MEĐUNARODNO REGIONALNO SAVETOVANJE O ELEKTRODISTRIBUTIVNIM MREŽAMA

REGIONAL CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION

Crna Gora, Herceg Novi, 5 - 8. oktobar 2004. / *Montenegro, Herceg Novi, October 5 - 8, 2004*

FAULT CURRENT CALCULATION DURING RECONFIGURATION OF DISTRIBUTION NETWORK

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ABSTRACT

This paper deals with reconfiguration problem in radial distribution network. During reconfiguration procedure is necessary to provide insight in fault current values. These values are very important for calculation of switchgear stress as well as for providing of appropriate relay functionality. In this paper is considered application of branch exchange method for optimization of network structure regarding fault current values. The main goal of the paper is to provide all equations for efficient calculation of fault currents after change of topology during branch exchange procedure. The equations give fault current values as function of: 1) Δ-change of network structure (exchange of positions of normally open and normally closed switches) and 2) pre-change fault current values. All considerations in the paper are illustrated by appropriate example.

Keywords: Reconfiguration, Branch-exchange, Fault current, Distribution network

1.INTRODUCTION

The mandatory request in exploitation of contemporary distribution networks is to provide the maximum in economic domain (minimal losses, postponements of investment, etc) without deterioration of technical functionality. These two requests are strongly coupled. E.g. minimization of technical losses directly means cheaper network operation and implicitly, in the same time, that network structure is "balanced". In this case word "balanced" means that length of feeders are equalized (normally if it is possible), loads are even distributed. This means that existence of long and heavy loaded feeder will be minimized and that functionality of e.g. relay protection will be improved (elimination of extremes means implicitly better protection). Therefore, network structure should be adjusted according to these requests. In sequel, it is necessary to find out optimal network structure that fulfills these requests. This means that an optimization procedure have to be applied to solving this problem. In this paper is considered technical aspect of this problem. Changing of network structure can be technically evaluated and multiplied by appropriated coefficient and in this way evaluated in economic aspect. The branch exchange is the optimization procedure that is applied in considerations in this paper. Considerations are focused on one part of technical evaluation –

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changing of fault current value during branch exchange procedure. For solution of this problem, one standard but not efficient solution can be always applied – network model can be established for each network structure after every change and then fault current values can be calculated. Application of this solution is NOT appropriate because in the radial and weakly meshed distribution network are applied normally branch oriented calculation methods that require layer structure of network. Having in mind that typical network structure sometimes contains hundreds and thousands of nodes, renumbering and layering of the network can be very time consuming job. In order to avoid this and to provide efficient calculation of fault current during optimization procedure a new approach is suggested. This approach is based on assumption that for calculation after branch exchange is used layer structure before change and that effect of change are taken into account by appropriate equations. In such a way, layer structure is always the same, while effect of changes are taken through equations.

The optimization method that is considered is branch exchange method is given in the second part of the paper [1,2]. This method is applied for minimization of total current stress of feeder bay breaker during faults (this is objective function). All relevant equations for calculation of this stress during branch exchange procedure are given in this part. Effect of branch exchange procedure can be located on relatively small part of network, so concept of a local network is used in consideration. In this case, the concept of local network means that all parts of network that are not directly involved in calculation procedure can be in some way equivalenced and in such a way significantly decreased dimensionality of calculation problem. In this paper consideration is focused on radial networks without distribution generators.

In the third part are given algorithm for application of optimization procedure. The next part is devoted to a small numerical example, while in two last parts are given conclusion and literature.

2. BRANCH EXCHANGE METHOD

All considerations that follow are illustrated by example given in figure 1. Both of feeders are fed from the same supply substation. They are denoted by (k) and (n). Feeder with NO switch is marked by (j) and feeder with NC switch with (i). NO switch is marked by empty while NC with filled black circle. Filled circles on beginning of feeders (k) and (n) denote feeder breakers.

