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THE METHOD FOR OPTIMIZING THE OPERATION OF THE ASYNCHRONOUS MOTOR BY ANALYZING ITS WORKING PARAMETERS

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ABSTRACT

Considering the increasing cost of electricity, a practice of lowering its non-production losses becomes important. As such optimization operation of the asynchronous motor in automated electrical machines finds uses in all fields of industry. The highest efficiency is achieved at loads closer to rated, efficiency also drops at torque lower than rated, and can drop to as low as 50% which leads to loss of effectiveness and a significant decrease of power coefficient. The paper explores the possibility of using a microcontroller to control the asynchronous motor. The work aims to develop the method for optimizing the operation of the asynchronous motor by analyzing its working parameters in the main operation regime. A special microcontroller unity was created to realize the soft start of a motor. When solving power draw problems of asynchronous motor, scientific achievements in the field of electric drives, thyristors and microcontroller systems, and software development were used. Paper also presents technical description if developed device. The methodology for optimizing asynchronous motor and device operation algorithms is also described. Microcontroller programming principles were reviewed and implementation was proposed for the algorithm to optimize power draw. The scientific novelty of obtained results lies in the development of the optimization method and implementation of the software-hardware solution for the optimization of the asynchronous motor. The practical significance lies in the development of hardware and software solution that provides soft start and decrease of unnecessary losses at partial loads. The developed device can be used by different industrial objects for complex control for asynchronous motors to achieve power savings at partial loads. Developed method for optimizing asynchronous is based on analysis of operating parameters and allows to control motors with lower power draw (maximum savings of current consumption is about 15%, for a dry run), which is supported by experimental data.

Keywords: induction motor, ifsb, thyristors, microcontrollers, soft start, optimization, partial load, efficiency.

INTRODUCTION

Problem Statement and Its Relation to Scientific and Practical Problems

Since its invention, the standard 3-phase asynchronous motor is one of the most known elements of industrial equipment. Owing to simple construction, relatively high effectiveness, it is likely to remain the main source of mechanical energy for industrial facilities. Electric motors - the main class of energy consumers in the world. According to various sources, about 60% of the world's electricity in the world is used by electrical motors; as such improving their effectiveness is an especially relevant problem [1].

Considering the increasing cost of electricity, a practice of lowering its non-production losses becomes important. As such optimization operation of the asynchronous motor in automated electrical machines finds uses in all fields of industry. It should be noted, that in many use cases, electrical motors mainly operate below rated load. In this case, the efficiency of electrical motor turns out to be significantly lower than at rated torque values. It is known, that the efficiency of asynchronous motor ranges depending on shaft load. The highest efficiency is achieved at loads closer to rated, efficiency also drops at torque lower than rated, and can drop to as low as 50% [2,3]. In reality, not many motors operate at rated loads, with the majority operating at significantly lower loads, due to electrical machine designs requiring capacity redundancy, which results in efficiency loss and lower power coefficient.

Currently, the control of the asynchronous motor is realized through one of the following methods:

- magnetic starters (allow to control the asynchronous motor by directly connecting it to alternating current grind;
- with help of thermal relay (over current protection);
- frequency control (control over rotational speed and torque is usually done with frequency transformer, which is based on altering AC frequency and voltage);
- thyristor control (semiconductor control);
- use of a microcontroller.

The work aims to develop a method for optimizing the operation of asynchronous motor by analyzing its working parameters in the main operation regime and the creation of special device using microcontrollers to realize soft start and optimization of power consumption of the asynchronous electric motor.

Literature Analysis

The start of any motor is accompanied by certain swathing in the power and control circuit. This utilizes relay-contact and non-contact devices. For asynchronous motors with the short-circuited rotor, the start usually boils down to feeding it with the full voltage of the power grid. Powerful asynchronous motors are turned on with lowered voltage and after the initial start, the stator is switched to full voltage. For asynchronous motors with phase rotor and DC motors in circuits with limited starter current in rotor and armature circuits, starter resistors are included, which are disconnected step-wise as motor speeds up. After the start is complete, starter resistors are completely shunted. The breaking process can also be automated. After break command after relay-contact devices, necessary switching occurs in power circuits. When the speed of the motor is close to zero, it is completely disconnected from the power grid. During the start procedure, step is disconnected after a specific time interval or depending on other parameters, while current and speed change [4-6]. To control power flow, major motor circuits require a mechanism for connecting and disconnection from the power supply. This is realized with uses of electromechanical switches, known as contractors. Even today, after more than a century since their invention, contact systems remain the most widely used way to control a motor. Nevertheless, there is a definite tendency towards more complex electronic control systems and electric motor control. Let's take a more detailed look at methods for the start and control of the electric motor.

Controlling Asynchronous Motor Using a Magnetic Starter

Magnetic starter - is a computational device designed to automatically connect and disconnect consumers from the power supply. Magnetic starter allows to remotely control, turn on and off consumers from power using a remote controller. magnetic starters find most useful in controlling asynchronous motors and realized their start, stop and reverse. The starter is a contactor, which can be equipped with additional devices such as a thermal relay, additional contract group or start button. As a side from simple on/off switching of the electric motor, the contactor can also be used to switch direction in which its rotor rotated i.e. reverse, by changing phase order, for which it is equipped with the second contactor. Switch for mort's windings from wye to delta is used to decrease start currents. Magnetic starter assembly can be open and closed (in a frame), reversive and non-reversive, with built-in thermal overload protection and without. Reversive magnetic starter (reversive assembly), consists of two three-pole contactors mounted onto a single base with mechanical or electrical block, to prevent simultaneous switching of contactors. Magnetic starter, contactor or relay has the power or blocking contacts. Power contacts are used for the commutation of powerful loads; block-contacts - control circuits. Power and block-contacts can be normally open or normally closed. Normally open contact is disconnected in a normal state. Normally closed contact is connected in normal state. Contacts of contactor, starter or relay on schematics are depicted in normal state. The connection of the motor through electromagnetic start also provides zero protection. When the voltage disappears, for whatever reason, the magnetic start also disconnects, breaking the circuit, as it is the same switching it off. The motor is shut down and after the voltage has been restored, it can only be started by manually switching it on. As such, the magnetic starter provides so-called "zero protection" [6-7]. In other words, the magnetic start provides soft start and zero protection, but does not allow for direct control over motor and affect its efficiency coefficient.

