# PULSE CONTROL OF SPEED OF POWERFUL SYNCHRONOUS ELECTRIC DRIVES OF POWER FACILITIES

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***The new way of pulse start-up and speed control of the synchronous electric motors, realised by means of a supply stator windings by current impulses directly from a network through thiristor the switchboard is presented. Current impulses are synchronised with position of a rotor and regulated on a phase and on width. The way of pulse control provides smooth operated start-up of the engine at a supply directly from a network of an alternating current without a car and network overload.***
***Masso-dimensions and cost of the equipment of pulse control several times it is less, than known devices.***
***The specified way of pulse control opens a new direction in the theory and practice of operated cars of an alternating current.***

***Key words*:** Pulse control, synchronous electric drive, stator winding, thyristor switch, pulse current phase, network overload.

Synchronous electric motors have unique characteristics – they can generate reactive current and control it (respectively, can reduce power losses in the network system and motor), stabilize voltage within the network system of high static and dynamic overload. This predefined the usage of synchronous motors in powerful electric drives (for instance up to 1...20 MW) of the power facilities, which are the electric drives of turbo compressors at main gas and oil pipelines, electric drives of the units of private needs at thermal power stations (drinking water pumps, blow fans, smoke exhausters), compressor units at metallurgical plants, etc.

In supplying power to the synchronous motor from a three-phase network of alternating current, rotating field is generated into the machine which captures excited rotor and brings it into rotation with strongly synchronous frequency speed of the network regardless of the load. Torque occurs and is regulated as a result of applying loading torque to the axis and dynamic displacement of the rotor from a synphased state at the synchronous speed. Speed of the stator rotating field, hence the speed of mechanic rotor rotation are identified by electric frequency of power supplying network – it is strictly constant making 50 Hz. Therefore, the speed of rotor rotation is strictly constant as well. This is one of the main advantages of the synchronous motor, but at the same moment it limits its operation potential.

The problem relating to impossibility or difficulty to adjust speeds of the synchronous motor, respectively the driving mechanism, has following two aspects:

1. <u>Starting the synchronous motor from stationary state bringing the rotation speed to synchronous for synchronizing with the network.</u>

The most simple and widely used way is asynchronous start. An essence of the asynchronous start is the following: exciting coil of the synchronous motor is short circuited through pure resistance, the stator coil switches on the industrial supply-line voltage. The synchronous motor starts as asynchronous with a short circuited rotor. In reaching subsynchronous frequency of the

rotation, the rotor coil breaks and direct exciting current is supplied to it. The machine after several oscillation is drawn into synchronism.
Direct asynchronous start causes hazardous (especially for powerful machines) electric, mechanic and thermal overloads: starting current reaches about 3....... 5 (up to 7 in some cases) multiple values of the rated current, and temperature on the rotor surface achieves 300.....500$^0$C. In starting the undertension on the network bus rod exceeds allowable standard limits. At the moment of switching, accelerated torque occurs into the motor and it negatively impacts stability of actuating mechanism and motor itself – blade retention connected to the turbine compressor motor, fastenings of rotor coils and end stator coil of the motor, articulators of the motor and the mechanism impair.

2. <u>Changing the rotation speed of loaded synchronous motor for technological purposes.</u>

For number of powerful producing mechanisms which are brought into the rotation through the synchronous motors – compressors, ventilators, pumps, etc. – the most reasonable way to regulate their performance is the change of the rotation speed. It would be rational to design efficient traction drives of alternating current with acceptable dimensioning specifications and cost estimations.

If it is impossible to adjust the motor speed, the unit performance (towards the reduction) changes by shutting a gate valve on the way to the injection actuating medium – gas, liquid, i.e. by artificial increase of losses. At the same time, factor of useful action of the motor decreases sharply and relative electrical losses increase. As for the energy, this is extremely unsatisfactory solution.

