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Sources of independent power supply for protection relay

***Abstract**. Nowadays, telemetry and relay protection, which are located directly on the protected element of the electric power system or inside of it are increasingly used in the electric power industry. For its supply, it requires an autonomous source of low power, which has a stabilized DC voltage. Existing devices are unreliable, expensive to manufacture and operate. This work offers power and relay protection and diagnostics with the help of autonomous power sources that can be used in the network with the help of current or voltage transformers, and with the help of an inductive converter placed in the end zone of an electric machine as well.*

Streszczenie.** W pracy nalizowano metody niezależnego zasilania układów przekaźnikowych zabezpieczeń. Układy takie powinny charakteryszować się małym poborem mocy, niezawodnością I niską ceną. **Źródła niezależnego zasilania układów zabezpieczeniowych

Keywords: Relay protection, diagnostic devices, autonomous power supply, stabilized voltage
Słowa kluczowe: przekaźniki, niezależne zasilanie, zabezpieczenia

Introduction.

Nowadays, protective relay and telemetry equipment, which are located directly on the protected element of the interconnected power system or inside it, are used in the electric power industry. Examples of such devices for high voltage overhead lines are peripheral telemetry posts for monitoring of gust-and-glaze loading [1] and single phase-to-earth fault protection [2, 14] and controlled network devices of D-FASTS type [3]. In electrical machines, such devices include overtemperature protection [4] and protection against electrical faults in stator windings [5], which are highly sensitive. In this case, the signal of faults in the electric machine is transmitted over the protective power cable using a power switch made up of two thyristors connected in parallel opposition. The use of new generation distributed network devices in electric power systems implies the use of independent DC power supply (IPS) with a voltage of U_0 = 6-12 V and current of I_0 = 0.05-0.2 A.

Sometimes light-rechargeable batteries are used as IPS [6]. However, such power supplies have low reliability due to environmental influences and high operating costs due to the need to regular monitoring of the status of the solar-cell panel and the battery.

When implementing protective relay and telemetry equipment located directly on the protected high-voltage element, the power for IPS can be obtained directly from the electric grid by means of current transformers [7, 8] or voltage [9]. However, this is often not possible, since the measuring transformers are nearly always located in the switchgear cubicle, i.e. at a considerable distance from the self-protected object. In this case, the solution to this problem is shown by the example of the implementation of the power supply for the protection of an electrical machine.

IPS for a low-voltage electrical machine.

The power supply for protection is got solved simplest in low-voltage electrical machines. In this case, the power for the IPS can be obtained from the electric grid by means of a small-sized and low-cost voltage transformer TV. Its primary winding is connected directly to the winding end and the grounding of the electrical machine in the terminal box [6]. And the secondary winding is calculated for supplying the IPS with voltage U_2 at the current I_2. The wiring diagram is shown in Figure 1, where 1 is the electrical machine; 2 is the power cable; 3 is the switch; 4 is the ring gauge transducer for protection against electrical faults in stator windings [5]; 5 is the thermistors for overtemperature protection [4]; 6 is the power switch with control block; 7 is the responsive protection. In this case, the transformer together with the IPS is placed in the protective casing together with the power switch and the control block 6 directly on the protected electrical machine.

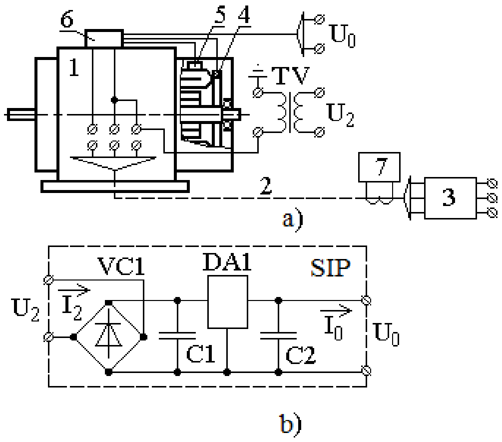

Fig. 1 IPS circuit, the power takeoff from the electric grid using a voltage transformer TV

One of the variants of the IPS circuit is shown in Fig. 1, b. The parameters of the elements of such IPS are determined on the basis of the values of the current I_0 and voltage U_0 which are required for power supply of protective relay and telemetry equipment. In this case, the diode bridge VC1 used in the IPS, capacities C1 and C2, as well as the voltage regulator DA1, should have a nominal voltage slightly higher than U_0, and the value of capacities C1, C2 should be sufficient to provide an acceptable level of fluctuation of U_0 with admissible electric grid parameters fluctuation [7] . In turn, the rated current of the diode bridge VC1 and the voltage regulator $DA1$ should be not less than current I_0. To calculate the transformer parameters for such a device, one can use the technique given in [8].

