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Modeling and Calculating the Probability of Fire Outbreak in Factories and Industrial Plants

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□ ABSTRACT □

International statistics have shown that the number of fire accidents resulting from electric equipment failures and non-functioning of protection systems is enormous. Overheating the coils of electrical motors leads to the possibility of the ignition of the insulation of electric conductors causing the spread of fire, especially if the frames of these motors contribute more to the spread of fires to the neighboring regions. The most common systems causing the increase of overloading electric motors are the non-symmetry of the input tension to these motors. This gives rise to a negative sequence of currents overlaying a direct sequence of currents leading to an additional increase in heating the rotor, stators, to the wearing and charring of the insulation of the motors, and finally to fire outbreak. In this research, we aim to estimate and calculate the probability of fire outbreak in electric equipment at industrial plants, checking the reliability embedded within the protection systems, so that the probability of fire occurrence resulting from induction motors is compatible with international standards and criteria.

Keywords: fire, theory of probability, electric cables

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نمزجة وحساب احتمالية نشوب الحرائق
في المعامل والمنشآت الصناعية

الدكتور جورج اسبر*
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□ الملخّص □

إن زيادة تسخين وشائع التجهيزات الكهربائية يؤدي إلى احتمال انهيار عازلية الكابلات الكهربائية، وبالتالي اشتعالها وانتشار الحريق وخاصة إذا كانت هياكل هذه التجهيزات مغطاة بطبقات من الغبار والمشبعة بالزيوت، فهي تساهم أكثر في انتشار الحرائق إلى المناطق المجاورة.

إن أكثر الأنظمة الشائعة المسببة لزيادة تحميل الآلات الكهربائية هي عدم تناظر توتر الدخل إلى هذه الآلات، وهذا يؤدي إلى ظهور تيارات التتابع العكسي التي تُضاف على تيارات التتابع المباشر، وهذا يقود إلى زيادة إضافية في تسخين وشائعها، وفي النهاية اهتراء عازليتها وتفحمها ونشوب الحريق.

نهدف في هذا البحث إلى تقدير وحساب احتمالية نشوب الحرائق في المنشآت الصناعية التي تستخدم التجهيزات الكهربائية، ومعرفة الوثوقية التي يجب أن تتمتع بها أنظمة الحماية لكي يكون احتمال حدوث الحريق الناتج بسبب هذه التجهيزات مطابقاً للمواصفات القياسية المعيارية العالمية.

الكلمات المفتاحية: الحرائق ، نظرية الاحتمالات ، الكبلات الكهربائية.

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Introduction:

International statistics have shown that the number of fire accidents occurring as a result of the failures of electric devices and the breakdown of protection systems is very considerable. The rate of fire accident in thermo-stations has amounted to 52%, at transformation stations to 45%, and at hydraulic stations to 5% out of the total rate of fires that happened for reasons not relating to the electric current. However, fire accidents resulting from electric equipment failures are at the rate of 16%.[1].

Overheating the rotating motor coils leads to the probability of the collapse of the insulation of electric cables, causing as a result their inflammation and the spread of fire, especially if the frameworks of these motors are covered with dust layers saturated with oils which contribute more to the spread of fire accidents to the neighboring areas.

Most cases of fire accidents arise from overheating the rotating motor coils resulting from the slowdown rotation of the rotor or the phase break in the stator or deflection in the net voltage from the allowed values or because of asymmetry in the phases voltages.[2].

The most common systems that cause overloading the electric equipment are the asymmetry of incoming voltage to this equipment. The values of the asymmetry factor could reach the breaking of the linear conductor in the feeding voltage of rate 28% which greatly exceeds the values permitted by the criterion of standard specifications.

Asymmetrical voltage leads to the appearance of adverse successive currents which are added to direct successive currents. This causes an additional increase in heating the coils of the rotor and stator, and finally the fast wearing of motor insulation.

Aims and Importance of this Research:

The importance of this research stems from the calculation of the probability of fire occurrence and explosions at industrial plants. Consequently, we obtain early information to avoid danger. Therefore, the research aims may be summarized as follows:

1-Predicting the probability of fire occurrence by investing in electric equipment at industrial plants.