Change and adjustment of the rotation speed of the synchronous motor now can be achieved by their frequency management, i.e. by changing the frequency and supply voltage of the motor through special adjustable thyristor converters of frequency and voltage (TCF) estimated for the motor capacity. They are extremely complicated devices which according to their dimensions, consumables, costs are similar to the motor and sometimes are even worse. Supply of the synchronous motors though such booster converters restricts natural potential of the synchronous motors – stability, overloading, regulation of the reactive current and voltage in the system, creates additional power losses within the converter, network and motor.

Frequency starting of the synchronous motors through (the thyristor converters of the frequency and voltage) TCF is also possible – starting is just the same as speed management with all the mentioned faults.

The above complications and faults of starting and speed management ways and facilities practically often exclude the possibility itself to control the synchronous motor speed through TCF the thyristor converter, especially for powerful synchronous motors (some 1......20 MW), while the problem of the speed control and its reliable starting are extremely important for the powerful synchronous motors. Within the limits of practical possibilities, there remain asynchronous starting and throttling performance control (by controlling the gate valve position), which, as mentioned above, is extremely unreasonable.

The author worked out principally new method and equipment for pulse starting of the synchronous motors providing smooth controllable starting in case of the supply directly from the alternating current network system almost without overloading the machine and network [1-

3]. With this method and equipment it is possible to control the speed of loaded synchronous motor [4].
The pulse control principles are the following: dosed pulses of the current, which interacting with the rotor flow, create pulse torque, skip to the armature stator winding of the actuated motor through the thyristor switch. Current pulses passing the stator winding interacting with the actuation flow create the torque pulses. In case an average value of the pulse torque exceeds the moment of load resistance, pulse-step increase of the rotation speed of the rotor in observed. In case these aspects are balanced, the rotation speed will never change.

The pulse start of the synchronous motors is performed according to the diagram presented on figure 1. Armature winding of the synchronous motor (SM) is connected directly to the alternating current network system through the pair of thyristors (thyristor switch - TS). Switch control system (CS) is connected to the network system and rotor position sensor (RPS) by synchronizing networks. Depending on current position of the rotor, the thyristors of anode or cathode group of the switch are activated so that the current direction into the stator winding corresponds with the rotor position and positive torque is created. By changing the angle of pulse generation (control angle) the duration, amplitude, current pulse area in the stator winding and drive current in the rotor winding and respectively the torque value and hence, the rotation speed can be controlled.

The above principle of torque development is completely different from the conventional one - asynchronous or synchronous.

In case of asynchronous or synchronous principles the rotating field is generated into the machine, and respectively the source of three-phase voltage is required. If it is necessary to change the speed, the frequency and supply voltage need to be controlled. This creates the above problems.

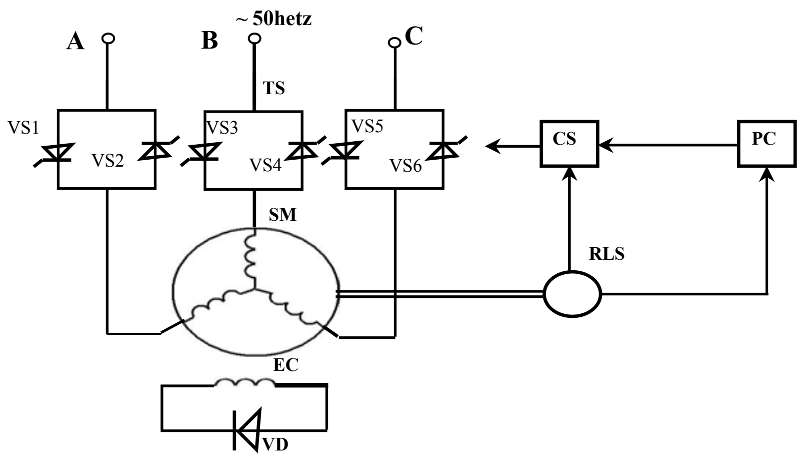



Figure 1. Diagram of Pulse Starting of Synchronous Motor:
SM – synchronous motor; TS – thyristor switch; D – diode; RLS – rotary position sensor; CS – control system; EC – exciting coil.

