SYSTEMS FOR SOFT-START OF MEDIUM VOLTAGE ELECTRIC MOTORS

CONTENTS

PROBLEMS ASSOCIATED WITH DIRECT START OF ELECTRIC MOTORS AND SOLUTIONS THEREOF

Direct-on-line start of a medium-voltage electric motor involves an inrush current of 6-8 times the rated value. It results in a torque burst transmitted to the mechanism driven via the motor shaft. During 1.5-2 seconds this torque consists of a direct component and an alternating component. The latter is up to 4 times as large as the rated torque of the motor. The alternating torque causes vibration of the motor and the mechanism. Electromagnetic forces arising in the stator windings cause displacement of wires relative to each other. These impact loads bring about destruction and breakdown of the stator winding insulation, burning-out of leads and interconnections between the coils, failure of gears, shafts and joint ends, etc. As a result, smooth production flow is disrupted and the throughput rate is reduced. Enterprises bear considerable expenses for repairing broken-down equipment.

Fig. 1 shows direct start oscillograms for a 5000 kW/6 kV squirrel-cage motor driving a pump. One can see that the start-up time is 5.7 s at a current of 6 Irat while the alternating component of the motor torque in the beginning of the transient amounts to 4.0-4.1 Trat.

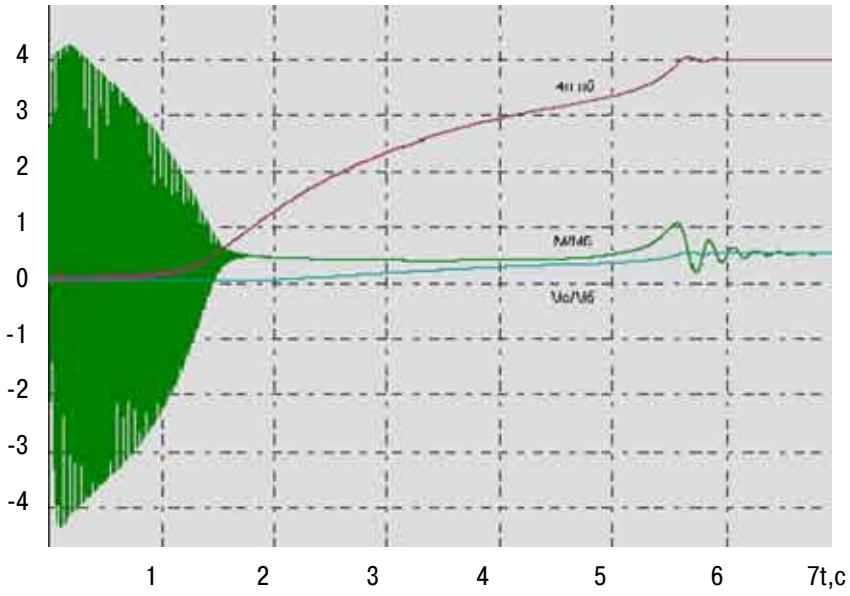

Fig. 1

If acceleration time exceeds 8-10 s, the motor start-up conditions become extremely harsh. In addition to large electrodynamic forces the motor windings are subjected to intensive heating by high start-up currents. In this case generated heat has no time to dissipate in the stator or rotor cores, causing overheating of the motor windings that results in deterioration of insulation and breakdowns. This can be exemplified in a breakage of 8000 kW/6 kV motor driving a turbocompressor, whose start-up time was 12-14 s. After 45 start-ups the insulation of the motor was practically destroyed by impact dynamic loads and overheating. A phase-to-phase short circuit occurred in the slot part of the winding, followed by ground fault in the outhang and inflammation of the motor.

Inrush currents have negative impact on the feeding network as well. They cause big voltage sags that affect operation of other equipment. Normal flow of technological processes is disturbed and enterprises suffer losses from underproduction.

