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CONTROL AND PROTECTION EQUIPMENT FOR THE AUXILIARY SERVICES OF THE ELECTRIC LOCOMOTIVES

Constantin Pătraşcu[1], Vasile Tulbure[2], Graţian Călin[3]

[1] *University of Craiova, e-mail: constantin.patrascu@comp-craiova.ro*
[2] *C.N. "CFR" S.A. B-dul Dinicu Golescu nr. 38*
[3] *S.N.T.F.M. "CFR MARFĂ" S.A. B-dul Dinicu Golescu nr. 38*

Abstract: The replacement of the asymmetrical three-phased system supply for the auxiliary services of the locomotive, imposed itself as a necessity due to its low reliability by comparison with the higher reliability of the symmetrical systems provided by frequency converters with active power components, especially of those that use IGBT transistors ("insulated gate bipolar transistors"). The modern solution of air supply to the pneumatic equipment of the locomotive and to the train, under conditions of maximum availability, by a single screw compressor with an increased power, imposed the use of a voltage and frequency converter. The « classical » solution using a direct start from a single phase power supply with three phase displacement condensers is no longer suitable for the higher powers and leads to both mechanical shocks and electrical overloads [1]. In this work, an equipment that provide the supply of the auxiliary services of the electric locomotives LE 5100kW is shown as being also integrated in the complex control and monitoring system of the locomotive.

Keywords: static converters, auxiliary services, locomotive

1. Introduction

The equipment consists of 4 modules of static frequency converters that are supplying the compressor of the locomotive in order to produce the compressed air, the ventilation of the breaking resistances, the fans of the main transformer, the oil pump and also two fan units for the traction motors ventilation.

The frequency converter module, with a rated power of 45kVA, supplies the units of three-phased consumers of the auxiliary services on the electrical locomotives and replaces the asymmetrical three-phased system of the auxiliary services (artificially done by batteries of condensers). The module works with variable voltage and frequency on starting and with steady voltage and frequency in idle running (3 x 380V, 50Hz), supplying the load units consisting of one or more motors within the locomotive auxiliary services.

The frequency converter module transforms the single-phase voltage (662 V AC, 50Hz) collected from the plugs of the traction transformer or the three-phase voltage (3 x 380V AC, 50 Hz) from an industrial plug into a symmetrical three-phase system with variable frequency (0 - 50 Hz) and voltage (0 - 380 V), needed to supply the units of three-phased motors of the auxiliary services of the locomotive.

The control and adjustment method is the sinusoidal pulse width modulation, with current and voltage control in order to keep unchanged the stator flux through the engine as to provide a sinusoidal starting current.

The converter modules of variable frequency for the supply of the auxiliary services of the electrical locomotives are protected against the hazard occurrence of the following events:

- short circuit on the alternative current output;
- overload on the alternative current output;
- fading of the 110 V DC voltage supply;
- over voltage in the DC intermediary circuit;
- over voltage on the high voltage input;
- over temperature on the heat-sinks of the power electronic components
- power supply out of the admissible voltage range (1 x 660 VAC ± 20%).
- grounding fault on the AC output

At the occurrence of a failure the converter receives the control signal « STOP ». After the "RESET" control it starts again if the failure disappeared. The restart can be performed even if the equipment is cut off from the 110 VDC supply.

2. Equipment description

The frequency converter module consists in the following assemblies, according to the block diagram shown in figure 1.