In case of the pulse principle, the unidirectional, “direct” current communicating with the constant flow of excitation and developing the torque runs into the stator winding at an interval of pulse existence. The torque value is regulated by the current value, i.e. by pulse width and amplitude which is completely subject to the external control independently from supply-line frequency and torque rate. Rotating field is absent in the machine. In principle, there is no need in three-phase power supply (starting was achieved even in one-phase power supply of the motor with grounded neutral).

Studies run on the computer model and tests performed on real samples of the powerful synchronous machines prove the above mentioned conditions.

Figure 2 presents the process of current pulse generation into the stator winding.

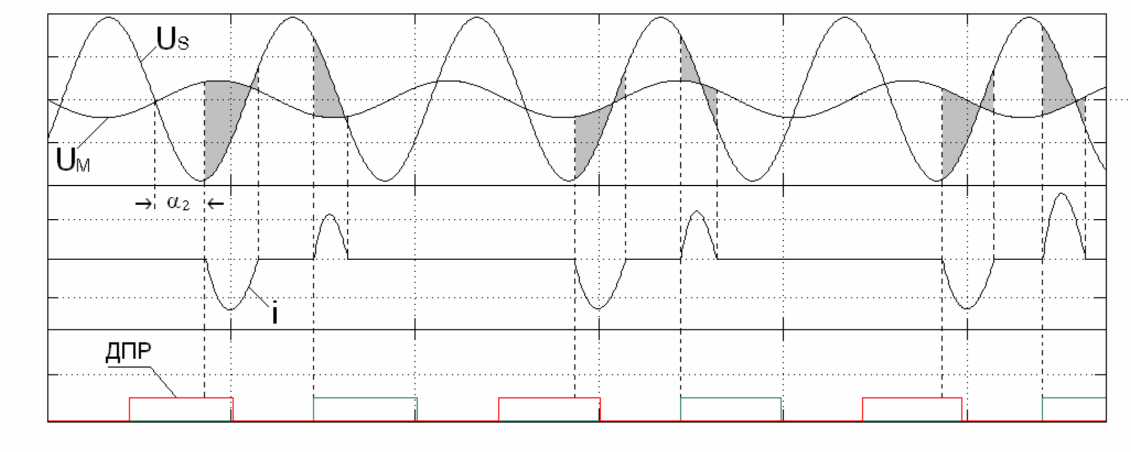



Figure 2. Process of Current Pulse Generation into Stator Winding

1) supply-line voltage Us; back electromotive force of the motor $U_M$; control angle (pulse generation) $\alpha_2$; 2) current pulses i; 3) clear aspects of rotary position sensor RPS are provided on figure 2 from top to the bottom along the axises.

Expression of the current pulse in the stator winding has the following form:

$$\mathbf{i_S(t) = \frac{1}{L_S}\int_{\alpha}^{t_k}\left[U_S \sin\omega_1 + U_M \sin\left(\omega_p t + \gamma_0\right)\right]dt},$$

where, Us, $U_M$ – amplitude of the supply-line voltage and back electromotive force; Ls – inductance of the stator winding; $\omega_1$ - supply-line frequency; $\omega_p$ - rotation speed of the rotary; $\alpha$ - control angle; $\gamma_0$ - original angle position of the rotor; $t_k$ - instant of current pulse termination.

Pulse torque value is specified in a following way:

$$\mathbf{M(t) = C \cdot i_S\left(t\right) \cdot i_b\left(t\right) \cdot \sin\gamma(t)},$$

where, C – constructive constant of the machine; $i_S(t)$ - current pulse function in the stator winding; $i_b(t)$ - current pulse function in the rotary winding.

