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Effects of Measures for Energy Loss Reduction on Suburban Distribution Networks

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Abstract – **The most often used measures for energy loss reduction in distribution networks are discussed in this paper: reconfiguration, voltage regulation, reactive power compensation, and conductors changing. Theoretical bases of the measures are given at the first. After that, effects of application of these measures on the real suburban distribution network are analyzed. It is shown that all measures should be analyzed simultaneously.**

Keywords – **Electric energy, losses, distribution network, reconfiguration, compensation.**

I. Introduction

Measures for energy loss reduction have received an ever increasing attention from the electric utility industry in recent years. However, unique recommendations for distribution utilities what measures should be applied still do not exist. This is consequence of different conditions in distribution utilities. Nevertheless, results obtained on one representative distribution network can be used on networks with similar configuration and similar profile of consumers.

Measures for energy loss reduction in distribution networks can be classified into two groups: organizational, and technical. Organizational measures are ones which do not require additional investments. These are: optimal load distribution, optimization of separation points of double feeding primary lines, voltage regulation, alignment of phase loadings in low voltage networks, and disconnection of distribution transformers in low load regimes in substations with two or more transformers. These measures we can realize in a short time and do not require any investment.

Technical measures are: reconstruction of network, application of capacitor banks, replacement of conductors or transformers, and automation of networks. Technical measures, on the difference of operational ones, require investments and have the long applying time.

Beside mentioned measures distribution utilities should perform measures for accurate reading of spend energy. These measures are periodical checking of accuracy of electric meters, and replacement of old electric meters with new ones which have better technical performances.

Efficiency of one measure for energy loss reduction can be estimated based on the effects of applying of this measure. For operational measures the effect is shown only by amount of

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Efficiency of one measure for energy loss reduction can be estimated based on the effects of applying of this measure. For operational measures the effect is shown only by amount of energy loss reduction. When technical measures are analyzed, investment expenditures must be considered. In [1,2] efficiency of technical measures is evaluated by time of returning of the investments.

Analyses of effect that some of measures for energy loss reduction have on real medium voltage suburban networks is presented in this paper.

II. Measures for Energy Loss Reduction

Reconfiguration

Reconfiguration of distribution network [3-6] is defined as changing of network topology by switching tie breakers and sectionalizing switches. Methods for solving of reconfiguration problem we can classify into three groups:

- methods based on optimization techniques,
- heuristic methods,
- methods based on artificial intelligence techniques.

The problem of finding the network configuration with minimum line losses, a mixed-integer, non-linear optimization problem, has been solved using branch-and-bound method. There is, however, no assurance of convergence when branch-and-bound is used for this type of optimization problem. Additionally, sometimes all relevant constraints can not be comprehended. Therefore, actual approaches for reconfiguration are based upon heuristic or artificial intelligence techniques (expert systems, fuzzy logic, and neuron networks). Heuristic methods are finding quested configuration following physics of problem. Two main approaches of these methods are:

- method of individual switch opening,
- switch exchange method.

The first heuristic approach is very efficient and determines the network configuration with minimum or near-minimum line losses based on special variation of branch-and-bound techniques. All network switches are initially closed converting a radial into meshed network. Network switches are then opened one at a time until a new radial configuration is reached. In this process, the switch to be opened at each stage is selected in order to minimize resistive line losses of resulting network.

The second heuristic approach achieves loss reduction by performing switch exchange operations. A switch exchange operation corresponds to the selection of a pair of switches, one for opening and the other for closing, so that resulting network has lower line losses while remaining connected and radial. Other network operating constraints, such as voltage limits and conductor ampacities are taken into account prior to or after performing switch exchange operation.

Expert systems, genetics algorithm, and neuron networks are also found application in solving of reconfiguration problem. Expert systems observe problem of finding optimal configuration as combination and heuristic problem. Application of genetics algorithm has shown as very efficient from the aspect of the time needed for solving of problem.

