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DEVELOPMENT OF THE SCHEME AND RESEARCH OF THE MATHEMATICAL MODEL OF THE VOLTAGE REGULATION DEVICE ON THE TRANSFORMERS WITH SWITCHING WITHOUT 10/0,4 kV EXCITATION

Abstract. *Mathematical model of the device of regulation of voltage is presented. Operation of the device on the transformer with switching voltage without excitation allows to control mode at various values of electrical remoteness and during asynchronous device start stabilizing the voltage.*

Keywords: *device of regulation of tension; power transformer; mathematical model; electrical remoteness; asynchronous device; switching voltage without excitation*

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РАЗРАБОТКА СХЕМЫ И ИССЛЕДОВАНИЕ МАТЕМАТИЧЕСКОЙ МОДЕЛИ УСТРОЙСТВА РЕГУЛИРОВАНИЯ НАПРЯЖЕНИЯ НА ТРАНСФОРМАТОРАХ С ПЕРЕКЛЮЧЕНИЕМ БЕЗ ВОЗБУЖДЕНИЯ НАПРЯЖЕНИЕМ 10/0,4 кВ

Аннотация. *Представлена математическая модель устройства регулирования напряжения. Работа устройства на трансформаторе с переключением без возбуждения позволяет контролировать режим работы при различных значениях электрической удаленности и во время пуска асинхронного двигателя, стабилизируя при этом напряжение.*

Ключевые слова: *устройство регулирования напряжения; силовой трансформатор; математическая модель; электрическая удаленность; асинхронный двигатель; переключение без возбуждения*

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РОЗРОБЛЕННЯ СХЕМИ ТА ДОСЛІДЖЕННЯ МАТЕМАТИЧНОЇ МОДЕЛІ ПРИСТРОЮ РЕГУЛЮВАННЯ НАПРУГИ НА ТРАНСФОРМАТОРАХ З ПЕРЕКЛЮЧЕННЯМ БЕЗ ЗБУДЖЕННЯ НАПРУГОЮ 10/0,4 кВ

Анотація. *Представлено математичну модель пристрою регулювання напруги. Робота пристрою на трансформаторі з перемиканням без збудження дозволяє контролювати режим роботи при різних значеннях електричної віддаленості та під час пуску асинхронного двигуна, стабілізуючи при цьому напругу.*

Ключові слова: *пристрій регулювання напруги; силовий трансформатор; математична модель; електрична віддаленість; асинхронний двигун, перемикання без збудження*

Introduction. Providing the necessary power quality in particular quality of voltage is an indispensable condition of production efficiency. An important task is the detection of rational application of voltage regulation means in distributive electrical networks as necessary quality coefficient of electric power [1] can be provided by establishing devices with different regulating opportunities [2 – 4; 8]. Development of multifunction devices is the effective direction of improvement of the electric power quality [5 – 6].

Local voltage regulation gives the chance of independent regulation and support of voltage levels on separate lines according to change of their loading regardless of voltage change on busbars of a supply center.

The main disadvantages of existing multifunction devices are step voltage regulation, dependence of amount of controlled valves on a number of control steps, rather high cost and usage of forced commutation.

In the proposed voltage control device (it is device in the further) thyristors control is carried out on the basis of the control when the voltage passes through zero which gives the chance to significantly reduce generation of higher harmonics in an electrical network. The minimum additive voltage on low voltage (LV) busbar will be in case of open anti- parallel thyristors *VS1−VS2* on tap “+5 %”, and maximum will be in case of completely closed thyristors and switched on longitudinally capacitor battery.

In fig. 1 the single-line diagram of the device in case of open thyristors on tap of “+5 %” and the direction of currents and voltages are given. In this mode the capacitor battery is switched on parallel to a tapping coil of the transformer.

