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SECTION 7. Mechanics and machine construction.

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ANALYSIS OF THE BASIC ELECTRICAL NETWORK PARAMETERS IN OPERATING EMERGENCY CONDITIONS IN OIL REFINERY ENTERPRISES AND THE USE OF AUTOMATIC TRANSFER SWITCH FACILITIES

***Abstract**: The article considers the basic electrical network parameters in case of emergency conditions in oil refinery enterprises. A scheme of short circuit and the response of automatic transfer switch, and equivalent circuit for short-circuit current calculation have been provided. Basic physic technical dependencies for short-circuit current calculation have been suggested. The analyzed material comprises technical characteristics of automatic transfer equipment, relay protection and automatic equipment. Shown physical calculations of basic electrical network parameters for automatic transfer switch facilities exemplified by an electric substation of an oil refinery plant of the Republic of Bashkortostan with single current-limiting reactor. Recommended a selection method of relay protection and automatic equipment on the basis of cut-off sensitivity factor calculations and meeting technical demands of sensitivity. Provided calculations make it possible to create and implement innovative automatic transfer equipment switching over from operating emergency conditions in less than 1 second.*

***Key words**: energy, power supply, relay protection, automatic equipment, single-way feed, automatic transfer switch, short circuit, oil extraction, cut-off sensitivity factor.*

***Language**: English*

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1. Introduction. Power supply reliability depends mainly on the absence of short circuit in schemes of interior and exterior structures of devices and equipment. Because of the high level of electrical equipment wear the number of short circuits determining power failure grows every year. In such cases dealing with power supply reliability is the responsibility of power consumers [1].

The latter applies all the more for enterprises with complex automatic processes and automation equipment. For example, oil and gas extraction and refining joint ventures, water supply and water drain joint ventures and so on.

On the other hand, the running of high-voltage motors, low-voltage motors of pump drives, control equipment of technological processes elements of these enterprises are strongly influenced by supply voltage failures [2] which can last only a few seconds. Such supply voltage failures occur dozens of times a year and cause extensive damage notwithstanding that they last seconds.

Certainly, to provide a high degree of power supply reliability for consumers, power supply diagrams by two or more sources at a time are used (circuits, transformers), because emergency switching of one of them will not cause a loss of voltage at connection terminals of receivers.

However, despite the obvious advantages of multiple-way feed for consumers, a great number of substations use single-way feed [3]. This way of feed is also used for the power plant sections because it is a less reliable but simpler scheme of power supply.

At the same time according to [4], the above-noted scheme makes it possible to reduce short circuit current and a loss of energy in supply transformer for a simpler relay protection and to create the required voltage regime for power flows.

Under electrical network growth a single-way feed is often the possible one because the previously established equipment and relay protection do not allow implementing parallel padding.

The downside of single-way feed is that the emergency switching of the working source causes power failure for consumers. This downside is mainly fixed by high-speed automatic transfer switch or by circuit breaker closing where network division occurs. For performing the operation a special automatic transfer switch equipment is widely used (in the following, ATS) [5], especially at the enterprises such as oil refinery plant.

2. Goal setting. From this perspective, the goal of the study is a search and analysis of different ways of power supply reliability growth with the use of automatic transfer switch equipment as exemplified by oil refinery plant of the Republic of Bashkortostan.

The topicality of the article is that an analysis of automatic transfer switch has been carried out with identification of strengths and weaknesses for the purpose of reliable and continuous power supply for consumers.

The scientific novelty of the research is that the reasons of power failure and power supply interruption which cause power supply instability and breakdown in the technological process have been identified, and calculated methods to remove them have been found.

3. Brief theory. Breakdown in the technological process [6] might do substantial damage to oil refinery plants which create products with high-added value and work with continuous multi-stage manufacturing process.

Technical features of refining determine areal disconnection of process units, long-range power supply networks (voltage *35, 110, 220 kV*), treed system (voltage *6 kV*), and, consequently, high probability of fault that causes under voltage in the entire network of an enterprise power supply.

Thus, based on [7] it is possible to say that for the preservation of technological process, break in power supply of control systems should not exceed the time ~ *0,1-0,4 s*.

One of the methods of power supply reliability growth of responsible offsets powered from two independent sources is the usage of ATS equipment.

The main disadvantages of actual ATS equipment are: **(1)** performance under only three-phase short-circuits; **(2)** missing operations for complex systems of power supply of oil extraction with several substations; **(3)** quite a long working time of equipment during emergencies.