High currents consumed by electric motors during start-up and the voltage sags involved complicate and sometimes make impossible powering motors from gas-turbine, diesel or other power facilities with limited capacity. As a result, personnel running medium-voltage motors strives for providing their uninterrupted operation for as long as possible, even though this is not required by technology. Correspondingly, considerable amount of power is wasted.

Due to high impact torque the guaranteed lifetime of equipment is shortened. As reported by development and production company “Regioturbocom Ltd.”, each start of the K-250 or K-500 centrifugal compressor with 1600 and 3150 kW motors reduces the unit lifetime by 50 hours (and up to 200 hours with larger compressor installations). Therefore manufacturers of MV-motors and mechanisms employing those limit the permitted number of start-ups to 50-60 per year. Consequently, compressor units with MV-motors are rarely stopped (in spite of such possibility from technological viewpoint), that causes unjustified power losses. Stopping a K-250 compressor for 8 hours at night and at holidays translates into annual energy saving of more than 3.5 million kW·h (depending on regional electricity charges – at least 100,000 USD a year).

The problem of eliminating start-up impact loads and voltage sags, and consequently raising the reliability of installations with MV-motors can be solved by using the UBPVD soft-start devices developed in our institute.

Depending on the load characteristics of a mechanism driven, two versions of the device can be offered:

UBPVD-V, intended for mechanisms with a “fan-type” load characteristics (centrifugal pumps, compressors, ventilators);

UBPVD-S, providing soft start of synchronous motors in mechanisms with high static torque and inertia (mills, exhausters etc.).

For soft start of MV-motors in “fan-type” installations both the versions (depending on the problem to be solved) can be used.

Impact loads as such can be excluded by using the UBPVD-V device. In this case the start-up current at the end of acceleration is about 2.5 Irat. If in addition to removal of impact loads limitation of the inrush current (at a level of 1-1.5 Irat) is required, we recommend to use the more sophisticated and expensive device, UBPVD-S.

UBPVD-S DEVICE FOR SOFT START AND SPEED CONTROL OF MEDIUM VOLTAGE SYNCHRONOUS MOTORS

The UBPVD-S device is intended for variable-frequency start-up of synchronous motors in mechanisms with heavy starting conditions e.g. ball mills, high-capacity turbocompressors, ventilators with high moment of inertia etc. This device employs a machine-commutated thyristor CSI and provides a start-up current not exceeding 1-1.5 Irat. The double-loop regulation structure of the device provides a wide range of start-up times and acceleration ramps.

Fig.2 shows a simplified schematic diagram of the UBPVD-S device. It includes three-phase current-limiting reactor CLR, three-phase medium-voltage thyristor rectifier R, smoothing reactor SR and machine-commutated inverter I. The device control system is based on a digital signal processor.

The motor is started with the UBPVD-S in a variable-frequency mode (with excitation). At frequencies below 5 Hz the inverter thyristors are commutated by interrupting the current with the thyristors of rectifier R. Then the motor e.m.f. becomes sufficient to provide natural commutation of the thyristors.