2-Putting a mathematical model for calculating the time of fire occurrence.

3-Checking the reliability of the protection systems, so that the probability of fire occurrence resulting from the running of electric equipment must be compatible with the international criterion specifications:

$$H \le 1 \cdot 10^{-6} \frac{1}{\text{year}} = 1.14 \cdot 10^{-10} \frac{1}{\text{hour}}$$

Method of Research and the Materials Used:

A mathematical model has been used to clarify the thermal and mechanical qualities of an electric motor working in circumstances involving asymmetry of voltages. Figure(1) illustrates the relations of phase currents C,B,A, of the motor coils with the asymmetry factor K_{2u}.

Calculations were made by means of symmetrical components by using the equivalent circuit in the form of the letter T for the sake of direct and indirect successions[4].

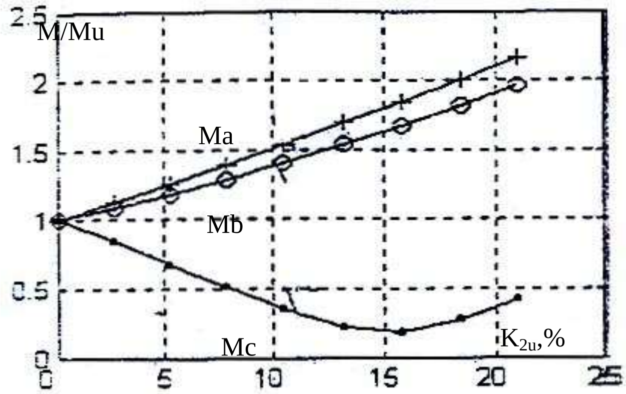

Figure (1)- relation of the phases currents C,B,A, of the electric motor with the asymmetry factor K_{2u}%

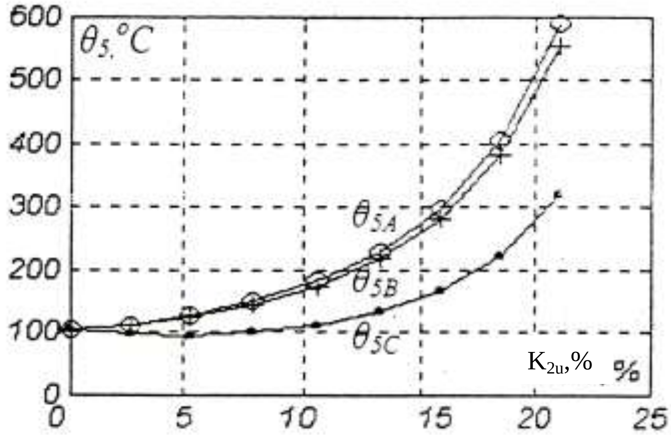

Figure (2)- relation of the increase of electric motor coils temperature for the sake of C,B,A, phases with asymmetry factor K_{2u}%

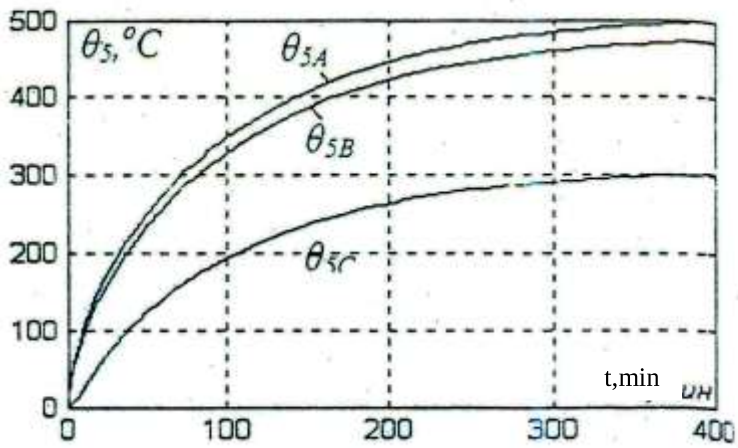

Figure (3)- curves of heating the electric motor coils for the sake of C,B,A, phases in the asymmetry factor K_{2u} = 20%

Figure (1) shows the current distribution in the phases of stator coils; (I_{1C} , I_{1B} , I_{1A}) are distributed in an irregular way. This results from the deformations of tension symmetry. On increasing asymmetry considerably, then the distribution of currents on phases could rise twice or even more; this causes the increase of heating in electric motor coils. The thermal status of electric motor has been calculated by means of differential equations which depend on thermo equivalent circuit[5].