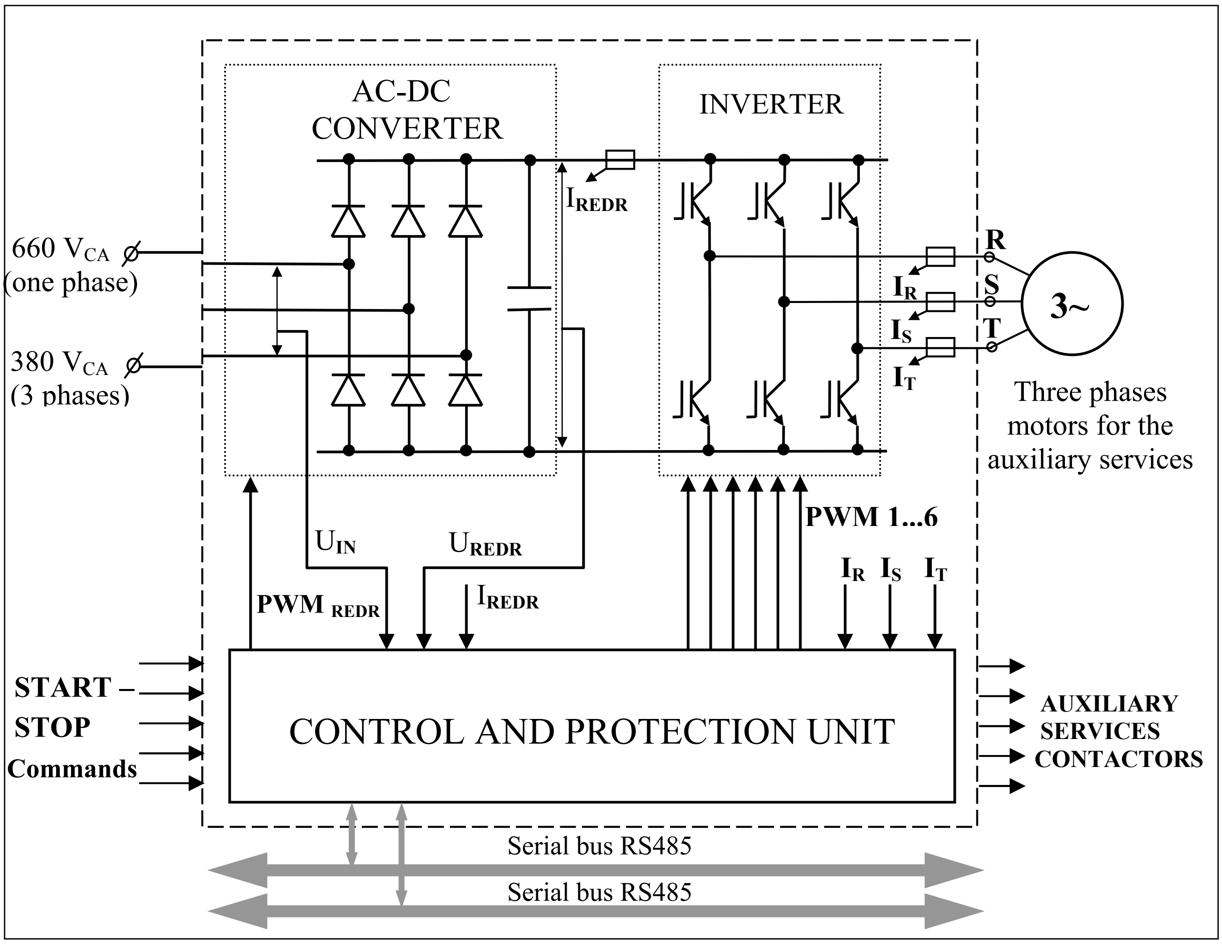

Figure 1. The electric diagram of a converter module

- Controlled rectifier bridge module

The controlled rectifier bridge module is the "interface" of the converter with both the single phase and the three phase supplying networks.
The rectifier bridge provides the power supply from both the secondary winding of the main transformer of the locomotive (1 x 660 VAC, 50 Hz) during traction and from the three phase industrial network (3 x 380 VAC, 50 Hz) of the testing stand for the auxiliary services of the locomotives in the depots.
The rectifier bridge is provided with protections for over-voltage and converts the single phase or three phase alternative voltage into the appropriate continuous voltage to supply the "inverter" module.

- Direct current intermediary circuit

The intermediary circuit is a direct current filter consisting of a condenser battery.
When the supply voltage fads the condenser battery works like a short time source of supply for the inverter bridge so that the small detachments of the pantograph from the wire, shorter than 500 ms, do not cut off the supply of the auxiliary services.

