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Improvement of soft starter circuit for high-voltage and high-power asynchronous motors

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ABSTRACT

The paper considers the issues of effective direct start of high-voltage asynchronous motors of high power with the help of “thyristor voltage regulator - asynchronous motor” (TVR-AM) system. To increase the voltage and power of TVR in the work it is proposed to use series-parallel connected groups of thyristors (TG) instead of one thyristor TVR. The requirements to TG control signals, providing fail-safe thyristor commutation, have been scientifically proved and experimentally verified. In the proposed work a microprocessor device is used to monitor and control the simultaneous opening and closing of thyristors in each phase. Thyristors opening and closing instructions into microprocessor memory were compiled into C++ program.

Key words: voltage, power, inrush current, thyristor group, induction motor

1. INTRODUCTION

The issues of "saving energy and resources, increasing the energy efficiency of technological machines and mechanisms in various sectors of the economy; reduction of energy and resource intensity of the economy, the widespread introduction of energy-saving technologies in production". The issues of "saving energy and resources" are the most important tasks. Direct starting of an induction motor causes the starting current to be 5÷8 times of the rated current. If the power is limited by the power supplied from a stand-alone generator or mains, the decrease in internal voltage leads to a decrease in power supply resistance, and when this line becomes larger, the magnitude of the starting current leads to a voltage drops in the mains. High inrush current creates significant forces between the conductors located at the front of the motor stator winding [1,2,6,7,8,9]. This leads to a gradual breakdown of the insulation (ointment) and premature motor failure due to a short circuit of the windings. Most of the mining enterprises and production enterprises are large-capacity, high-voltage alternating current electrical systems. These electrical devices are connected directly to the network (types from 630 kW to 8 MW are used in conveyors, grinding mills, excavators, supply pumps of thermal power plants) [8,9,10,11,12,15,16].

The analysis of research results, publications in the scientific literature showed that they consider the motors of small and medium power, for which the manufacturer manufactures serial thyristor voltage converters (TVR), and to which the method of soft start can be applied, then the starting current of AM will not exceed the allowable values and the motors will not be subject to frequent repairs [1,2,4,5,6].

To eliminate such a gap, in order to increase the voltage and capacity of the TVC, this paper proposes to use series-parallel connected thyristor groups instead of a single thyristor to reduce their overvoltage and overcurrent [1,2,10,11,13].

In order to significantly increase the allowable voltage and power of the converter, it is proposed to use series-parallel connected thyristor groups (TG) instead of a single thyristor of TVR, thereby reducing their overvoltage and overcurrent.

Technological variation of volt-ampere characteristics of such valves during their manufacture make it difficult to operate a group of thyristors connected in series or in parallel. In case of parallel connection of thyristors some devices are overloaded by current in order to decrease their loads. Also, for the same reasons of technology, series connection

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results in individual units being overloaded with voltage. This phenomenon causes thyristors to fail prematurely. To eliminate such failures, we present the results of critical analysis of operation of thyristors connected in parallel and in series in dynamic modes of their switching on taking into account dynamic conditions of AD start-up in terms of their use for TVC-AM system.

2. RATIONALE FOR THE PROPOSED SOFT STARTER METHOD FOR INDUCTION MOTORS

The main problem of the proposed TVR will be that there is an urgent need to ensure simultaneous unlocking of all thyristors of one TG. A delay in the time of unlocking of one of them will lead to overloading of other thyristors or failure of switching of the TVR, thus - to a stop of the entire technological process [1,2,3,12,14].

The purpose of this work is to justify the requirements for TG thyristor control signals, which should ensure thyristor switching without disruption.

Based on the second Kirchhoff's law, the main value of the phase voltage of the stator winding in the AD start mode can be written as the sum of the voltage drops in each thyristor connected in series (Fig.2.4)

$$U_f = u_1 + u_2 + u_3 + \cdots + u_N, \quad (1)$$

where is $u_1, u_2, u_3 \ldots u_N$- voltage drops in 1, 2, . . . N - number of thyristors.

Operation mode of series connection of thyristors will be energy efficient in case of successful solution of problem of uniform distribution of reverse and forward voltages in static and dynamic modes. If values of reverse currents and leakage currents, values of forward voltage in conducting state, p-n decoupling capacitors, turn-on delay time and turn-off time of individual devices are dispersed, then the condition of efficiency - simultaneous release of thyristors is not fulfilled.