Controlling Asynchronous Motor Using Thermal Relay

Thermal relay - is an electric device used for overcurrent protection of electric motors. The longevity of electrical equipment strongly depends on overloads, to which it is subjected during its operation. For each object, there is a dependency of current flow time on its value, at which reliable and long-term operation of equipment can be guaranteed. At rated current values, the duration of its flow is equal to infinity. When current is higher than rated, lead to an additional increase in heat output causing accelerated aging of insulation. So the higher the overload, the lesser the time it can be sustained.

To avoid possible overheat, a thermal relay, which chosen according to operating current, is connected between magnetic starter and asynchronous motor. Thermal relay protects the electric motor from breaking and operation under failure conditions, like without one of three phases. The main characteristic of thermal relay is a dependency of switch time on loader current (time-current characteristic). When checking the time-current characteristic of thermal relays, it is important to consider from which state (cold or hot) it switches to. When analyzing thermal relays, it is important to consider that, heat elements in relays are unstable at short circuit current. Heating of bi-metallic plate in thermal relays depends on environment temperature i.e. if temperature rises, the relay switching time decreases. For temperature conditions that significantly differ from rated, an additional tuning of thermal relay or switch to heat element that is more suited for real temperature may be required. In order to mitigate the effect of environmental temperature on relay switching, a relay with longer switching time should be chosen [5-8].

Strictly speaking, the relay does not control a motor but protects it from unacceptably long overheating, including phase loss, phase asymmetry and is added layer of protection. They are designed as a complementary device for control circuits and to be built into magnet starters.

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Frequency Control

Variable Frequency Drive (VFD) - system for controlling rotor frequency of the asynchronous (synchronous) electric motor. The principle of VFD is based on changing the frequency of the alternating current. It consists of the motor itself and the frequency transformer. Based function, frequency transformers realize the following methods for controlling asynchronous motor:

- scalar control;
- vector control;
- direct torque control (DTC).

Let's take a look at those methods.

Scalar or Frequency Control

Asynchronous electric drives with asynchronous control are the most common. They are used to drive compressors, fans, pumps and other mechanisms that require constant rpm (speed sensor is used), or other technological parameters (such as instant pressure in pipe systems, with uses of the respective sensor).

Principle of scalar control - amplitude and frequency of supply voltage changes according to law $\frac{\mathrm{U}}{\mathrm{f}^{\mathrm{n}}} = \mathrm{const}$, where $n \geq 1$. The exact dependency varies on per case basis, depending on the drive loads. Frequency is usually the independent influence, and voltage at a specific frequency is determined by a type of mechanical characteristic and values of critical and start torque [9-10]. Due to scalar control, asynchronous motors have constant overload capability that does not depend on voltage frequency; however, at frequencies low enough, there can be a significant drop in torque. The maximum values of scale control range, at which regulation of the rotor's rotation speed can be achieved without loss of resistant moment, does not exceed 1:10.

Scalar control is rather simple to implement, however, it has to major disadvantages. First, if the shaft has no speed sensor installed, then it is impossible to control its speed, as it depends on the load. Installing speed sensor solves things problems, but the second problem remains - the inability to control torque. A torque sensor can be used, but their cost tends to exceed the drive itself. And even with a torque sensor, the torque control would be incredibly inertial. And another «but» - scalar control is characterized by the inability to simultaneously control speed and torque, as such priority is given to the value that is most important for the application. When feedback is required to control the speed and torque of the motor, vector control is used.

Vector Control

Vector control is a method to control synchronous and asynchronous motors that, that not only for the harmonic phase (scalar control) currants (voltages) but also provides control over the magnetic current of the rotor. First implementations of vector control principles and improved precision algorithms require rotor position (speed) sensors. In general, "vector control" means interaction of controller devices with a "spatial vector" that rotates with the same frequency as the field of the motor. Fir electrical drives with vector control had built-in flux sensors, which significantly limited the usage of such drives. The control system of modern electrical drives allows us to calculated rotation speed and torque. The only required sensors are for the stator phase current. Specially developed structure of control system provides independence and almost non-inertial regulation of main parameters - shaft torque and rotation speed. To date, the following vector control systems have been formed:

- sensorless - shaft is not equipped with a speed sensor;
- a system with speed feedback.

The use of vector control methods depends on the application field of electric drives. If a range of speed measurements does not exceed 1:100 range, and precision requirements are within ±1, 5%, then sensorless control systems are used. If speed measurements are within 1:10000 range an more, and precisions requirements are high (±0,2% at rotation frequency 1 Hz), or if shaft positioning required, or torque control at low rotation frequencies, then system with speed feedback is used [10-12].

Advantages of vector control:

- high precision level for control over shaft rotation speed, despite possible lack of speed sensor;
- the rotation at low frequencies is smooth without hitches;
- with speed sensor installed, nominal torque values at almost zero speed;
- fast response times to load - load swing almost have no impact on the speed of electric drive;
- high motor efficiency coefficient, due to lower losses causes by magnetizing and heating.

