ANALYSIS AND EVALUATION OF OPTIMUM OPERATIONAL STATUS OF ELECTRICAL STATIONS

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1. GENERAL CONSIDERATIONS

Dimensioning of electricity transformation stations and points is made when new consumers electricity supply is designed, and for periodic verification of installed power(determination of load degree). Re-dimensioning of electricity transformation stations and points is required when technologies and enterprises are updated, entailing reducing electricity consumption, as well as in the case of changing manufacturing profiles.

Adopting the optimum electricity supply solution for industrial consumers is a complex issue involving the analysis of a great number of restrictions and factors, with determining, quasi-determined and random character.

2. THEORETICAL BASIS OF OPTIMUM EVALUATION

In the design of SEE (SE, LE) connection of mining electricity distribution systems, the following problems should be solved:
- satisfying requirements of mining consumers;
- ensuring optimum safety degree for each development stage (of the area of the mining consumer), simple and economical solutions, adapted per categories and classes of consumers;
- adopting modular and elastic schemes allowing adaptation, in any stage, to modern solutions than might intervene in electricity installation, possibility of electricity supply for unforeseen objectives;
- adopting a flexible structure of the optimization criterion allowing the highlighting of possible differential solutions of influence factors;

Establishing electricity supply solutions for industrial consumers is a complex activity in which a series of factors having a direct influence on those should be considered.

The principal elements influencing the chosen solution are:

- Value of investment;
- Value of probable annual penalties caused to the consumer;
- Value of exploitation expenses;
- Number of electricity supply means;
- Type and place of fixing the automation equipment;
- Normal supply diagram of the consumer.

The preoccupation regarding the optimization of nominal power of electricity transformers, and the optimization of the configuration of transformation and distribution stations from the mining consumers, depending on the absorbed power,

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is justified by the important savings of electricity that might thus be obtained.

To obtain an as exact as possible value, most often two optimization criteria are applied: "cost of minimum losses of power and electricity” (CPW) and “total updated expenses) (CTA).

Operation of electricity transformers according to the optimum regime plan involves establishing the number of transformers in operation and their loading, so that the total losses would be minimal. It is required to disconnect the loaded transformers with an average of less than 40% of the nominal load and redistribution of power among the transformers left in operation, according to the loads of the supplied consumers.

To impede the decrease of safety level in the electricity supply, an AAR device is required, which should provide automatic connection of the stand-by, in the situation of a possible disconnection of an operating transformer.

When the load od the distribution station supplying the mining consumers undergo significant variations, in order to obtain a functioning regime as favorable as possible from the point of view of total losses of power or energy, and from the point of view of minimum annual cost, respectively, it is recommended to install several transformers.

In this situation, the problem is connecting or disconnecting a transformer, in case of total load variations per station, so that the plan of optimum functioning should be permanently followed.

Single-core diagrams, frequently met for electricity stations above ground in mines, are shown in Figs. 1 a, b and c.