Therefore, it is necessary to take measures to ensure uniform voltage distribution in series connection [1,2,3,14,15].

Let's analyze the dynamic process of inclusion of a group of parallel connected thyristors for direct start of high-voltage high-power motor. If at time t1 a control signal is applied to the control electrode of thyristor T1, then during time $t_1+T_{turning}$ it will turn on and the full inrush current of AM starts to flow through thyristor T1(Fig-1).

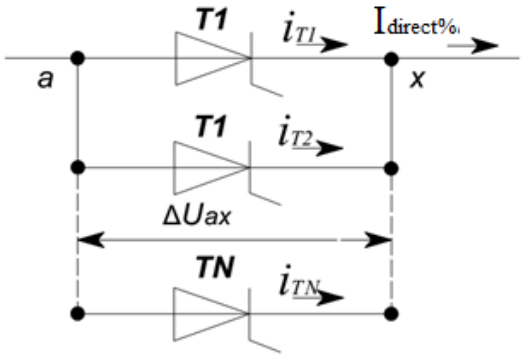

Figure 1. Thyristors in a thyristor group connected in parallel

Thyristor T2, to the control electrode of which the opening signal is supplied with a delay (that is, at the moment of time $t_1+t_{turning}$) will not open, because at that moment the potential difference U_{ax} between the points of input «*a*» and output «*x*» will be equal to zero due to the current flowing in the thyristor T1. To determine the permissible duration of the delay time of the signal to the control electrode of thyristor T2, assume that the signal is applied at the time $t_1+\Delta t$.

3. SOLUTION OF THE PROPOSED SOFT STARTER METHOD FOR INDUCTION MOTORS

If $t_3 \leq \Delta t \leq t_{turning}$, then the value of the potential difference between the points «*a*» and «*x*» (fig-2) will be $\Delta U_{ax} \approx (10 \div 90)\% \cdot U_{direct\ voltage}$, the current through T1 will intensively increase from 10% to 90% of the full inrush current I_{inrush} and the probability of thyristor T2 opening will be low. If $0 \leq \Delta t \leq tz$, the magnitude of the potential difference $\Delta uax \approx (100 \div 90)\% \cdot U_{direct\ voltage}$, the current through T1 will slowly increase from 0 to 10% of the value of full inrush current I_i and the probability of opening of thyristor T2 (Fig. 2) will be high. At the same time, the probability of failure of thyristor T2 switching is not excluded. Therefore, the first and necessary condition for operation of thyristors connected in parallel in GT, as well as in case of series connection of thyristors, is a simultaneous supply of control signal to all thyristors of TG. The delay time depends on the magnitude of the control current and the resistance of the control electrode circuit. An approximate graph of the delay time dependence on the control current value is shown in Fig. 2. As follows from the above graph, in order to reduce the delay time, the control current should be chosen not less than the rectifying current [1,2,3,4].

The rise time depends on the type of thyristor and on the nature of the circuit load (purely active or active-inductive), so it can be up to 1 μs. To reliably unlock an individual thyristor, the duration of the control pulse must be longer than the turn-on time, so th.upr= 1÷3 μs.