- Three-phased inverter bridge provided with IGBT

The inverter bridge is composed of three modules each of them containing two IGBT transistors which are supplied with continuous voltage and which provide a sinusoidal voltage at the output, controlled by mean of the filling factor of the pulse width modulation at the power transistors.
The inverter bridge is equipped with special protection circuits preventing the overloads and short-circuits. At the output of the inverter bridge a symmetrical three-phase voltage is provided (between 0 and 380 V with a variable frequency between 0 and 50Hz), thus a quasi-sinusoidal current flow through the asynchronous motors.

- Control, adjustment and protection unit

It generates the control pulse for the transistors of the inverter bridge performing as well the functions of protection and signalisation. The basic function of the inverter bridge control consist in generation of the firing pulses so that an imposed voltage/frequency characteristic is achieved (finally a certain steady frequency of the motor voltage supply in order to control the motor speed) with respect to the maximum switching frequency of the inverter. The control schematics include a current adjuster that compares the value of the currents of the three phases of the output circuit to a maximum imposed value and a voltage adjuster that provides the correction of the width of the firing pulses of the inverter bridge in order to achieve an output voltage of 380 VAC for both inputs, three phase 380VAC voltage supply and single phase 660VAC. The control unit survey every exceeding of the following parameters: the output phase current for motor (motors unit), the output voltage, the DC intermediary circuit voltage and the over-temperature of the heat-sinks of the power electronic components. The control unit receives the START/STOP signals from the locomotive drive posts through a galvanic insulated interface and sends control signals by some relay contacts to some contactors allowing the connecting or disconnecting of certain motors of the locomotive auxiliary services.

The dialogue with the displaying equipment -placed in the driving posts of the locomotive- is performed with two RS485 serial buses. The status of the locomotive ventilation blocks is shown on the screen of the displaying equipment from the driver post.

In case of some faults or anomalies in the converter module running, a diagnosis report is established with the main locomotive computer, so the values of the relevant parameters are stored in a non-volatile memory, in order to find out later about the reasons that caused their occurrence.

The control, adjustment and protection is performed around a signal processor TMS 320F241. The block chart of the unit is shown in figure 2 [3].