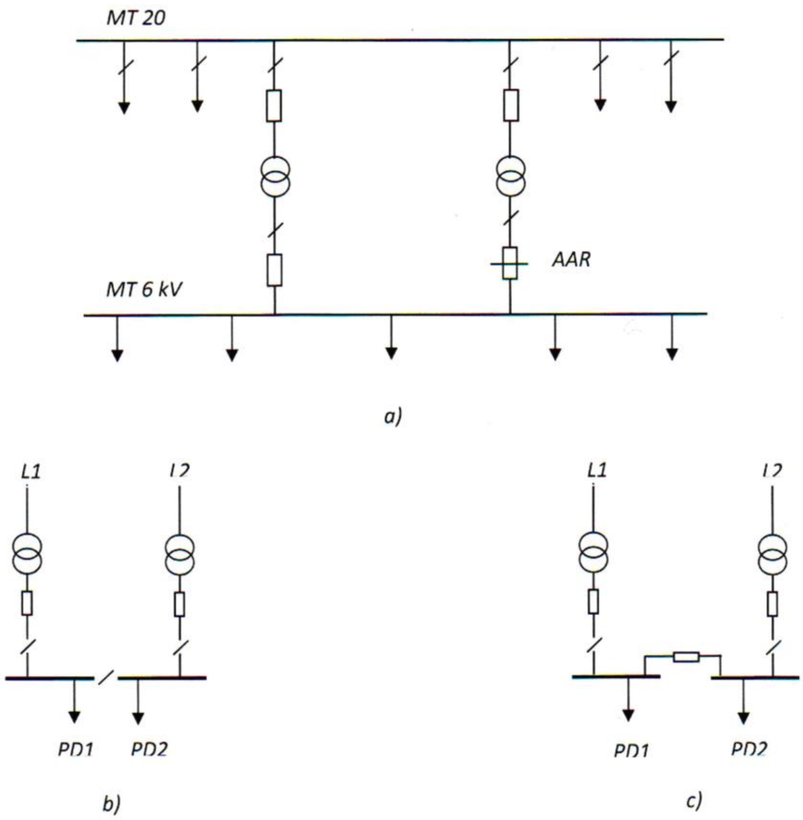

Fig. 1. Single-core diagrams of electricity distribution stations, MT/MT, used above ground in mines (2x100% type configuration).

For the analysis, the following basic hypotheses are admitted: nominal power of transformers is the optimum, the characteristics of the commuting apparatus of the same type are identical, and the instant absorbed power (S) is considered variable in time (along a working day). The commuting apparatus can be provided with an AAR system.

a) With two transformer units of continuous bars on the MT (6kV) side;
b) With two transformer units of sectioned bars on MT (6kV), by isolator;
c) With two transformer units of sectioned bars on MT (6kV), by circuit breaker.

The calculation formulae are shown below for the absorbed power where commuting between the two situations is required, depending on the optimization criteria applied and the factors of influence considered.

Considering the two possible situations mentioned above, and applying the criterion of minimum power loss (CP), noting with:

$$\Delta P_{12} = \Delta P_1 - \Delta P_2 \qquad (1)$$

The difference of total power losses in transformers, in kW, referring to the two conditions, the following formulae are obtained:

When reactive power losses are ignored:

$$\Delta P_{12} = \frac{\Delta P_{kn}}{2} \cdot \left(\frac{S}{S_{nT}} \right)^2 - \Delta P_0$$
$$S = S_{nT} \sqrt{\frac{2 \cdot \Delta P_0}{\Delta P_{kn}}} \qquad (2)$$

When the reactive power losses are considered as well :

$$\Delta P_{12} = \frac{1}{2} \cdot \left(\Delta P_{kn} + k_e \cdot \Delta Q_0 \right) \cdot \left(\frac{S}{S_{nT}} \right)^2 - \left(\Delta P_0 + k_e \cdot \Delta Q_0 \right)$$
$$S = S_{nT} \sqrt{\frac{2 \cdot \left(\Delta P_0 + k_e \cdot \Delta Q_0 \right)}{\Delta P_{kn} + k_e \cdot \Delta Q_{kn}}} \qquad (3)$$

The optimum or economical power when the commuting of transformers are justified, referring to the two situations, by the application of minimum cost criterion for power and energy CPW, is determined by the formula:

$$\frac{1}{2} \left(\Delta P_{kn} + k_e \cdot \Delta Q_{kn} \right) \cdot \left(\frac{S}{S_{nT}} \right)^2 \cdot C_k - \left(\Delta P_0 + k_e \cdot \Delta Q_0 \right) \cdot C_0 = 0 \qquad (4)$$

The analytical calculation formula of the optimum power, expressed in kVA, is:

$$S_{ec} = S_{nT} \sqrt{\frac{2 \cdot \left(\Delta P_0 + k_e \cdot \Delta Q_0 \right) \cdot C_0}{\left(\Delta P_{kn} + k_e \cdot \Delta Q_{kn} \right) \cdot C_k}} \qquad (5)$$

The optimum kunf loading coefficient for annual load peak is determined with the formula:

$$k_{1.\inf} = \sqrt{\frac{2 \cdot \left(\Delta P_0 + k_e \cdot \Delta Q_0 \right) \cdot C_0}{\left(\Delta P_{kn} + k_e \cdot \Delta Q_{kn} \right) \cdot C_k}} \qquad (6)$$

The final result is the analytical expression of optimal power for which commuting transformers are justified economically, with reference to the two situations of reservation of the electric station(passive reserve and active reserve):

$$S_{ec} = S_{nT} \cdot \sqrt{\frac{2 \cdot (\Delta P_0 + k_e \cdot \Delta Q_0) \cdot (C_p + C_w \cdot T_f \cdot T_{20})}{(\Delta P_{kn} + k_e \cdot \Delta Q_{kn}) \cdot (C_p + C_w \cdot \tau \cdot m_r \cdot T_{20})}} \quad (7)$$