Voltage regulation

There are system and regional regulation of voltage levels. System regulations are performed by changing motion of synchronous generator. However, voltage regulation can be performed as regional by installing equipment for changing reactive power flows. Node voltages and reactive power flows are in correlation, therefore we can affect on voltage profiles by installing compensation accessories.

Regional voltage regulation can also be made using tap changing transformers. There are two types of these transformers on which:

- tap changing is possible only when transformer is unloaded,
- tap changing can be made under loading.

Obviously, only second type of transformer can be used for regulation of voltages. Voltage regulation in distribution networks by tap changing transformers are based on the principle of voltage drop compensation of unique line. This means that consumer installed into some node gives constant voltage level regardless of load changing or voltage changing on high voltage busses. This regulation is known as compounding voltage regulation. Real and reactive power of node i are change with voltage changing as:

$$P_i = P_{ri}\left(\frac{V_i}{V_r}\right)^{k_{pv}} , \quad (1)$$

$$Q_i = Q_{ri}\left(\frac{V_i}{V_r}\right)^{k_{qv}} , \quad (2)$$

where V_i is voltage of node i, V_r rated voltage of network, k_{pv} and k_{qv} static coefficients of real and reactive power change with voltage changing.

Reactive power compensation

Three principal problems occur on compensation of reactive power [7-9]:

- selection of compensation equipment type,
- optimal placement of equipments,
- optimal size of compensation equipments.

Solving of these problems is very difficult and requires considering of following factors: power and energy losses, costs of delivered power and energy, occupation of line and transformer capacitances, bed consequences due to decreasing of voltage quality. Economic valorisation of all these factors is difficult. Therefore, problem is solved considering only investment and costs of power and energy losses whence influence of other factors are neglected.

When we are finding optimal solution of compensation problem, optimal criterion must be presumed. This criterion has effect on selection of objective function. Mathematical model for compensation problem is made of mentioned objective function and constraints.

Optimal planning of compensation accessories depend on the nature of reactive loading. If reactive loads are “stilly” compensation only lead to better node voltages and power factors. If nonlinear character of loads is dominated or loading changes rapidly, it is possible to occur overvoltages or flicker. Then selection of compensation equipment is made in order to satisfy technical normative.

Extensive usage of static compensation equipments is caused by great progression of thiristor technique. Selection of optimal pleasing of capacitors and their size depend on the used mathematical model. This problem can be solved on the way that nodes for installing of capacitors are selected at the first, and then optimal size of capacitors is found. Second approach is solving of these two tasks simultaneously.

Replacement of conductors

When detail analysis of energy losses is made, conductors of lines that are identified as potential “neck” of network (large losses) can be replaced by ones with bigger cross section area in order to reduce energy losses. Selection of lines that will be replaced and optimal cross section areas of new conductors we should made comprehending all possible operational measures for losses reduction. Calculating annual costs before and after replacement for any distribution line, we can obtain loading on which replacement of conductor is reasonable.

III. Test Example

Analyses are made on two representative networks, and due to similar conclusions are obtained, in this paper are presented only results of 10 kV distribution network shown on the Fig. 1. This is one typical suburban network. Total length of 158 lines is 48 km (63 underground cables with total length 27.3 km, 95 overhead lines with total length 20.7 km), 72 distribution transformers with total rated power 30 MVA (Table I). The most frequently used are aluminium cables with cross section area of 150 mm^2, and ACSR overhead lined with 50 mm^2 and 70 mm^2 cross section areas. Consumers are dominantly individual residential houses. The houses are heating on coal, wood or electrical energy. Power factor in network under analyses is 0.95. This network is one typical suburban network in our country. Small circles on Fig. 1 represent substations 10/0.4 kV/kV.