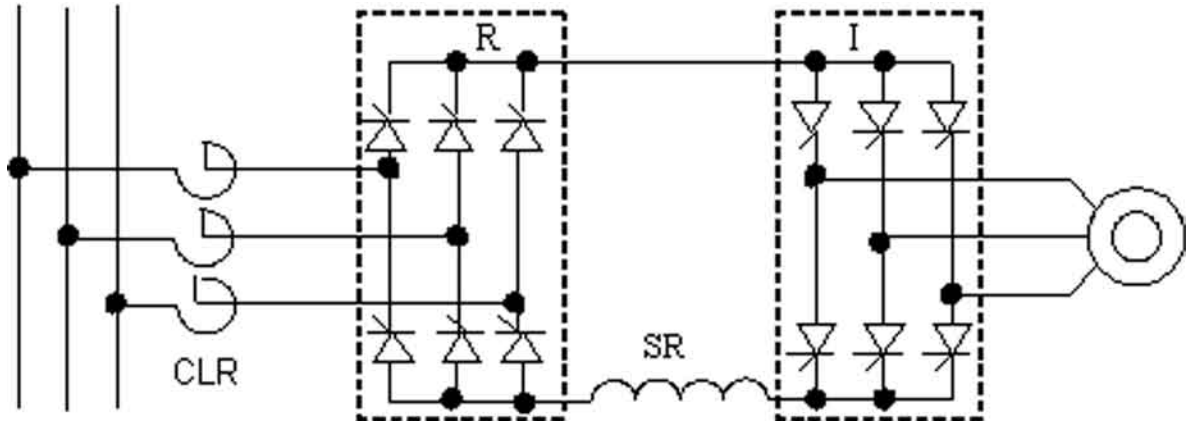

Fig.2 UBPVD-S device structure

The UBPVD-S device provides maximum reliability of the electromechanical system since it incorporates a set of protections from motor stall, short circuit, system overload, front- and back-end overvoltage, phase-loss, wrong phase sequence and voltage sags in the feeding network. The device also provides a number of PLC functions and permits programming of the device parameters. The user can reprogram the settings of the regulators, select acceleration and deceleration ramps, current limitation level, acceleration time and perform emergency stop. The soft-start device can be supplied built into a system based on an industrial PLC and providing serial soft start of several MV-motors.

The UBPVD-S can also be used for regulation of speed (version with enhanced cooling of power modules) in a range from 15 to 100% of the rated value. In this case the motor must have a capacity margin of 20-25% as compared to the capacity consumed by the mechanism driven. For motors driving mechanisms with load torque independent from speed (e.g. ball mills, loaded conveyors) additional cooling will be required. The speed regulation system based on the UBPVD-S device (with phase-controlled thyristors) is 3-5 times cheaper than IGBT- or IGCT-based frequency converters. Besides, it is simpler and consequently more reliable.

UBPVD-S DEVICES ARE PROTECTED WITH A PATENT
CONFORMANCE CERTIFICATE №ССВЭ RU.M064.H.00672.

PARAMETERS OF UBPVD-S DEVICES:

Device type	Rated voltage (line), kV	Maximum capacity of motor started, kW	Rated current, A	Device size
UBPVD-S-6-200 УХЛ4 UBPVD-S-6-500 УХЛ4 UBPVD-S-6-800 УХЛ4 UBPVD-S-6-1250УХЛ4	6	1600 4000 6300 10000	200 500 800 1250	1500
UBPVD-S-10-200 УХЛ4 UBPVD-S-10-500 УХЛ4 UBPVD-S-10-800 УХЛ4 UBPVD-S-10-1250 УХЛ4	10	2500 6300 10000 12500	200 500 800 1250	2x1825

У UBPVD-V DEVICE FOR SOFT START OF MEDIUM VOLTAGE ELECTRIC MOTORS

The UBPVD-V device is intended for soft start of MV synchronous and induction motors of mechanisms with “fan-type” (load torque is proportional to the square of speed) load characteristics, e.g. centrifugal compressors, pumps, fans, exhausters, smoke extractors etc.

The device constitutes a thyristor voltage regulator (Fig.3) and provides limitation of current and its rise rate by changing the firing angles of the thyristors via pulse control system (PCS). In the course of a preset start-up time the stator voltage is gradually raised from zero to its rated value. The current rises smoothly and is limited to a preset level, excluding impact torque harmful to the motor and the mechanism. The UBPVD-V device has the following protections:

overcurrent protection against excessive start-up currents and short-circuits;

time-current protection against overload of power thyristors;

protection against protracted motor start;

protection against open-phase fault and excessive asymmetry of phase currents;

protection against operation with faulty power thyristors.

The UBPVD-V device provides four programmable settings of initial current limitation from 1.0 to 5.0 Irat. This option permits to start several motors with different capacity from the same device. The UBPVD is fitted with a high-speed RS-485 interface for remote control from a process control system.

