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Development planning of the electric power network at the Ravne steelworks

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Abstract. In the paper, we present a process of development planning for the distribution power network at the Ravne steelworks for a ten-year period, precisely for 2011–2020. In the first part we describe a general approach to network planning, lay down the planning objectives and determine the methodology and technical and economic criteria according to which the network will be developed. Next, the current state of the Ravne power network (topology, equipment, power consumption) is described. Based on the measurement results, the state of the power quality is assessed with a particular emphasize laid on the flicker and harmonic distortion. We then make a simulation model of the steelworks power distribution network by using the DIgSILENT PowerFactory program. In the last part we propose a development plan for the Ravne steelworks based on the general planning criteria. We considered the current state of the power network (load, power quality), age of the equipment used, planned reconstruction and the predicted growth in electricity consumption.

Keywords: flicker, power-supply quality, reactive-power compensation, distribution-network development.

1 INTRODUCTION

The main purpose of power network planning is to assure an adequate power quality and reliable power supply both for the current and future power consumers. The main goals pursued in such planning can be summarized in the following points:

- determination of the necessary reinforcement and modernization of the network to assure adequate power quality and undisturbed power supply, accounting for the rising power demand and aging network elements,
- enabling technically and economically optimal network development, to achieve an adequate cost-efficient level of the power supply,
- determining the network elements performance specifications to assure optimal utilization,
- determining an optimal work-completion schedule.

When laying down a development plan, the main data required are in particular the data on the network current state including the network topology, data of the network elements, data about the network load and also load forecast about the expected network load for the period covered by the development plan.

Of a particular importance for a good development plan are the methods to be used in analysing the operating states, reliability of the consumers' supply, economic analysis and planning criteria providing the limits that should not be exceeded in order to assure the power-supply quality, uninterrupted power supply and also optimal development of the network.

As seen, the most important element of the power network is forecasting the power demand meeting. With this respect the most important data is that of the planned increase in the power demand meeting (e.g. production expansion, new users); where such data is not available, statistical forecasting methods are used. They include both statistical processing of the consumption data for a given power consumption area as well as consideration of the load-growth forecast in a particular industrial branch. Besides the basic objectives of the power network planning, in-depth analysis of the reactive power and flicker are also very important. Reactive-power compensation is a serious problem to be solved by large industrial consumers, mainly because of the potential resonances and consequently amplification of harmonics. Also to be accounted for is flicker which occurs as a consequence of operation at characteristics of arc furnaces. They negatively affect power consumers in a relatively large area.

2 CRITERIA FOR POWER-SYSTEM DEVELOPMENT PLANNING

As mentioned above, the goal of development planning of a power network is to enable continuous power supply and to assure an adequate level of power quality. Moreover, the network should be developed in an economically optimal way. The design criteria can be divided into the technical and economic criteria. The technical criteria are the power-supply reliability, voltage quality and admissible loading of the network elements [1].

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2.1 Power-supply reliability

It is important that power supply is reliable as each power failure may result in considerable financial losses; in some cases it may also harmfully affect the load operation.
Power supply interruptions are either planned or unplanned. For power consumers the number and duration of power supply interruptions is important. The parameters used as criteria for power supply reliability are: the number of long unplanned interruptions per year, the number of short unplanned interruptions per year and the total duration of unplanned interruptions per year. To determine the power-supply reliability of the planned network, we need to know: system topology, integrated switching elements, data about the protective-devices operation, data about reliability of individual elements (or failure frequency) given by statistically determined values (for transformers, lines, circuit breakers, etc.), share of the permanent and transient failures, time-to-failure elimination, time to provide emergency power supply and automatic reclosure time.
The damage caused by power outages can be reduced by having the network correctly reconfigured.

2.2 Voltage quality

For the consumer devices to operate properly, the power quality or voltage quality is of the key importance. According to the currently applicable Slovenian legislation, the voltage quality must comply with the provisions of the EN 50160 standard [2]. According to the standard, the electromagnetic disturbances in the low-voltage (LV) and medium voltage (MV) network are identified at the consumption point, i.e. at the point of intersection between the consumer and the public power distribution network.