The meaning of the new values appearing in the above formulae and the units is the following:

Tn – updated value of a functioning duration of n years and the expression is:

$$T_n = \sum_{x=1}^{n} (1 + a)^{-x} \quad (8)$$

C_0 – cost in updated values of a unit of power loss in iron for n years of functioning, in €/kW;

C_k – cost in updated values of a unit of active power loss in short circuit and in the hypothesis of an r rate of increase of the annual load peak, in €/kW;

C_p – specific cost of installed power in basic power stations of equivalency, in updated values, in €/kW;

C_w – average specific cost per system of kWhour of losses, calculated at the transformation station level of ÎT/MT or MT/JT, in €/kWh;

m_r – load multiplier as:

$$m_r = \frac{1}{(1 + a) \cdot T_n} \cdot \sum_{m=0}^{n-1} \frac{(1 + r)^{2m}}{(1 + a)^m} \quad (9)$$

Where r is the increase rate of the annual load peaks in the respective period, and a is the updating rate. When r=0 and n=20 years, and n=30 years, respectively, the load multiplier m_r=1;

The rest of the values have the known meaning shown before.

It can be seen that all the characteristics of the different values specific to kWhour of losses C_w go through the same point D (Fig. 2), where the derivate:

$$\frac{dk_1}{dc_w} = 0 \quad (10)$$

The value of the ordinate of the intersection point D ends with the formula:

$$\tau_D = \frac{T_f}{m_r} \quad (11)$$

The value of the ordinate of the intersection point D corresponds to the specific cost of energy losses $C_w = 0$:

$$k_{ID} = \sqrt{\frac{2 \cdot (\Delta P_0 + k_e \cdot \Delta Q_0)}{\Delta P_{kn} + k_e \cdot \Delta Q_{kn}}} \quad (12)$$

Analogically, as in the case of CPW criterion applied for the determination of the optimum load coefficient in the first year of exploitation of a transformer, in this case as well, in the hypothesis of minim of costs of losses and power and electricity, the theoretical field of variation of the optimal load in the annual load peak is limited by two characteristics:

$$k_{1.\inf.1} = \lim_{c_w \to 0} k_{1.\inf} = \sqrt{\frac{2 \cdot (\Delta P_0 + k_e \cdot \Delta Q_0)}{\Delta P_{kn} + k_e \cdot \Delta Q_{kn}}} \quad (13)$$

$$k_{1.\inf.2} = \lim_{c_w \to \infty} k_{1.\inf} = \sqrt{\frac{2 \cdot (\Delta P_0 + k_e \cdot \Delta Q_0) \cdot T_f}{(\Delta P_{kn} + k_e \cdot \Delta Q_{kn}) \cdot \tau \cdot m_r}} \tag{14}$$

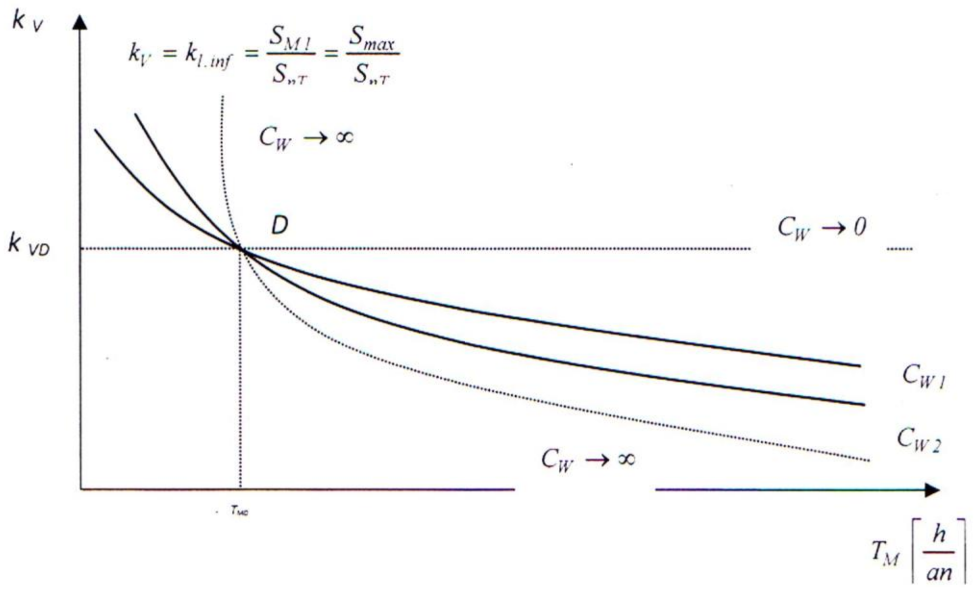

Fig. 2. Economical loads for the annual load peak, for the TT-AN and TTU-NL type power transformer series