TABLE I
RATED POWERS AND NUMBER OF DISTRIBUTION TRANSFORMERS FEEDED BY MEDIUM VOLTAGE NETWORK SHOWN IN FIGURE 1

Rated power (kVA)	100	160	250	400	630	1000
Number of transformers	4	4	34	6	16	8

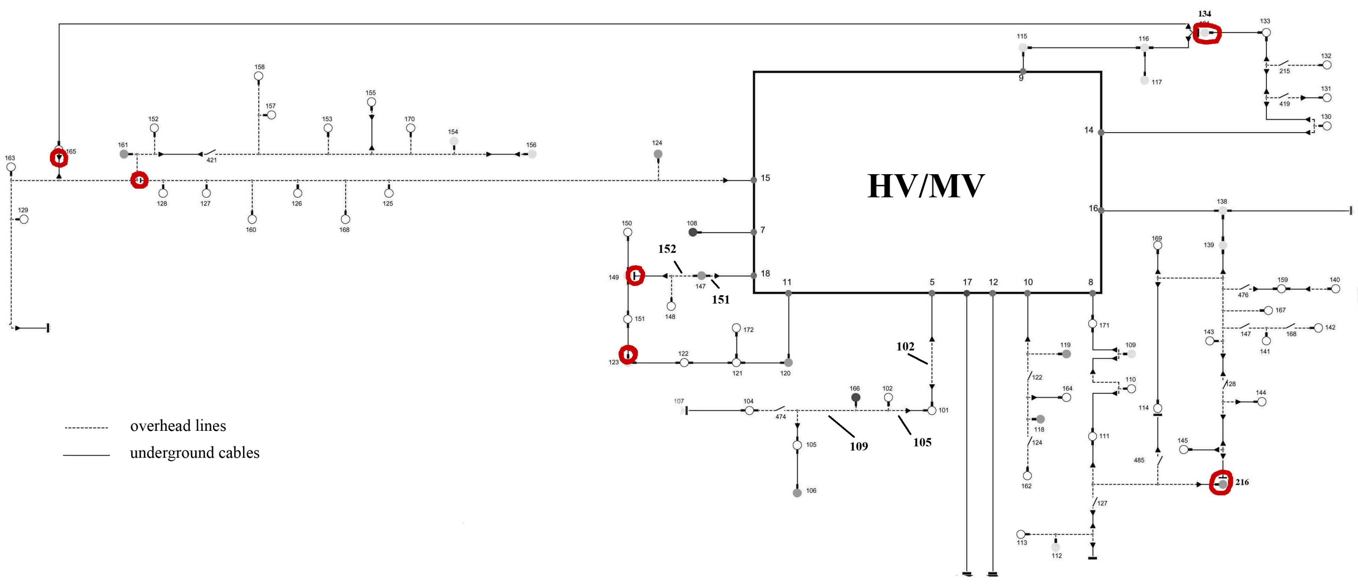

Fig 1. Medium voltage 10 kV suburban distribution network

TABLE II
INFLUENCE OF VOLTAGE REGULATION ON THE ENERGY LOSSES

		k_{pv}=2, k_{qv}=2		k_{pv}=1, k_{qv}=1		k_{pv}=0, k_{qv}=0		k_{pv}=1.7, k_{qv}=2.5	
U_{rn}	1	1.05	0.95	1.05	0.95	1.05	0.95	1.05	0.95
Delivered energy (MWh)	52207.5	54910.9	44949.7	53557.8	48397	52168.3	52325.6	54497.4	45965.6
Total energy losses (MWh)	1252.34	1318.76	1079.53	1266.75	1208.55	1213.87	1371.12	1306.54	1108.06
Percentage losses (%)	2.40	2.40	2.40	2.36	2.50	2.33	2.62	2.40	2.41
Line losses (MWh)	663.38	699.84	572.88	663.55	662.92	626.37	777.28	691.32	592.78
Transformer losses (MWh)	588.96	618.92	506.65	603.20	545.63	587.50	593.84	615.22	515.28

The data needed for analyses are collected for period from September 1 to March 31. Maximal value of real power of network during observed interval is 20.5 MW, and total delivered real energy is 52207.5 MWh. Based on these data at the first we made estimation of node loads during interval under consideration.