In the capacity of such IPS it is possible to use one of the economy-priced commercially available power adapters, e.g. for various electronic equipment, in particular for charging cell phone or smartphone batteries.

IPS for a high-voltage electrical machine.

This method of power taking off from the electric grid for IPS to supply high-voltage electrical machines protection of particularly low power is unacceptable. This is caused by the considerable size and high cost of the high voltage transformer. In this case, the power can be taken off by means of commercially available slip-over current transformer (TA) of TZRL type [10] as shown in Figure 2, where 1 is a split core ring with the factory-made secondary winding (not shown in the figure); 2 and 3 are the upper and lower parts of the plastic body of TA obtained by casting method; 4 and 5 are a bolt and a nut for fastening the upper half of the body to the bottom one; 6 is core of the cable with insulation; 7 is an additional insulation between the housing of the current transformer and the cable core installed to provide the required insulation class.

This is the design of a slip-over current transformer which allows it to be mounted on the cable without removing the sealing end bell.

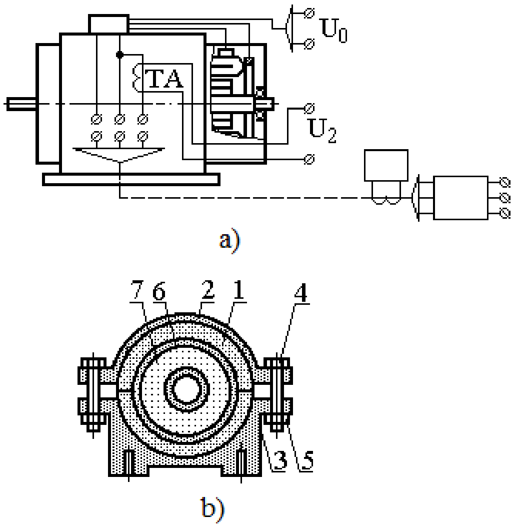

Fig. 2 - Design and circuit scheme of the current transformer for power takeoff

However, it remains unclear whether the available secondary winding TA is able to provide the IPS with a sinusoidal current value I_2 at the voltage value U_2. In this connection, there is a need to develop a simple method that will allow us to evaluate the potential of such TA for powering the IPS with parameters of voltage U_0 = 6-12 V and current I_0 = 0.05-0.2 A.

Traditionally, a substitution circuit, which is shown in Figure 3, a., is used while modeling the processes in the current transformer, where R_2 and L_2 are the resistance and inductance of the secondary winding, M_{21} is the coefficient of mutual induction of the primary and secondary windings; and $R_н$ and $L_н$ are the load resistance and inductance of a zero-phase sequence transformers. To determine the parameters of the elements of this circuit it is necessary to use dimensions of the core ring and its dependence curve $B = f(H)$, which are shown in Fig. 3, b and 3, c. When scheming this circuit it is taken into account that the current value I_1 does not depend on the load of the current transformer.

As is known, processes in a current transformer are described by a first-order differential equation with variable coefficients. The complexity of determining the parameters of a current transformer by solving this equation depends significantly on the way of representation of dependence $B = f(H)$ [11,12] and the assumptions made.

It is easy enough to determine the parameters of some elements of the circuit in Figure 3, but it is also possible to do if the current transformer works only on the linear part of the dependence $B = f(H)$, and the current I_1 is sinusoidal. In this case, the current I_2 in the secondary winding, the magnetic flux $\Phi_т$ in the core and the EMF E_2 which is induced in the secondary winding by the current I_1, will also be sinusoidal. In this case, the determination of the current transformer parameters can be carried out in complex form using the following mathematical expressions.