Despite obvious advantages, vector control also has disadvantaged - high computational complexity, the operation requires knowledge if its parameter. That aside, speed oscillation at constant load is higher than that for scalar control. Some fields require the use of electric drives with scalar control. For instance, group electric drive in which one transformer power few meteors.

Thyristor Control (Semiconductor Control)

Thyristor control over electric motors is becoming more popular. Thyristor drive has such important qualities as, reliability, high-efficiency coefficient, small size, low weight, and low power for thyristor control. Thyristors are used to control both AC and DC motors. Rotation frequency of the asynchronous motor is implemented by including thyristors into stator or rotor circuit. In the first case, thyristors allow controlling amplitude or AC voltage frequency of stator winding, i.e. electromagnetic momentum of the motor. The inclusion of thyristors into the rotor circuit allows for gradual, almost step-less control over resistance in the rotor circuit, thus controlling the frequency of its rotation.

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Electronic frequency transformers are commonly used to control the speed of the asynchronous or synchronous motor, by varying output voltage frequency. In simple cases, the frequency and voltage are controlled with set V/Hz characteristics; in more advanced transformers utilize the so-call vector control. Thyristors can be used in conjunction with relay-contact devices. Thyristors are used as power elements and connected to the stator circuit, relay-contact devices are connected to the control circuit. Use of thyristors as power commutators allows for stator voltage to be set from 0 to nominal value during start, limiting of current motor momentums, implement effective breaking or step-wise operation.

Phase voltage regulation - regulation of voltage by changing the opening angle of thyristors, TRIACs, thyratrons, or other devices assembled as rectifier or key. Change in opening angle causes the load to receive incomplete sine waves (usually without frontal edge), which results in lower voltage. Such regulation is used for soft start, current control for a charge of batteries and other applications. The advances of phase regulation are low cost, simplicity of transformer and control circuit. Main disadvantages - distortion voltage curve in the feed line, large pulsation coefficient of output voltage, low power coefficient. Distortion of feed voltage shape is due to that during half period the load resistance changes (sharp drop when valves open), which causes increased corned a voltage drop on resistances of source and grid [11-12].

Control Using Microcontrollers

For some relatively simple tasks, control of electric motors using microcontrollers and specialized circuits is the most sensible solution. Owing to high durability, reliability, low-cost high efficiency, asynchronous electric motors are widely used in many industrial objections. However, their disadvantage is operation at only rated voltage when connected to a powerline. This necessitates the use of frequency transformers to control the rotation frequency of these motors. The most common control algorithm is to maintain a constant voltage/frequency (V/Hz) ratio. The vector control algorithm can be realized with automated code generation. Capability and performance of 16-bit microcontrollers are usually sufficient for the implementation of a vector control algorithm with floating-point calculations. This allows for creating a compact and cheap device for frequency control. However, such devices are programmed once on installation, assuming rated power and any attempt to change that require complete reprogramming. As such, microcontrollers are used to implement devices for a soft motor start or separate PPC, which are programmed once with motor data and are unchanged over the motor's lifespan [13-15].

The present paper report developments a microcontroller-based device for diagnostics and asynchronous electric motor control optimization, with software for it that allows for control in three main directions:

- soft start;
- failure analysis (emergency stop in case of one of three phases);
- direct motor control, by lowering operating operation voltage on all three phases using PPC, while preserving rated rotation speed i.e. useful power, and thus, lower power consumption.

Outline of Previously Unsolved Part of the General Problem

Theoretical Basis and Calculations for Microcontroller Device for Optimization Operation of the Asynchronous Motor Based On Analysis of Operating Parameters

As previously described, up to date there are no devices that allow for complete optimization and automation of asynchronous motor. This paragraph describes a theoretical basis for the microcontroller-based device for the realization of soft start, optimization of power consumption and protection from an emergency operation. Figure-2 shows a schematic of a developing device [2-5].

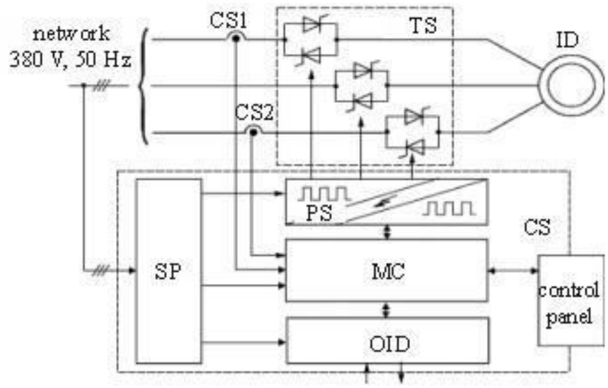

Figure-1. Schematic of a control device for asynchronous motor:

Abbreviation used on Figure-1:

CS - control system; TS - 3-phase thyristor switch; SP - the source of power; PS - thyristor control pulse shaper; MC - microprocessor controller; OID - output-input device; ID - induction drive motor; CS1, CS2 - current sensors.

PROBLEM STATEMENT

Technical Description of Developing Device

To implement soft start and optimize power consumption of three-phase asynchronous, a device was developed with the purpose of phase impulse control for regulating the voltage of each phase and current control. The device consists of three identical power modules for each phase and digital control. The schematic of the power module is shown in Figure-2 [3-5].