Analyzing the disadvantages it is possible to say that the main purpose of reliability growth of a power supply scheme of an oil refinery plant is identification of technical feasibility of automatic fast emergency source switch equipment as well as identification of allowable switching mode determined by a status of a power supply network.

Even in modern electromechanical automatic transfer switch equipment [8] switching cycle takes ~ *3-5 s*, while transient processes may take more than *10 s*. In this context, ATS function is not able provide favorable conditions for self-starting of all the electric motors. This can cause disturbance of the current technological process.

In applying second-generation ATS devices with fast multiprocessing fault detectors [9], switching time may take less than *0,1 s*. However, introduction of such devices requires fast switches and protections installation which will heavily influence the cost of production and cost recovery.

On the other hand, the total power of self-initiated electric motors cannot exceed *30%* of supply transformer. It means that field discharge and resynchronization of synchronous motors are not required and inrush currents of motors make only ~ *2,5* of rated current which makes it possible to increase motor recourses.

Most industrial plants are powered from two-transformer step down substations with *(220-110-35)/6 kV* voltage with independent sections on the voltage level of *6 kV*.

Every section (working/protection) is powered from its transformer through a local switch while a selection switch disconnects. In case of a fault in a network powering one of the sections, ATS disconnects its in feed and a selection switch.

Thus, ATS is one of the ways of supplying power consumers [10], connected to electrical power supply system with no less than two in feeds, with standby power supply. ATS is focused on reliability growth of electrical power supply system.

Generally, ATS should function in a minimum amount of time after disconnecting a working power supply. The device should function at any time, in case of loss of bus voltage of consumers, regardless of the reasons causing accidents.

There is one more requirement determined by infeasibility of multiple transfer switch – ATS functions one time. Generally ATS is implemented by relay protection and automatic equipment [11].

Uninterruptable power supply may also be implemented differently supplying every consumer from two sources at a time, this model, however, has some drawbacks. Short circuit currents under the parallel padding are much higher than under separate power supply to consumers, loss of energy is much higher in supply transformers.

Finally, relay protection is more complex than in case of separate power supply. It means that additional accounting of power flows affecting operating regime of the whole system is required.

Under-voltage relays [12] or phase control relays connected to protected sections through voltage transformers serve as a discriminating element for ATS in high-voltage power networks. In case of voltage reduction on a protected section of electrical network, a relay sends a signal to automatic-transfer scheme.

However, zero voltage condition (for example, a local switch was disconnected on purpose) is not yet sufficient for ATS device to start operating instantly.

Thus, it is important to implement ATS operating mechanism properly. The device should be switched on when a loss of power supply occurs for any reason or power supply becomes insufficient (or deficient) for consumer, a loss of one of current phases occurs or the voltage is insufficient.

In such a case, certainly there occurs disconnect of incorrect (or basic) in feed and connection of another, proper (regular) in feed. In this case there is no limitation for a consumer, and the necessary voltage remains.

We suggest that this simple mechanism is not only meant for protection of interests of a consumer of electric power but also it is meant to protect electric installation works and powerful devices from power interruption on an industrial scale.

4. Short-circuit current calculation. In planning and running any electric-power system it is necessary to consider possible faults and off-normal operational modes. The most common and the most dangerous at the same time are short circuits [13].

Accident conditions prevention or prevention of accident evolution may be provided by fast disconnection of a damaged element, this is what relay protection and automatic equipment are used for.

We calculated the basic electric network parameters for ATS operating on *10 kV* voltage used on substations of an oil refinery plant *PJSC JSOC "Bashneft" of the Republic of Bashkortostan*.

The object of planning is a cable line with a voltage of *10 kV*. A network with a voltage of *0,4 kV* is *300 m* long and is made of electric conductor *"A70"* (main bare conductor).

ATS is installed on the lowest voltage. The load factor of substations transformers is equal to *1*. The load factor of lines is ~ *0,8*.

A line with a voltage of *0,4 kV* is loaded by *28%* of the total capacity of transformer supply. Power factor for all types of consumers is ~ *0,8*. An original scheme for calculations is provided in figure *1*.

