REDUCTION OF POWER AND VOLTAGE LOSSES IN LOW VOLTAGE NETWORKS BY REACTIVE POWER COMPENSATING

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SUMMARY

The main goal of the paper is initiation of new approach aiming to reduce power losses. Simultaneously, some voltage problems at the low voltage networks ends are solved. Basic idea is incorporation of compensation of reactive power deep in the low voltage networks. Several examples, presented here, show our experiences in method applying.

INTRODUCTION

The initial idea of this method development was after implementing power system analysis on technical losses distribution over the facilities of the different voltage levels. All electric magnitudes are dynamic moment values by their character, but generally the mean electric values are used for comparing purposes. The technical power losses consist of active and reactive power losses depending on load flows in the power distribution system during the year.

Active component of power losses are inevitable during electricity supply process depending on power lines lengths, power lines characteristics (lead material and geometry) and load function. Although, reactive power losses are minor part of the total technical losses, our focus is exact on them. They are caused by reactive power flows depending on synchronous machines that are installed and deposited over the low voltage lines. It is easy to see that dominant participation of reactive power losses are in low voltage (LV) lines.

Nowadays, the last stage in reactive power compensating is in the LV blocks in substations MV/LV. Basic function of these compensation batteries is in reactive power reducing of inductive transformers 10/0.4 kV power load. Generally, these compensation batteries (nominal power) are over dimensioned with installed reactive power solely for transformer compensation (magnetizing core), so they also reduce a part of reactive power arise in the LV lines. Designed capacity banks reduce reactive power and correlated losses in middle and upper voltage networks and simultaneously increase power lines capacity.

Because of that, natural reactive power demands of installed electrical appliances pass almost completely throughout the LV networks while only the uncompensated part of reactive power pass through the middle and upper voltage levels lines. According our measures and quantified evaluations performed in power network DP “Elektra” Slavonski Brod (part of national board distribution), losses caused by the reactive power are around 8% of all technical losses in middle and low voltage network. The same losses in low voltage networks are even around 18%.

REACTIVE POWER COMPENSATION

Power Factor

The power factor is electric load parameter that is used for defining explicit ratio between active and reactive power load. Power factor in LV networks rates from 0.6 during the summer nights (load minimum) to 0.9-0.95 during the winter evenings (load maximum). During wintertime there is depreciation of reactive power loads due to dominating heater devices. It is also very interesting observation that daily distribution of reactive power loads is remarkably balanced, in correlation with the same active power load distribution.

New Approach

The method is based on the reactive power compensating in the starting sections of LV feeder by installing capacitor battery in the depth of the feeder. The application of this method is very cheap and simple, gaining quick reduction of active power losses and enhancement of voltage circumstances in low voltage networks. Each application step needs enough engineering time engagement to calculate all solutions and select the best one with minimum losses and simultaneously to meet all voltage conditions. Maximum voltage values during load minimum need not to be exceeded.

Power line losses directly depend on load as time function (daytime and season). Total estimated losses in LV networks is 34% according to total technical losses in entire distribution network (MV and LV) of analyzed distribution area, even it raises to over 40% during the days with maximum amounts of power flow.

Capacitors Mounting Location and Nominal Power

Disposing of compensation battery mounting point deep in the line (pole) and the battery nominal power selection is determined by power flow calculation. Described technique is based on load flow calculation for radial feeders that are consisted of four conductors (three phases and one neutral wire).

There are several necessary preconditions for calculation performing like input variables - active loads in each node, voltage and load at the start feeder point and output control variables like maximum of voltage and line capacity. Also, calculation has to take under consideration unbalanced consumption of electrical energy for 24-hour period with spatial and time layouts of power flows and belonging losses.
Here, uncertainty of consumer’s loads during the day is solved on the base of their percentage in total input load and values of time-changeful input loads. Following fundamental expressions represent calculation basics:

$$\Delta P_n = \frac{P_n^2 + Q_n^2}{U_{n-1}} - R_n$$  \hspace{1cm} (1)

$$\Delta Q_n = \frac{P_n^2 + Q_n^2}{U_{n-1}} - X_n$$  \hspace{1cm} (2)

$$U_n = U_{n-1} - \frac{R_n P_n' + X_n Q_n'}{U_{n-1}} - \frac{X_n P_n' - R_n Q_n'}{U_{n-1}}$$  \hspace{1cm} (3)

$P_n'$ - active load in start of section (n-1,n),
$Q_n'$ - reactive load in start of section (n-1,n),
$U$ - node voltage,
n, n-1 - node numbers
$R_n$ - line resistance in section (n-1,n),
$Q_n$ - line reactance in section (n-1,n).

Power lines are divided into partitions between feed node, consumption nodes and end node. Sometimes, there are a few partitions on secondary line branches. Input active and reactive load of specific node decrease from node to node as the calculation come to end point of the power line. In other words, power line that is completely designed of the same electric cable has greatest losses in the first partition (between the first or feeding point and the first consumption point). Calculated voltage at the first consumption point is the starting voltage for the second (next) line partition.

Output calculation results are active and reactive load losses and voltage losses in each network partition between two nodes. At first, power system engineer wants to be aware of network losses before any further action. Serious scientific work need to be critically inspected – here, calculation results (voltage losses) are compared with measured values at several nodes.

The worst case of line voltage loss is during the period of peak load, so it is designed voltage diagram depending on nodes (numbers). This diagram, given from calculation, depends on distance between feeder node and focused consumption node and also, load amounts between each node. Here, the detection of system partition with voltage problems (low voltage values) is defined.