The optimum load coefficient at the upper limit is determined by the formula:

$$k_{1.\sup} = 1.6 \cdot k_{1.\inf} = 1.6 \cdot \sqrt{\frac{2 \cdot (\Delta P_0 + k_e \cdot \Delta Q_0) \cdot (C_p + C_w \cdot T_f \cdot T_{20})}{(\Delta P_{kn} + k_e \cdot \Delta Q_{kn}) \cdot (C_p + C_w \cdot \tau \cdot m_r \cdot T_{20})}} \tag{15}$$

3. TECHNOLOGICAL REFURBISHING POSSIBILITIES OF MEDIUM VOLTAGE CELLS

One of the solutions of technological refurbishing of electricity distribution stations implemented within C.N.H.-S.A. , and to which we took part, has been the refurbishing of Romanian make medium voltage cells, with Siemens vacuum circuit breakers, a solution adopted at TD 4 Petrila Mine.

It is generally acknowledged nowadays, that the superiority of vacuum circuit breakers lies especially in the high reliability and durability and low maintenance costs, compared to all the other known technologies, applied in the control and protection of medium voltage electricity distribution.

The qualities of the vacuum circuit breakers are mainly due to:

- simple and robust design of the quenching room (Fig. 3);
- small distance between the contacts (approx. 1 kV/mm), due to the very good dielectrical qualities (more than 340 kV/cm in even field) of the intense vacuum(10^5 ... 10^{-9} mbar), leading to the execution of simpler designs for actuation mechanisms and lower energy;
- extinguishing the electrical arc in maximum a semi-period (10 ms), irrespective of the value and type of electricity (up to the nominal breaking capacity warranted by

the manufacturer), vacuum commuting apparatus being actually known as apparatus with no critical electricity;

- low thermal strain of the contacts in the process of commuting, due to the short period of time of burning of the electrical arc(<10 ms), to the low voltage drop on the electrical arc (40 …75) V and the specific development and burning of the electric arc in vacuum.

For currents up to 10 kA or for contact system with axial magnetic field, the electrical arc burns diffusely, all over the surface of the contact, thus the specific energy developed per unit of contact surface is low, not being able to cause serious wear to the contacts, and for higher currents than 10 kA in the case of radial magnetic field, the electrical arc is rotated on the contact ring(Fig. 4) with speeds of the order of 100 m/s for the intense voltages, the leg of the electric arc always meeting cold surfaces, not being able to cause significant wear to the contacts.

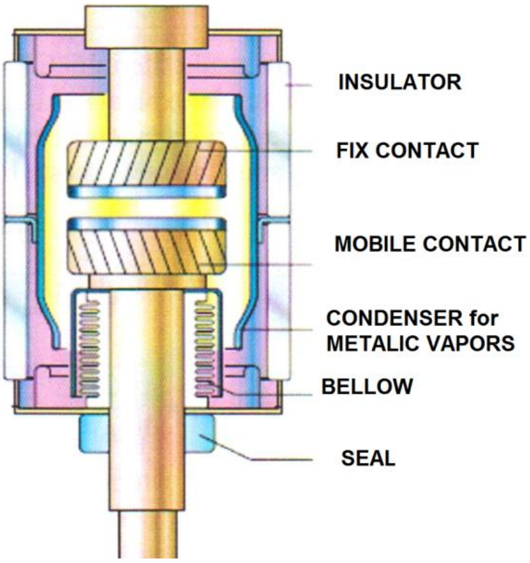

Fig. 3. Extinguishing room

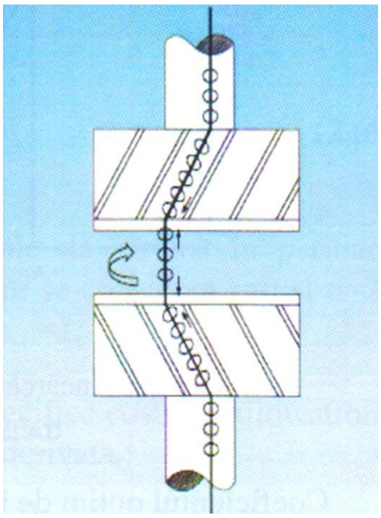

Fig. 4. Voltage lines and direction of concentrated electric arc movement

Due to these constructions, contact systems and phenomena (burning of electric arc in intense vacuum), manufacturers warrant vacuum extinguishing rooms with no maintenance for over 1000 shutdowns and breaks of short circuit voltages for nominal capacity, simultaneously with 10 000 maneuvers of shutting-opening at nominal current and voltage.