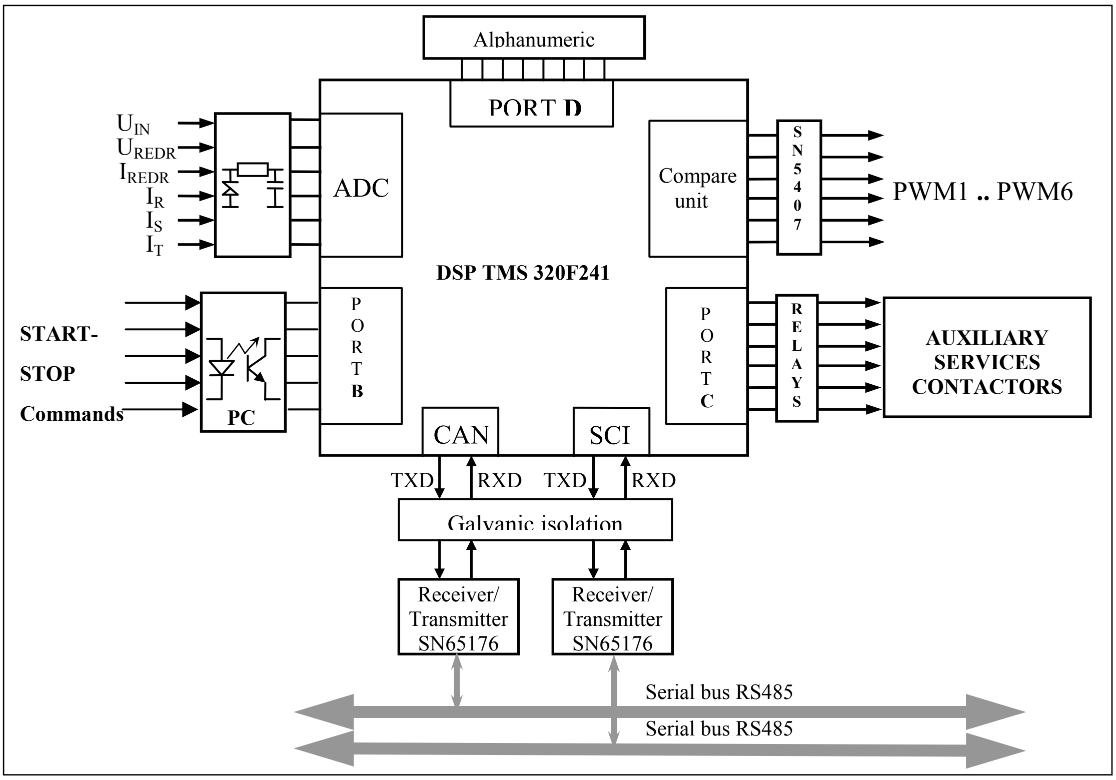

Figure 2. The block chart of the control unit for the converter modules

In order to control the voltage of the frequency converter modules, a control method derived from the scalar control was implemented as to perform the *change of the stator voltage proportionally to the frequency (V/f = constant)*, in closed loop, taking into account both the changes of the voltage supply of the converters and the occurrence of an overload in the motors.

The converter module can be programmed to run on the basis of a lot of voltage to frequency characteristics that may be selected depending on the equipment actuated from three types of characteristics, mainly:

- linear $U = k_0 * f + k_1$
- according to an equation of degree 0,5 $U = k_0 * f^{0,5} + k_1$
- through linear inter-polarity between a number of pre-established points

3. The control method of the three-phase sinusoidal system

In order to generate the firing pulses of the inverter bridge with the task to obtain o sinusoidal shape of the current through the motors, we used the **sinusoidal pulses width modulation** method. A variable amplitude of the analogical voltage is achieved through the change of the filling factor of some pulses of fixed period (PWM period) [2]. The application of an integral over the period T_{PWM} (through a pass down filter) results in getting on output of the average voltage value of the pulse on the T_{PWM}

duration. Depending on the filling factor, the level of the average voltage represents a value among the supply voltages of the controller. The corresponding modulation of the filling factor allows the generation of a sinusoidal voltage too, as shown in figure 3.a.

The filling factor t_D from a T_{PWM} interval can be calculated using the value u(i) of a sinusoidal wave:

$$\mathbf{t_D = T_{PWM}/2 + u(i)*T_{PWM}/2}$$

where: $-1 \le u(i) \le +1$; $0 \le i \le N$ (the number of sampling points of the sinusoid).
Generally, there is a whole freedom in choosing the length of the PWM interval. Nevertheless, physically, the choosing range for the values of minimum and maximum time (the lowest and highest f_{PWM} frequency) is limited. The lowest frequency depends on the quality of the low-pass filter or on the current smoothing capability of the motor fed from the PWM output. A further requirement is the fact that an important number of applications require that f_{PWM} is over the audio limit (about over 16 kHz).

On the other hand, the switching losses increase with the increased PWM frequency, accordingly. Further, the power switching elements allow a maximum switching frequency (for example, about 30 kHz for the IGBT transistors). From these points of view, together with the electromagnetic compatibility demands, is better to maintain f_{PWM} as low as possible.