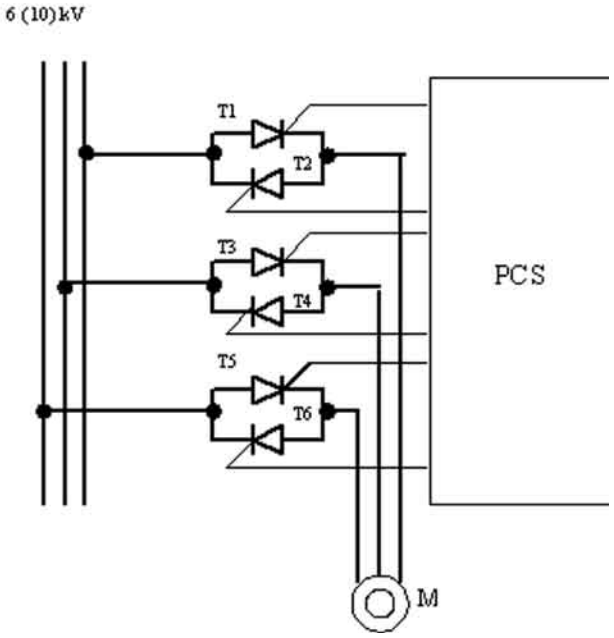

Fig.3 UBPVD-V device structure

PARAMETERS OF UBPVD-V DEVICE

Device type	Rated voltage (line), kV	Maximum capacity of motor started, kW	Rated current, A	Maximum current of power circuit during 60 s max., A	Device size
UBPVD-V-6-125 УХЛ4	6,0; 6,3; 6,6	1000	125	350	750(1500)
UBPVD-V-6-250 УХЛ4		2000	250	750	750(1500)
UBPVD-V-6-400 УХЛ4		3150	400	1400	750(1500)
UBPVD-V-6-630 УХЛ4		5000	630	1800	1500
UBPVD-V-6-800 УХЛ4		6300	800	2500	1875
UBPVD-V-6-1250 УХЛ4		10000	1250	3400	1875
UBPVD-V-10-125 УХЛ4	10,0	1600	125	350	1500
UBPVD-V-10-250 УХЛ4		3150	250	750	1500
UBPVD-V-10-400 УХЛ4		5000	400	1400	1500
UBPVD-V-10-630 УХЛ4		8000	630	1800	1875
UBPVD-V-10-800 УХЛ4		12500	800	2500	1875
UBPVD-V-10-1250 УХЛ4					

As to design, the UBPVD-V devices have two versions: 1500 (1875) mm and 750 mm wide (Figs. 4,5). The compact version with a width of 750 mm is recommended for building into active installations lacking in free room and other similar conditions.

SOFT START SYSTEMS FOR MV-MOTORS BASED ON UBPVD DEVICES

Fig.4
UBPVD-V-6- (10)-(125-1250)

Fig.5 UBPVD-V-6-(125-400)
(compact version with width of 750 mm)

To reduce customer's expenditures we developed and introduced a soft-start system (SS) for several motors connected to one or several busbar sections using one UBPVD device. The SS provides both direct-on-line and soft start of any motor chosen. The start-up process is controlled with a PLC that excludes possibility of emergency conditions associated with personnel errors. Use of the SS translates into considerable saving as compared to starting each motor with a separate UBPVD device. For example, in case of four motors use of the SS reduces the spends for soft-start (per motor) almost by two thirds.

The SS is operated from a control panel and local control console. The PLC provides the required sequence of operations, necessary laws of current regulation and motor acceleration as well as protection and interlock functions. The mnemonic diagram located on the control panel indicates current states of MV switches and motors whereas the display shows tips for the personnel performing a soft start. The control panel can employ an LCD with a keyboard and LED mnemonic diagram, sensor operator's panel with a color display or personal computer (Figs. 6-8).

All events occurring in the SS, including commutation of switches and operation of protections, are recorded into the memory of the control panel. They can be displayed in text form with indication of occurrence time. This provides easy troubleshooting of the system.

