METHODOLOGY FOR DETERMINATION OF 110/35 kV AND 110/20 kV SUBSTATION REVITALIZATION ORDER

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determination of 110/35 kV and 110/20 kV substation revitalization order, which are the oldest owned by Elektrovojvodina and deserve special treatment. It is necessary to note that in Elektrovojvodina during the last 25 years there is a process of transfer from 110/35/10 kV systems to 110/20kV systems, and currently both supply systems coexist.

Many years of experience in planning of 110/35 kV and 110/20 kV substation revitalization has directed us towards elaboration on site state indices and its development, as foundations for development of an objective methodology for the future revitalization plans. This methodology has brought to the same level both the TS 110/20 kV reconstruction, without the change of transforming system (which is the usual case in Serbia and around the world) and TS 110/35 kV reconstruction, where transformation system change is expected.

1. OPERATION CRITERIA

1.1. Age of site components

110/X kV substation consists of a few essentially different parts, therefore it is important to determine the age of each such part during the determination of the age of the whole site. Buildings, fences, access roads and internal roads are mainly built at the same time. Determination of age of all these site parts gives the first data for determination of age indices. Another important part of the substation consists of poles, beams, supporting structures, grounding, ropes and insulators, which are also mainly built at the same time. The third separate section of the substation is the 110 kV power section. The fourth part which is observed separately is the X kV (35, 20, 10 kV) power section. The fifth part consists of the 110/X kV power transformers. Sixth part consists of uninterruptible power supplies and all accompanying protection, measuring, control, communication and signaling equipment. Components from third to sixth as numbered earlier, are often built in stages and that must be taken into account during determination of the K1 index which represents the age of the whole site. Each separate part Sj of the substation is assigned with its age and the values obtained this way are multiplied with the percentage of participation pj of the observed part in the total value of the substation. Index K1 is obtained as a sum of multiples of years of age and percentage of participation of site parts. There can be as many of these factors as it is appropriate for the particular case.

\[ K_1 = S_1p_1 + S_2p_2 + S_3p_3 + S_4p_4 + S_5p_5 + S_6p_6 \]
After obtaining the age index, its value is normalized by relative ratios between sites to the maximum value of 10.

1.2. Outage indices for the last 5 years

Indicator that most accurately shows the total time during which the customers are left without electricity is SAIDI (System Average Interruption Duration Index). This indicator shows for how long on average each customer was left without electricity. The most convincing indicator which shows the number of outages is SAIFI (System Average Interruption Frequency Index). This indicator represents how many times on average, each connected customer was left without electricity. For this application the outage indicators are determined by observation of all power line outages, transformer outages, or MV feeder outages, when the cause of outage was any event or malfunction on the substation. Indicator value calculation is done in comparison with the total number of customers connected to the observed substation. Outage indicators were marked with $K$ and its value is obtained by adding the value SAIDI (in hours) and SAIFI, which refer to the customers supplied from the particular substation during the period for which outage data exist.

$$K_2 = \sum \text{SAIDI} + \sum \text{SAIFI}$$

Five year period is sufficient for adequate evaluation of this indicator influence. After obtaining the outage index, its value is normalized by relative ratios between sites to the maximum value of 10.

1.3. Operation problems

Problems on operation of transformers, 110 kV equipment, MV equipment as well as all secondary equipment, shown with the number of interventions, depending on the importance of the equipment on which the intervention is needed, are evaluated by indicator $K_3$. This indicator is also used for processing of problems of function failure of equipment, such as switchgear, protection relays, control and automation. This indicator encompasses the problems staff has during operation of particular equipment or during monitoring of substation parts operation. Importance factors are assigned to the parts of substation: for transformer $F_1 = 10$, for 110 kV equipment $F_2 = 9$, for MV equipment $F_3 = 6$, for secondary equipment $F_4 = 5$. These importance factors are multiplied with the number of problems $B_n$ recorded during the observed time period, which should be at least 5 years long.

$$K_3 = \sum (F_1 \times B_1 + F_2 \times B_2 + F_3 \times B_3 + F_4 \times B_4)$$

After obtaining the indicator of operation problems, its value is normalized by relative ratios between sites to the maximum value of 10.

1.4. Equipment load

One of indicators which significantly influence the age of site, and mainly the 110/X kV transformers is the long term load, which results in cumulative temperature influence as well as the influence of other insulation degradation factors. For this purpose it is sufficient to observe the load during last five years, but in case data for a longer period are at disposal, that should be recommended.

In power distribution utilities there is mainly data about absolute maximum power and about transmitted energy through the transformer during the year.