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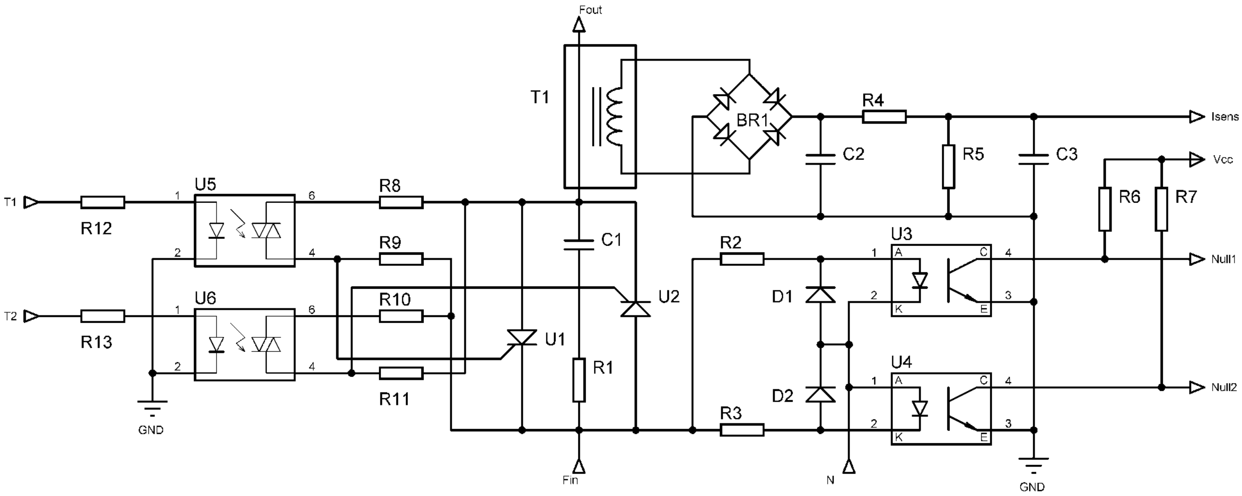

Figure-2. Power module for single phase.

Main blocks f power modules:

- Power thyristors U1 и U2, each operates in its half-period.
- Snubber circuit R1-C1, prevents false thyristor triggering in case of interference.
- Optocoupler U5, U6. galvanic isolation of power and control sides
- Circuit for measuring average phase current, implemented using current transformer T1, rectifier BR1-C2, voltage divider R4-R5 (can be replaced with a trimmer), used for setting limits of measured current with a given transformer and filtering capacitor C3. The current transformer also provides galvanic isolation of power and control parts.
- A detector of sine wave transition through zero at diodes D1, D2 and optocouples U3, U4, which also provide galvanic isolation.

Detecting transition of sine wave through zero necessary phase impulse control, i.e. for calculating thyristor open-angle. use of two optocouple is necessary for precise detection of transition moment. Oscillograms, recorded from output Null1 and Null2 is shown in Figure-3. When sine wave transitions through zero into positive half-period, LED lights up, opening transistor of optocouple U3. There is a drop-in upper oscillogram, which causes the interruption of the microcontroller. When sine wave transitions to negative half-period, optocouple U3 closes, and U4 - opens [16-18]. Unclear signal periods are due to transistor opening faster than closing (which defines its maximum switching frequency). As such transition into negative half-period is detected by a drop at output Null2.

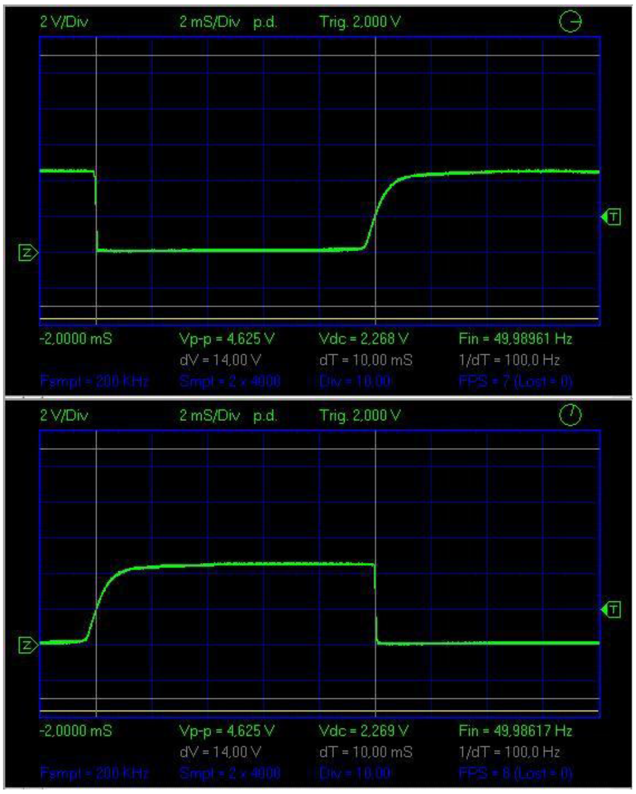

Figure-3. Oscillograms Null1 (top) and Null2 (bottom).

Thyristor opening angle α is defined by the time between the detection of sine wave transition through zero and open impulse sent to respective thyristor depending on the sign of half-period (Figure-4).

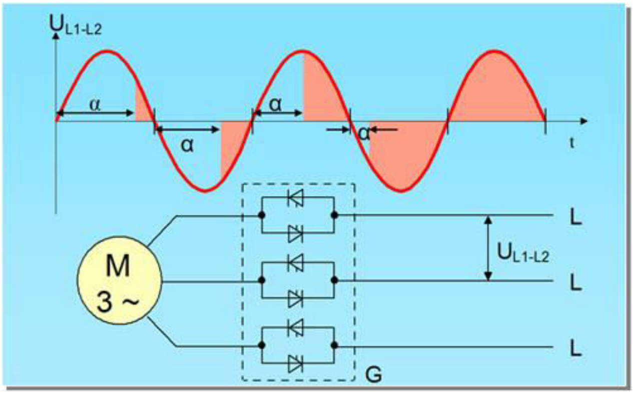

Figure-4. Change of thyristor opening angle.