The SS can perform serial start-up of any number of motors, provided they are fed from one 6(10) kV switchgear. An example system with UBPVD-V device for starting four motors supplied from two busbar sections is shown in Fig.9 where the following designations are used:

U- soft-start device UBPVD-V;
M1... M4 – motors to be started;
Q1.1...Q1.4 – working MV switches;
QF1, QF2 – starting MV switches;
KA1...KA4 – starting commutation apparatuses (motor-driven disconnectors type RVU, MV contactors or switches);
CC – control cabinet with a PLC;
CP – control panel.

When e.g. motor M1 is started, the following sequence is performed. If all pre-start conditions are met the indicator displays "start allowed". By pressing button "Start" the operator activates the following start-up algorithm:

- commutation apparatus KA1 is switched on and motor M1 is connected to the output of device U;
- front-end switch QF1 is closed and device U is connected to busbar section 1 and power elements of the UBPVD are tested under working voltage. If the test is successful the thyristors of device U are fired and the motor starts to accelerate;
- as the motor reaches the rated speed, the start-up current drops to a value that is determined by the actual load on the motor shaft. Working switch Q1.1 closes, the thyristors close as well and device U is disconnected from section 1 with switch QF1. In the same manner commutation apparatus KA1 is switched off.

Now the start-up process is over and the SS is ready for starting a next motor.

Fig.10 shows an SS system with an UBPVD-S device used for soft start of 6 mill installations. In this diagram the following designations are used:

M1... M6 – motors to be started;
Q1-Q6 – working motor-side switches;
QF1-QF2 front-end switches for connecting the UBPVD-S to the busbar section powering the motor to be started;
RVU1-RVU6 motor-driven disconnectors installed in cabinets CRVU1-CRVU2;
CLR – current-limiting reactor;
CR - smoothing reactor;
SW – switch providing no-current commutation of the disconnectors installed in cabinets CRVU1 CRVU2;
Qsh – shunting switch;
CC - control cabinet with a PLC;
CP – control panel.

The PLC controlling the soft-start system receives a command to start a certain motor and switches its exciter on. Then switch SW, the disconnector corresponding to the motor and front-end switch QF are closed. As the PLC receives acknowledgement of their commutation, it gives the command to start up the mill to the frequency converter control system. The control

Fig.6
Control panel with LCD

Fig.7
Control panel with touch panel

Fig.8
Control panel based on PC

system analyzes the condition of the frequency converter, including thyristors' operability and state of protections. Then the motor is accelerated to the synchronous speed. As the motor reaches the synchronous speed and the phase shift between the stator and the mains voltages is minimized, the UBPVD-S device is shunted with switch Qsh and the motor is connected to the mains via the current-limiting reactor. When the motor is synchronized the corresponding working switch closes. Now the motor is powered directly from the mains. The apparatuses partaken in the start-up are switched off in the following order: front-end switch QF, switches SW and Qsh, and disconnector RVU.

The soft-start systems have a number of advantages in comparison with analogous systems of other manufacturers:

- easy maintenance due to mounting the power thyristors of the UBPVD in pull-out units;
- every device assembled is tested at the institute testing facilities equipped with MV synchronous and induction motors;
- design of the SS component parts meets the most up-to-date requirements.

The SS employ high-speed digital signal processors and provide:

- forming of acceleration/deceleration ramps;
- flexible control algorithms;
- wide set of control functions and user-friendly interface with a TFT display (Fig.11), keyboard and LED diagnostics;
- remote control via high-speed RS-485 interface permitting use of the SS as a part of a process control system;
- estimation of soft-start system influence on the enterprise power system with the digital oscilloscope function (Fig.12);
- qualitative and quantitative analysis of the condition of installations and mechanisms using start-up oscillograms and the event log (date of last start-up, overall acceleration time, last start-up maximum current, overall number of start-ups). It allows to judge if any servicing is necessary;
- wide set of protection functions.

The SS can be shipped in a container version with heating, lighting and ventilation (Fig.13). In this case the equipment is supplied fully bused with all secondary connections as a turnkey installation.

There is much experience of using the SS at cluster and booster pump stations, water supply facilities and compressor installations. An SS with four 8 MW 10 kV synchronous motors at oil pump station was successfully introduced. The soft-start systems pay for themselves within 1-1.5 years.