Based on these considerations, significant preoccupation exists in Romania as well, both among manufacturers and users, to carry out and apply medium voltage electricity distribution equipments, fitted with circuit breakers based on vacuum commuting technology. Vacuum commutation circuit breakers' performances (exploitation parameters, size, weight) involved new tendencies in the design of these equipments.

Medium voltage apparatus enclosed in interior metal case (cell) with insulation in air, fitted with vacuum room extinction circuit breaker, is meant for distribution and transforming stations supplied by cables. The tendency worldwide is to manufacture these products with as low as possible costs in view of reducing investment and maintenance expenses.

An important role in attaining the objectives from above is played by the design, spacing and volume of the cell, as well as the design of the equipping apparatus its technical level and functions achieved by it in a functional unit.

The principal tendencies have been the following:

- Use of insulating materials allowing reduction of volume of functional units;
- Reduction of the number of compartments and access only in the front in the case of apparatus in metal case resistant to free arc;
- Change of cell architecture by achieving a straight line for the primary energy transfer circuit from the general bars to the cable;
- Change of architecture of the cell fitting to reduce size;
- Use of fitting apparatus with multiple functions;
- Use of special insulators allowing capacitive dividers 9 for signaling the presence of voltage), measuring sensors and voltage protection;
- Use of a multifunctional protection, measuring, control and signaling relay, based on microprocessor method.

Solution adopted at Petrila Mine

Petrila Mine, like any of the other mines in general, is an important industrial energy consumer, having in exploitation several medium voltage distribution stations, providing operation of equipment and tools specific to mining.

Taking into consideration the importance of continuous functioning of certain types of equipment, such as: main ventilation stations, compressors, and extraction machines, the problem of initiating modernization and technological refurbishing of electricity distribution stations has been raised.

Medium voltage cell is made up of a case made up of the compartment for cables, and general bars, compartment for carriages that could be de-fastened, and low-voltage compartment.

Broaches provide the working position in the connected stage of the circuit breaker on the general bars and isolated position in disconnected stage (Fig. 5).

Fig. 5. Fixing the circuit breaker

The front part of the circuit breaker is accessible entirely from the outside, connecting, disconnecting reinforcement maneuvers being easily done, with no significant efforts. Both reinforcement and fastening of the breaker are done with special keys, which make these maneuvers easier, circuit breakers adapted to these types of carriages are manufactured by a manufacturer specialized in them. The way of connecting reinforcements is also known, the system of bars mounted in cells being Romanian made. For electricity and voltage transformers, Romanian made has also been considered, with a known, classical solution of fixing. Problems occurred in the modification of the front door, which had to keep the aspect and size of the circuit breaker and to allow access to its front part; cutting out at the exterior has been practical and looked well, but when several circuit breakers had to be handled in neighbouring cells, the width of the front doors opened for de-fastening at least at 90°, took up from the working space, making them thus insufficient, interventions having become cumbersome.

4. CONCLUSIONS

Due to the relatively high duration of restarting these elements, discontinuities occur in the production process, and in many situations, dangerous working conditions. These fallouts of the network elements lead to lack of voltage for consumers, which may be the signal for starting automatic control, with the condition of an adequate interconnection of various network elements, they not always being provided with spare elements, in the conditions of meeting the restrictions required by the operation of equipment in potentially dangerous atmospheres.

Control automation is possible in electricity transformation and distribution stations, in distribution points providing for complex powered faces or main conveying flows, in main transformation and distribution station on the ground, where several transformers are connected in parallel, operating with low loading coefficients. Automatic control is possible in other cases as well, but it is not economically viable in all the cases, due to the less important consumers.

The analyses made so far regarding electricity distribution systems in various underground showed that network elements with the highest influence on mining electrical energy systems, in case of defects, are commutation equipments for high and low voltage lines and mains.

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