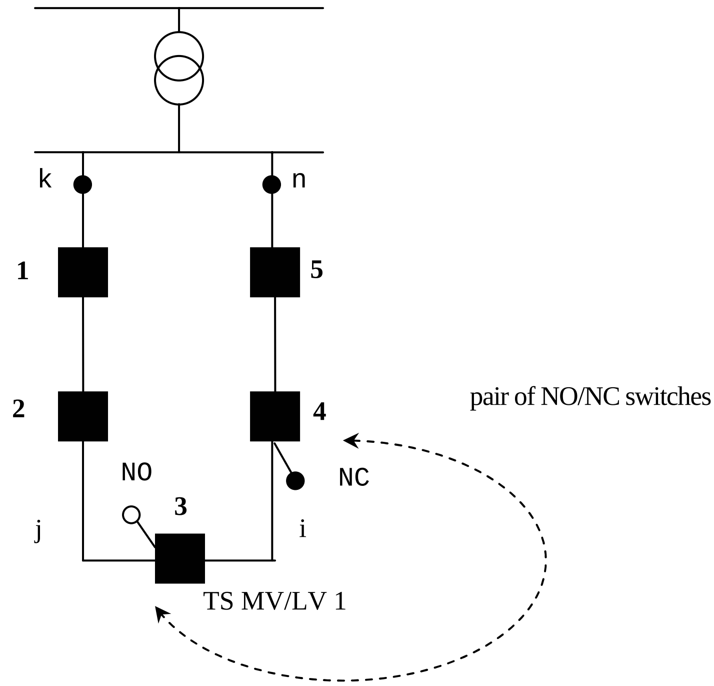

Fig 1. – Local network with two feeders

Branch exchange method are generally applied in the three steps:

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1) Identification of a coupled pair of normally opened (NO) and normally closed (NC) switches in the part of network of interest [1,2]. Generally speaking, this pair can be identified on virtual loops trough part of network of interest (local network). Virtual loop consists of two radial parts of a network supplied from the same point and separated by one NO switch. One such loop is given in figure 1 where one such loop comprises two shown feeders.

   After exchanging of NO/NC switches all parts on virtual loop have to be energized. Exchanging of NO/NC equipment means that NO become NC and NC becomes NO equipment.

2) Exchanging of NO/NC switches – one such exchange is given in figure 1, where are given two feeders with belonging distribution transformer substations medium/low voltage (TS MV/LV); Calculation of all necessary fault current values.

3) Calculation of objective function values and decision-making about the next step.

It is presumed that are known Thevenin impedances from any of locations where are positions of NO/NC switches (these impedances can be easily calculated by procedure given in [3, 4]). Value of the fault current on the feeder head during fault occurrence on the end of the feeder (j) is also known.

Derivation of equation for fault current value after branch exchange

Let consider direction of branch exchange from branch (j) to branch (i) – figure 1. After this operation feeder (i) belongs to feeder (k). The first step means calculation of coefficient coef in the following way:

$$coef = \frac{I_{breaker\_fault\_end\_j}}{I_{branch\ j}}, \tag{2.1}$$

where:

$I_{breaker\_fault\_end\_j}$ – value of the fault current trough breaker during fault occurrence on the end of the feeder j,

$I_{branch\ j}$ – value of fault current through branch j during fault occurrence on the end of the feeder j.

The next step is calculation of Thevenin impedance (Norton admittance) for a new position of NO switch (new position of NO switch is on branch (i) close to substation 4). This new admittance is calculated as:

$$\frac{1}{Y_{new}} = \frac{1}{Y_{j\_old}} + Z_{branch\_i} \tag{2.2}$$

where:

Y_{new} – equivalent Norton admittance from new position of NO switch,

Y_{j_old} – equivalent Norton admittance from beginning position of NO switch,

Z_{branch_i} – impedance of branch (i).

Having Y_{new} is not difficult to calculate fault current value on new position of NO switch. Having value of this fault current, it is necessary to calculate current on the opposite side of branch (i). Without distribution generators this calculation is trivial and it can be considered that fault current on opposite side of branch (i) is the same as on fault location. Value of the current trough breaker on the beginning of the feeder (k) is calculated using coefficient from relation (2.1):

$$I_{breaker\_faulth\_end\_i} = coef \cdot I_{branch\_j\_change\ NO/NC}, \tag{2.3}$$

where:

$I_{breaker\_faulth\_end\_i}$ – value of fault current trough breaker during fault occurrence on end of branch (i) where is location of new NO switch,

$I_{branch\_j\_change\ NO/NC}$ – value of fault current through branch (j) during fault occurrence on end of branch (i).

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It is necessary to point out that current trough breaker on the feeder (k) beginning is calculated without calculation of all network state.