EXPERIMENTAL

To simplify programming and omit the use of expensive controllers with sufficient interrupt inputs, three simples control per each phase were used. Each controller processes interruption through zero of its phase receives delay time t from the shared bus and opens corresponding thyristors with specific timing. The operation algorithm of each controller is shown in Figure-5.

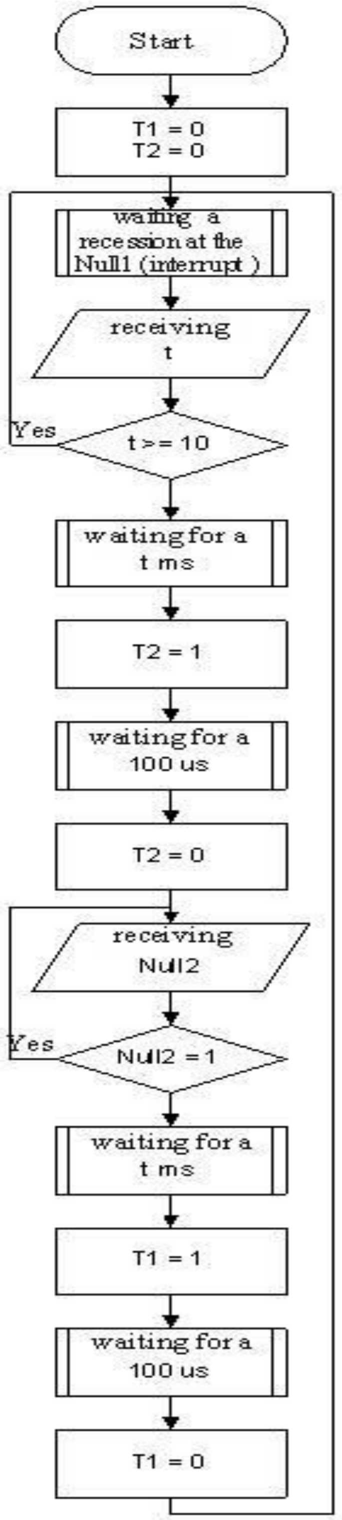

Figure-5. Executing the controller algorithm.

Algorithms work in the infinity loop and are only interrupted when the device turns off. All controllers share the same clock generator [18-20]. As such by changing t on the bus, the main controller control all three executing controllers i.e. sets the opening angle for all thyristors simultaneously and indecently for all three phases.

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For project implementations, executing microprocessors ATtiny24 was chosen to control each motor phase and main microprocessor ATmega8. As with the majority of modern 8-bit microcontrollers, AVR is a typical specimen of Harvard [21-23]. Program memory and data memory are split into different address spaces. CPU has two independent buses: 16-bit for communicating with ROM and 8-bit for communication with RAM. Command length of AVR a multiple of 16-bit and cam be 2 or 4 bytes. Harvard architecture can simultaneously fetch command from ROM and operate variables in RAM, which significantly improves. In this case, the microcontroller can execute commands only from ROM, but for majority applications for which it is to be used, this is not much of an issue. AVR controllers have two-stage command conveyers implemented. During the execution of the current command, the next instruction is being fetched and decoded.

AVR has a RISC instruction set (Reduced Instruct Set Computers. Such implementation assumes a small set of well-designed instructions, with the majority, have the same execution time (cycle). Core cycle of AVR - if on a period of clock gen cycle [22-24]. Bus for transferring delay time to executing controller is 4-bit wide, i.e. it can transfer values from 0 to 15. In a real-world scenario, at a power line frequency of 50 Hz, the duration of one half-period is equal to $\frac{T}{2} = \frac{1}{2F} = \frac{1}{2 \cdot 50} = 0{,}01s = 10ms$. As such, by providing value t in milliseconds, the control is implemented in increments of 1 ms or 10%. At t = 0 thyristors open immediately after sine wave transitions through 0 i.e., completely open. At t = 10 and more thyristors are always closed [23-26].

Such a circuit is sufficient for soft start, current monitoring and optimization of power consumption. The feedback can be implemented by monitoring current consumption or frequency of shaft rotation, however, because a device is developed for motors operating with a constant load, there is no need to monitor shaft rotation frequency, as its decrease at constant voltage frequency (initial braking) leads to high current consumption. The control schematic is shown in Figure-6.

