Reconfiguration as a Measure for Reduction of Energy Losses in Distribution Networks

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Abstract – **Reconfiguration as one of measures for energy loss reduction in distribution networks which do not requires investment is considered in this paper. A classification of reconfiguration methods is proposed. After this, detailed consideration of a heuristic method for reconfiguration of distribution networks is made. This method is based on the concept of optimal flow pattern. Results of analyzes made on real distribution networks show that reconfiguration should be performed in all cases where it is technically possible.**

Keywords – **Reconfiguration, Distribution network, Losses, Energy**

I. INTRODUCTION

Reduction of power losses in distribution networks should be considered as a part of general task which aims to enhance work efficiency of power systems. Since active and reactive power flows can be influenced in various ways and therefore the power losses, there is a wide range of measures for reduction of electric energy losses. These measures can be classified on different ways, but the most common is into: organizational and technical [1-3].

Organizational measures are those whose application leads to more economically exploitation of the network, and where is no need for additional investments. These measures include: optimization of load distribution, finding the optimal place of decoupling the distribution lines with two side feed, network reconfiguration, voltage regulation, disconnecting of transformers in periods with low load in substations with two or more transformers, balancing phase loads in low voltage networks etc. Besides they don't need additional investments, these measures can be accomplished in relative short period of time.

Technical measures for loss reduction include: network reconstruction, installation of compensation devices, conductor replacement at high loaded sections of distribution lines, replacement of overloaded or insufficiently loaded transformers, network automation etc. These measures require financial investments and they are usually fulfilled in relative long period of time.

Besides the already mentioned, it is necessary to bear in mind the measures taken for as much accurate measuring of consumed electric energy as possible. These measures contain: regular work conditions for instrument transformers and energy meters, replacement of older generation measuring devices with devices which have better characteristics, periodic checks of working accuracy of the measuring devices.

Reconfiguration of distribution networks is defined as altering the topological structure of distribution feeders, by changing the open/closed status of sectionalizing and tie switches in order to achieve optimal configuration [3-8]. From definition of reconfiguration, it can be seen that starting point in solving the reconfiguration task is defining the criterion (or more of them), which determine the optimal reconfiguration of distribution network. This criterion of optimality should be qualitative (or measurable).

There are lots of reasons for changing the configuration of distribution network and basically they can be divided into: a) improvement of network in normal conditions, b) supplying consumers in incidental conditions. Within the improvement of network in normal conditions, it can be distinguished two most important subgroups: reduction of power losses and eliminating of overloaded elements.

Reconfiguration can be considered as a planning task or real-time task. Reconfiguration task on daily, monthly or season planning level relies heavily on load estimation, which carries some uncertainty, therefore highly accurate calculations are not necessary here, and there is no need for particularly fast and reliable algorithms. On the other hand, real-time reconfiguration, which is possible only in fully automated system, demands high speed data acquisition as well as extremely fast reconfiguration algorithms. Considering the fact that every closing or opening of the switch reduces its operational life, it can be concluded that for small improvements of working conditions, reconfiguration has no sense.

In terms of loss reduction, reconfiguration task is reduced on determining the sectionalizing and tie switch whose opening and closing induces loss reduction. Since reconfiguration doesn't require additional investments, it should be always applied when technical capabilities allow its usage. Therefore, in this paper is made classification of the methods for reconfiguration and pointed to potential of their application, from aspect of electric energy losses. The effects of reconfiguration application are envisaged on a real distribution network.

II. METHODS FOR RECONFIGURATION OF DISTRIBUTION NETWORKS

Depending of mathematical model and applied solution technique, methods for reconfiguration of distribution

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network, whose aim is to reduce power losses, can be globally divided into three groups [3, 8]:

- methods based on the application of optimization techniques,
- heuristic methods,
- methods based on the application of artificial intelligence techniques.