2.3 Resonance phenomenon taking place in the network

In planning a power network, a special attention should be paid to resonance states that might take place in the power system. Any of the electric circuits containing elements of an inductive and capacitive character has one or more resonance frequencies at which the system impedance can attain very high or very low levels, resulting in increased current and voltage harmonics. If a network impedance is, for example, near harmonic frequency ω_h, a small load-current harmonic component will at this frequency already result in a high-harmonic voltage component.
The resonance phenomenon is a serious problem when installing capacitors for reactive-power compensation. The resonance frequency of the system generally decreases with the increasing power of the compensator and with decreasing the resonance frequency of a tuned filter. While the resonance frequencies depend on the system inductance and capacitance, the impedance value at resonance depends on the resistive component of the system elements.
Impedance frequency characteristics should be determined prior to installing any compensation capacitor into the power system. It should be taken into account that any change in the network topology or network elements (transformer replacement, short-circuit power variations, etc.) affect the resonance frequency. We must also be fully aware that the loads are a source of harmonics causing high-harmonic distortion in the network.

2.4 Network-element loading

Concerning the network element loading, it is important that power lines and transformers are adequately loaded and that voltage drops do not exceed the set limit values. Overhead and cable lines can be loaded up to their thermal-capacity limit. Thermal current is determined on the basis of the maximum temperature at which the power line operates safely without damaging the conduction line and its insulation.
As to line loading, important factors to be considered are its losses and voltage drops. To avoid the relatively large losses, a line may operate at its thermic limit only to provide emergency power supply. To avoid power losses under normal operating states, the load shall not exceed:

- 50 % of the thermal limit for overhead power lines,
- 75 % of the thermal limit for cables.

In emergency states, the power lines can be loaded up to their thermal limit permitted by the voltage drops.
Transformers can be permanently loaded with their rated power if their temperature does not exceed the upper limit over-temperature. It should be noted that the nominal data are given for a specific outdoor temperature, usually 20˚C. The transformer operational lifetime is determined by the lifetime of its insulation and depends mainly on the temperature. Permissible duration of the overload also depends on the transformer previous load.
The permissible MV and LV line maximum voltage drop is typically 10 %, although a drop of maximally 7.5 % is recommended. In accordance with the EN 50160 standard, the lowest voltage in emergency operation should not be more than by 15 % lower than the nominal, and in normal operating states not more than by 10 % lower.

2.5 Primary equipment operational lifetime

For overhead lines and cable lines the expected lifetime is 40 years. For the HV/MV power transformers the predicted lifetime is 35 years and for the polyethylene insulated cable lines and MV/LV power transformers 30 years.

3 Description of the Network

The loads at the Ravne steelworks are connected to the Central Transformer Substation (CTS) which is connected to the 110 kV transmission grid with two transmission lines, namely the HE Dravograd and the Ravne TS. The transmission power line running from the Ravne TS to substation at the town of Ravne is disconnected most of the time to avoid the too high flicker levels in Ravne. In CTS there are busbars of three voltage levels. The 110 kV busbar system can be separated in two busbar systems with each being powered from its 110 kV transmission line. The 20 kV busbars have two separate systems with one supplying an arc furnace and ladle furnaces and the other powering other consumers at a 20 kV voltage level. At the 5 kV level there are two busbar systems. In normal operational states, all loads are connected to the first 5 kV system, while the second is not used. The 20 kV and 5 kV busbars can be interconnected with two 20/5 kV power transformers, both of the nominal power of 2.5 MVA. In normal operational states, they are disconnected. A simplified single-pole scheme is shown in Fig. 1 [1].

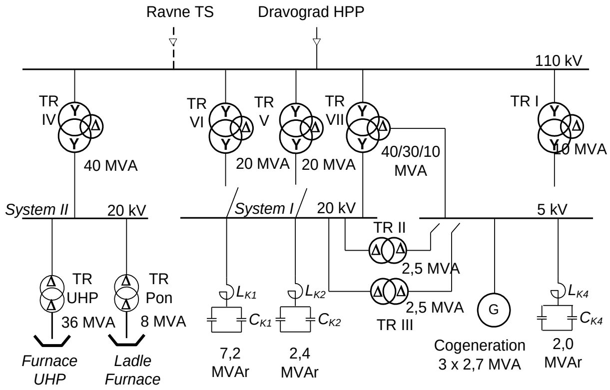

Figure 1: Simplified unipolar scheme of the Ravne power network.