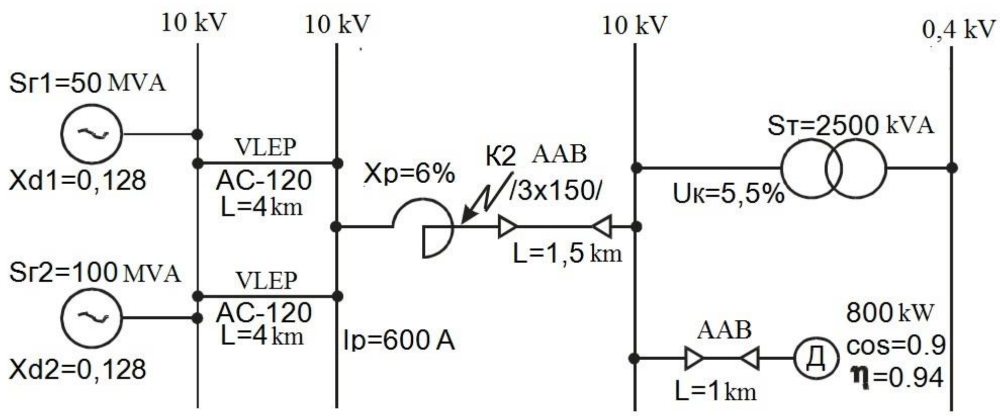

Figure 1 – An original scheme of short circuit and ATS equipment functioning

Based on [14] let us draw an equivalent circuit according to technical characteristics of the network given above.

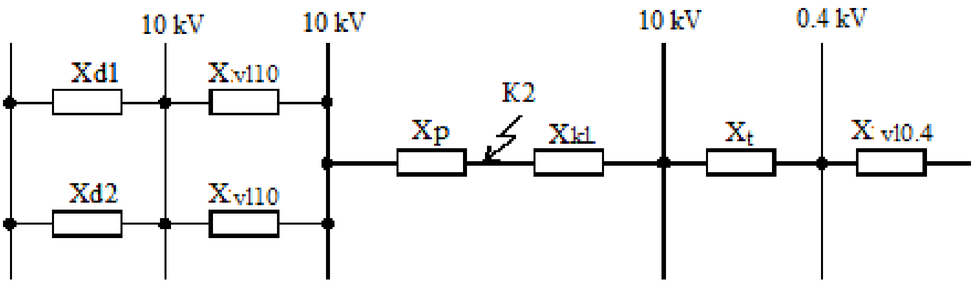

Figure 2 – Schematic equivalent circuit for short-circuit current calculation

4.1. Calculation of network elements resistance. First, let us calculate the resistance of the first generator Z_1.

$$Z_1 = X_{d1} \cdot \frac{U_{n^2}}{S_{n.g1}} = 0{,}128 \cdot \frac{10^2}{50 \cdot 10^3} = 0{,}256 \cdot 10^{-3}\ \hat{I}hm \quad (1)$$

where X_{d1} is sub-transient generator resistance, according to technical data we set it equal to *0,128 Ohm;* U_n is nominal voltage which equals to *10 kV*; S_n is generator nominal power.

Let us determine resistance of the second generator Z_2.

$$Z_2 = X_{d2} \cdot \frac{U_{n^2}}{S_{n.g2}} = 0{,}128 \cdot \frac{10^2}{100 \cdot 10^3} = 0{,}128 \cdot 10^{-3}\ Ohm \quad (2)$$

Now we determine total resistance of generator Z_g.

$$Z_g = \frac{Z_1 \cdot Z_2}{Z_1 + Z_2} = \frac{0{,}256 \cdot 10^{-3} \cdot 0{,}128 \cdot 10^{-3}}{0{,}256 \cdot 10^{-3} + 0{,}128 \cdot 10^{-3}} = 0{,}085 \cdot 10^{-3}\ Ohm \quad (3)$$

According to [15], we determine resistance of a line with a voltage of *10 kV* considering active resistance of R_0 line of *"AC-120"* electric conductor (main bare conductor) which equals *0,25 Ohm/km;* inductive reactance of X_0 line for *"AC-120"* conductor (main bare conductor) which equals *0,38 Ohm/km;* the length of L_{10} line *(km)* of *10 kV.*

$$\begin{aligned} R_{10} &= R_0 \cdot L_{10} = 0{,}25 \cdot 4 = 1\ Ohm; \\ X_{10} &= X_0 \cdot L_{10} = 0{,}38 \cdot 4 = 1{,}52\ Ohm; \\ Z_{L1_{10}} &= \sqrt{R_{10}^2 + X_{10}^2}\ Ohm; \\ Z_{L1_{10}} &= \sqrt{1^2 + 1{,}52^2} = 1{,}82\ Ohm. \end{aligned} \quad (4)$$

As we have two aerial lines of *10 kV* of equal cut-off and length, their resistances are equal. These lines are in parallel connection, which means they can be represented as resultant impedance Z_{L10}.

$$Z_{L10} = \frac{Z_{L1_{10}} \cdot Z_{L2_{10}}}{Z_{L1_{10}} + Z_{L2_{10}}} = \frac{1{,}82 \cdot 1{,}82}{1{,}82 + 1{,}82} = 0{,}92\ Ohm \quad (5)$$

