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SENSITIVE AND SELECTIVE SHORT-CIRCUIT PROTECTION – A NECESSARY CONDITION FOR THE EFFICIENT OPERATION OF MILL UNIT GROUPS

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ABSTRACT. The article proposes a conception, technical implementation and assessment of the selectivity and sensitivity for earth-fault protection of a group of motors driving mill units. Solutions are found to the problems related to the sensitivity and selectivity of similarly operating protection systems implemented by conventional approaches as well as electro-mechanical or electronic units.

ЧУВСТВИТЕЛНИТЕ И СЕЛЕКТИВНИ ЗАЩИТИ ОТ КЪСИ СЪЕДИНЕНИЯ – НЕОБХОДИМО УСЛОВИЕ ЗА ЕФЕКТИВНА РАБОТА ПРИ ГРУПА МЕЛНИЧНИ АГРЕГАТИ

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РЕЗЮМЕ. В статията се предлага идея, техническа реализация и оценка на селективността и чувствителността за защита от земни съединения за група двигатели, които задвижват мелнични агрегати. Преодоляват се успешно проблемите свързани с чувствителността и селективността на подобни по функции защити, осъществени с конвенциалните подходи и с електромеханична или електронна елементна база.

The mill units in modern highly-productive mills are powered by synchronous motors of several MW and their number reaches and even exceeds 10.

After grinding and classification, the ore is directly fed as slurry (without intermediate storage buffer volumes) to the valuables extraction stage. Therefore, any stoppage of the mill units will immediately affect the technological process. Especially unfavorable and inadmissible are shut-downs of normally operating units as faulty units break down. This may happen in the absence of sufficiently selective and sensitive short-circuit protection thus creating a problem for electric motors operating in series. In this case it is difficult to identify the mill where the motor has short-circuited so as to shut it down thus allowing the others to continue operating.

The problem of protecting a group of comparatively high-powered motors has been known and discussed for a long time now. Engineering solutions to that problem exist [1, 2, 3]. Some of these solve it by means of selectivity and partly by sensitivity but for a limited condition, i.e. all motors in the group should operate simultaneously. These cases are possible in practice. One example are the drives of production conveyance systems which should normally operate simultaneously. However, for a group of mill units this condition is not only dispensible but also scheduled and emergency repairs, ore shortage, etc., for long periods may require the operation of a smaller number of mills. In some solutions [1] the contradictions between sensitivity and selectivity cannot be overcome successfully.

A principle is developed further and an engineering solution is proposed [5] here which allow the increase in both selectivity and sensitivity of protection. At the same time there is no limiting condition for simultaneous operation of all motors in the group. Earth-fault protection is proposed. The earth-fault currents in the isolated neutral are limited both by the conductance of the isolation and the capacity of the power lines (in this case cable power lines). Under high humidity conditions, typical of mill plants, the leakage currents can increase up to dangerous values.

The limited sensitivity of the conventional earth-fault protection is determined by the need for correlating the operating current with the external earth fault current [4] according to the expression:

$$I_e = \frac{k_s}{k_{rr}} I_c \qquad (1)$$

Where K_s is a selectivity coefficient of external earth faults,which is assumed to be equal to 4 for protection operating without time delay
K_{rr}– rate of return coefficient of the protection (Dropant/pick up ratio)
I_c – self-capacity current of the protected circuit.

$$\left(1 \le l \le k - 1; \quad k + 1 \le l \le n\right)$$

The sensitivity condition is satisfied [3] for:

$$I_{c\Sigma} - I_c \geq I_e \tag{2}$$

Wehere $I_{c\Sigma}$ is the total earth-fault capacity current.

Taking into account (1), condition (2) takes the form:

$$I_{c\Sigma} \geq \left(\frac{k_s}{k_{rr}} + 1\right) I_c = (5 - 6) I_c \tag{3}$$

The sensitivity can be increased considerably by introducing a group protective system of earth-faults responding to the relationship between the total earth-fault current in the faulted circuit and the self leakage current of each normally operating circuit. A protective system designed on this principle can be adjusted to the imbalance current I_d of the differential current transformer (zero phase sequence current) in a normal operating mode adjusted to the rate of return coefficient κ_{rr} of the protection actuator.

$$I_e = \frac{I_d}{k_{rr}} \tag{4}$$

The protection selectivity depends on the relationship between the magnitudes of the earth-fault currents in the faulted motor and in each of the unfaulted motors, which is illustrated in Fig. 1. The figure shows a group of *n* motors powered by a transformer TR-MV with a 6kV secondary winding with an isolated neutral.