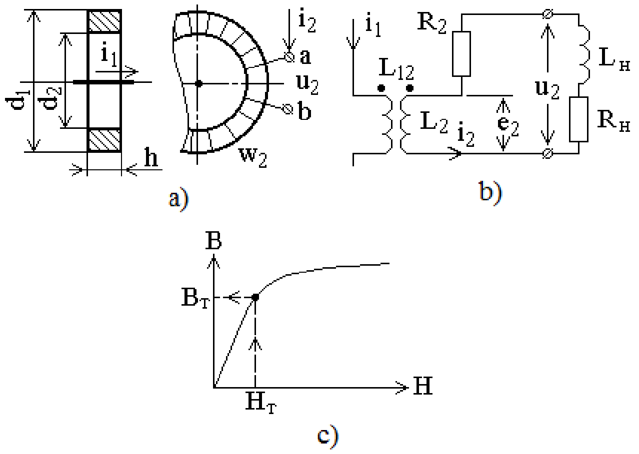

Fig. 3. Transformer substitution circuit and magnetization curve of its core

If the type of transformer used is known, it is easy to determine from the relevant reference literature the dimensions of the core ring, the steel grade from which it is made and the magnetization curve of this steel, as well as the number of turns of the secondary winding and its resistance R_2.

When the current I_1 in the primary winding TA with the number $w_1 = 1$ in accordance [13] with [Theoretical Basics of Electrical Engineering] is known, the magnetic field strength of the ferromagnetic core with the open-circuit secondary winding is defined as

(1) $$H_т = I_1 w_1 / \pi d_{cp},$$

where $d_{cp} = (d_1 + d_2)/2$ is the average diameter of the core; $H_т$ is magnetic field strength in the core ring.

The induction $B_т$ of the magnetic field in this core is determined according to $H_т$ on the magnetization curve as shown in Figure 3, в. In accordance with the assumptions made, the magnetic permeability of core steel will be constant and, taking into account [Theoretical Basics of Electrical Engineering], is defined as

(2) $$\mu_т = B_т / \mu_0 H_т,$$

where μ_0 is the magnetic permeability of vacuum.

In this case, the magnetic flux in the core from the primary winding at $w_1 = 1$

(3) $$\Phi_{1т} = \mu_т \, \mu_0 \, I_1 \, S_т / \pi d_{cp},$$

is and the mutual flux linkage of the windings is

(4) $$\psi_{21} = w_2 \Phi_т = \mu_т \mu_0 I_1 S_т w_2 / \pi d_{cp} ,$$

where $S_т = h(d_1 - d_2)/2$ is the cross-sectional area of the core ring according to Figure 3, b.

In this basis, the coefficient of mutual induction is

(5) $$M_{21} = \psi_{21} / I_1 = \mu_т \mu_0 k_{нам} w_2 h(d_2 - d_1)/2\pi d_{cp} ,$$

and the resistance of mutual induction of windings is

(6) $$X_{21} = 2\pi f_1 M_{21} ,$$

where f_1 is the supply frequency.

The magnetic flux in the core from the current I_2 in the secondary winding is

(7) $$\Phi_{2т} = \mu_т \mu_0 I_2 w_2 S_т / \pi d_{cp} ,$$

and the mutual flux linkage of the windings is

(8) $$\psi_2 = w_2 \Phi_{2т} = \mu_т \mu_0 I_1 S_т w_2^2 / \pi d_{cp} .$$

As a result, the inductance of the secondary winding is

(9) $$L_2 = \psi_2 / I_2 = \mu_т \mu_0 w_2^2 S_т / \pi d_{cp} ,$$

and its inductive resistance is

(10) $$X_2 = 2\pi f_1 L_2 .$$

Thus, the EMF (Electromotive force) induced in the secondary winding of the transformer is

(11) $$E_2 = j\omega M_{21} I_1 ,$$

and the current in the secondary winding and its terminals voltage are

(12) $$\dot{I}_2 = \dot{E}_2 /(Z_2 + Z_н) = j\omega M_{21} \dot{I}_1 /(Z_2 + Z_н) ,$$

where $\omega = 2\pi f_1$ is the pulsatance. The output voltage of the secondary winding is

(13) $$\dot{U}_2 = \left[j\omega M_{21} \dot{I}_1 /(Z_2 + Z_н) \right] Z_н ,$$

where $Z_2 = R_2 + jX_2$ and $Z_н = R_н + jX_н$ are the operating impedance of the secondary winding and load of the current transformer.