Most of the consumers are connected to their own 20 kV or 5 kV busbars. The 20 kV substation of Valjarna I has two 20 kV busbars connected to the CTS.

3.1 *Power consumption*

Monitoring the power consumption at the point of the Ravne steelworks connection to the transmission system is made by energy meters recording power consumption on a 15-minute basis. Feeders are equipped with current meters SIMEAS recording the current values in second intervals. Fig. 2 shows the total annual power consumption in the area of the Ravne steelworks in the period 2006–2010.

3.2 *Reactive-power compensation*

Reactive-power compensation is very important for power system operation. At least two of its aspects should be addressed. The first is appropriate compensation meaning that compensators are adequately sized and flexible to enable the corresponding cosφ. The second aspect is proper configuration of the compensators (resonance frequency of the tuned filter) to prevent increasing of the harmonic components in the network.

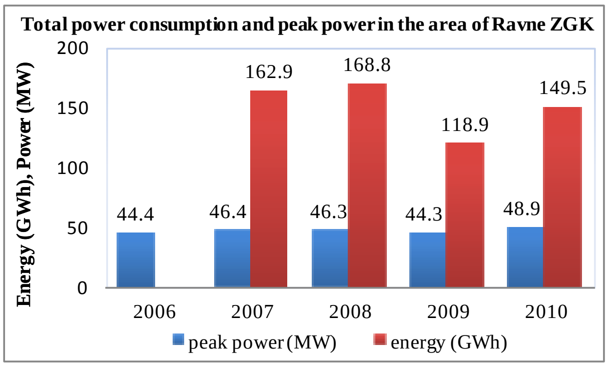

Figure 2: Total annual power consumption in the area of the power network of the Ravne steelworks in the period 2006–2010.

3.3 *Results of the power-quality measurements*

Measurements of the power quality are used to illustrate the power-supply quality in Ravne power network, particularly with regard to flicker and harmonics as the most impacting voltage-quality parameters. Voltage-quality measurements were performed at the 110 kV and at 20 kV busbars (system I).

Flicker (P_{lt}) exceeds the limit values of the EN 50160 standard in which the maximum values, taking into account 95 % of the measurement time, range between 2.4 and 2.8 (the maximum limit value is 1.0) [4]. Fig. 3 shows the phase values of long-term flicker (P_{lt}_L_1, P_{lt}_L_2, P_{lt}_L_3).

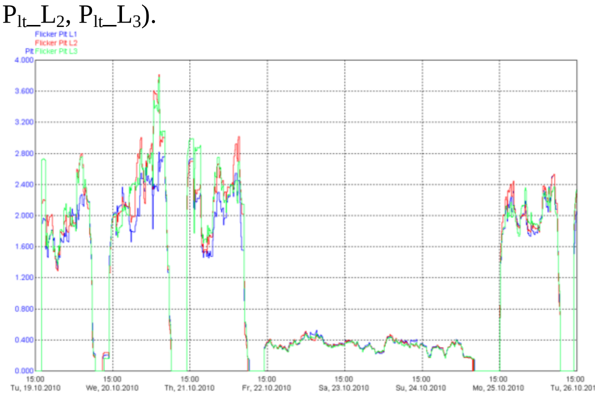

Figure 3: Development of long-term flicker, 110 kV busbars.

Flicker is mainly the consequence of the electric arc-furnace operation. A smaller proportion of flicker is contributed by other power consumers at the Ravne steelworks and also by some other consumers in the power transmission network.

There are also some events due to which the threshold value is exceeded because of over-voltages between phase lines and grounding. However, this is due to slightly higher voltage levels at the 110 kV busbars at the time of our measurements. Other parameters of the voltage quality are within the limits defined by the EN 50160 standard.

The voltage asymmetry is low. Considering 95 % of the measurements time, it reaches the values of up to 0.3 % (the limit is 2 %).