Figure (2) illustrates the relation of increasing the motor coil temperature with the asymmetry factor. It is clear therefore that increasing temperature degree in the electric equipment coils in the asymmetry factor K_{2u} = 20% reaches 510, 480, 285 centigrade of C,B,A phases. This is much greater than the permitted suggested values(1). The increase of electric equipment temperature affects the period of insulation services. From heat curves and in asymmetry factor mentioned in figure(3), and by using a mathematical method for calculating the period of insulating material service[6], we can obtain the time period of insulation material service at the most temperature exposed, being 5 A equaling 3.2 hours. That is, tension at the motor entrances, (e.g. at about 20% and the failure of the protection system at work, then after 3.2 hours), will be a collapse in the motor coil insulation or any rotating electric device. The work of such a system will continue until the coils char and insulation begins to inflame. Given this, the temperature of the electric device frame will rise to a degree allowing the dust layer saturated with inflammable materials on the frames of those electric devices to inflame. This will lead to the spread of fire to the neighborhood if the surrounding circumstances permit this to happen. As a result, by investing in the electric equipment, fire could break out when the following accidental events conform in time and place: Increase the temperature of electric equipment frames, for example, (when one of the feeding phases breaks one of the electric equipment), in addition to the failure in operating protection cutouts, and the presence of flammable materials on the frames of equipment.

The probability of fire occurrence $Q_{(t)}$ resulting from the presence of electric equipment during the period (t) equals the probability $P_{8(t)}$ and after entering all the elements used in the system, which are:

- Protection of the electric device.
- Flammable materials present in case of their allowing fire occurrence being observed at the time (t):

- The break of one phase
- Failure of the protection system
- Presence of flammable materials on the device frame.

$P_{8(t)}$ probability may be calculated by using the system of differential equations:[7]

$$\left.\begin{aligned}
\dot{P}_1(t) &= (\lambda_1+\lambda_2+\lambda_3)P_1(t)+\mu_1P_2(t)+\mu_1P_3(t)+\mu_1P_4(t)\\
\dot{P}_2(t) &= \lambda_1P_1(t)-(\mu_1+\lambda_2+\lambda_3)P_2(t)+\mu_2P_5(t)+\mu_3P_6(t)\\
\dot{P}_3(t) &= \lambda_2P_1(t)-(\lambda_1+\mu_2+\lambda_3)P_3(t)+\mu_1P_5(t)+\mu_3P_7(t)\\
\dot{P}_4(t) &= \lambda_3P_1(t)-(\lambda_1+\lambda_3+\mu_3)P_4(t)+\mu_1P_6(t)+\mu_2P_7(t)\\
\dot{P}_5(t) &= \lambda_2P_2(t)+\lambda_1P_3(t)-(\mu_1+\mu_2+\lambda_3)P_5(t)\\
\dot{P}_6(t) &= \lambda_3P_2(t)+\lambda_1P_4(t)-(\mu_1+\lambda_2+\mu_3)P_6(t)\\
\dot{P}_7(t) &= \lambda_3P_3(t)+\lambda_2P_4(t)-(\lambda_1+\mu_2+\mu_3)P_7(t)\\
\dot{P}_8(t) &= \lambda_3P_5(t)+\lambda_2P_6(t)+\lambda_1P_7(t)
\end{aligned}\right\} \quad (1)$$

The system of equations (1) is solved by the presence of primary conditions as follows:

$P_1(0)=1, P_2(0)=P_3(0)=P_4(0)=P_5(0)=P_6(0)=P_7(0)=P_8(0)=0$, which are calculated from the applied hypotheses which show at the beginning of the time period that no failure leading to the conductor break (phase) could be observed; protection of electric devices being in a healthy position. The frames of this equipment being clean, i.e. without any flammable materials on them.