Mathematical simulation. For the scheme in case of open thyristors (Fig. 1) differential equations for circuits have the following form:

circuit I
$$i_1 r_l + i_1 x_{\text{л}1} + L'_1 \frac{di_{tr}}{dt} + M'_{12}\frac{di_2}{dt} + L_1\frac{di_1}{dt} + M_{12}\frac{di_2}{dt} = U_{\text{PS}}\,; \quad (1)$$

circuit II
$$-\frac{1}{C}\int i_C\,dt + L'_1\frac{di_{tr}}{dt} + M'_{12}\frac{di_2}{dt} = 0; \quad (2)$$

circuit III
$$L_2\frac{di_2}{dt} + M_{12}\frac{di_1}{dt} + M'_{12}\frac{di_{\text{tr}}}{dt} = i_2 z_{\text{C}} = U_2. \quad (3)$$

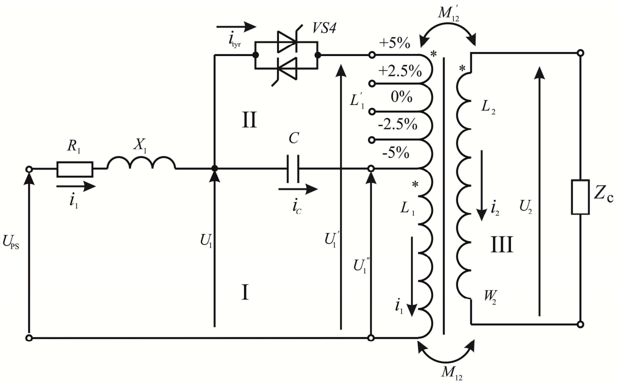

Fig. 1. The scheme of the device when operating on tap of "+5 %"

In Fig. 2 the single-line diagram of the device in case of completely closed thyristors is given.

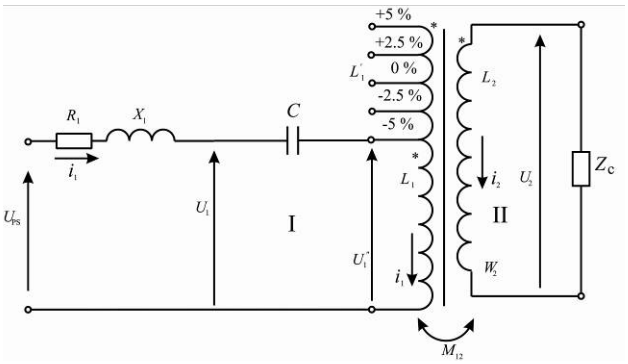

Fig. 2. The scheme of the device with completely closed thyristors

For the scheme with completely closed thyristors (Fig. 2) differential equations for circuits have the following form:

circuit I
$$i_1 r_1 + i_1 x_1 + \frac{1}{C}\int i_1 dt + +L_1 \frac{di_1}{dt} + M_{12}\frac{di_2}{dt} = U_{PS}; \qquad (4)$$

circuit II
$$M_{12}\frac{di_1}{dt} + L_2\frac{di_2}{dt} = i_2 z_C = U_2. \qquad (5)$$

In the environment of visual programming of Simulink Matlab the mathematical model of the device which functional flowchart is given in Fig. 3 was developed.

The scheme consists as of standard units of a library of packet of Simulink Matlab (the transformer, system, thyristors, the unit of voltage measurement, the unit of measurement of current, the switch of an alternating current, force loading, asynchronous device (AD), units for receiving signals) and of difficult virtual subsystems (loading control unit, the unit of comparing, management system, the switch of taps) [10].

For simulation it is accepted a power transformer having nominal capacity of 1000 kVA. The parameters of this transformer are given in table 1. It enters an electrical network of rural area with voltage of 10 kV. This area is characterized by branching and the considerable (to several tens of kilometers) length of trunk areas of power lines [9].

1. Parameters of a mathematical model of a power transformer TM-1000/10

Winding	Parameter	
	Active resistance, r, Ohm	Inductance, L, Gn
The primary	0,54	0,00832
The secondary	0,0044	0,000014
The adjusting	0,054	0,000876

Power of the capacitor bank was accepted according to calculations [6] and makes $Q_{CB} = 100$ kvar.

Researches of the device were conducted for such cases:

1) operation of the transformer at electric remoteness $\lambda_T = 16,5$ % with active and inductive loading (β_T = 0,8; *cos φ* = 0,8);

2) operation of the transformer at the AD start with nominal capacity of $P_{nom.AD} = 250$ kVh .