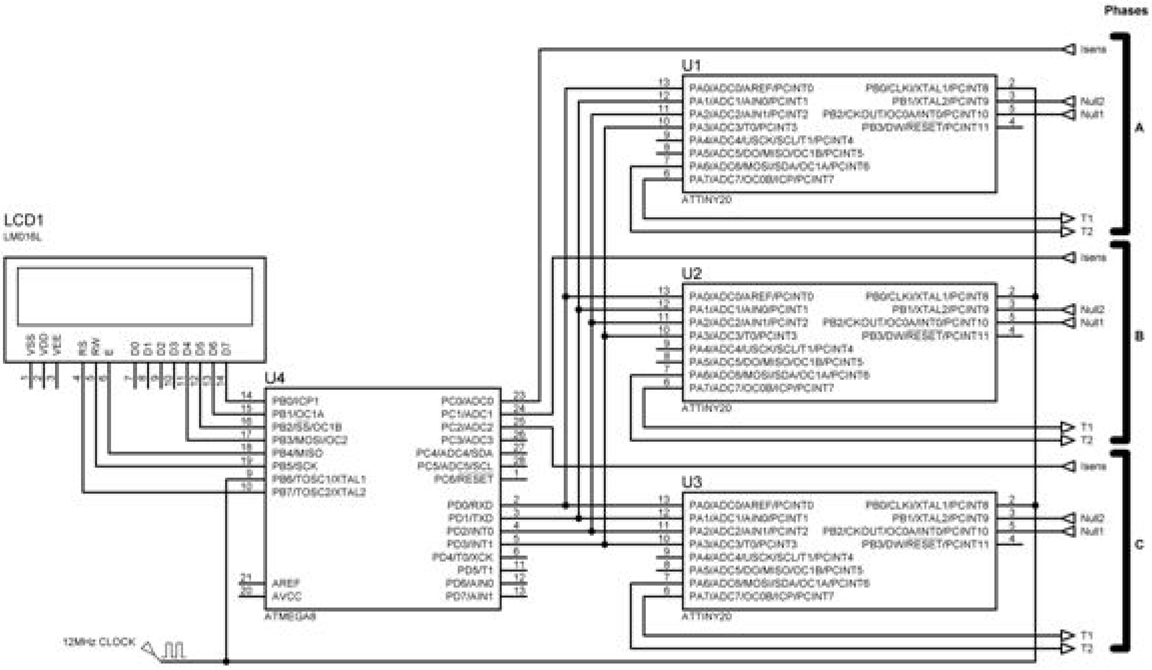

Figure-6. Control schematic.

Indicator LCD1 is used to display an operating regime. Additional buttons or switches can be connected to the main controller to alter operating parameters. Power supply circuits are not shown. The devices are powered by stabilized 5V. Directly near power output of each controller and indicator blocking capacitors are installed. Blacking capacitors are also connected to the AREF output of main control, and AVCC output (voltage reference for controller ADC) is connected through LC-filter. A stable source of the reference voltage is necessary for the precise measurement of analog values, which in this case is current consumption for each phase [27-28].

Optimizing Operation of Asynchronous Motor

Optimization methodology:

a) Soft start implementation.

b) Set initial operating voltage.

c) Step-wise increase of operating voltage to the rated value.

d) Wait for the motor operation to stabilize.

e) Optimizing power consumption.

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f) Step-wise decrease of opening voltage until current consumption rises.

g) Increase voltage one step, to return to previous (optimal) value, at which consumed current is minimal, while torque is sufficient to overcome the load.

h) Failure state protection if one of the phases drops. Constant monitoring of consumed current on each stage of algorithm and immediate shutdown of controlling impulses to thyristors if at least one phase is at 0 current.

Operating Algorithm

The operating algorithm developed according to this methodology can be split into three parts - soft start, finding operating voltage and regular monitoring for voltage loss on one or more phases.

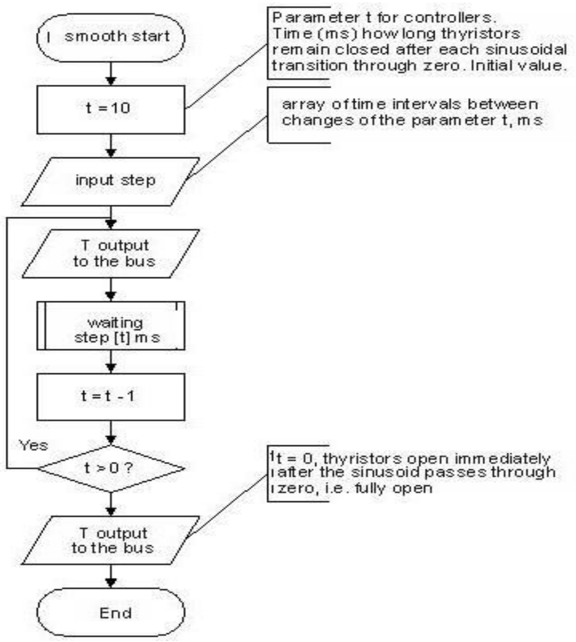

Figure-7. Soft start algorithm.

The phase loss means motor operation while there is no power coming through at least one of the feed wires. Phase loss can occur due to: wire got torn, the fuse blew, loss of contact in one within the phase. In three-phase mode, each winding has current flowing that is offset by the 3rd of the period. When one phase is lost its winding has no current flowing through it, while windings of the other two phases have not to phase offset. Despite winding connected to wires of three-phase supply, currents in them match in time. Such operation is called a single phase. Unlike the rotating magnetic field generated by three phases, the single-phase magnetic field is pulsing. It changes over time but is stationary along the circumference of the stator. If phase loss occurred before the motor is powered, the resting rotor would be caught between two equal filed but with different signs, thus canceling each other. As such the motor wouldn't turn even with the unloaded shaft. If phase loss occurs while the motor is powered on the rotor would continue turning, albeit with lower torque. To prevent such failure state operation, the software constantly monitors currents in all three phases, and shuts the motor off at least one of them is 0. The soft-start is implemented as a gradual increase in operating voltage of phases, starting from initial value U_0 until it reaches rated blue. Value U_0 is chosen based on shaft load. In some cases, it is more beneficial to increase starting voltage fast than linear, to ease acceleration at massive loads, and then switch back to linear control. Device's soft start algorithm changes voltage step-wise. There is an option to set initial voltage U_0 and array of parameters - transition time between two stages. The soft-start algorithm schematic is shown in Figure-8.

In a proposed algorithm, the final value U_{op} is a rated voltage, i.e after start the thyristors stay completely open. After the motor starts, it is important to wait until it reaches its rate operation parameters. This depends on a few parameters such as motors power, wear conditions, shaft load, etc.

