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Influence of the Electric Reactor Magnetic Field on the Electromagnetic Relays

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Introduction

One of the mean criterions of power system reliability is capability of system to keep the satisfactory level of voltage in the time of the short circuit. Ad hoc the special inductive elements without ferromagnetic core – electric reactors - are used. Simultaneously they limit the short circuit current.

Electric reactor is the source of the strong magnetic field. The magnetic field of the reactor arises especially in the time of short circuit action. When the rated current of electric reactor is equal to 1,6 kA, in the moment of the short circuit it can reach 50 kA. The modeling results of the magnetic field, which creates electric reactor, are presented in [1, 2]. We can see that in the places where the cases with protection relays are mounted the magnetic field grows to the value 70 kA/m.

The short circuit is emergency action dangerous for all power system and it must be quickly localized. The relay protection system is used for this. All equipment is arranged compactly in the power plants. The some part of the relays of the protection system is situated in the close vicinity of the electric reactor. The magnetic field is used for the electromagnetic relay control. Therefore the strong outer magnetic field can disturb the action of the electromagnetic relays.

The electric reactor is the three-phase device. The rotating magnetic field with variable direction of field arises near the reactor, usually. But the magnetic field can be directed along the concrete direction in the short circuit action especially when the short circuit is in one phase. This direction is not known in advance. The relays can be acted by the magnetic field of other power equipment, too. Therefore when the relays are mounted the every its position can be dangerous in the short circuit case.

To warrant the reliability of relay protection system we must to explain what influence can do the outer magnetic field for the electromagnetic relays of different sorts which are used in the relay protection system [3, 4].

The action of outer magnetic field to the relay of the direct current

The typical design of the electromagnetic relay of the direct or alternating current is showed in the Fig 1. The main parts of relay are: magnetic circuit M, the moving part of magnetic circuit – armature A and the excitation coil of the magnetic field EC. Because the current is not passing in the excitation coil EC between the magnetic circuit M and armature A is air gap AG. When the current i_0 is passing in the EC the armature A is attracting to magnetic circuit M the contacts related with A are connected or disconnected and the required electric circuit is connecting.

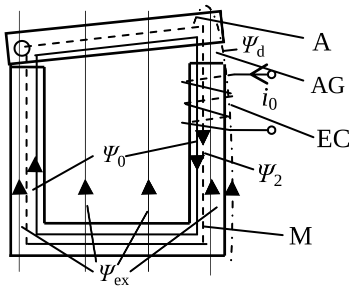

Fig. 1. The design of the electromagnetic relay and its magnetic fluxes

The current i_0=I_0=const is invariable in the electromagnetic direct-current relay. This current creates the magnetic flux Ψ_0=const, which attracts the armature A.

We suppose that in the air gap AG and excitation coil the outer alternating magnetic flux Ψ_{ex} acts and it is parallel to the flux Ψ_0. Therefore, in the half period of flux Ψ_{ex} alternation the directions of the fluxes Ψ_{ex} and Ψ_0 are the same and in the other half period these fluxes are directed on the contrary. We choose the initial phase of the flux Ψ_{ex} equal to π

$$\Psi_{ex} = \Psi_{exm} \sin(\omega t + \pi). \quad (1)$$

Some part of the outer flux acts in the air gap AG but it is not passed inside the excitation coil EC. We name this flux as leakage flux and note as Ψ_d

$$\Psi_d = \Psi_{dm}\sin(\omega t + \pi). \tag{2}$$

Magnetic flux Ψ_{ex} creates the internal voltage u_0 in the excitation coil EC

$$u_0 = -\frac{d\Psi}{dt} = \omega\Psi_{exm}\sin(\omega t + \frac{\pi}{2}). \tag{3}$$

The internal voltage u_0 creates the current i_2 in the excitation coil

$$i_2 = \frac{\omega\Psi_{exm}}{\sqrt{(\omega L)^2 + R^2}}\sin(\omega t + \varphi), \tag{4}$$

where the R and L are the resistance and the inductance of the excitation current, accordingly

$$\varphi = \arctan\frac{R}{\omega L}. \tag{5}$$

The current i_2 creates the magnetic flux Ψ_2, which can be expressed as follows

$$\Psi_2 = Li_2 = \frac{\Psi_{exm}}{\sqrt{1+(\frac{R}{\omega L})^2}}\sin(\omega t + \varphi) =$$
$$= \frac{\Psi_{exm}}{\sqrt{1+(\frac{R}{\omega L})^2}}(\cos\varphi\sin\omega t + \sin\varphi\cos\omega t). \tag{6}$$