By solving the system of differential linear equations according to reference[6,7], we obtain:

$$P(t) = P(0)\exp(At) \quad , \qquad (2)$$

Where: $P(t) = (1,0,...)$ line ray containing the primary conditions

$$P(t) = [P_i(t)]_{i=1}^{\infty} \text{ ray} - \text{line}$$

$$\begin{aligned} -\alpha_1 &= 1 - (\lambda_1 + \lambda_2 + \lambda_3), \\ \alpha_2 &= 1 - (\mu_1 + \lambda_2 + \lambda_3), \\ \alpha_3 &= 1 - (\lambda_1 + \mu_2 + \lambda_3), \\ \alpha_4 &= 1 - (\lambda_1 + \lambda_2 + \mu_3), \\ \alpha_5 &= 1 - (\mu_1 + \mu_2 + \lambda_3), \\ \alpha_6 &= 1 - (\mu_1 + \mu_2 + \mu_3), \\ \alpha_7 &= 1 - (\lambda_1 + \mu_2 + \mu_3). \end{aligned} \qquad (3)$$

Average time may be calculated until the emergence of the first fire from the equation system[5]:

$$\left.\begin{aligned} &(\lambda_1 + \lambda_2 + \lambda_3)\tau_1 - \lambda_1\tau_2 - \lambda_2\tau_3 - \lambda_3\tau_4 = 1 \\ &-\mu_1\tau_1 + (\mu_1 + \lambda_2 + \lambda_3)\tau_2 - \lambda_2\tau_5 - \lambda_3\tau_6 = 1 \\ &-\mu_2\tau_1 + (\lambda_1 + \mu_2 + \lambda_3)\tau_3 - \lambda_1\tau_5 - \lambda_3\tau_7 = 1 \\ &-\mu_3\tau_1 + (\lambda_1 + \lambda_2 + \mu_3)\tau_4 - \lambda_1\tau_6 - \lambda_2\tau_7 = 1 \\ &-\mu_2\tau_2 - \mu_1\tau_3 + (\mu_1 + \mu_2 + \lambda_3)\tau_5 = 1 \\ &-\mu_3\tau_2 - \mu_1\tau_4 + (\mu_1 + \lambda_2 + \mu_3)\tau_6 = 1 \\ &-\mu_3\tau_3 - \mu_4\tau_2 + (\lambda_1 + \mu_2 + \mu_3)\tau_7 = 1 \end{aligned}\right\} \quad , \qquad (4)$$

In the case, when $\frac{\lambda_i}{\mu_i} \leq 0.01$ ، $i = \overline{1.3}$ then from the equation system (4), we find τ_1 the average time until the first fire. If all the system elements at the beginning of the first time period are present in the safety case, then:

$$\tau_1 = \frac{\mu_1\mu_2\mu_3}{\lambda_1\lambda_2\lambda_3(\mu_1\mu_2\mu_3)} \quad ,$$

$$\mu_i = \frac{1}{d_i} \quad , \quad \lambda_i = \frac{1}{\overline{d}_i} \quad , \quad i = \overline{1.3} \quad . \qquad (5)$$

Where: $\overline{d}_1, d_1$ represent the average of the time period between the emergent breaking of one of the feeding phases of the electric equipment and the continuation average of the work system,

$\overline{d}_2, d_2$ represent the average of time part (separation) between failure of protection means at work and the continuation average of the presence of protection means in the failure position,

$\bar{d}_3, d_3$ represent the average of time part (separation) between the emergence of heat on the materials suspending on the frames of electricequipment and the continuation average of the presence of hot materials (dust) on their frames.

