp. 1258-1264, 2000.

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