Methods based on the application of optimization techniques belong to category of nonlinear programming. As mentioned before, criterion of optimality should be qualitative (or measurable). Attaching technical constraints to the criterion of optimality (objective function), in general, leads to nonlinear dynamic task. As such, it can be solved with some of the well-known optimization techniques. Reconfiguration problem can be mathematically formulated in relation:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} \Delta P_{ij} \qquad (1)$$

Subject to:

$$\sum_{i=1}^{n} \underline{S}_{ij} = \underline{S}_{j} \qquad (2)$$

$$S_{ij} \leq S_{ij\max} \qquad (3)$$

$$\Delta U_{ij} \leq \Delta U_{ij\max} \qquad (4)$$

$$\sum_{\forall ft} \underline{S}_{ft} \leq \underline{S}_{ft\max} \qquad (5)$$

$$\prod_{\forall ft} \lambda_{ft} = 1 \qquad (6)$$

where:

C_{ij} - weight loss coefficient for the section with initial node *i* and end node *j*,

ΔP_{ij} - power losses in section *i*,*j*

S_{ij} - load of the section *ij*,

S_j - power consumption at node *j*,

ΔU_{ij} - voltage drop on section *ij*,

f_i - subset of the feeders supplied by transformer *t*,

λ_{ft} - coefficient with value of 1 if a feeder is radial, otherwise it is 0.

In general, problem of finding the optimal configuration of the network is problem of mixed integer programming. For real distribution networks, with very large sizes, finding the solution of this kind of optimization task can last a very long time. In some cases it may happen that some procedures do not converge at all. Besides, sometimes it's not possible to validate all relevant constraints.

Therefore, modern approaches to the reconfiguration of distribution networks are based on heuristic methods and techniques of artificial intelligence (expert systems, fuzzy logic and neural networks). The essence of heuristic algorithms, based on nature of the problem, is to find the optimal configuration. Within these methods, two main approaches are distinguished:

- methods with gradual opening of the contour ("minimum current" algorithms),
- methods with a single opening of the contour ("branch alteration" algorithms).

The essence of methods with gradual opening of the contour, or "minimum current" algorithms, is to initially close all switching devices, where radial network is transformed into meshed network (contour network). Then, switching devices in contour sections are opened one by one, until radial structure of the network emerges. Choice of opening switching device is performed with aim to minimize the power losses. Where, in every step the opening switching device is placed in section with the lowest current intensity, determined from optimal distribution requirement of power flow.

Methods with a single opening of the contour ("branch alteration" algorithms) are constrained on one executive operation with network where two switching devices change their open\close status, or shifting the load from overloaded feeder (or transformer) to relative lower loaded feeder (or transformer). These methods are very effective, because they don't require calculation of whole regime after changing the open\close status of switching devices. Their shortcoming is reflected in the fact that the final solution is a local optimum.

Artificial intelligence methods have a wide range of power applications. In expert system applications, task of finding the optimal configuration is treated as combinatorial and heuristic problem. When determining the solution, the list of the best network configurations is formed and supplemented (by the value of objective function) in every moment. This list is used to generate new possible network configurations. Generation is done by closing the normally opened switching devices and successively opening the switching devices is sections of formed contour. Thereby, every opening means creation of the new radial configuration with certain value of the objective function.

Application of genetic algorithms for solving the reconfiguration task of distribution network, gives very good results from aspect of time needed for finding the global optimum or solution which is near the global optimum. In these algorithms, every string (coded discrete information) contains information about possible radial structure of the network with calculated value of objective function which meets the certain constraints.

In solving the reconfiguration problem, neural networks can find significant application because they have the ability to perceive connection between nonlinear nature of power flows and its structure which corresponds to minimum of the losses. Although, application of neural networks allows abbreviation of time needed to obtain the solution, wider use is difficult because of:

- long time needed for their training,
- training must be made for every distribution network,
- accurate training file must be provided to neural network in order to give acceptable results.

It should be noted that the solution obtained by using neural networks is accurate as much as used data during the training are accurate.

Considering the fact that in reality the most common are heuristic methods, method with gradual opening of the contour (“minimum current” algorithms) will be more exposed.

In this approach, reconfiguration procedure starts with closing all switches in network, and thus the meshed distribution network is formed [3, 8]. Since distribution networks usually work radial, reconfiguration algorithm predicts one after another opening of the loops, on the way that allows achieving the optimal configuration with minimum of managing actions. The optimal configuration means states in which are had the optimal power flows, or power flows in branches which are producing minimal active losses in the network. These power flows are obtained from solving the Kirchhoff’s laws written for the given network.

From the previous exposure follows that optimal power flows are found starting from the meshed network. That means that switch, which should be opened (to open the loop), is selected in the last step, because then only one loop exists in the network while the rest of network is radial. It is clear that in preceding steps can be several loops, which doesn’t match with real conditions.

