The impact of reconfiguration on power losses in smart networks

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***Abstract* — There is quite a lot of losses in electricity transmission, because is produced in large power plants that are located at great distances from end-users. About 10% of the energy is lost during transmission. Power losses depend on climatic conditions, parameters, and network configuration. Some can be influenced, some not. Climate conditions cannot be influenced, but network topology can be changed. This article focuses on the use of controlled switching and reconfiguration divisional switches on power lines to influence the power losses in the network.**

Keywords — network topology; power losses; reconfiguration

I. Introduction

Nowadays, the so-called centralized generation of electricity is most often used. Centralized generation is a form of electricity generation in which electricity is produced in large power plants which are located at great distances from end-users. Power grid consists of the following elements: power plants, electricity substations, transformers and from branches (lines), which are connect the producers and consumers. After production, electricity is transformed into higher voltage levels to reduce transmission losses in the grid. Near end-users, electricity is transformed back to lower voltage levels [1], [2].

As the share of renewable energy sources increases, the classic centralized scheme is transformed into decentralized electricity generation. In households, thanks to renewable energy sources, it is already possible to produce electricity [3]. Therefore, in the electrical scheme, new resources and new technologies emerge, thus requiring new communication between them. It is important that the individual components can communicate with each other, react to each other, and we can watch all the important parameters of the network and whether we can change it. After these changes, the network becomes more intelligent, created SMART GRID.

Smart grids are automated systems that use technological devices to monitor electrical power flows in the grid to maximize energy efficiency [4]. According to the European Commission, smart grid can be described by the following aspects:

- flexibility - responds to consumer demands
- availability – renewable energy sources can be connected to the grid.
- reliability - always ensures security of electricity supply.
- economy - effective energy management, power loss reduction [5].

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II. Steady-state model

To investigate the impact of the reconfiguration on power losses in the electricity distribution system it is necessary to solve steady state. Steady state is a condition where the line parameters does not change in time. In real terms, such a condition due to the variable load climatic conditions, failures, etc. does not exist. Simplification can be envisaged in the calculations if these conditions remain unchanged until the end of the calculation.

The Fig. 1 show the network topology that was used in the calculations. In the Fig. 1 the black lines characterize that the branches cannot be changed, but the red lines characterize it can be changed. It can be use reconfiguration for these branches.

Grid parameters, so the line parameters are characterized by a Table I. This Table contains the names of the lines, contains from which node to which node they go and the R and X parameters, so the resistance and reactance.

The Table II are also contains the parameters of the branches. These branches will be used to change the network topology which will cause the power losses to change. The losses depend on the parameters of the lines. If the resistance is high, more losses will occur on the line.

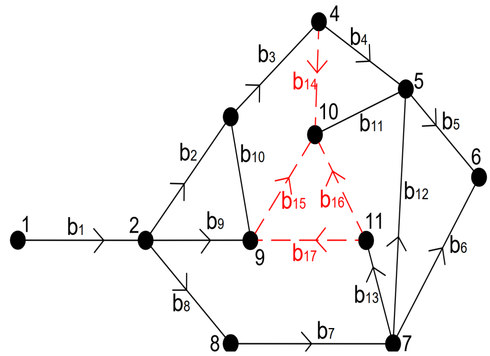

Fig. 1. Network topology

TABLE I. BRANCH PARAMETERS

Branch	*Start node*	*End node*	*Resistance R [Ω]*	*Reactance X [Ω]*
1	1	2	0,9	0,99
2	2	3	1,25	0,8625
3	3	4	2,07	1,05
4	4	5	1,05	0,714
5	5	6	1,932	0,924
6	7	6	0,69	0,33
7	8	7	1,242	0,594
8	2	8	1,173	0,561
9	2	9	1,035	0,495
10	3	9	0,966	0,462
11	5	10	0,897	0,429
12	7	5	0,552	0,264
13	7	11	0,552	0,264

TABLE II. BRANCH PARAMETERS, WHERE IS POSSIBLE TO MAKE RECONFIGURATION

Branch	*Start node*	*End node*	*Resistance R [Ω]*	*Reactance X [Ω]*
14	4	10	0,552	0,264
15	9	10	1,449	0,693
16	11	10	1,242	0,594
17	11	9	0,759	0,363

Parameters of the nodes characterized by the Table III. Active and reactive power are characterized the consumption, which is also emphasized by sign (-).