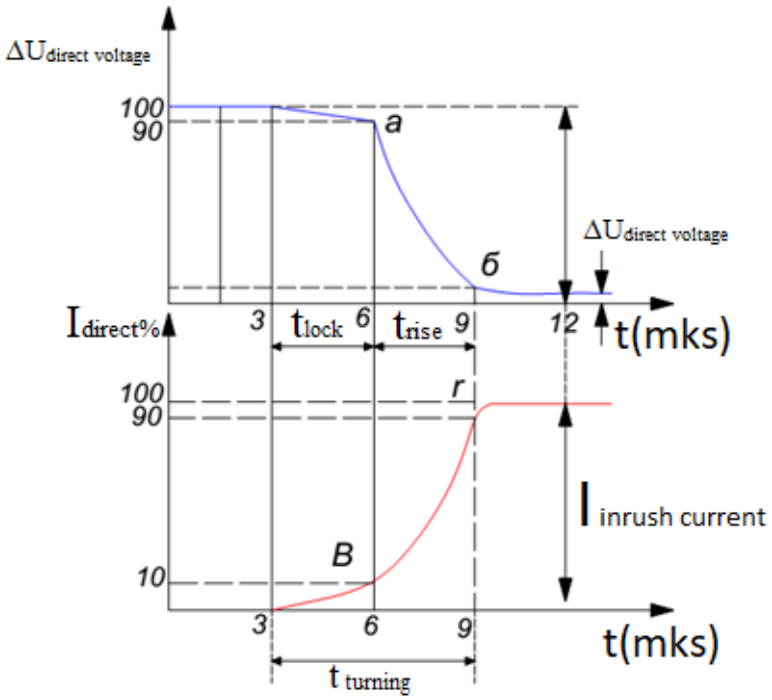

Figure 2. Timing diagrams of electromagnetic processes of thyristors

Thyristors can be connected in two different ways: series connection of independent *n* thyristors, each of which contains *m* parallel connected branches (fig-3.) or parallel connection of *m* independent rows, each of which consists of *n* consecutive thyristors.

The group connection in this circuit is structurally uncomplicated and provides sufficiently full use of thyristors on current and on voltage. The conditions under which the thyristors connected in series must open relatively simultaneously to provide reliable control of the AC motor drive have been presented above. This condition was reduced to the fact that the first and necessary condition for operation of the thyristor group is the simultaneous supply of the control signal to all thyristors of thyristor groups. To verify the recommendations from the conclusions and conclusions made in the second chapter of this work, the power circuit of the simulation model of the thyristor voltage converter

(TICC) was assembled. In the circuit, one basic thyristor in one phase of the TPN, was replaced by a group of thyristors, consisting of series-connected (a_1-b_1), (a_2-b_2),….(a_m-b_m) chains, each of which is connected in parallel with each other.

Instead of the second base thyristor, which should be connected in counter-parallel to the first base thyristor of the FTC, the same thyristor groups were adopted, which are connected in counter-parallel to the above group of thyristors. Thus, one phase of FTC was formed. To simulate the load in the experimental setup is used active-inductive resistance or AD (Fig.3.), which allows to regulate not only the value, but also the load factor.