The remotely-controlled disconnectors series RVU (conformance certificate №ССВЭ RU.M064.H.00857), developed by VNIIR, and compact (750x1100x2200 mm) UBPVD-V device considerably reduce the size of the soft-start system. This is especially important when the system is installed into a container. The cost of switching equipment is reduced by approx. 50%.

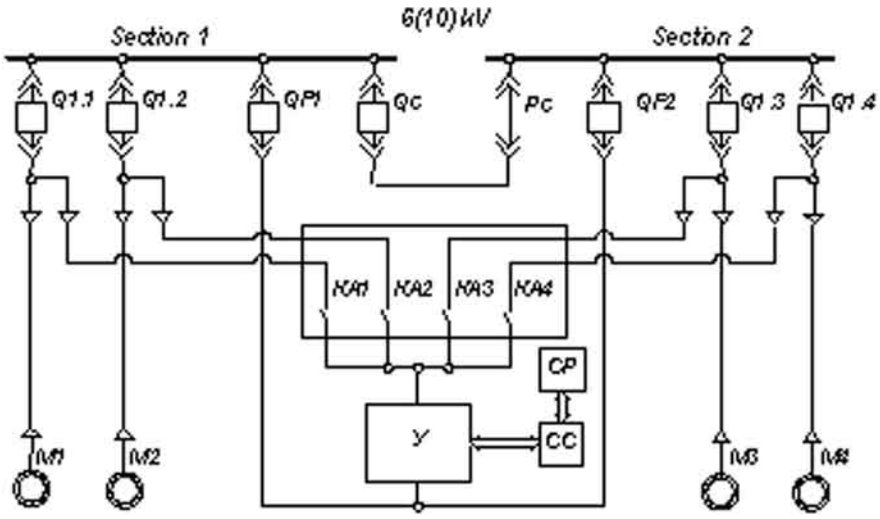

Fig.9 Single-line diagram of soft-start system based on UBPVD-V

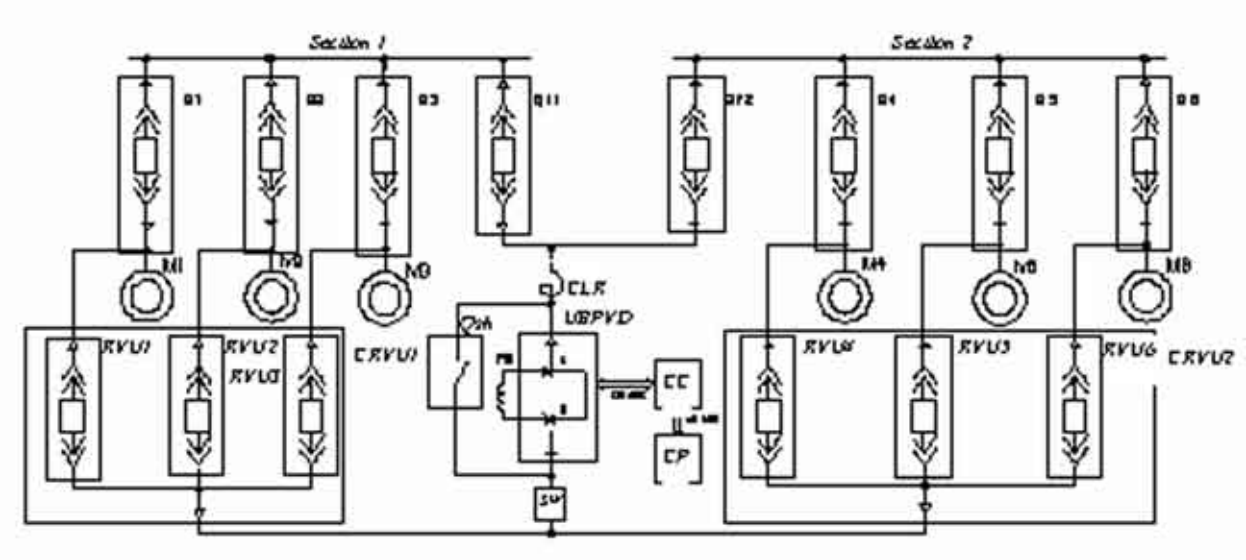

Fig.10 Soft-start system for starting 6 mill installations with UBPVD-S

TECHNICAL SUPPORT

JSC "VNIIR" carries out the whole cycle of works associated with soft-start systems. First, preliminary study is conducted and an inquiry form is filled out. This allows to take into consideration features of the power supply (power network, autonomous power station) and the installations to be started, possibility of using some customer's equipment in the soft-start system, availability of free room for installing the system, etc. Basing on the data obtained a technicocommercial offer is drawn up and sent to the customer or developing organization. The offer states the concept of the soft-start system recommended and contains a list of equipment to be supplied, its cost and delivery terms. Prior to signing the delivery contract, detailed technical requirements to the system representing an inseparable part of the contract are sent to the customer for co-ordination. JSC "VNIIR" develops schematic and connection diagram of the SS, component list and that of the cables recommended. These documents are forwarded to the customer or development organization as soon as possible.

As the equipment of the SS is assembled it is thoroughly tested with MV motors of VNIIR's testing facilities. Specialists of VNIIR fulfil installation and adjustment and hand over the turnkey system to the customer.

VNIIT developed a computer model of the soft-start system. The model provides calculation of the main parameters of the start-up process: start-up current, motor torque and acceleration time. The simulation results allow to choose the optimal value of start-up current and acceleration time. Besides, the customer can make sure about efficiency of the system offered.