TABLE III. ACTIVE AND REACTIVE POWER AT NODES

	Consumption	
Node	*Active power P [MW]*	*Reactive power Q [MVAr]*
1	0	0
2	-2,50	-0,60
3	-1,80	-0,40
4	-1,20	-0,30
5	-1,50	-0,35
6	-1,50	-0,35
7	-1,50	-0,35
8	-1	-0,20
9	-1	-0,20
10	-0,70	-0,14
11	-0,70	-0,14

At node 1, the voltage is 23 kV. With the help of these parameters (line parameters, active and reactive power at nodes and with voltage at node 1) was solve the steady state. To the solve steady-state, Newtons iteration method was used. It is an iteration method which starts with initial value V_0. Calculation runs until the difference between two iteration steps is smaller than a predefined limit ε. The stopping conditions for the iteration is when: $|V_i - V_{i-1}| < \varepsilon$. Absolute value is necessary because final value can be negative. The negative value means that we have already exceeded the correct value. The Newton method tends to converge very quickly, however, the speed of convergence depends strongly on the chosen initial value V_0 [6].

Newton iteration method was solved in the program MATLAB. The software consists of two separate environments - numerical and graphical [7]. In this article was used the numerical environment. Lines and node parameters were defined in the software MS Excel. MATLAB imported these parameters from the software MS Excel and with Newton iteration method was calculated the steady state. Import these parameters from MS Excel was important, as it was less opportunity for error compared if we had written everything for ourselves. In addition, this made the program general, because in other grid, where are other parameters it is enough to rewrite the excel table and MATLAB will calculate the result.

Total active and reactive power losses were calculated in the Matlab and results have been exported to the Excel.

Total active losses in the network without reconfiguration, so when the black lines on the Fig. 1 was on and the red lines was switch off, was 0,5706 MW and the total reactive power losses was 0,5033 MVAr. The next section will describe how the loss changes with reconfiguration.

III. APPLICATION OF THE RECONFIGURATION

Network reconfiguration for the reduction power losses is a relatively new phenomenon. It became known especially when new technologies and smart grids were used. This term describes the implementation process of remote-controlled switches sectional that are preselected. Switches can be turned on and off, which can cause network losses to change [8], [9], [10], [11].

It is important to calculate how many options can be used to turn the branches on or off. In practical life this does not used. Nowadays there are a specific number of lines, which are connected, disconnected to the grid. In the future, when it comes to smart grids, this will be a good option for a combination of lines (for example: the consumption of the nodes will be given. This can be used to determine if specific lines need to be turned on or off, or a combination of these may be needed).

We can use the combinatorial formula. This example is a combination without repetition because we can find out how many ways we can turn on and of these 4 lines.

The general formula for combinatorics, when the order is not important, is follows [12]:

$$C_k^n = \binom{n}{k} = \frac{n!}{k!\,(n-k)!} \quad (1)$$

In our case we have 4 lines, which can be turned on as follows:

- 1 is turn on, the remaining 3 are off.
- 2 are turn on and 2 are turn off.
- 3 are turn on and only 1 is turn off.
- Every lines are turn on.

The following formulas are obtained:

$$C_1^4 = \binom{4}{1} = \frac{4!}{1!\,(4-1)!} = 4 \quad (2)$$

$$C_2^4 = \binom{4}{2} = \frac{4!}{2!\,(4-2)!} = 6 \quad (3)$$

$$C_3^4 = \binom{4}{3} = \frac{4!}{3!\,(4-3)!} = 4 \quad (4)$$

$$C_4^4 = \binom{4}{4} = \frac{4!}{4!\,(4-4)!} = 1 \quad (5)$$

Thus, a total of 15 possibilities can occur if combined with 4 line. These possibilities are shown in Table IV.

All options are shown in the Figures from Fig. 2 to Fig. 7. For the active power losses are shown from Fig. 2 to Fig. 4, for reactive power losses are shown from Fig. 5 to Fig. 7. The power losses vary considerably depending on which line is switched on or off. In this case, the power loss was lower compared to the original data.