Evaluating that:

$$\sin\varphi = \sin(\arctan\frac{R}{\omega L}) = \frac{R/\omega L}{\sqrt{1+(R/\omega L)^2}}, \tag{7}$$

$$\cos\varphi = \cos(\arctan\frac{R}{\omega L}) = \frac{1}{\sqrt{1+(R/\omega L)^2}}, \tag{8}$$

we obtain

$$\Psi_2 = \frac{\Psi_{exm}}{1+(R/\omega L)^2}\sin\omega t + \frac{\Psi_{exm}(R/\omega L)}{1+(R/\omega L)^2}\cos\omega t. \tag{9}$$

In the ideal case when $R/\omega L \to 0$ and $\Psi_d \to 0$ the flux Ψ_2 will be equal to flux Ψ_{ex} and will be directed contrary. Therefore it could be compensate the flux Ψ_{ex}.

In the real relay we must evaluate the R and Ψ_d. Flux Ψ_{ex} expressed by (1) we can present by two components

$$\Psi_{ex} = -\frac{\Psi_{exm}}{1+(R/\omega L)^2}\sin\omega t - \frac{\Psi_{exm}(R/\omega L)^2}{1+(R/\omega L)^2}\sin\omega t. \tag{10}$$

Evaluating, that $\Psi_d = -\Psi_{dm}\sin\omega t,$ total magnetic flux of air gap Ψ_Σ can be expressed of (9) and (10)

$$\Psi_\Sigma = \Psi_0 + \Psi_{ex} + \Psi_2 + \Psi_d =$$
$$= \Psi_0 - (\frac{\Psi_{exm}(R/\omega L)^2}{1+(R/\omega L)^2} + \Psi_d)\sin\omega t + \frac{\Psi_{exm}(R/\omega L)}{1+(R/\omega L)^2}\cos\omega t. \tag{11}$$

This magnetic flux is pulsated. When the amplitude of Ψ_{ex} is big, the action of relay can be delayed to 10 ms. The contacts of relay can be periodically connected and disconnected independently on the relay control current I_0.

The disruptive alternating magnetic flux can evoke other negative effect. The excitation coil EC will be heating by the current i_2 complementary to the heating by control current I_0. The complementary heat power P can be calculated as follows

$$P = \frac{1}{T}\int_0^T i_2^2 R dt = \frac{R\omega^2\Psi_{exm}^2}{2(\omega^2 L^2 + R^2)}. \tag{12}$$

When the outer magnetic flux is large the relay can quickly overheat.

The action of outer magnetic field to the relay of the alternating current

The design of the alternating-current relay is the same as the direct-current relay (see Fig. 1). The control current in the alternating-current relay is sinusoidal

$$i_0 = I_{m0}\sin\omega t. \tag{13}$$

This current creates the sinusoidal magnetic field in the air gap AG. The flux Ψ_0 of this field is sufficient for the armature attraction

$$\Psi_0 = \Psi_{0m}\sin\omega t. \tag{14}$$

Suppose that in the air gap AG and excitation coil EC of this relay acts the outer magnetic flux Ψ_{ex}, analogically with direct-current relay. The flux Ψ_{ex} is expressed by (1). It is directed contrary to magnetic flux Ψ_0. In the air gap AG acts the leakage flux Ψ_d, too. It is expressed by (2). The flux Ψ_{ex} evokes the current i_2 and magnetic flux Ψ_2, expressed by (9). We obtain the total magnetic flux Ψ_Σ of the air gap AG summing Ψ_0, Ψ_{ex}, Ψ_d and Ψ_2

$$\Psi_\Sigma = [1 - \frac{\Psi_{exm}}{\Psi_{0m}}\frac{(R/\omega L)^2}{1+(R/\omega L)^2} - \frac{\Psi_{dm}}{\Psi_{0m}}]\cdot\Psi_{0m}\sin\omega t +$$
$$+ \frac{\Psi_{exm}}{\Psi_{0m}}\frac{(R/\omega L)}{1+(R/\omega L)^2}\cdot\Psi_{0m}\cos\omega t = \Psi_I + \Psi_{II}. \tag{15}$$