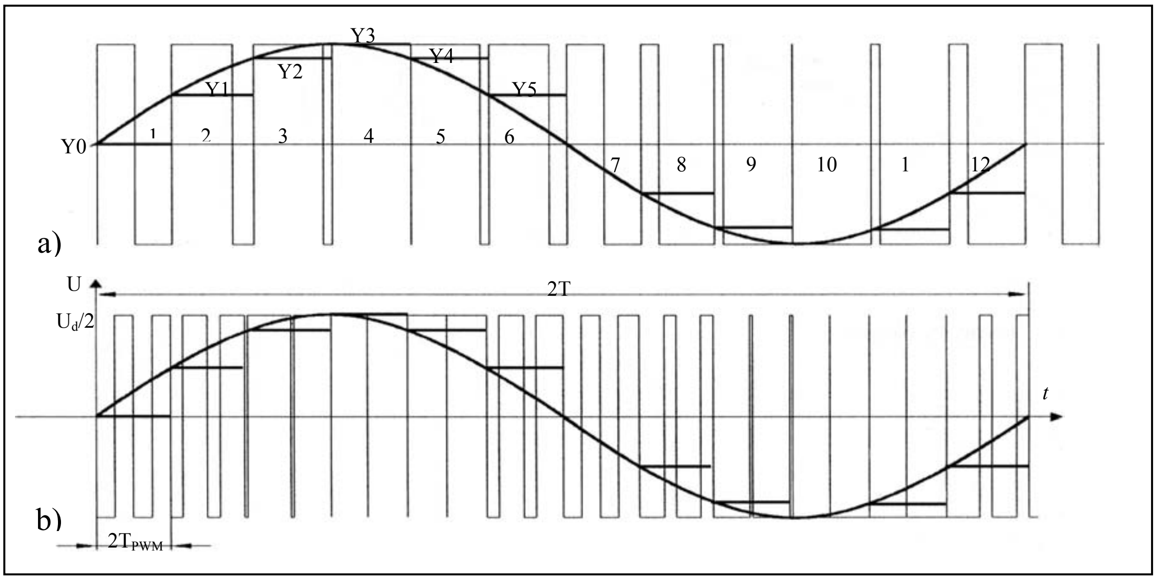

Figure 3. Generation of a sinusoidal voltage

Both the frequency and the amplitude of a sinusoidal wave can be changed.
The peak of a sinusoidal wave depends on how much the ascending fronts of the filling factor deviates from the T_{PWM} period centre. That means that the amplitude may be chosen so that it comes within 0 volts and VDC/2.

In the formula above mentioned for t_D, the voltage value u(i) have to be replaced with the new value of voltage u`(i), that may be calculated as follows:

u`(i) = u(i) * a, where a = the requested amplitude factor, that may be chosen between 0% and 100%

Changes of the sinusoidal wave frequency may be obtained in three different ways:

- by changing the time interval T_{PWM}

- by changing the sampling points number - N
- by changing the repetition factor - Z

Taking into consideration these possibilities of changes of the sinusoidal wave frequency, the formula for the sinusoidal wave frequency becomes:

$$\mathbf{f_{SIN} = 1/T_{SIN} = 1/(T_{PWM} * N * Z)}$$

where: T_{PWM} = PWM interval
N = number of sampling points
Z = repetition factor for each sampling point

The switching frequency f_{PWM} may be selected between 800 Hz and 2.5 kHz, the change of the voltage frequency at the sinusoidal output being done through the change of the number of points of the sinusoid sampling. The occurrence of the over-current in the motor has to determine a deviation from the prescribed voltage/frequency characteristic, in the sense of current lowering, keeping the frequency unchanged, too.

4. Conclusions

The use of frequency converter modules for supplying the auxiliary services of the electrical locomotives led to obtain particular electrical and technical–economical performances:

- higher current capability for the driven motors, under nominal load during starts.
- easy starting both for the compressor and for all the other driven motors, keeping a constant torque all over the starting period and eliminating the mechanical shocks. The shape of the alternative current of the motors is close to sinus and that causes low losses and low heating.
- the use of the IGBT power transistors increased the efficiency of the converter by mean of reducing the switching losses and conduction losses,
- the achievement of a higher degree of availability specific for static equipment corroborate with the expenses trend toward negligible.
- the use of several control and protection units of auxiliary services, interconnected through a communication network, allows to increase the reliability of the assembly by the possibility to re-allocate the elements of the auxiliary services to other static converters modules, or by maintaining of one or even more equipment with static converters in stand-by in order to be connected when a failure occurs.

5. References

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