Suppose the earth fault occurred in phase A of the k th motor ($1 \leq k \leq n$) at point k located at a relative distance $в$ from the neutral of the motor windings. In compliance with [3] for the direct earth fault current at point *k* we can write:

$$\dot{I}_k = -3в\dot{U}_A\left(g_e + j\omega C_e\right) \tag{5}$$

Where $\dot{U}_A$ is phase voltage;
g_e – equivalent conductance of the system to earth;
C_e – equivalent capacity of the system to earth.

For the equivalent conductance of the system to earth and the equivalent capacity of the system to earth for this particular case the following expressions are valid

$$g_e = g_f + \sum_{I=1}^{n} g_i = g_f + ng_i \tag{6}$$

$$C_e = C_f + \sum_{I=1}^{n} C_i = C_f + nC_i \tag{7}$$

Where g_i is conductance to earth of the line which powers the group of motors;
C_f – capacity to earth of the line which powers the group of motors;
g_i – condutance to earth of the i^{th} protected circuit consisting of the i^{th} motor and the cable line connecting it to the switchgear;
C_i – capacity to earth of the i^{th} protected circuit.

The self leakage current in the i^{th}

unfaulted circuit is:

$$\dot{I}_b = -3в\dot{U}_A\left(g_i + j\omega C_e\right) \tag{8}$$

The relationship between the total earth fault current in the faulted circuit and the self leakage current in each of the unfaulted circuits accroding to (5), (6), (7) and (8) is:

$$\frac{\dot{I}_k}{\dot{I}_e} = \frac{g_f + j\omega C_f}{g_i + j\omega C_i} \tag{9}$$

This relationship determines the requirements for selectivity to the group protection of single phase earth faults. Since the relative distance b does not participate in the expression (9), the selectivity of the device does not therefore depend on it.

The block diagram of the proposed group protection of single phase earth faults for n synchronous motors powered by the transformer isolated neutral grid is shown in Fig. 1. Uniform protection channels are connected to the protected circuits. The signals from the differential current transformers DCT_i, converted accordingly by the coordinating units COU_i, regulation units RU_i and diode rectifiers DR_i ($1 \leq i \leq n$) are transmitted for comparison to the resistor Rc. When an earth faults occurs in the k^{th} protected circuit ($1 \leq k \leq n$), the potential at the rectifier output $DR_к$ is several times higher than the potentials at the outputs of the other rectifiers according to the expression (9) and as a result, current flows only through the threshold unit TU_k. The threshold units TU_i are adjusted to operate under current flowing through them which corresponds to the imbalance current I_d of the differential current transformer in a normal operating mode corrected by the rate of return coefficient k_{rr} of the threshold units. When the threshold unit TU_k operates, the shut-down signal is transmitted to circuit breaker QFk through the switch unit SDU_k.

The functions of the corrdinating units $eCOU_i$ can be performed by electronic current transducers – voltage and amplifiers; units RU_i, R_i from current-adjustible rectifier circuits TU_i of comparators. The functions of all units can be integrated in a microprocessor controller.

The efficiency of the principle has been investigated theoretically and experimentally under laboratory conditions. The condition for selectivity of group protection from earth faults, expressed by the selective shutdown coefficient k_{sds}, is

$$k_{sds} = \left|\frac{\dot{I}_e}{\dot{I}_k}\right| = \left|\frac{g_i + j\omega C_i}{g_f + j\omega C_f + (l+1)(g_i + j\omega C_i)}\right| \quad (1 \leq l \leq n-1) \tag{10}$$

The expresison on the right side of the inequality (10) as a function of *l* takes a maximum value for *l = 1*, and as a result, the final form of the condition for selectivity of protection k_{sds} is

$$k_{sds} \geq \left| \frac{g_i + j\omega C_i}{g_f + 2g_i + j\omega\left(C_f + 2C_i\right)} \right| \qquad (11)$$

The connection proposed and the defined zones allow the implementation of a short-circuit protection system in the electric drives of mill unit groups of high sensitivity and selectivity.