An example of start-up simulation for an installation with MV motor is shown in Fig.15. On can see that the current rises to the breakaway value of 1.33 Irat in 0.3 s without any bursts. Then it linearly rises to 2.4 Irat during 10 s excluding impact loads as well.

To provide qualified servicing of the soft-start system at customer's, personnel training is organized. The training program acquaints the students with theory of power semiconductors, speed control of synchronous and asynchronous motors, operating principle of the UBPVD-V, UBPVD-S and SS. They are provided with necessary knowledge on commissioning and servicing the system, and trained to operate soft-start systems and devices.

JSC "VNIIR" provides warranty and post-warranty servicing of the SS.

SOFT-START SYSTEMS FOR MAIN LINE PUMPS OF JSC «TRANSNEFT»

In July, 2004, a prototype soft-start system for STD-8000-2 (10 kV, 8000 kW) synchronous motors passed acceptance tests at oil-pump station "Popovka" of JSC "Provolzhsknefteprovod". After 41 successful start-ups the system was officially put into operation in September, 2004. This project is unique and has no analogies in Russia. Successful realization of the project was facilitated by optimal selection of the system components (UBPVD-V soft-start device, PLC), their high quality and reliability, self-diagnostics functions and advanced control algorithms. The system is well-matched to the existing equipment of pump station "Popovka" and meets very strict technological requirements of JSC "AK Transneft".

The system provides serial start of 4 pump units. It removes "water-hammer" effect in the pipeline, reduces starting currents of the motors and improves operating modes of power distribution equipment. The high-throughput PLC provides optimal control algorithms and monitoring of the start-up process with event-logging and recording of measured parameters.

JSC "VNIIR" built 4 line pump soft-start systems for the Baltic pipeline system. The project was developed by JSC "Giprotruboprovod" (Moscow) with participation of VNIIR. The soft-start systems are put into commissioning at pump stations "Sestroretskaya", "Bykovo", "Pes" and "Pravdino" in 2005.

Institute "Sibneftetransproekt" in collaboration with "VNIIR" developed soft-start systems for 8 pump stations of JSC "Trabssibneft" in Krasnoyarsk. We also collaborate with JSC "Samaragiprotruboprovod", with whom we developed projects of soft-start systems for STDP8000 (8000 kW, 10 kV) motors at pump stations "Lazarevo" and "Sumsi".