Indicator for evaluation of this influence is marked as $K_4$ and its value is obtained as the sum of maximum power $P_m$ in MW compared to the transformer installed power $P_a$ and average annual load $P_a$ in MW compared to the transformer installed power.

$$K_4 = \frac{\sum P_m}{P_a} + \frac{\sum P_a}{P_a}$$

After obtaining the load index, its value is normalized by relative ratios between sites to the maximum value of 10.

1.5. Partially done reconstructions

Because of large problems in operation, particular substations have been partially reconstructed. Some parts of the facility have therefore been brought to a highly functional level and that fact must be taken into account with the indicator $K_5$. The value of this indicator is obtained by determining the amount of percentage share of the value of reconstructed part of the site $P_r$ compared with the value of the whole substation. Factor $P_r$ is determined by adding of values of all reconstructed parts of the substation $V_r$, and the obtained result is divided by the total value of the substation $V_{TS}$.

$$P_r = \frac{(V_r / V_{TS}) \times 10}{10}$$

Indicator $K_5$ is obtained by subtracting $P_r$ from number 10.

$$K_5 = 10 - P_r$$

The value of factor $K_5$ is normalized by relative ratios between sites to the maximum value of 10, for the site which has the smallest reconstructed part.

1.6. Maintenance expenses

Assumption for usage of this indicator is implementation of operation accounting, which will enable recording of maintenance expenses on the 110/x kV substation level and determining of accurate value of every particular substation. By tracking the expenses of intervention, planned annual and investment maintenance during the last 5 years by sites, would enable comparable evaluation of maintenance expenses influence to the site revitalization order.

The value of indicator $K_6$ is obtained as relative ratio of sum of expenses of all mentioned maintenance types $T_a$ and the total value of the site $V_{TS}$.

$$K_6 = \frac{\sum T_a}{V_{TS}}$$

After obtaining of indicator of maintenance expenses its value is normalized by relative ratios between sites to the maximum value of 10.
2. REGULATORY CRITERIA

2.1. Damages from non-supplied electricity

When determining the quality of supplied electricity, the most important indicator is power supply interruption. Depending on the customer characteristics, power supply interruption can cause larger or smaller damages but consequences are always unpleasant for the customer. Indicator ENS (Energy Non Supplied) shows total energy non-supplied to customers during the observed year. Delivery interruption causes damages to the customer and also to the supplier. Damage that customer suffers depends on its own type. This damage can be equivalent to the value of undelivered electricity according to the price paid by the customer but sometimes it can have a few times larger value. At the beginning of this indicator usage, average value of undelivered electricity for the average price of electricity at the utility level can be taken as the reference value. The ENS value can also be taken as a measure of damage. In the following period efforts should be taken to categorize the customers with regard to this request. The customers are sorted in 5 groups: public systems – K, health institutions – Z, administration centers – A, industry – I and households – D. Each group of customers is assigned with appropriate damage value \( C_k, C_z, C_a, C_d \) and the values determined this way are multiplied with the undelivered electricity to that group of customers of the observed substation. The value of damage at the supplier is determined by average price of delivered electricity at the supplier level \( C_{ED} \).

The indicator \( K_7 \) is calculated as a sum of damage suffered by the supplier and the customer, expressed in dinars and presented for the last five years.

\[
K_7 = \sum (ENS \times C_{ED} + ENS_k \times C_k + ENS_z \times C_z + ENS_a \times C_a + ENS_d \times C_d)
\]

After obtaining the substation importance indicator its value is normalized by relative ratios between sites to the maximum value of 10.

2.2. Distributor penalties

For electricity delivery outages which can be described as extreme by outage duration and frequency, a methodology must be introduced for penalizing the distributor i.e. discounts for the customers who suffer this kind of interference must be introduced.

Indicator measuring must be accurate and reliable. For example, introduction of new meters with remote reading, implies that these meters have the ability of recording the duration of each electricity outage. Application of distribution management system (DMS) on substations is also necessary or a minimum technical solution which records all outages. Besides this, it is necessary to have regulations on the state level which manage supplier–customer relationship regarding quality of electricity.

When these assumptions are met it will be possible to determine the participation of particular substation in the total expense of paying customer penalties \( P_{TS} \). Based on this data the indicator \( K_9 \) will be determined and it is equivalent to customer refund in dinars for the past five years.

\[
K_9 = \sum P_{TS}
\]

After obtaining of indicator of penalties its value is normalized by relative ratios between sites to the maximum value of 10.