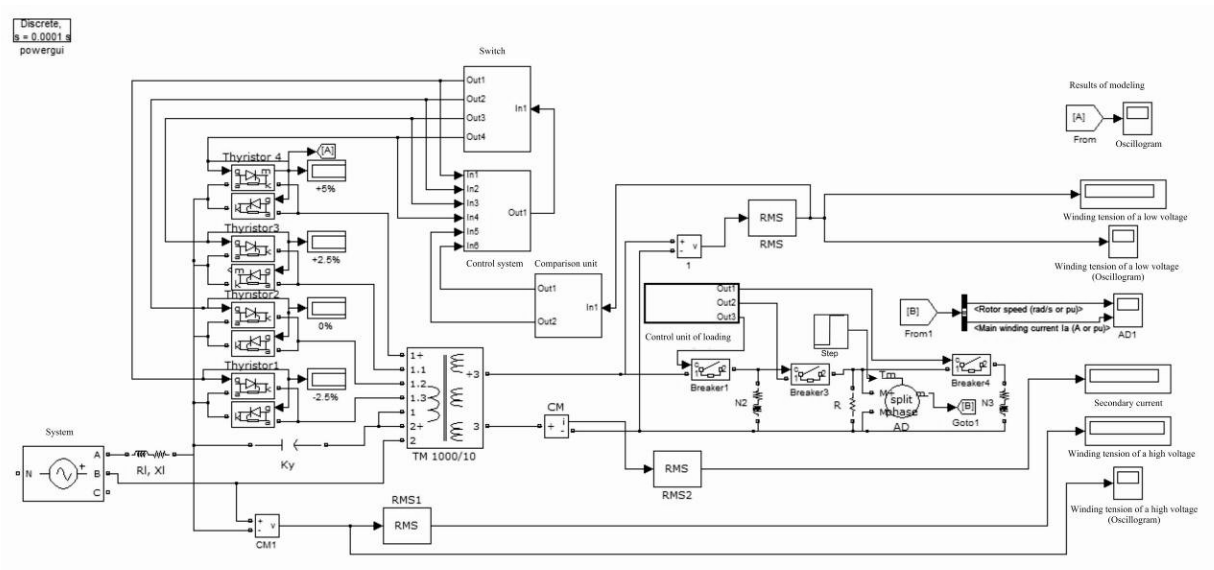

Fig. 3. The scheme of the investigated model in the environment of visual programming of Simulink Matlab

During simulation the voltage losses [7] at each site of an electrical network are considered, and it is accepted that all transformers work with loading β_T = 0,8 and power factor of $\cos\varphi$ = 0,8.

Results. In Fig. 4 and Fig 5 the oscillograms of operating values of voltage on transformer LV output at electric remoteness and at the AD start with the device and without it respectively are presented. In the mode of the minimum active and inductive loadings voltage on a winding of LV is 394 V as shown on the oscillogram (Fig. 4, a). When hooking up the maximum active and inductive loading voltage is reduced to 358 V.

At such voltage it is possible blackout of lighting and AD capsizing.

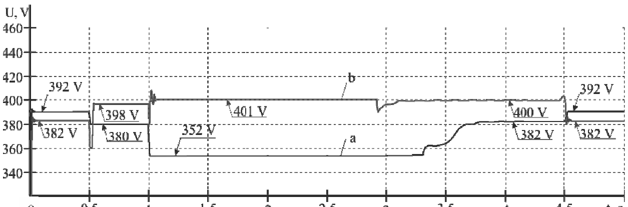

Fig. 4. The oscillogram of the operating value of voltage on a transformer LV winding at electric remoteness $\lambda_T = 16,5$ %:
a – without device; b – with device