In the applied practical cases, we always commit ourselves to the following proportions:

$d_2 >> d_1$ and $d_3 >> d_1$,

Here we may rewrite relation (5) as follows:

$$\tau_1 \cong \frac{\mu_2\mu_3}{\lambda_1\lambda_2\lambda_3} , \qquad (6)$$

If we give a value to the time break between two examinations of the atmosphere pollution test inside the factory θ and the time break between two examinations of the protection systems θ_2, then μ_3 and μ_2 may be found from (7):

$$\mu_j = \frac{1}{\theta_j - \frac{1}{\lambda_j}\left[1 - \exp(-\lambda_j \theta_j)\right]} , \qquad (7)$$

On completing the following two conditions and from relation (6), we find:

$$\mu_2 = \frac{2}{\theta_2^2\lambda_2}, \qquad (8)$$

$$\mu_3 = \frac{2}{\theta_3^2\lambda_3}. \qquad (9)$$

When we compensate for relations (8) and (9) by relation (6), we could obtain:

$$\tau_1 \cong \frac{4}{\lambda_1\lambda_2^2\lambda_3^2\theta_2^2\theta_3^2}. \qquad (10)$$

The probability of fire occurrence in factories, where there is electric equipment during the time (t) equals the probability of protection system presence in defense position (waiting); the calculation of probability $P_8(t)$ may be found by the system of differential equations (1), where:

$$Q(t) = P_8(t). \qquad (11)$$

Applied example – we have the following primary given quantities:

$\bar{d}_1 = 7340$ h - the average of time break between the emergence of the phase break in the net which feeds electric equipment,

$d_1 = 5.6 \cdot 10^{-5}$ h - average time required for the protection system on the break of one of the feeding net phases of those electric equipment,

$\bar{d}_2 = 15400$ h - average of time breaks between the failure of the work of protection systems,

$\theta_2 = 2160$ h - time break between maintenance of protection systems,

$\bar{d}_3 = 520$ h - average time break between the emergence of dust saturated with flammable materials on the frames of electricequipment,

$\theta_3 = 180$ h - time break between observations of the presence of flammable materials on the frames of electric equipment.

We calculate the probability of fire occurrence through: $t = 8760$ h of electric equipment invested in an industrial plant and comparing the results with the specifications of international standards estimated at $Q_0(8760) = 1 \cdot 10^{-6}$ and the European specifications equaling $Q_0(8760) = 1.1 \cdot 10^{-6}$.

Solution- by using the primary given quantities of the example, we find μ_1, μ_2, μ_3 and $\lambda_1, \lambda_2, \lambda_3$:

$$\mu_1 = \frac{10^5}{5.6} = 17857 \quad 1/h$$

$$\mu_2 = \frac{1}{2160 - 15400\left[1 - e^{-\frac{2160}{15400}}\right]} = 6.9 \cdot 10^{-3} \quad 1/h$$

$$\mu_3 = \frac{1}{180 - 520\left[1 - e^{-\frac{180}{520}}\right]} = 3.6 \cdot 10^{-2} \quad 1/h$$

$$\lambda_1 = \frac{1}{5.6} = 1.36 \cdot 10^{-4} \quad 1/h$$

$$\lambda_2 = \frac{1}{15400} = 6.49 \cdot 10^{-5} \quad 1/h$$

$$\lambda_3 = \frac{1}{520} = 1.92 \cdot 10^{-3} \quad 1/h$$

We compensate the information mentioned above in the equation system (1), and by using the computer and the performed program, we obtain: $P_2(8760) = Q_0(8760) = 4.42 \cdot 10^{-3}$, we compare the obtained result with the criterion value which is: $Q_0(8760) = 1 \cdot 10^{-6}$, we find that the securing from fire is not achieved in the industrial plant which invests electric equipment. We find that there is danger of fire outbreak. Therefore, maintenance measures must be taken seriously.

Conclusions and Recommendations:

1-By means of this method we can calculate the probability of fire occurrence resulting from the work of electric equipment at industrial plants, and we can also predict the times of their occurrence. This, in turn, allows us to take the required measures to avoid danger. A computer program has also been used to perform calculations.

2-The presented mathematical method allows evaluating the electricl equipment performance at industrial plants.

3-The program achieving the mathematical model greatly facilitates obtaining results.

The former presented method allows us to evaluate the performance of electric equipment at the industrial plants.

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