Calculation of breaker stress

Having value of fault current trough breaker during fault for all variant NO/NC switch – exchange, breaker stress can be calculated. For exchange position of NO/NC switch given in figure 1, breaker stress on feeders head (k) and (n) in basic structure (before branch exchange) can be calculated as:

$$S_{th\ basic\ (k)} = \sum_{t=1}^{4} \nu_t \cdot \lambda_t \cdot t_{t\_(k)} \cdot \sum_{m \in \alpha_k} l_m \cdot I^2_{breaker\ (k)tm} \tag{2.4}$$

$$S_{th\ basic\ (n)} = \sum_{t=1}^{4} \nu_t \cdot \lambda_t \cdot t_{t\_(n)} \cdot \sum_{m \in \alpha_n} l_m \cdot I^2_{breaker\ (n)tm}\ , \tag{2.5}$$

where:

t – type of fault (1 – single phase, 2 – two phase, 3 – two phase to ground, 4 – 3 phase),

ν_t – coefficient for all types of fault (3 for t=4; 1.5 for t=2 and 3; 1 for t=1),

λ_t – intensity of t type fault on line per unit length,

$t_{t\_(k)}$ – tripping time of breaker (k) ($t_{breaker(k)} + t_{relay}$)[1],

$t_{t\_(n)}$ – tripping time of breaker (n) ($t_{breaker(n)} + t_{relay}$),

α_k – set of branches that belongs to feeder (k),

α_n – set of branches that belongs to feeder (n),

l_m – length of branch (m),

$I_{breaker\ (k)tm}$ – value of t type fault current trough breaker (k) on beginning of feeder (k) in basic structure for fault on the end of line (m),

$I_{breaker\ (n)tm}$ – value of t type fault current trough breaker (n) on beginning of feeder (n) in basic structure for fault on the end of line (m).

After exchange position of NO/NC switches, breaker stress on beginning of feeders (k) and (n) can be calculated as:

$$\begin{aligned} S_{th\ new\ (k)} &= S_{th\ basic\ (k)} + \Delta S_{th\ (k)}, \\ S_{th\ new\ (n)} &= S_{th\ basic\ (n)} - \Delta S_{th\ (n)}, \end{aligned} \tag{2.6}$$

where:

$$\Delta S_{th\ (k)} = \sum_{t=1}^{4} \nu_t \cdot \lambda \cdot t_{t\_(k)} \cdot \sum_{m \in \alpha_{k-n}} l_m \cdot I^2_{breaker\ (k)tm} \tag{2.7}$$

$$\Delta S_{th\ (n)} = \sum_{t=1}^{4} \nu_t \cdot \lambda \cdot t_{t\_(k)} \cdot \sum_{m \in \alpha_{k-n}} l_m \cdot I^2_{breaker\ (n)tm} \tag{2.8}$$

where:

$\alpha_{k\text{-}n}$ – set of branches between considered NO/NC switches.

Values of $I_{breaker\ (k)tm}$ current in equation (2.7) are calculated using equations (2.1) – (2.3), while values $I_{breaker\ (n)tm}$ in equation (2.8) are known from state prior branch exchange. It is necessary to point out that all calculations are performed in small part of network – local network that contains only network between NO and NC switches. This moment is crucial for provision of very efficient calculation during branch-excange method.

Total breaker stress (objective function) is:

$$S_{total} = \sum_{p=1}^{br} S_{th(p)}, \tag{2.9}$$

[1] it is considered application of time defined relays (relay tripping time is constant for faults along feeder.

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where:

br – is total number of breakers in distribution network.

If total breaker stress after branch exchange is smaller, direction of branch exchange is appropriate. Otherwise, direction should be changed (in opposite direction).

Obviously, this proposed method provides very efficient calculation of fault current in part of network of interest (especially in network structure with numerous number of nodes).

3. ALGORITHM

In this algorithm is given description of procedure that provides minimization of breakers stress. It is considered optimization inside one root (supply substation) of the network:

1. Identification of position of NO switches; identification of virtual loops.
2. For each loop, identification of adjacent NC switches on virtual loops in considered network; these NC switches constitutes set of NO/NC switches pairs. Appropriate local network is identified also.
3. Selection of the first virtual loop.
4. Selection of one of two possible directions for moving along selected virtual loop.
5. It is taken the pair of NO/NC switches in accordance with selected direction with minimal number of branches on the loop between its switches. Selected pair is removed from the set of NO/NC switches pairs for this loop. If no more pairs, jump on step 11.
6. Calculation of coefficient using equation (2.1).
7. Calculation of equivalent impedances (2.2), currents (2.3), breaker stress (2.4-2.6).
8. Comparison of total stress breakers on the loop before and after branch exchange.
9. If the total breaker stress (2.9) after branch exchange is less; this direction stay valid. Jump on step 5. If stress after branch exchange is greater direction is changed. Direction can be changed only once for selected loop. If direction is changed twice go to next step.
10. Selection of the next loop from set of identified loops; jump on step 4. If no more loop go to next step.
11. End.