Figure 3 presents an oscillogram of pulse starting process.

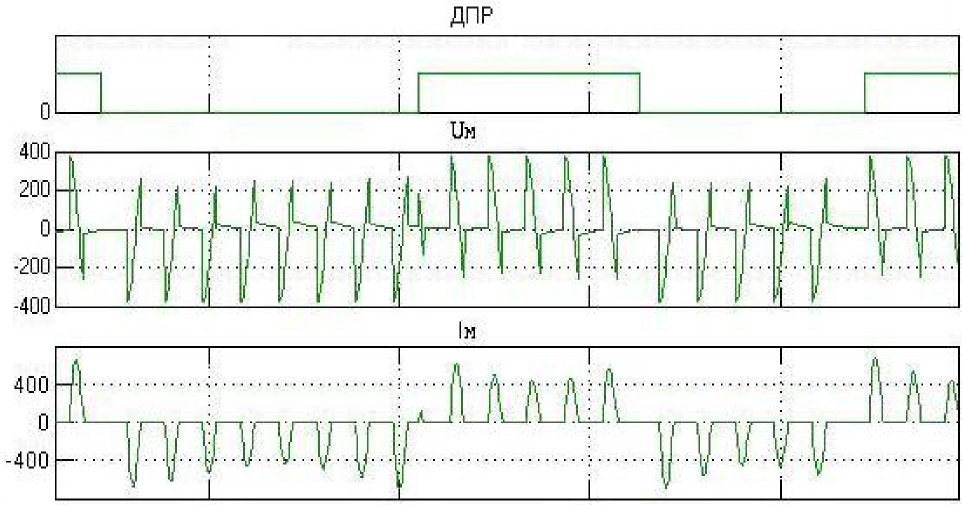


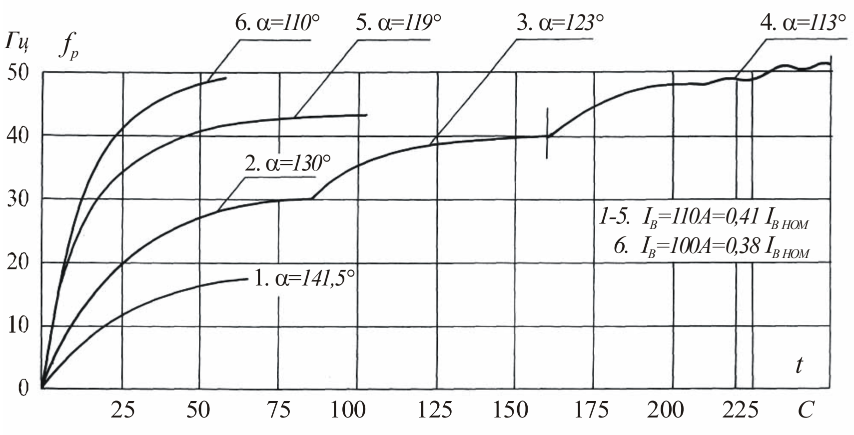

Figure 3. Oscillogram of Pulse Starting Process of 800 kW СТД-800 Synchronous Motor at 4,2 Hz rotation speed.

1) Clear aspects of the rotary position sensor RPS; 2) voltage on the rotary stator winding $U_M$; 3) pulses in the stator winding $I_M$ are provided on figure 3 from top to the bottom along the axises.