Assuming that a single-phase current limiting reactor [16] of *"RB 10-630-1.OUZ"* type is optimized for continuous current at natural cooling of *10 kV (for 630 A)*, let us calculate reactor resistance:

$$Z_R = \frac{X_R}{100} \cdot \frac{U_n^2}{\sqrt{3} I_{n.c.} \cdot U_{av}} = \frac{6}{10} \cdot \frac{10^2}{\sqrt{3} \cdot 0{,}63 \cdot 10{,}5} = 0{,}55\,Ohm \quad (6)$$

where X_R is relative resistivity of a reactor (in percentage terms) equals *6%* according to original data; $I_{n.c}$ is design current (in *kA*) equals *0,63 kA* according to technical data; U_{av} is average voltage of a line.

4.2. Calculation of cable line resistance. Considering that inductive reactance at *1 km* of cable depends little on a cut-off, it follows from [17] that for cables with a voltage of *10 kV* it is possible to accept that the value of inductive reactance equals (should be considered equal) X_0 = *0,08 Ohm/km.* Active resistance with *150 mm* cut-off is set equal to R_0 = *0,194 Ohm/km*. Let us calculate the resistance of cable line Z_{cab}.

$$\begin{aligned} R_{cab} &= R_0 \cdot L = 0{,}194 \cdot 1{,}5 = 0{,}291\,Ohm \\ X_{cab} &= X_0 \cdot L = 0{,}08 \cdot 1{,}5 = 0{,}12\,Ohm \\ Z_{cab} &= \sqrt{R_{cab}^2 + X_{cab}^2}\ Ohm \\ Z_{cab} &= \sqrt{0{,}291^2 + 0{,}12^2} = 0{,}314\,Ohm \end{aligned} \quad (7)$$

Let us calculate resistance of a line with a voltage of *0,4 kV*.

$$\begin{aligned} Z_{L0,4} &= \sqrt{R_{0,4}^2 + X_{0,4}^2} = \sqrt{0{,}068^2 + 0{,}028^2} = 0{,}074\,Ohm \\ R_{0,4} &= R_0 \cdot L_{0,4} = 0{,}85 \cdot 0{,}08 = 0{,}068\,Ohm \\ X_{0,4} &= X_0 \cdot L_{0,4} = 0{,}35 \cdot 0{,}08 = 0{,}028\,Ohm \end{aligned} \quad (8)$$

where R_0 is active resistance for conductor *"A-35"* (main bare conductor) equal to *0,85 Ohm/km*; X_0 is inductive reactance of a line for conductor *"A-35"* (main bare conductor) equal to *0,35 Ohm/km*; $L_{0,4}$ is a length of the line (in *km*) with the voltage of *0,4 kV*.

Let us draw an equivalent circuit considering the simplifications performed.

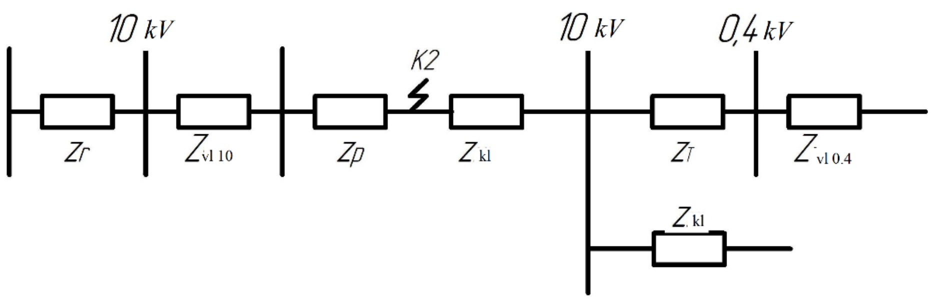

Figure 3 – Equivalent circuit for short-circuit current calculation at point *K2*

4.3. Calculation of short-circuit current at point *K2*. First let us calculate total resistance up to point *K2*.

$$Z_{t2} = Z_{t1} + Z_R = 0{,}9201 + 0{,}55 = 1{,}47\,Ohm \quad (9)$$

Current of three-phase short circuit will be equal to:

$$I_{sc}^{(3)} = \frac{10}{\sqrt{3} \cdot 1{,}47} = 3{,}92\, kA \quad (10)$$

Let us calculate current of two-phase short circuit at point *K2*:

$$I_{sc}^{(2)} = 0{,}87 \cdot 3{,}92 = 3{,}41\, kA \quad (11)$$

We calculate design current of a motor:

$$I = \frac{P}{\sqrt{3} \cdot U \cdot \cos\varphi \cdot \eta} = \frac{800}{\sqrt{3} \cdot 10 \cdot 0{,}9 \cdot 0{,}94} = 54{,}6\ A \quad (12)$$

Based on technical data from [18], according to warming-up allowance we take a cable with *S* cut-off of *16 mm²*; inductive reactance of a line X_0 will be set equal to *0,08 Ohm/km*; let us consider (electrical) conductivity of the cable for aluminium $\gamma = 32 \frac{m}{Ohm \cdot mm^2}$.