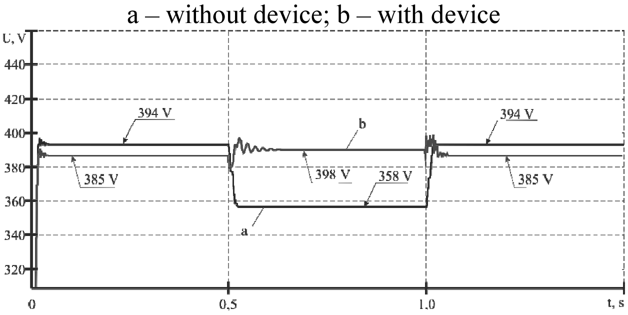

Fig. 5. The oscillogram of the operating value of voltage on a transformer LV winding at change of loading and the AD start:
a – without device; b – with device

Therefore during the operation of the transformer on the chosen tap at electric remoteness $\lambda_T = 16,5$ % it is not only provided the normalized deviation of voltage on clips of electroreceivers, but dangerous conditions for personnel and equipment are created.

In the mode of the minimum loadings during the operation of the transformer on tap of "+5 %" voltage on a winding of LV makes 385 V, and without device - 394 V. as seen on the oscillogram (Fig. 4, b). In the mode of maximum loadings the control system closes thyristors therefore capacitor bank is included longitudinally with the supply line. In this case voltage on a winding of LV makes 390 V, and without device - 358 V.

Application of a device in such electrical network gives the chance to significantly increase voltage in the mode of maximum active and inductive loadings due to switching of taps, and also compensation of jet resistance of power line.

While investigating the AD start without device (Fig. 5, a) the transformer works with the minimum active and inductive loading, voltage in the supply center equals the electrical line voltage, and voltage on a winding of LV of the transformer represents 392 V. In the time interval of 0,5, …. ,1 s the transformer works with loading coefficient β_T = 0,8, in this case voltage on a winding of LV of the transformer is 380 V. At the time of 1 s hooking up of winding of the AD stator to an electrical network occurs, wherein starting current cause's almost instant voltage reduction to the value of 352 V. In the course of dispersal the AD voltage on its clips increases not significantly, but when a rotor speed is 80 % of nominal, it gradually increases, reaching 382 V. At the time of 4,5 s power loading is disconnected, the transformer passes into the idling mode, and voltage on a winding of LV represents 392 V .

Thus, during the AD start or at change of electrical remoteness voltage without use of the device reduces much below of admissible and voltage represents 382 V, without device - 392 V.

At the time of hooking up loading the control system (Fig. 5, b) which works behind voltage deviation, switches off tap of "+5 % " and switches on tap of "–2,5 %", thus voltage on a winding of LV of the transformer represents 398 V. At the time of the AD start the control system removes the operating signals from thyristors therefore the capacitor bank is turned on lengthwise with the supply line, and the transformer works with the minimum coefficient of transformation. In this case voltage on a winding of LV is 401 V, and without device - 352 V. When the AD achieves subsynchronous speed the control system turns on tap of "–2,5 %" and voltage is stabilized on the value of 400 V, without device - 382 V . When disconnecting the AD and loading the control system turns on tap of "+5 %", again, thus the transformer works in the mode of minimum loadings, and voltage on a winding of LV is 382 V, without device - 392 V.

Advantages, disadvantages and area of application. Advantages of the device are possibility of load voltage control in an extended range, reduction of installed capacity of transformers under the terms of powerful electrical motors start, balancing of voltage on a transformer LV winding. The main disadvantages of existing multifunction devices are step voltage regulation, existence of a large number of thyristors, emergence of transition processes in capacitor banks when switching of taps. The device can be used in urban, industrial and rural electrical networks to improve quality of the electric power as on the existing transformers with switching without excitement and on the projected transformers.

Conclusion. The developed mathematical model of the device of regulation of voltage gives the chance to research its work at changing the electric remoteness of transformers, start of asynchronous electric motors, change of the load graph. Thus there is an opportunity to control electric parameters practically in any point of the scheme [8]. Researches showed efficiency and effectiveness of the device the use of which gives the chance to stabilize voltage according to the time of self-start of the group of electric motors and other difficult operating modes. The further analysis and research of the offered device, in particular parallel work with other transformers, and influence of regulation of voltage on transformers working in parallel are provided.

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