Procedure exposed previously can be simplified. This is achieved if only one switch is closed at a time instead of simultaneously closing all of the switches and forming the meshed network and then opening the switches one after another in order to obtain radial configuration. On that way a single loop is formed and radial configuration is obtained by opening the same or some other switch inside the loop, depending of optimal power flow results applied on the branches of a loop. As mentioned before, optimal power flows in branches of formed loop, are obtained by solving the Kirchhoff's laws for given loop.

Feeder reconfiguration algorithm begins with power flow calculation of radial network. Switch which is normally opened now is closing to form the loop. Normally opened switch can be selected depending of voltage on the switch or arbitrarily. There are three options:

- Normally opened switch on whose contacts the voltage has the highest value is closed (as effect of maximal voltage difference, there is expectation of gaining the maximal loss reduction).
- Switch on whose contacts the voltage has the lowest value is closed (because of minimal voltage value, expectation is very slow convergence of the solution).
- Switches are selected arbitrary.

It can be shown that gained final solution is the same regardless of the selection.

Closing the normally opened switch, changes the distribution of power flows and is needed to find the new solution. Here is assumed that consumption is replaced with constant current obtained by determining of power flows in radial network.

Previously exposed procedure that is radial network calculation start, forming of the loop by closing the normally opened switch, determining optimal power flows and forming of the radial network is repeated as long as it brings the loss reduction.

III. Test Example

In order to demonstrate the effects of reconfiguration as a measure for reduction of energy losses, in this chapter are displayed results for power loss calculation in distribution network with rated voltage of 10 kV, illustrated in Fig. 1. In this figure, circles marks the 10/0.4 kV/kV substations.

Insight into calculation results enables finding the critical spots in terms of power losses. Line sections which represent "critical spots" in terms of losses are circled in Fig. 2. Power losses are identified in 15 sections (of 158) and their value is 525.22 MWh, which represents 79.2 % of losses in all distribution lines of the observed 10 kV distribution network.

Applying these reconfiguration methods with minimal loss criterion, determines the optimal configuration of network. Translation of current stage to optimal requires 8 manipulations to be done (4 openings and 4 closing). In Fig. 2 there are market spots which represent made manipulations.

To perceive the effects of reconfiguration, in Table I are illustrated calculation results for the losses before and after reconfiguration. It can be seen that for considered period of time, reconfiguration leads to loss reduction of 154.8 MWh.

TABLE I
CALCULATION RESULTS FOR POWER LOSSES MEDIUM-VOLTAGE DISTRIBUTION NETWORK BEFORE AND AFTER THE RECONFIGURATION

	Before reconfig.	After reconfig.	Difference
Supplied energy (MWh)	52207.5	52052.7	154.8
Total power losses (MWh)	1252.34	1105.21	147.13
Power losses in percent (%)	2.4	2.123	0.277
Distribution line losses (MWh)	663.382	516.218	147.164
Transformer iron losses (MWh)	299.473	301.24	-1.767
Transformer copper losses (MWh)	289.485	287.75	1.735

IV. Conclusion

The paper points to the possibility of using reconfiguration to reduce energy losses in distribution networks. Classification of the methods is proposed, and after that the methods with gradual opening of the contour (“minimum current” algorithms) is discussed in details. This is heuristic method which proved to be very suitable for solving reconfiguration tasks, considering complexity and insufficient