This technique is quite simply implemented on a computer and makes it possible to calculate the voltage and current of the secondary winding for any primary current I_1 and load resistance $Z_н$. This, in turn, allows us to calculate the parameters of the IPS circuit in Figure 4, a, in order to provide the required voltage U_0 and current I_0 at its output.

Proof-of-feasibility of the proposed method for determining the parameters of a current transformer with an additional secondary winding for power take-off for an IPS was made using the example of a slip-over current transformer of TZRL type with a current rating of 300/5. The core of the transformer is made of steel E-330 with dimensions d_1 and d_2 equal to 144 and 94 mm at $h = 60мм$. The current transformer was supposed to be used to power the self-protection equipment with U_0 = 12V and I_0 = 0.2A of the induction motor AO-93-4 with no-load current $I_{xx} = 57{,}0A$ at the rated current $I = 127{,}5A_{ном}$.

The results of calculation and experiment of the voltage and current of the secondary winding for loads in the form of an ammeter with the resistance and inductance equal to $R_н = 0{,}2\,Ом$ and $L_н = 0{,}16\,мГн$ are given in the table below.

Table 1 - Experiment / calculation results

№	1	2	3	4	5	6	7	8	9
I_1 , A	15,0	30,0	45,0	60,0	75,0	90,0	105,0	120,0	135,0
I_2 , A	0,5 / 0,492	1,0 / 0,983	1,5 / 1,475	2,1 / 1,967	2,55 / 2,458	3,15 / 2,950	3,55 / 3,442	4,1 / 3,939	4,65 / 4,425
U_2 , V	0,152 / 0,145	0,293 / 0,289	0,44 / 0,451	0,58 / 0,579	0,72 / 0,724	0,86 / 0,862	1,01 / 1,013	1,13 / 1,013	1,31 / 1,302

The table 1 continues here

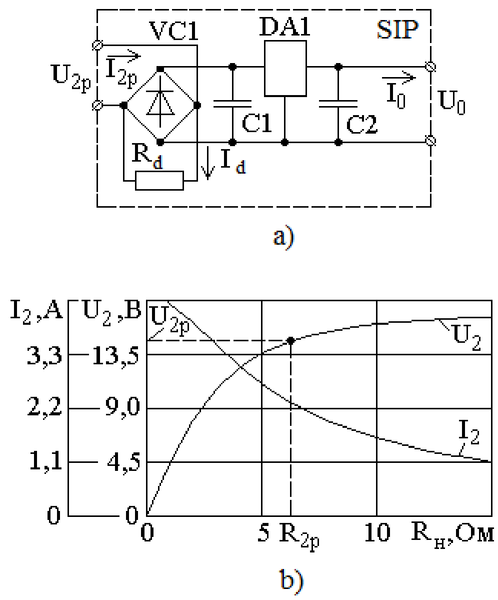

Fig 4. Dependence of voltage and current in secondary winding TA on load Resistance

Comparison of the results of this table shows that the modeling error does not exceed 5% in the most unfavorable case. Thus, this method can be used to calculate the parameters of IPS.

In this connection, the calculation of IPS parameters is carried out as follows. Initially, the dependences $U_2 = f(Z_н)$ and $I_2 = f(Z_н)$ for the selected current transformer are calculated. For this case, the calculation results are shown in Figure 4, a. Then, the input resistance is determined as

Then, according to $U_{2p} = 1{,}2 U_0$ and the dependence $U_2 = f(Z_н)$ the input resistance R_{2p} of the IPS, rated current I_{2p} is determined. In accordance with $R_0 = U_0 / I_0$ the data obtained, the value of the additional resistance is

(14) $$R_{доп} = R_0 R_{2р} /(R_0 - R_{2р}) .$$

When starting an induction motor the current in the primary winding increases to the value $k_{кпт} I_{1н}$. In order to prevent the growth of the voltage at the input of the IPS, one can use two series-opposite connected stabilitrons, which are capable of providing a voltage at the output of the secondary winding $U_{2р} = 1{,}2U_0$ in no load operation.

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