3. IMPORTANCE OF SUBSTATION AND READINESS OF MV NETWORK

3.1. Estimation of substation importance

Estimation of substation importance, based on importance of customers it supplies is assessed with indicator \( K_9 \) whose value ranges from 0 to 10. For the observed substation a table is created which presents types of customers sorted by importance and percentual share in the total delivered electricity at the substation. The customers are sorted in 5 groups: public systems – K, health institutions – Z, administration centres - A, industry - I and households - D. Each group of customers is assigned with importance factor: \( F_k = 9, F_z = 10, F_a = 5, F_i = 7, F_d = 3 \) and so determined values are multiplied with participation percentage \( p \) of the observed group of customers in the total delivered energy at this substation. Indicator \( K_9 \) is obtained as a sum of products of importance factors and participation percentages.

\[
K_9 = F_k \times p_k + F_z \times p_z + F_a \times p_a + F_i \times p_i + F_d \times p_d
\]

After obtaining the substation importance indicator its value is normalized by relative ratios between sites to the maximum value of 10.

3.2. Energy perspective of the substation

Based on the energy demand growth planning, with occurrence of new customers of growth of the existing ones, each substation gets its own level of perspective. Based on planned growth of load during a 5 year period, the value of indicator \( K_{10} \) is determined. The value of this indicator for each substation is determined as the ratio of power at the end of the 5 year planned period \( P_s \) to the reference value during the year of calculation \( P_r \).

\[
K_{10} = P_s / P_r
\]

Maximum value 10 is assigned to the substation with maximum power increase and the value of indicator for each substation is normalized by establishing relative relations between locations.

3.3. Fitness of MV network

Fitness of MV network is evaluated by two influential factors. One represents readiness of MV network for long term operation of the substation and the other one is obtained from estimation of time after which the 20 kV network will be
ready to take the consumer supply, based on avaliable funding.

Analysis of MV network and demand is done based on energy perspective point of view. Intention of transition from 10 kV to 20 kV is observed as well as the degree of preparation of the MV network, which is supplied from the particular substation, for 20 kV voltage supply. As the degree of network readiness grows so does the indicator \( S_{\text{MV}} \). If transition to 20 kV supply is not desired the indicator \( S_{\text{MV}} \) after 10 years we will still have \( S_{\text{MV}} \). For relevant substations it was necessary for the mid term plan, to arrange the order and extent of work on this substations which have to change the voltage level equaly with the other locations at which this is not the case.

4. EXAMPLE OF USAGE OF DEVELOPED METHODOLOGY

Currently in Elektrovojvodina there are 12 substations 110/35 kV, which are 33 to 48 years old. Due to age of these substations it was necessary for the mid term plan, to arrange the order and extent of work on this substations, which was not easy at all. Current practice did not have any developed methodologies for this purpose and according to aforementioned procedure a list of 12 observed locations has been made. Table 1 shows rating results based on nine, out of eleven factors. For the remaining two factors there is not sufficient data yet.

### TABLE 1 – RECONSTRUCTION ORDER RATING OF TS 110/35 kV

<table>
<thead>
<tr>
<th></th>
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<td>10</td>
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<td>4,3</td>
<td>46,1</td>
<td>4,056</td>
<td>1,025</td>
<td>5,4</td>
<td>54,3</td>
<td>11</td>
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</table>
Elektrovojvodina currently examines possibility of 3 110/20 kV substations reconstruction, whose parts are from 23 to 48 years old. The age of these substations and exploitation problems on power and protection gear are the reasons to determine the reconstruction order. Table 2 shows the results of application of the developed methodology on the particular 3 substations.

**TABLE 2 – RECONSTRUCTION ORDER RATING OF TS 110/20 kV**

<table>
<thead>
<tr>
<th>TS</th>
<th>K1 Age (year)</th>
<th>K2 Outages 2002-2006</th>
<th>K3 Oper Prob</th>
<th>K4 Load</th>
<th>K5 Part Recon</th>
<th>K6 Maint Exp</th>
<th>K7 Damage Sp-Sa</th>
<th>K8 Penal</th>
<th>K9 Importance TS</th>
<th>K10 Energy persp</th>
<th>K Sum</th>
<th>Rating</th>
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<tr>
<td>SO1 Point</td>
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<td>4</td>
<td>7</td>
<td>4,52</td>
<td>8,4</td>
<td>9,9</td>
<td>33,6</td>
<td>4,02</td>
<td>1,88</td>
<td>10</td>
<td>54,8</td>
<td>3</td>
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<tr>
<td>SE1 Point</td>
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<td>15,5</td>
<td>7</td>
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<td>VRS2 Point</td>
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**5. CONCLUSION**

Presented methodology, declared through eleven influential factors enables pretty convincing determination of reconstruction order of TS 110/35 kV, and through 10 equivalent factors of TS 110/20 kV. This is the first attempt to adopt one solid methodology for this purpose, which must be improved in the following period, during which utility companies anyway enter extreme organization and economy changes.

**6. REFERENCES**