Based on results of load estimations and load flow calculations, for each moment of observed interval we calculated real and reactive node powers for four combinations of k_{pv} and k_{qv}. Results of analyses of voltage regulation (Table II) show that absolute value of energy losses as well as total delivered energy depend on the voltages as well as on the load category of consumers. Therefore, percentage energy losses should observed for concluding how regulation of voltage affect on losses. Results shown in Table II show that voltage of root node (U_{rn}) should be keep on maximal values whenever it is possible.

For state of network in the moment when total delivered power is maximal we analyzed reconfiguration for losses reduction. Results of calculation show that eight switching operations should be performed to obtain optimal configuration (four switches are opened and same number are closed). Switches that should be opened/closed are denoted on the Fig. 1. Table III shows energy loss calculations results before and after reconfiguration is made. For considered interval energy losses will be decreased for 154.8 MWh if reconfiguration is made.

TABLE III
DECREASING OF ENERGY LOSSES EFFECTED BY RECONFIGURATION

	Actual configuration	After reconfiguration	difference
Delivered energy (MWh)	52207.5	52052.7	154.8
Total energy losses (MWh)	1252.34	1105.21	147.13
Line losses (MWh)	663.38	516.22	147.16
Transformer losses (MWh)	588.96	588.99	-0.03

Analyse of optimal location and sizes of capacitors are made for actual configuration of network as well as for the state obtained after reconfiguration was made. Having in mind standard sizes of capacitors, and using optimization approach, we conclude that installation of capacitors in substations 10/0.4 kV/kV should be made on following way:

- if rated power of distribution transformer is 1000 kVA capacitors of 90 kVAr are installed,
- if rated power of distribution transformer is 630 kVA capacitors of 60 kVAr are installed.

This means that in analyzed network we should install 8 capacitors of 90 kVAr and 16 capacitors of 60 kVAr. Results of losses reduction due to compensation an actual configuration are shown in Table IV, whence results of compensation after reconfiguration is made are shown in Table V. Returning time of investments in capacitors is 2.3 years.

TABLE IV
RESULTS OF REACTIVE POWER COMPENSATION

	Without compensation	With compensation	difference
Delivered energy (MWh)	52207.5	52154.2	53.3
Total energy losses (MWh)	1252.34	1199.73	52.61
Line losses (MWh)	663.38	624.64	34.74
Transformer losses (MWh)	588.96	575.09	13.87

TABLE V
RESULTS OF REACTIVE POWER COMPENSATION AFTER RECONFIGURATION OF NETWORK IS MADE

	Without compensation	With compensation	difference
Delivered energy (MWh)	52052.7	52007.1	45.6
Total energy losses (MWh)	1105.21	1060.81	44.4
Line losses (MWh)	516.22	485.65	30.57
Transformer losses (MWh)	588.99	575.16	13.83

TABLE VI
LINE LOSSES BEFORE AND AFTER CHANGING OF CONDUCTORS

	Losses before changing (MWh)	Losses after changing (MWh)	Returning time of investments
102	38.00	18.8	2.66
105	15.81	10.97	10.56
109	15.14	10.51	16.56
151	102.6	71.22	4.07
152	87.58	60.80	4.77

Analysing structure of losses (losses distribution throughout the network elements) we identified five lines on which replacement of conductor may be reasonable. These are overhead lines denoted in the Fig.1 by numbers 102, 105, 109, 151, and 152. Cross section areas of these lines are 35 mm^2 and 50 mm^2. Energy losses in these lines for actual state of network is shown in the second column of Table VI. If mentioned lines are replaced with ACSR 70 mm^2 conductors, losses are decreased as shows third column of Table VI. Column four of Table VI contain data about returning times of investment on changing of conductors. Replacement of line 102 is obviously payable, whence for lines 151 and 152 we must consider long time forecasting of loads.

IV. CONCLUSION

Effects of measures for energy loss reduction are analyzed in this paper. Analyse is made on real suburban medium voltage distribution network. Results of calculations show that reconfiguration and voltage regulation should be applied whenever is possible. Additionally, it is shown that investment in installing of capacitor banks is reasonable regardless organisation measures are previously applied or not. Changing of some conductors (increasing of cross section area) also may have very short returning time of investment and therefore must be considered in analyse.

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