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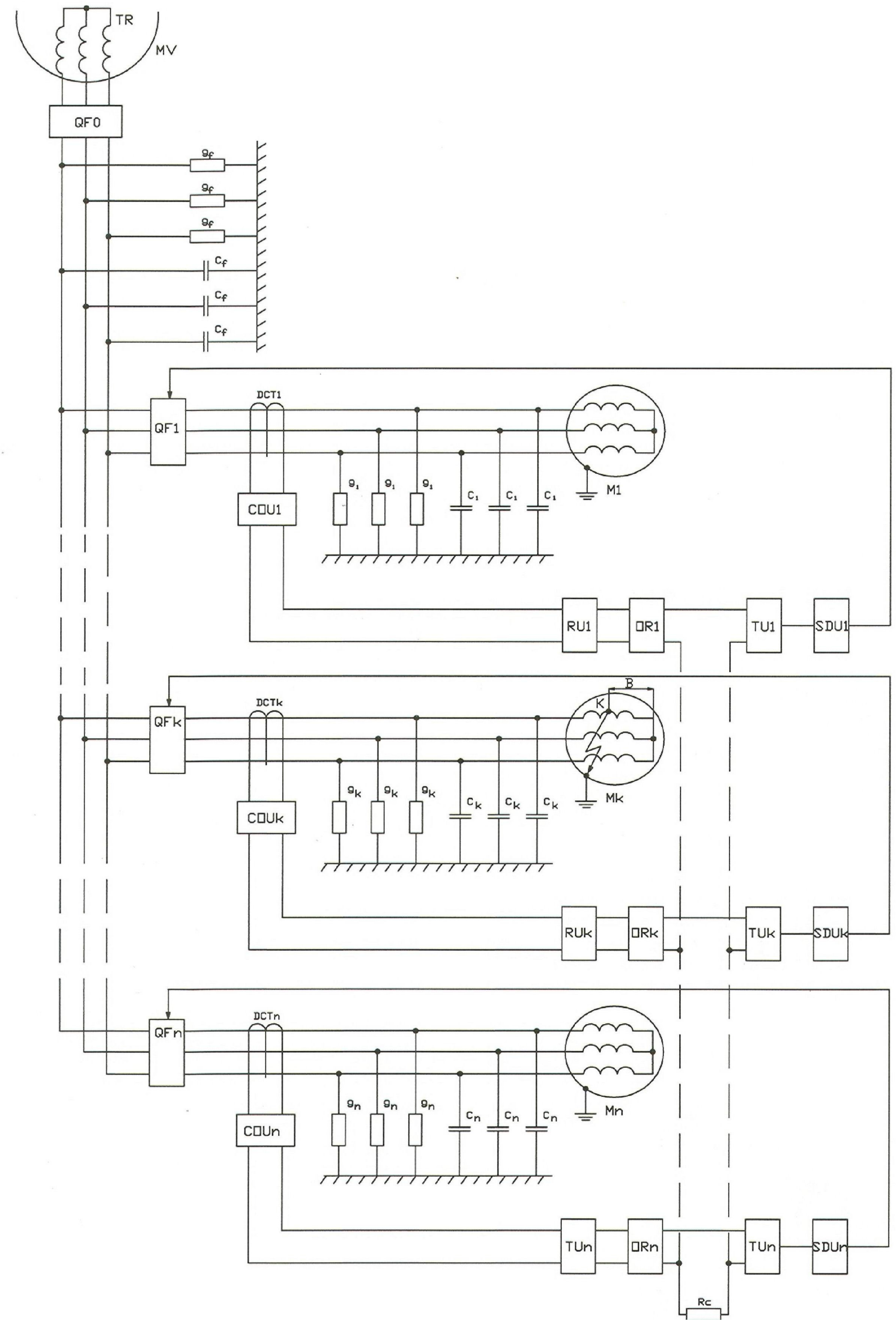

Fig.1. Block diagram of group protection of single phase earth faults for n synchronous motors