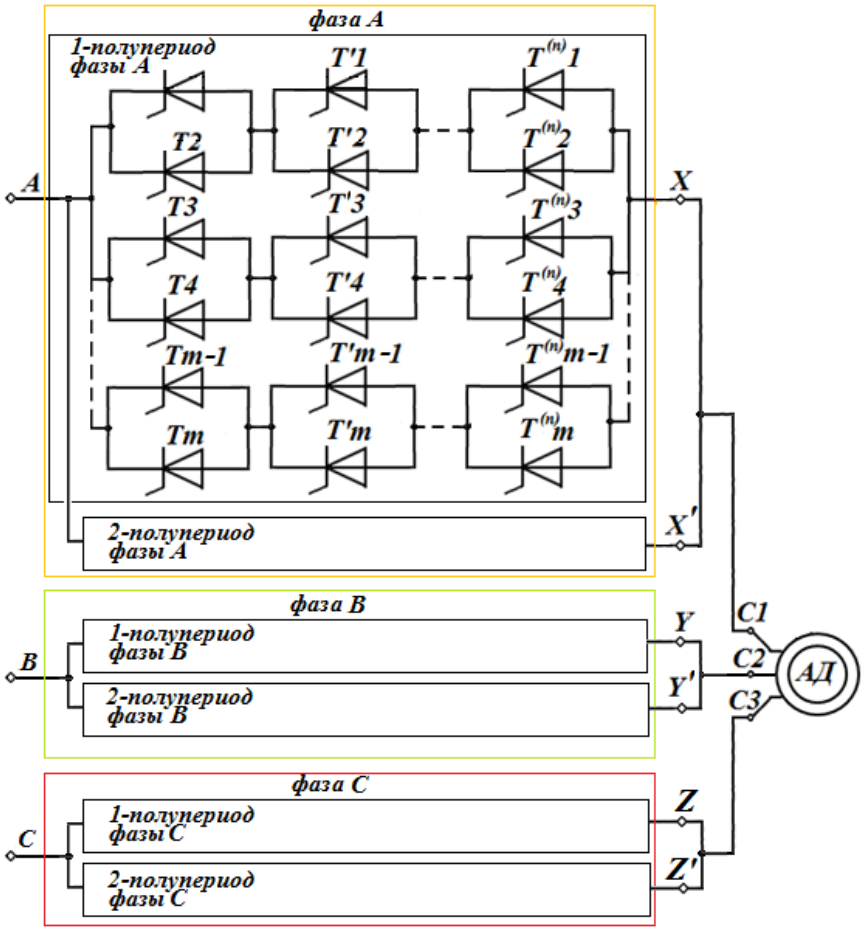

Figure 3. Power diagram of TPN-AD simulation model

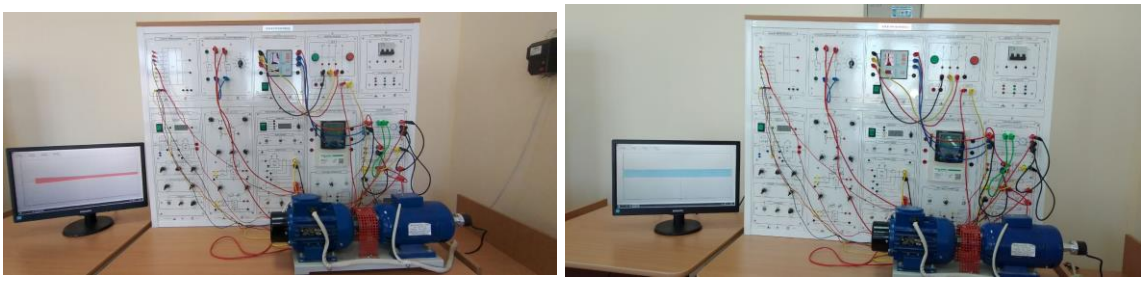

Figure 4a. Investigation of TPN-AD on the laboratory bench

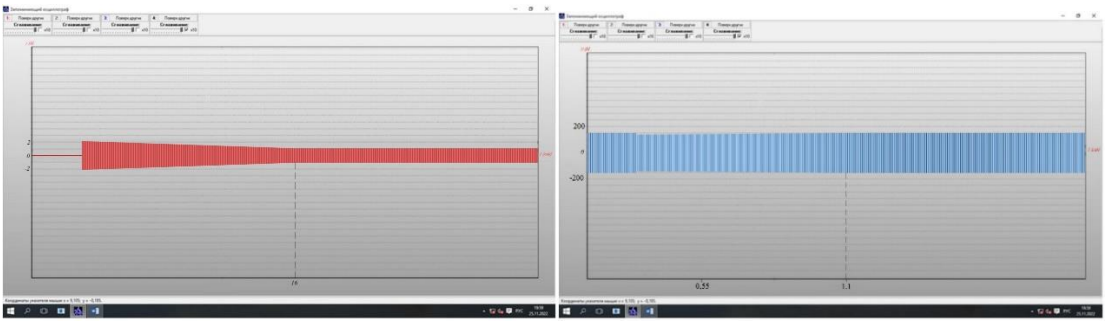

Figure 4b. Oscillogram of soft-start of AD of high power, current and voltage, taken with an oscilloscope

We can get the current and voltage oscillograms shown in the 4a, 4b- figure. It can be seen that the starting current value has decreased from 7 times to 3 times. And the voltage value decreased by 2% for a short time and increased again.

4.CONCLUSION

The first and necessary condition for operation of thyristor group is simultaneous supply of control signal to all thyristors of thyristor group. Minimum duration of control pulse, for thyristor group of "TVC-AM" system must be greater than turn-on time for these thyristors. It is necessary to ensure the start of AM with an active-inductive load, for which purpose a capacitive compensating capacitor of reactive power must not be included in the circuit between TVC and AM. To ensure reliable commutation of thyristor groups - without failures, it is necessary to ensure the starting process of AM with load other than purely active load (i.e. to ensure the active-inductive load), which corresponds to the impedance of AM. If there is a compensating capacitor in the circuit of a TVC-AM, it is a prerequisite that it is included outside the TVC -AM system, hence, at the input of the TVC.

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