It consists of sinusoidal Ψ_I and cosinusoidal Ψ_{II} components. These components create the electromagnetic forces F_I and F_{II}, accordingly

$$F_I = \frac{\Psi_{0m}^2(1-\cos 2\omega t)}{4\mu_0 S_\delta}[1 - \frac{\Psi_{exm}}{\Psi_{0m}}\frac{(R/\omega L)^2}{1+(\frac{R}{\omega L})^2} - \frac{\Psi_{dm}}{\Psi_{0m}}]^2 \approx$$

$$\approx [1 - 2(\frac{R}{\omega L})^2\frac{\Psi_{exm}}{\Psi_{0m}} - 2\frac{\Psi_{dm}}{\Psi_{0m}}]\frac{\Psi_{0m}^2}{4\mu_0 S_\delta}(1-\cos 2\omega t). \tag{16}$$

$$F_{II} = \frac{\Psi_{0m}^2}{4\mu_0 S_\delta}\left(\frac{\Psi_{exm}}{\Psi_{0m}}\right)^2 \frac{(R/\omega L)^2}{[1+(\frac{R}{\omega L})^2]^2}[1+\cos 2\omega t] \approx$$

$$\approx \frac{\Psi_{0m}^2}{4\mu_0 S_\delta}\left(\frac{\Psi_{exm}}{\Psi_{0m}}\right)^2 (R/\omega L)^2 [1+\cos 2\omega t]. \qquad (17)$$

We can express the sum F_n of unvarying components of the forces F_{In} and F_{IIn} as follow

$$\begin{cases} F_n = F_{In} + F_{IIn} = K_n F_0, \quad F_0 = \dfrac{\Psi_{0m}^2}{4\mu_0 S_\delta}, \\ K_n = 1 - [2\dfrac{\Psi_{dm}}{\Psi_{exm}} + (\dfrac{R}{\omega L})^2 (2 - \dfrac{\Psi_{exm}}{\Psi_{0m}})]\dfrac{\Psi_{exm}}{\Psi_{0m}}. \end{cases} \qquad (18)$$

The force F_0 acts in the alternating-current relay when the outer magnetic flux is absent ($F_0 = F_n$, when $\Psi_{exm} \to 0$ and $\Psi_{dm} \to 0$). The coefficient K_n shows the relative variation of force F_n because the outer magnetic fluxes Ψ_{ex} and Ψ_d. The dependence of K_n on the ratios Ψ_{exm}/Ψ_{0m}, Ψ_{dm}/Ψ_{exm} and $R/\omega L$ is complicated. The dependences of K_n on the ratio Ψ_{dm}/Ψ_{exm} are presented in Fig. 2 for ratio $R/\omega L$=0,1 and in Fig.3 for ratio $R/\omega L$=0,05.

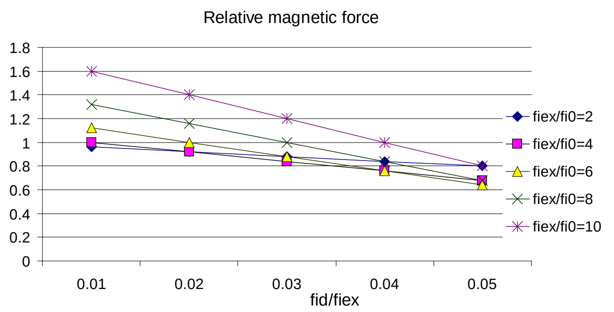

Fig. 2. Dependence of K_n on the Ψ_{dm}/Ψ_{exm}, when $R/\omega L$=0,1, for different values Ψ_{exm}/Ψ_{0m}

We can see of Fig. 2 and 3 that the coefficient K_n considerably decreases, when amplitude of the outer magnetic flux Ψ_{exm} is some times more than amplitude Ψ_{0m} of flux created by excitation coil. The increase of leakage flux Ψ_d decreases K_p especially when Ψ_{exm}/Ψ_{0m}>5.