We count active resistance R_0 and total resistance Z_{sc} of the line:

$$R_0 = \frac{1000}{\gamma \cdot S} = \frac{1000}{32 \cdot 16} = 1{,}9\, Ohm \quad (13)$$

$$Z_{sc} = \sqrt{R^2 + X^2} = \sqrt{0{,}08^2 + 1{,}9^2} = 1{,}901\, Ohm \quad (14)$$

4.4. Selection of relay protection and automatic equipment. Protection from multi-phase short circuit should be considered in two-phase performance [19] and it should be switched during the same phases throughout the resistance network to provide switching out in most cases of double ground faults of only one point of fault.

Protection, as a rule, should be in one relay, two relay or three relay performance. For that let us choose relays of closing current and release current *"RT85/1"*.

Let us calculate setup current for the above-noted relay type:

$$I_{an} = \frac{k_{rel} \cdot k_{part}}{k_{res} \cdot n_t} \cdot I_{load} = \frac{1{,}2 \cdot 1}{0{,}85 \cdot 60} \cdot 480 = 11{,}29\ A \quad (15)$$

where k_{rel} is reliability factor equal to *1,2*; k_{res} – reset coefficient for relay of *"RT-85"* type equal to *0,85*; k_{part} – partial star network factor which is equal to *1*; n_t – turn ratio of transformation for current transformers equal to *60*; I_{load} – load current, running through a cable line.

Let us calculate operative current of a cut-off:

$$I_{t.o.} = \frac{k_{rel} \cdot k_{part}}{n_t} \cdot I_{sc}^{(2)} = \frac{1{,}2 \cdot 1}{60} \cdot 3410 = 68{,}2\ A \quad (16)$$

As setup current almost fits the magnitude ~ *12 A*, take up the relay setup for a higher operative current of a cut-off ~ *70 A*.

Finally, let us calculate cut-off sensitivity factor, considering that the calculated value should be greater than *2*, for meeting demands of sensitivity.

$$k_{sens} = \frac{I_{r/\min}}{n_t \cdot I_{an}} > 2$$

$$k_{sens} = \frac{3410}{60 \cdot 7} = 8{,}12 > 2 \quad (17)$$

From this perspective, according to provided calculations, it is possible to say that the time of cut-off functioning and cut-off pick-up ratio of the relay *"RT85/1"* meet the demands which require applying this relay protection at the substations of oil refinery plants.

5. Conclusions and summary. In modern times, competent physic technical calculations, further development and improvement of ATS equipment with its operating reliability growth, providing rapidity up to the level which is necessary for preservation of dynamical stability of complex electromotive load, makes it possible to retain continuity of technological process of oil extraction, to reduce the likelihood of dangerous operational modes occurrence (for example, hydraulic shock, oil spill), and to boost economical efficiency of oil-extracting complex.

It means that the existing ATS equipment at substations *35/6 kV* oil extraction, oil refinery with different combination of substation loads with the time of functioning *5-20 s*, will cease to be the reason of process units disconnection at short-term disturbance of power supply in supply lines (for example, *35, 110 kV*, total supply fail).

On the other hand, even one successful switching can possibly provide continuity of installation operation and will eliminate the demand of rerun (next run) or switching. That is, correct calculations might provide full return on investments which are necessary to install kits on the nodes.

From this perspective, modern ATS equipment might provide connection of a separate source of energy (for example, generator, rechargeable battery) or perform closing of circuit breaker which separates network, and it is possible to raise the break in power supply up to *0,3-0,8 s*.

That means, while projecting innovative ATS schemes it is important to consider the capacity of supply transformer and energy source strength supplying parallel system. This condition is a prime and necessary tool for reliable and consistent operating of large enterprises.

That is why implementation of ATS equipment into power supply systems of oil and gas industry enterprises is possible only after detailed assessment of the existing scheme of power supply, calculation of network parameters at operating emergency conditions and economic efficiency, as well as a full picture of the difficulties arising during operation of the equipment.

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