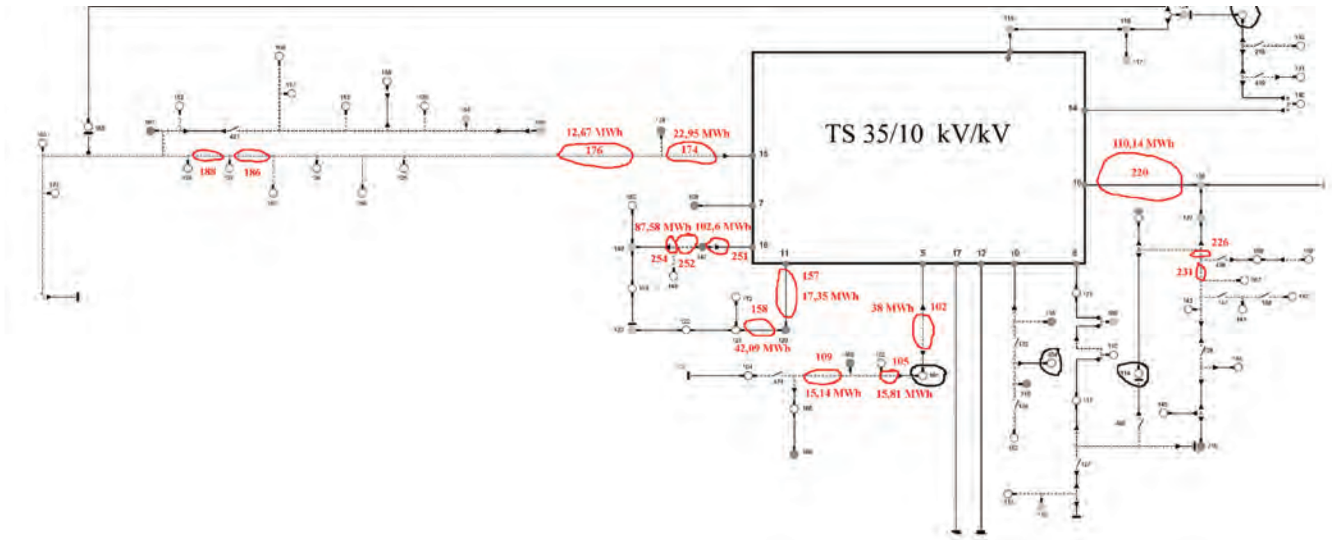

Fig. 1. Critical spots in 10 kV distribution network supplied from substation 35/10 kV/kV

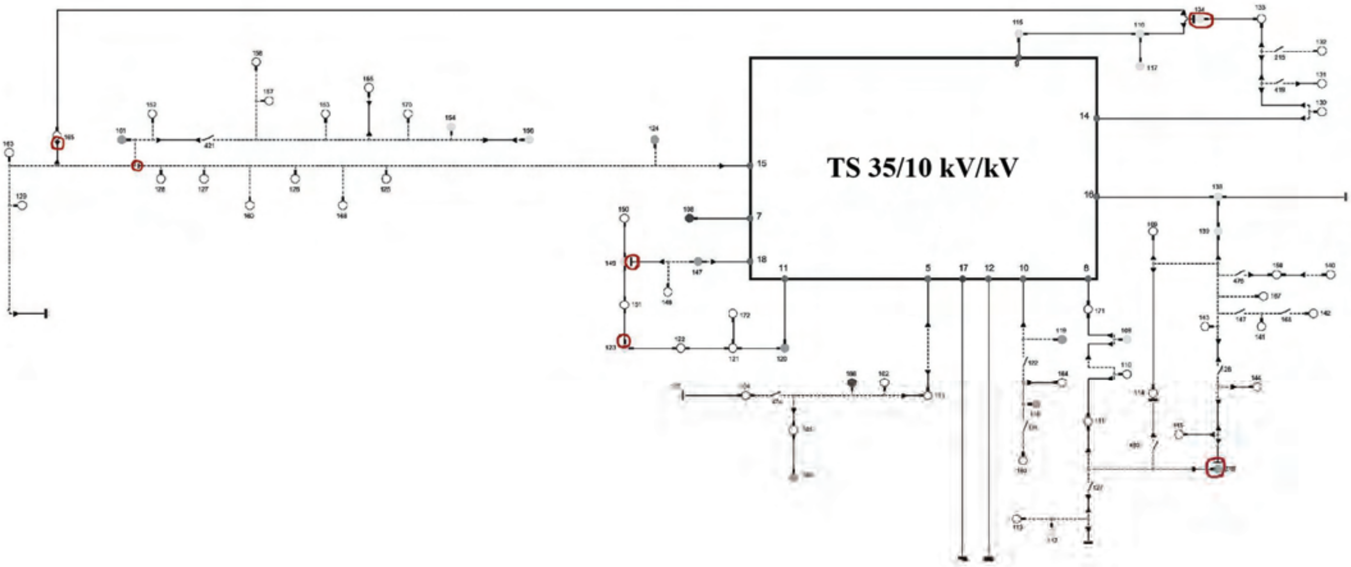

Fig. 2. Medium-voltage distribution network after the reconfiguration

reliability of data. Analyses that were undertaken by the authors on actual networks show that reconfiguration should be conducted always when technical capabilities allow that.

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