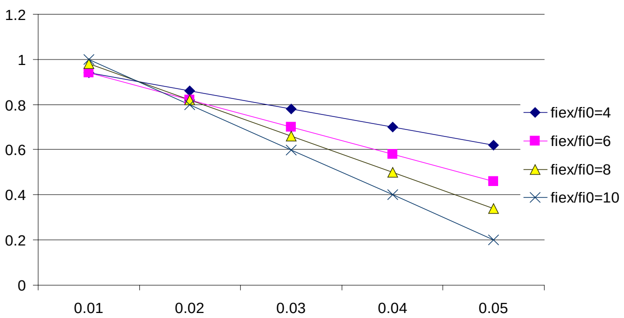

Fig. 3. Dependence of K_n on Ψ_{dm}/Ψ_{exm} when $R/\omega L$=0,05 for different Ψ_{exm}/Ψ_{0m} values

The action of the outer magnetic field to the induction relay

In the induction relay the influence of the outer magnetic field is important when the excitation coil is arranged in the branch of the magnetic circuit which the induction disc is not intersect. In the Fig. 2 it is showed the induction relay with two poles: screened P1 and non-screened P2. The induction disc ID is under these poles. When the sinusoidal excitation coil i_0 is passed to the excitation coil EC, the magnetic fluxes Ψ_{01} and Ψ_{02} are created in the magnetic circuit branches with P1 and P2, correspondingly. They intersect the induction disc.

We suppose that the outer alternating magnetic flux Ψ_{ex} acts perpendicular to the induction disc ID and parallel to the excitation coil EC axis. We divide this flux into three parallel fluxes: Ψ_{ex0} in the branch with coil EC, Ψ_{ex1} in the branch with pole P1 and Ψ_{ex2} in the branch with pole P2. Let the initial phases of fluxes Ψ_{ex0}, Ψ_{01} and Ψ_{02} coincide in the magnetic circuit branch with excitation coil EC. In the branches with poles P1 and P2 the flux $\Psi_{ex1}(\Psi_{ex2})$ will be directed contrary than flux $\Psi_{01}(\Psi_{02})$ (see Fig. 4).

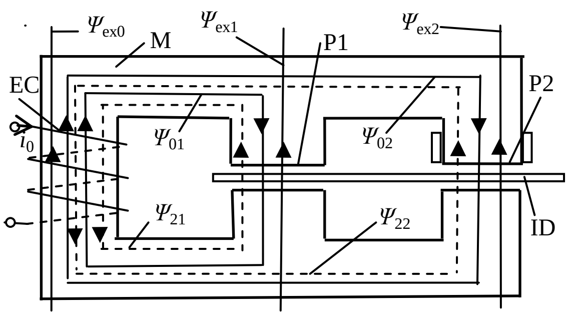

Fig. 4. The magnetic fluxes of the induction relay

The flux Ψ_{ex0} inducts the electromotive force e_2 and current i_2 in EC. The current i_2 creates the flux Ψ_{21} in the branch with pole P1 and Ψ_{22} in the branch with pole P2. Analogically as in the direct-current relay we find that difference between the initial phases of fluxes $\Psi_{21}(\Psi_{22})$ and $\Psi_{01}(\Psi_{02})$ is equal to φ-π. The angle φ is expressed by (5), where R and L are the resistance and inductance of EC.

The fluxes Ψ_{21} and Ψ_{22} are parts of flux Ψ_2

$$\Psi_2 = \Psi_{21} + \Psi_{22}, \quad \Psi_{21} = k_1 \Psi_2, \quad \Psi_{21} = k_2 \Psi_2. \qquad (19)$$

There k_1=const., k_2=const., k_1+k_2=1.