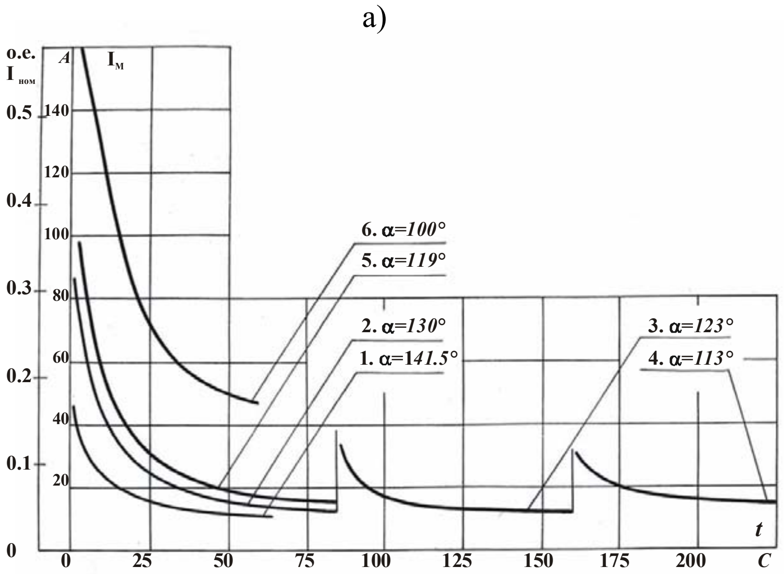
So, in case of the proposed pulse control, the synchronous machine behaves like dc machine. This is principally new phenomenon for the alternating current machine. At the same time new positive results which are principally unachievable for the conventional alternating current machine, either asynchronous or synchronous are achieved. In particular, in case of <u>power supply of the motor directly from the industrial supply-line</u> with unchanged frequency and voltage, the following is achieved:

1. adjustable torque enabling to provide smooth start and speed control of the motor torque by external means, in particular by phase of current pulse generation, is developed in the motor by means of pulse currents running into the stator winding;
2. the motor rotation speed does not depend on the frequency of the network system – it is determined just by the parameters and position of the current pulses. In experiments run on real machines the rotation speeds complying to 75 Hz. i.e. 1,5 times more than rates speed were achieved;
3. automatic self-excitation of the motor and its adjustment independent from the rotation speed in case of stationary motor too are provided. This is achieved in a following way: section of the alternating voltage of the network (dark area on figure 2) is applied to the time interval of the thyristor in an open condition and in running the current pulse into the stator winding; this voltage transforms into the rotary exciting coil, is rectified by diode and initiates self-excitation current of the motor. In that, the value of induced excitation current automatically "adjusts" to the conditions of torque development at the given speed. This allows to design brushless motor constructions without external machine or static exciters;
4. absolute switching of the system devices which is excluded in case of the speed control by means of thyristor inverters is provided;
5. automatic operative synchronization with the network upon finishing starting and "self-starting" in case of short power supply interruption are provided;

Figure 4 provides characteristics of the pulse starting of 2500 kW ТДС-2500 synchronous motor.




a)




b)

Figure 4. Characteristics of Pulse Starting of 2500 kW ТДС-2500 Synchronous Motor:
a – characteristics of the rotation speed alternation from time (starting from the stationary condition) at various current pulse values; b – characteristics of the motor current alternation upon starting.

Symbols and comments:
t – time, c; $f_P$ – rotation speed, equivalent of frequency, Hz, frequency of 50 Hz corresponds to the rated rotation speed; $\alpha$ - control angle determining current pulse value; small pulse width and amplitude correspond to large angle values; $I_B$ – excitation current; $I_{B\ \text{rated}}$- rated excitation current; $I_M$ - motor current; current is given in both absolute values A,, and in relative units in rated current fraction, $I_M / I_{M\ \text{nom}}$.

As illustrated on figure 4, smooth pulse starting of the synchronous motor at transient stator current significantly lower than the rated current and at static current of some 5% of the rated current is provided.

Dimensions and cost of the pulse control equipment is several times less than the dimensions and cost of the famous frequency controlled devices, since in case of the pulse control just one thyristor set (in thyristor switch) against two (in rectifier and inverter) and against high voltage reactor, and sometimes against matching power transformers in the well-known equipment is used.

The mentioned way of the pulse control opens a new direction in theory and practice of the controlled machines of the alternating current.

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