4 SIMULATION OF THE RAVNE NETWORK OPERATION

Operation of the Ravne distribution network was analyzed using the DIgSILENT PowerFactory [5] software. Using the Ravne network simulation model, the load-flow was simulated. We observed the power flows in power lines and voltage drops appearing as a consequence of the line and transformer maximum loading.

In our simulations we used the available power parameters of cables and transformers as well as data of the maximum power consumption of individual feeders. Knowing the cable and transformer power transmission capacities, we checked the network-cable load at the maximum load according to the cable current capacities. Being unlikely for all the loads to operate at the maximum power at the same time, our simulations were made also at reduced loads enabling us to determine the loading of the main power transformers in the Ravne network.

The Ravne power distribution network is operated radially with all tie switches open in normal operating states. In the event of a failure, the tie switches can be closed, thus powering the loads from a different location. During our simulations we examined both the normal and as well as emergency operating states, the latter including reconfiguration of the network upon failure occurrence.

4.1 Implementation of the third sector busbar

With our simulations we also considered the option of a third busbar system at the 20 kV voltage level (System III) of the Central Substation. Our aim was to evaluate the levels of harmonics and flicker at System III. The source of flicker is mainly the arc furnace, while the sources of harmonics are, besides the arc furnace, also the converter drives connected to System I. We came to the conclusion that the Total Harmonic Distortion (THD) of System III is about three-times lower than the distortion of System I. The most distinct is the fifth harmonic. However, it should be noted that the harmonic distortion is highly dependent on the impedance of the system, which is also subject to the reactive-power compensation. Flicker levels of System I and System III are almost the same and vary only a little from the values at the 110 kV level. Some of the loads at the 20 kV level can cause a small increase in flicker, while directly connected motors, in principle, reduce flicker slightly.

4.2 Analysis of the power consumption growth at the Ravne steelworks

In assessing the future power consumption, we assumed that the power consumption will increase in the years to come and it is expected to return in 2012 to the values of 2008 (before the economic crisis). The growth in the power consumption after 2012 was estimated at 1.5 % annually. Similarly, we estimated that the peak power consumption will increase by 1.5 % per year, as shown in Fig. 4. In the near future (between 2013 and 2014), a new ESR III substation is foreseen to be constructed, which the existing electroslag remelting (ESR) furnaces and two additional ESR furnaces (each of 2.4 MVA) will be connected to. We therefore further increased the peak power consumption of the active power in forecasting for 2013 and 2014, in each year for 2.27 MW (less than assessed in previous studies). For those years we also increased the power consumption for 2.3 GWh annually, which corresponds to 1000 furnace operating hours per year.

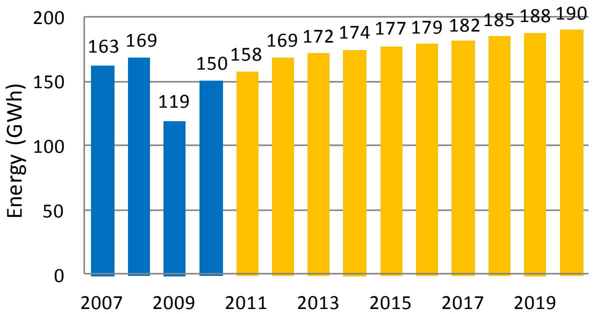

Figure 4: Total active-power consumption in the area of the Ravne network (current and foreseen).

4.3 Simulations with increased load (2020)

Using the simulation model of the Ravne steelworks network, we tested loading of the network elements with an increased load as a consequence of the production expansion in Ravne. We simulated the state predicted for 2020, where compared to 2010 we assumed a 1.5 % annual growth in power consumption and power for all the existing loads throughout the Ravne network, except for the UHP, VPP and ESR furnaces. We also considered that the power consumption will increase due to new loads (two ESR furnaces) and new topology, meaning a new TP ESR III and transition of the TP Kisikarna to the 20 kV level. Our simulations showed that there were no excessive values appearing in none of our scenarios.

5 DEVELOPMENT PLANNING AT THE RAVNE NETWORK

The development plan for the Ravne steelworks network foresaw network reinforcement and modernization to assure reliable and efficient network operation.