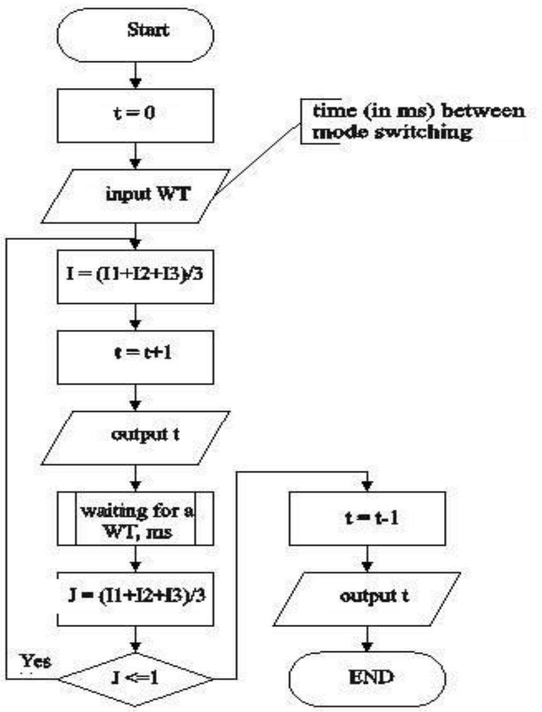

Figure-8. Algorithm to optimize power consumption.

The proposed algorithm boils down to finding minimum current consumption. To achieve this, the voltage is gradually decreased (one stage per cycle step) and consumed current is measured. Because feed voltage frequency remains constant shaft rotation frequency should also be constant. When operating voltage decreases, so does torque. When toque is not sufficient, the motor starts to slow down, i.e. its rotation frequency drop. In turn, this leads to increased current draw. This by lowering the voltage and measuring current, the braking

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can be identified by an increase in current on the next step. As such the optimal operation parameters are those of step before the current increase. Figure-9 shows the schematic representation of the power consumption optimization algorithm. The devices were programmed using the Code Vision AVR C Compiler environment.

RESULTS AND DISCUSSIONS

An Experimental Test of the Developed Device

The developed device and software were experimentally tested at the department of electrical machines and renewable power sources. The tests were conducted with the three-phase motor with the shorted rotor, 4.5 kW.

The lab setup allowed to regulated shaft load by pressing brake pads against the drum fixed on the motors shaft, and measure current and power draw for all three phases.

The stage is to put together and test circuit for starting motor and tuning device parameters related to phase current draw and detecting voltage transition through zero (Figure-9).

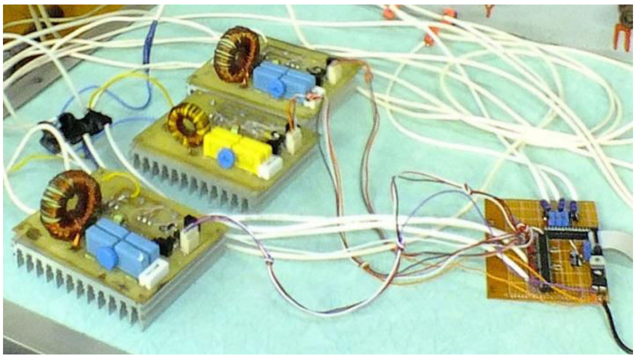

Figure-9. The assembled motor control device.

The setup consists of three-phase AC power supply, with 220V linear voltage, digital three-phase ammeter for precise current measurements, three moving magnet ammeters, 50 A fuse, and developed control device трёх. In addition, a digital multimeter and oscilloscope were used for measuring voltage and waveforms. The motor was powered through mechanical contactor allowing for switching between delta and wye

The completely assembled setup is shown in Figure-10.

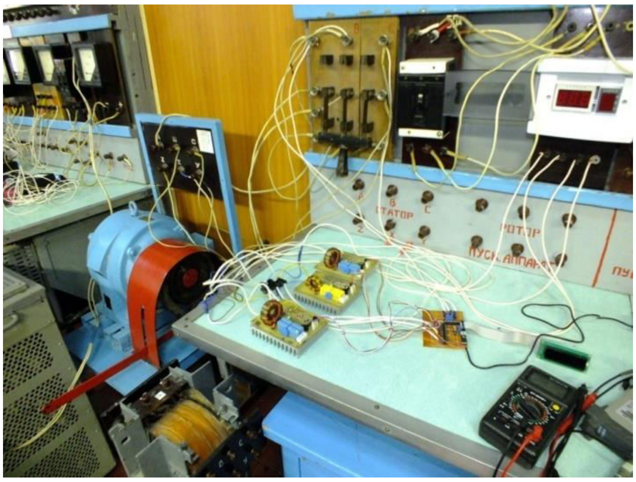

Figure-10. Experimental setup for measuring device parameters.

Soft Start Tests

When testing a soft start, the main operating parameters of the muter were recorded without and with the developed device. Starting current, in wye and delta configuration, during switching from wye to delta, and for operation in wye and delta were measured. Measurements were conducted for haft loads no more than 10% of rated.

Table-1. Current values without a device.

Start current wye (each phase, approx)	100 A
Start current delt» (each phase, approx)	20 A
Current during wiring switch «wye-delta» (each phase, approx)	35 A
Operating current, «wye»	2 A
Operating current «delta»	8 A

When the motor is connected through a developed device, start current for delta and wye wiring were:

Table-2. Current values with the device.

Start current wye (each phase max)	20 A
Start current delta (each phase, max)	8 A

As can be seen from experimental data, the developed device reduced start current by 5 times for wye wiring, and by about 2.5 for delta wiring. I.e. devices proved its effectiveness for a soft start implementation.

Emergency Shutdown Tests

The emergency shutdown was tested by disconnecting phase wires one by one, before and during operation of the mort. The devices immediately stopped sending control signals to thyristors i.e. shutting the motor down.

The protection is implemented as follows: the device controls current in each phase and shuts the mot

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down if the current is zero for at least one phase. This also serves as self-regulation, as protection would kicking if one of the thyristors dies.