4. EXAMPLE

A small example network presented in figure 2 is used for illustration of the algorithm. Considered network consist of one supply substation 110/20kV and one subastation 35/10kV, 14 MV/LV substations and 7 cable (20kV), 7 cable (10kV) and 5 overhead 10kV lines.

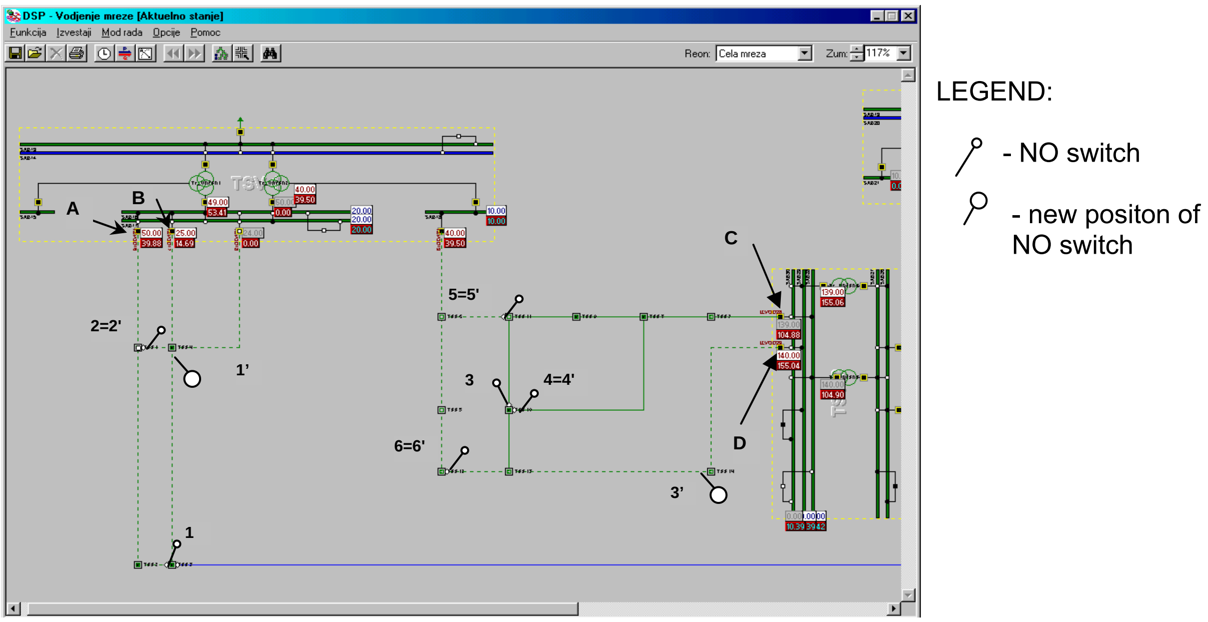

Figure 2 – Test network

Breakers are marked from A to D. NO switches for basis structure are marked from 1 to 6 while NC switches in optimal structure are marked from 1' to 6'.

Calculated results for 3-phase faults are given in Table 1 for basic and optimal structure.

Table 1 – Calculated breakers stress in basic and optimal structure in example network

	Basic structure	Optimal structure
Breaker A	3.415	4.356
Breaker B	6.200	5.183
Breaker C	1.664	2.151
Breaker D	1.523	0.299
Σ entire network network	***12,802***	***11.898***

It is not difficult to notice that breaker stress is less then in basic structure. It is necessary to point out that only two NO switches change their positions – switches 1 and 3. Above displayed results confirms that changing position of NO/NC switches can reduce breaker stress and in such away improve technical and economic aspects. Above-mentioned procedure also opens possibility to be included in algorithms for multi-approach optimization.

5. CONCLUSION

This paper describes procedure for reconfiguration of distribution network using branch exchange method applied in optimization procedure. Very important support for efficient application of this method is developed in this paper – it is offered very simple procedure for fault current calculation during branch-exchange procedure. All necessary calculations are limited on small part of network – local network limited with position of NO/NC switches. This moment significantly decreased dimensionality of calculated problem and provides high efficiency.

Verification of proposed algorithm is accomplished on small example distribution network. Application of developed procedure open possibilities for including procedure in multi criteria approach for optimization of network structure.

6. LITERATURE

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