5.1 Cable feeders and main transformers

Recommendations for the network reinforcement were given on the basis of the age and life expectancy of the primary network equipment and on the simulation results showing the feeder and transformer load. The simulation results showed that feeders and transformers were not overloaded under normal operating states. Under emergency operating states some of the connections were highly loaded (up to 100 % of the thermal current), but such operation was not permanent and is permissible for a limited amount of time. In our simulations we also took into account the maximum measured feeder loads.

The main problem regarding the cable feeders was their age. Particularly problematic were the oil-insulated cables which are about 40 years old and require relatively expensive maintenance.

The main problem regarding the transformers is especially the age of the stand-by transformers which are at the end of their operational life expectancy. Being stand-by transformers, i.e. not in permanent operation, their operational life is believed to be extended.

5.2 Smart-grid concept

One of the main directions imposed on power-system development leads towards the smart-grid concept. In smart distribution networks, generators and also loads play an active role and participate in network control. A higher network efficiency and flexibility can be achieved through further network automatisation, ICT network-linking-controllable elements and introduction of modern compensation devices.

5.3 Reactive-power compensation

Because of unpredictability of the compensator operation on the 0.4 kV voltage level (automatic switching based on the local power consumption) and the possibility of the occurrence of the resonance points over a wide frequency range, the main compensation at the MV level must improve impedance states at the harmonic frequencies characteristic for the power network at the Ravne steelworks. A possible solution is a 20 kV tuned-filter compensator with four levels of the nominal power of 3 MVAr. One level should be tuned to the frequency of 141 Hz, one to the frequency of 240 Hz and two to the frequency of 335 Hz.

Using such compensator, the resonance points from the load side of the 20 kV busbars in system I are located at frequencies where harmonics are not present (Fig. 5). Also, the compensators at the 0.4 kV voltage level do not substantially affect the resonance points.

5.4 Flicker compensation

The main power-quality problem within the Ravne steelworks and also in the Slovenian power transmission network is flicker. To solve the flicker problem, the possibility was considered of connecting an additional furnace of 70 MVA in the Ravne steelworks. Simulation results showed that the only solution allowing an adequate flicker minimisation is connecting the Ravne steelworks to the 220 kV voltage level and the connection of a static-var compensator (SVC) [6]. This way the flicker problem would be solved when the existing 36 MVA furnace and the new 70 MAV furnace are in operation. Independent operation of the 70 MVA furnace with no dynamic compensation is also acceptable, but it increases flicker in the power transmission system both in Slovenia and Austria. The simultaneous operation of the 36 MVA and the 70 MVA furnace is not acceptable without dynamic compensation. Instead, a SVC should be used to maintain flicker within the set limits. The flicker level of the new furnace depends also on construction and operation of the furnace [5]. Results of our flicker simulations are given in Table 1. Results under I present the current status, under II connection of the 70 MVA furnace to the 220 kV system, under III connection of the 36 MVA furnace to the 220 kV system and under IV connection of the 36 MVA and 70 MVA furnaces and a SVC to the 220 kV system.