The next method step is estimation of capacitance bank location and the battery nominal power. Power flow calculation is made several times – alternating different capacitors bank location and the battery nominal power. Here, the second condition has to be met: the voltage maximum at any line point need to be lower then 244 V, even during the minimal loads. New series of diagrams of feeder’s depth voltage for different cases of capacitance location and several nominal powers are designed for better visual presentation.

The method consists of these steps:

1. Determining the LV feeders with highest amounts of technical losses. They are determined by the calculations based on the sum of the annual consumption of all connected consumers in observed LV feeder.
2. Preparing the input data for calculation:
   a) 24-hour measuring of active/reactive power and voltage in the starting point of the LV feeder line and 24-hour measuring of voltage in the end of observed LV feeder, for several characteristic days;
   b) the disposition of consumers along the LV feeder and their annual consumption and
   c) topology and technical data of LV feeder.
3. Calculating the load flow along the LV feeder with results: spatial and time division of active and reactive power and voltage losses.
4. Based on previous step results, selecting the location of battery mounting and choosing capacitor battery nominal power (discrete units). It results in two different ways:
   a) maximum reduction of active power losses,
   b) maximum reduction of voltage losses.

**REDUCTION OF ACTIVE POWER LOSSES**

**Reactive Power Compensating**

Important influence factors in capacity bank nominal power selecting and battery mounting location determining are active power losses caused by reactive load flow in the low voltage feeder. This procedure consists of two steps:

a) Additional reactive power losses of low voltage line in both cases (before and after battery mounting) are compared, and the difference gives amount of decreasing active power losses. Battery losses have to be also added to additional losses. Decrease of active power losses is possible for feeders with high reactive load flow, especially with capacity banks of lower nominal power and mounting location near the feeder starting point.

b) Active load savings are calculated in middle voltage network caused by reactive load flow decreasing. Described calculation is made separately for transformation 10/0.4 kV, 10 kV power line, transformation 35/10 kV and for 35 kV power line. Total diminution is a sum of calculated values along the parts of the middle voltage network.

Power load depends on daytime, so calculation has to be done according the day load curve for each power system element. The result is daily decrement of active load losses. Power system calculations a) are performed for all pair combinations of capacity bank nominal power and possible mounting location, while the calculations b) are used only for different bank nominal loads. At the end, results of active power losses decrement in LV feeder a) and also in MV network b) are summed-up and make the base for creating diagram for active power losses comparing for each variant.

Such a graphical approach makes easier for design-engineer to recognize and select the best solution (maximum money savings).
Other Methods and Their Combinations

The best method results and savings are achieved if other proposed methods applied in combination with described reactive load compensation process a). These methods are:

- b) increasing of conductors capacity in starting parts of LV feeder and
- c) load phases balancing in depth of LV feeder.

All suggested methods are applied on the base of the same node to node load flow calculation. In the first case a) the most important factor for deciding on the end line point of increasing conductors capacity is the greatest ratio of decreasing active load losses and invested money. In the second case b) line in-depth phase redistribution of the consumers connected on the one phase gives better symmetred load with minimum losses in neutral wire.

EXAMPLE

An example of reducing losses in radial overhead LV feeder No. 3., transformer substation (TS) number 127 is shown on Figures 1. and 2. Feeder has 40 sections inside the total length of 960 m. In node 20. feeder splits in two radial ways, from nodes 21. to 33, and from nodes 34. to 40. Phase conductor area intersection is 50 mm² AlFe.

The spatial layout of daily losses is shown on Figure 1. Next diagrams show:

- blue - losses without reduction losses methods applied,
- red - method a) mounting of capacitor battery, nominal power of 20 kVA into 20th node of LV feeder,
- white - method b) increasing of intersection of conductors from 1st to 20th section by adding new conductors 70 mm² Al,
- green - method a) + b) combined and applied together.

It is clear to see great improvements in losses reducing, mostly in methods a) and b) combined.

Figure 2. shows possible reduction of daily losses in observed LV feeder. Additionally red line shows losses reducing given by load phase balancing.

Application of reactive load compensation method a) obtains daily losses decrease of 19% (57 kWh to 46 kWh). Connected investment with used method a) is 150 euro, so return time of investment is 0.5 year with quantified decrease of annual load losses of 4.0 MWh and Croatian price of 7.5 eurocent per kWh.

Maximum daily losses reducing of 70% (57 kWh to 17 kWh) is accomplished by combination of methods a), b) and c). Expenses of this methods applying are 2.800 euro, so with annual losses reduction of 15 MWh return time of invested money is 2.5 years.

Figure 3. shows the influence of applied methods on voltage losses reducing in observed LV feeder. The spatial division of one phase-voltage is shown in the moment of maximum power load. Minimal allowed voltage according to IEC standard is 207 V (231 V – 10% of nominal voltage). Before methods applied, voltage losses fall below minimal allowed value after node 14 of observed LV network. With application of methods a) and b), voltage in whole observed LV feeder is in allowed range (above minimum).

![Figure 1. Spatial diagram of daily losses in observed LV feeder](image-url)
CONCLUSION

Using described reactive power compensating method in the depth of LV feeder is possible to reduce active power losses in LV feeder up to 15%, and reduce voltage losses up to 8% depending on power load in LV feeder and total length of the power line. These new application of capacity batteries additionally reduce reactive power flows in the middle and upper voltage levels of the power system and make important technical savings. Described tool initiation requires enough engineers time for each power line and some extra time for controlling measures and calculations during the year.

REFERENCES