TABLE IV. COMBINATION OPTIONS

B14	B15	B16	B17	→	4
B14 – B15	B14 – B16	B14 – B17	B15 – B16	→	4
		B15 – B17	B16 – B17	→	2
B14 – B15 – B16		B14 – B15 – B17		→	2
B14 – B16 – B17		B15 – B16 – B17		→	2
B14 – B15 – B16 – B17				→	1

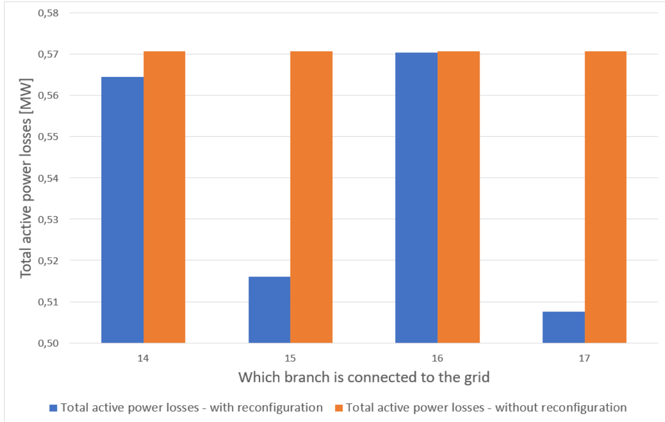

Fig. 2. Depending of total active power losses to which branch is connected to the grid

Figures from Fig. 2 to Fig. 4 characterized how it changes the total active power losses. The worst results, with the smallest reduction in loss, were achieved when only one line was connected to existing networks. When we started to combine them, except in one case, the loss significantly decreased, around 10 %. Best results are shown in the Fig. 4, when the lines are combined. Similar results are obtained after switching on 15-17 and 14-16-17. The active power losses decreased around 14 %.

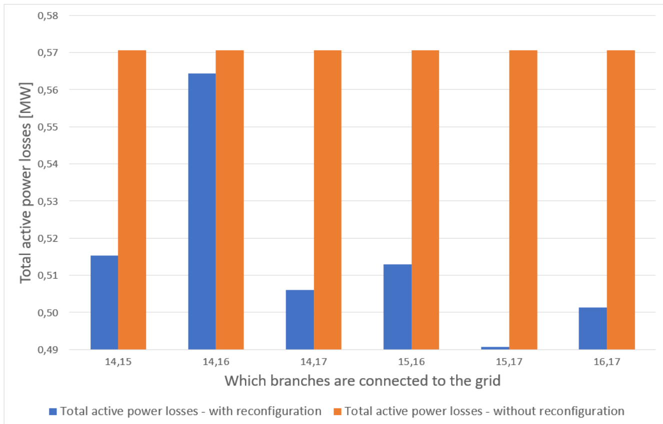

Fig. 3. Depending of total active power losses to which branches are connected to the grid – part 1

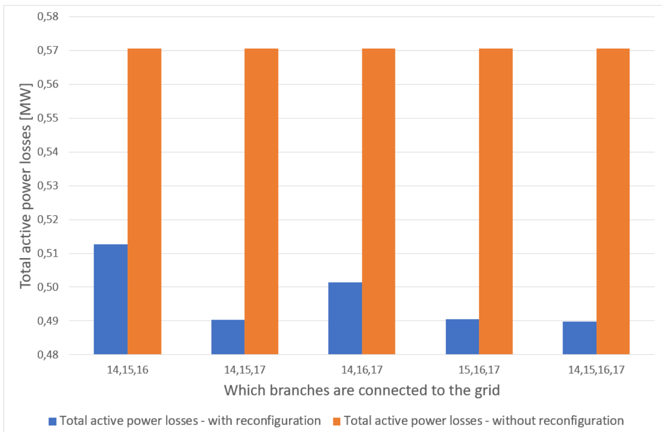

Fig. 4. Depending of total active power losses to which branches are connected to the grid – part 2

Like active power losses, even the losses of reactive power have decreased. Even in this case, the best solution is to have all the lines turned on. In this case the loss only decreased by 9 %. The reason for this is that the initial value was lower, so it does not appear as much. But the extent of the decline is also noticeable here.

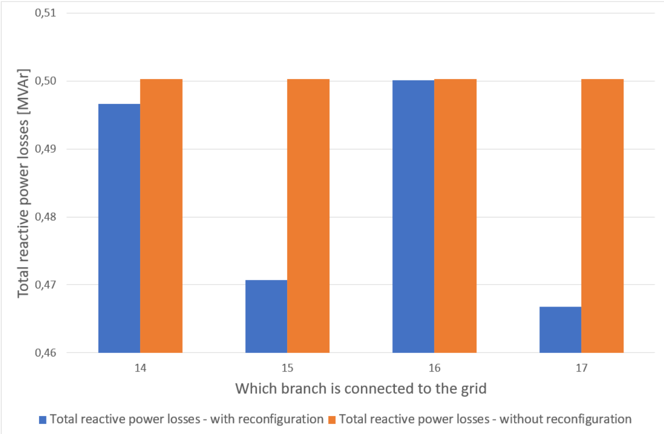

Fig. 5. Depending of total reactive power losses to which branch is connected to the grid