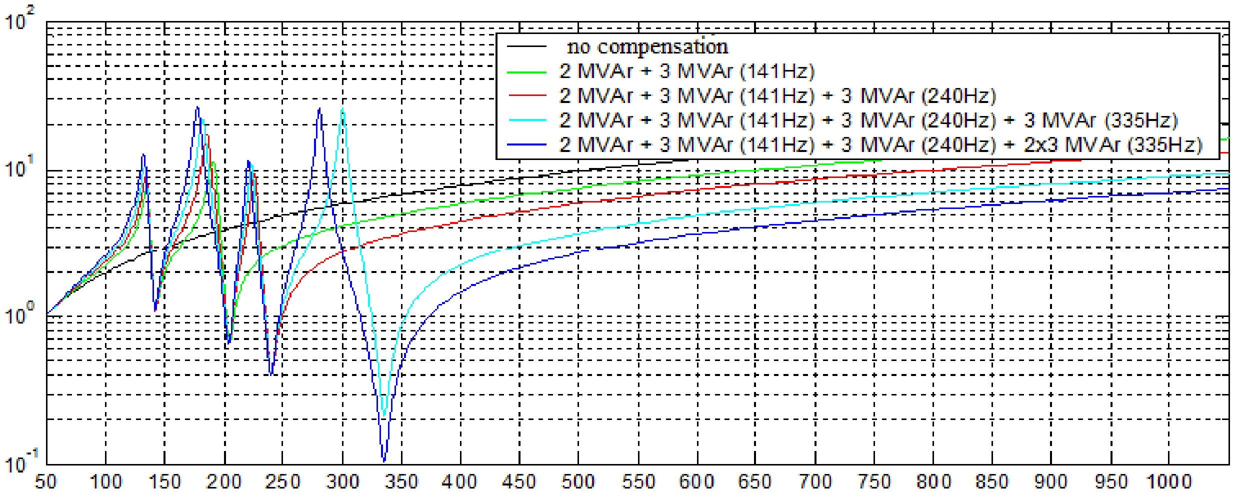

Figure 5: Frequency characteristic of the network impedance at the 20 kV busbar system.

Table 1: Flicker values for the Ravne steelworks connected to the 220 kV voltage level.

TS	Voltage level (kV)	I. Ravne 36 MVA	II. Ravne 70 MVA	III. Ravne 36 MVA	IV. Ravne SVC+36+70
Žel. Jesen.	110	7,17	7,04	7,16	6,94
Moste	110	1,52	1,58	1,55	1,41
Žel. Ravne	110	3,24	5,04	3,16	3,92
Žel. Štore	110	1,24	1,20	1,14	1,23
Okroglo	110	1,53	1,59	1,56	1,41
Kleče	110	1,09	1,16	1,11	0,99
Beričevo	110	0,86	0,94	0,88	0,77
Lj. Center	110	0,91	0,98	0,93	0,82
Slovenj Gradec	110	1,85	0,56	0,49	0,55
Podlog	110	0,93	0,85	0,76	0,85
Pekre	110	0,74	0,44	0,37	0,40
Hudo	110	0,50	0,53	0,47	0,48
Divača	110	0,23	0,27	0,25	0,21
Beričevo	220	0,60	0,74	0,65	0,56
Podlog	220	0,45	0,76	0,59	0,59
Kleče	220	0,59	0,71	0,64	0,54
Beričevo	400	0,60	0,73	0,65	0,56
Podlog	400	0,45	0,67	0,54	0,50
Okroglo	400	0,71	0,83	0,75	0,64
Obersielach (AT)	400	0,27	0,58	0,42	0,45
Obersielach (AT)	220	0,25	0,80	0,55	0,62

6 Conclusions

The aim of the paper was to show the process of the power-distribution network planning for the case of the Ravne steelworks industrial network. The development plans was prepared for a ten-year period. An investment schedule was determined, too.

At the beginning of the paper, some general guidelines for the distribution power network planning were given and planning objectives, methodology, technical and economic criteria were described.

Operation of the Ravne steelworks network was analyzed by means of simulations. Using the network model, power flows and feeder and transformer loads were determined and voltage drops were analysed. Besides the normal operating states, emergency operating states were also evaluated. The power consumption growth and the peak-power growth for a ten-year period were also assessed. The issues of flicker and reactive-power compensation were addressed. In such compensation a particular attention should be paid to appropriate dimensioning of the filter-choke compensators to avoid increasing the harmonics in the network elements. To solve the flicker issue, we used several scenarios and came to the conclusion that the only comprehensive solution is connection of the Ravne steelworks to the 220 kV voltage level, which would also allow further expansion of production.

In the last part of the paper, development plans for the Ravne network were proposed. The reason for the relatively considerable funds to be invested into the Ravne network is the age of some of the network elements which are already at the end of their expected operational life.

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Jurij Bizjak graduated in 1992 from the Faculty of Electrical Engineering of the University of Ljubljana. In 1992–2003 he was employed with Petrol Energetika l.l.c. Ravne. First he worked as a technical assistant in the area of power enginnering. Since then he has been occupying the post of Director. The scope of his work includes reliable operation of the electric power system (EPS), EPS development and power demand meeting of all in the region of Ravne and Štore.

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