The total fluxes $\Psi_{\Sigma 1}$ and $\Psi_{\Sigma 2}$ in the branches with poles P1 and P2 can be expressed as follows:

$$\begin{aligned} \Psi_{\Sigma 1} &= (\Psi_{01m} - \Psi_{ex1m})\sin\omega t - \Psi_{21m}\sin(\omega t + \varphi) = \\ &= (\Psi_{01m} - \Psi_{ex1m} - \Psi_{21m}\cos\varphi)\sin\omega t - \Psi_{21m}\sin\varphi\cos\omega t \approx \\ &\approx (\Psi_{01m} - \Psi_{ex1m} - \Psi_{21m}\cos\varphi)\sin\omega t, \end{aligned} \qquad (20)$$

$$\Psi_{\Sigma 2} \approx (\Psi_{02m} - \Psi_{ex2m} - \Psi_{22m}\cos\varphi)\sin\omega t. \qquad (21)$$

We can write by (9):

$$\Psi_{21\mathrm{m}} \cos\varphi = \frac{k_1 \Psi_{\mathrm{ex0m}}}{1 + (R/\omega L)^2}, \quad (22)$$

$$\Psi_{22\mathrm{m}} \cos\varphi = \frac{k_2 \Psi_{\mathrm{ex0m}}}{1 + (R/\omega L)^2}. \quad (23)$$

When the magnitude of outer magnetic flux Ψ_{exm} is equal to (20-30) % of magnetic flux created by excitation coil EC, the total magnetic flux can be too small for induction relay action. Therefore, the induction relays are more sensitive to outer magnetic field than direct– or alternating-current relays.

Conclusions

1. The strongest magnetic fields are near electric reactors in electric plants. These fields can disturb the electromagnetic relays action.
2. In the direct-current relay the outer magnetic field can delay the action and evoke the contacts disconnection.
3. The alternating-current relay can not act when the outer magnetic flux is some times more than the inner magnetic flux. The especially dangerous is leakage magnetic flux which is not intersected the excitation coil.
4. Induction relay can not act, when outer magnetic flux reach some tens percentages of the magnetic flux created by relay excitation coil.

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The strongest magnetic fields are near the electric reactors in the electric plants. These fields can do the unwished action to electromagnetic relays. The outer magnetic field can delay the action of direct-current relay and awake the contact vibration. The alternating-current relays can not act, when the outer magnetic flux exceeds the flux created by the relay excitation coil some times. The especially dangerous is the leakage magnetic flux which acts in the air gap of relay but it passes by the excitation coil. The induction relay can not act, when the outer magnetic flux is equal to some tens percentages of magnetic flux which creates the excitation coil of the relay. Ill. 4, bibl. 4 (in English; abstracts in English, Russian and Lithuanian).

Е. Морозенков, Ю. А. Вирбалис. Влияние магнитного поля электрического реактора на электромагнитные реле // Электроника и электротехника. – Каунас: Технология, 2010. – № 8(104). – С. 73–76.

В электростанциях самые сильные магнитные поля образуются вблизи электрических реакторов. Эти поля могут оказывать неблагоприятное влияние на электромагнитные реле. В реле постоянного тока внешнее магнитное поле может задержать воздействие реле и вызвать дрожание контактов. Реле переменного тока могут не сработать, если внешний магнитный поток несколько раз превышает магнитный поток, создаваемый катушкой возбуждения реле. Особенно опасен магнитный поток рассеяния, пересекающий рабочий промежуток реле, но непопадающий в катушку возбуждения. Индукционные реле могут не сработать, если внешний магнитный поток составляет несколько десятков процентов потока, создаваемого катушкой возбуждения реле. Ил. 4, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Morozionkov, J. A. Virbalis. Elektrinio reaktoriaus magnetinio lauko įtaka elektromagnetinėms relėms // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 8(104). – P. 73–76.

Elektros jėgainėse stipriausi magnetiniai laukai susidaro elektrinių reaktorių aplinkoje. Šie laukai gali daryti nepageidautiną poveikį elektromagnetinėms relėms. Nuolatinės srovės relėse išorinis magnetinis laukas gali pavėlinti relės veikimą ir sukelti kontaktų virpėjimą. Kintamosios srovės relės gali nesujungti kontaktų, jei išorinis magnetinis srautas relės žadinimo ritės sukuriamą srautą viršija kelis kartus. Ypač pavojingas yra sklaidos magnetinis srautas, veriantis relės darbinį tarpelį, bet neveriantis žadinimo ritės. Indukcinės relės gali nesujungti kontaktų, jei išorinis magnetinis srautas sudaro keliasdešimt procentų relės žadinimo ritės sukuriamo srauto. Il. 4, bibl. 4 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).