Optimization of Power Consumption

Power optimization was tested by measuring the operating current through motor phases at different loads, with and without a device. Tests were conducted with delta wiring, as with wye wiring the developed power was 3 times lower than rated. Current vs. shaft load savings and power savings vs. shaft load plots are shown in Figure-11 and Figure-12 respectively. Each test was conducted at least 3-time s and results are compiled into the table.

Table-3. Current values at different loads.

Load, %	Current without devices, A	Current with devices, A	Saving, %
10	8.1	6.9	14.8
30	9.2	8.3	9.8
80	11.0	10.7	2.7

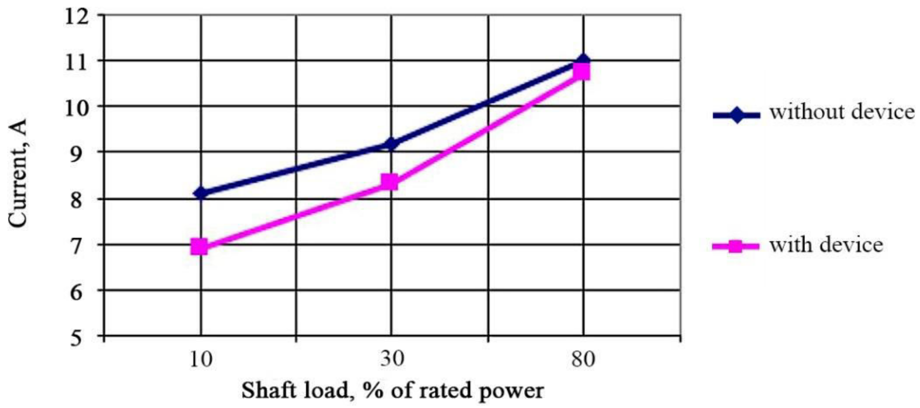

Figure-11. Plots of a current draw vs. load.

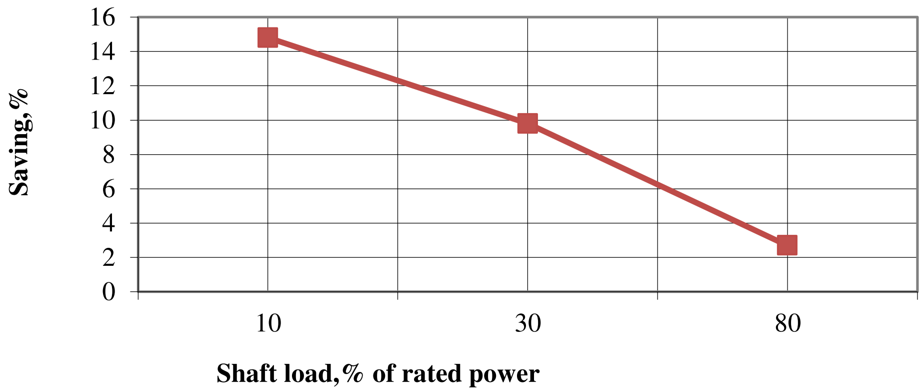

Figure-12. Power savings vs. shaft load plot.

Experimental results revealed that developed devices for motor control, which is based on lowering the voltage of three-phase using PPC, while preserving rated rotation speed i.e. useful power, does indeed work. The devices were observed to decrease voltage until the motor starts to slow down, after which the voltage is raised to previously rpm. All regulations were within one minute.

The power draw when connected through developed deices, at 10% rated load, decreased by 15%, compared to direct operation. At 30 % rated load, the current draw is lower by about 10 %. And at 80 % rated load - 3 %. Thus with the load increases to the rated value, the savings benefit of the device decreases, and ideally, should be zero at rated load. Thus the maximum savings of 15% are achieved for dry operation. As such use of the device is justified for application where loads less than rated are expected.

CONCLUSIONS

Power savings are one of the key requirements for the development of new technologies. Because electric motors are one of the main power consumers in the various production field, improving automated electric derives with decreasing non-production costs is a rather relevant problem. Quite often, the electric motor operates with a load significantly less than rated. Motor efficiency varies depending on the shaft load. The highest efficiency is achieved at loads closer to rated, efficiency also drops at

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torque lower than rated, and can drop to as low as 50% The highest efficiency is achieved at loads closer to rated, efficiency also drops at torque lower than rated, and can drop to as low as 50% which leads to loss of effectiveness and the significant decrease of power coefficient.

The work aims to develop a method for optimizing the operation of asynchronous motor by analyzing its working parameters in the main operation regime and the creation of special device using microcontrollers to realize soft start and optimization of power consumption of the asynchronous electric motor. Throughout the conducted work, an analysis of existing control methods was conducted. Based on this analysis, the microcontroller control method was chosen. A theoretical basis for controlling algorithm for special microcontroller dices, which is designed to implement the function of soft mort start, check for failure state operation, and motor control by lowering the voltage of three-phase using PPC, while preserving rated rotation speed i.e. useful power, lowering power draw.

The paper also provides a technical description of the developing device. Microcontroller programming principles were reviewed and implementation was proposed for the algorithm to optimize power draw which lies in finding minimum current draw. The device was experimentally tested to validate its operation, and it was found that voltage decreases until the motor starts slowing down, which trigger voltage increase to previous rpm value. All regulations were within one minute.

The current draw when connected through developed deices, at 10% rated load, decreased by 15%, compared to direct operation. At 30 % rated load, the current draw is lower by about 10 %. And at 80 % rated load - 3 %. Thus with the load increases to the rated value, the savings benefit of the device decreases, and ideally, should be zero at rated load. Thus the maximum savings of 15% are achieved for dry operation. As such use of the device is justified for application where loads less than rated are expected. The developed device can be used by different industrial objects for complex control for asynchronous motors to achieve power savings at partial loads.

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