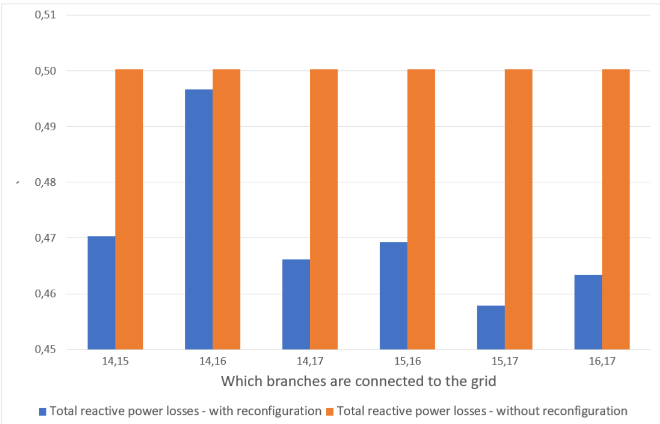

Fig. 6. Depending of total reactive power losses to which branches are connected to the grid – part 1

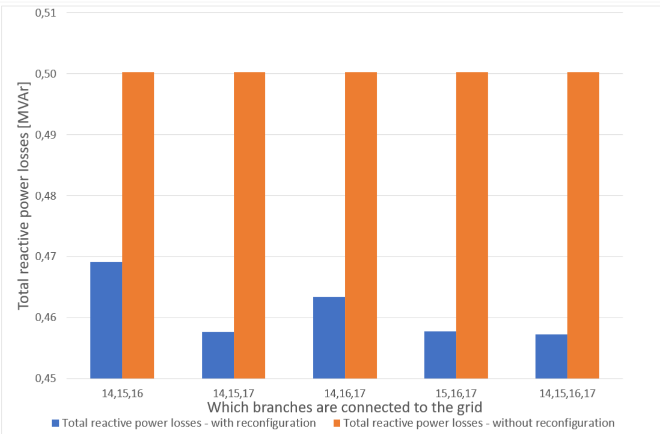

Fig. 7. Depending of total reactive power losses to which branches are connected to the grid – part 2

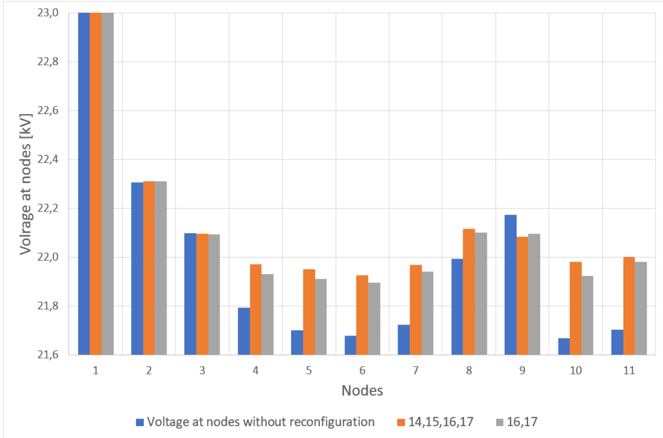

Fig. 8. Voltage change in the network depending on the branches connected to the network

It is also important to look the voltage at the nodes network because the voltage will be within the allowable range. This is shown in the Fig. 8.

The worst value of the voltage at the nodes is then when we are do not use reconfiguration. The worst value is in the node 10. The difference of voltages between node 1 and node 10 is 1,4 kV. If to the network are connected lines 16 and 17, the voltage at the node 10 is higher. However, it can also be seen that the voltage it has risen not only in this node but also in the other nodes. The best values are than when all the lines are connected to the grid.

It was not necessary to examine the overload of the wires in this article, as the worst values were generated when only wires 0-13 were considered. If reconfiguration was used, new wires were connected, only better results were always obtained. The voltage at the nodes increased, the loss decreased, the load on the wires also decreased.

IV. Conclusion

This paper discussed the impact of network reconfiguration on active and reactive power losses. It was shown how the power losses in the network change depending on the shutdown of individual lines. When the reconfiguration is well resolved, the power losses are decreased compared to what it was in the steady-state model. In case of an inappropriate shutdown, losses may will increase significantly. It is also necessary to consider the voltage due to its change during network reconfiguration. In addition, the currents in the line must also be looked at. In this article it was not necessary to examine the overload of the wires, because the worst values were generated, when reconfiguration was not used. When reconfiguration was used, only better results were generated. All options should be considered to determine if reconfiguration can help or not.

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