About the Analytical Methods Applying for Fault Diagnosis of the Static Converters from the Electric Locomotive

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Abstract - **In this paper, the results of the monitoring and diagnosis system based on the analytical methods of the auxiliary ventilation service of the electric locomotive which is supplied from the static converter are presented. Because of the complexity of the electric locomotive structure and of the big number of components, a large number of the parameters must be monitored and detected the range of variation of their imposed values. Consequently, a large variety of monitoring and diagnosis procedures have been developed. In literature in the field, the many advanced fault diagnosis methods were presented. Using the analytical method, the analytical model of the static converter was developed using the Matlab Simulink. Starting from the model of the static converter, three types of the faults were simulated: losing inverter supply, interrupting of the inverter output phase and biphasic shortcircuit at inverter output. For all three types of mentioned faults, the wave-forms of motor speed, electromagnetic torque and electric currents have been registered. These waveforms were compared with those corresponding to the normal operation regime. The impact of the type of fault on the waveforms was pointed out. The results were analyzed based on the evolution of the motor parameters in the normal and abnormal operating regime.**

Keywords: *static converter, electric locomotive, fault diagnosis, Matlab Simulink.*

I. INTRODUCTION

One of the most important components of the electric locomotives is the electric traction system. Being an energy supplier of the electric locomotives, the failures of the electric traction component will directly lead to serious operational accidents. The faults diagnosis of the electrical system is the most complex component in the electric locomotive. The electrical system means the main circuit, auxiliary services and control circuit also. Due to the complexity of the electric locomotive structure and the big number of components, a large number of the parameters must be monitored and the range of variation of their imposed values must be detected. Consequently, a large variety of monitoring and diagnosis procedures have been developed. In literature in the field, the many advanced fault diagnosis methods were presented. Diagnosis of electrical systems is a topical issue in the concerns of specialists. The necessity was determined by the large set of measurement points and the large number of possible faults analyzed. The needed algorithms to determine the operation state - normal or abnormal is based on new concepts and new automated diagnosis systems which were developed, such as expert systems.

According to the fault diagnosis theory the diagnosis methods are divided in the following categories [1]: methods based on the mathematical model, methods based on the signal processing, methods based on the artificial intelligence (fault three method, expert system method, fuzzy logic method, neural network method). The methods based on signals means selecting from the set of measured signals from the process, on those containing information and data about abnormal functioning of the equipment. Analyzing the selected signals are defined the possible symptoms of the defects. Likewise, the time moment of occurrence of each defect is localized and the possible causes of the defect are established [2]. The methods based on knowledge are mostly used for the complex systems diagnosis for which, the knowledge about process is sometime incomplete. The system behavior is qualitatively described using the knowledge which is expressed as rules or facts, obtained through the human empirical observations. For the complex systems, by means the qualitative models, the relation between cause, defect and symptom can be de-fined, using the fault tree concept. Based on fault trees, the abnormal operations, the defects and their causes can be identified. The methods based on the analytical models, compare the behavior of the analyzed system with the one obtained using the mathematical model, corresponding to the normal operation of the system. This method is more efficient than the one based on the signals, if it is possible to obtain the analytical model. The methods based on signals select the signals which contain information and data specific to the fault operation from the multitude of the signals measured from the process. By analyzing the selected signals, the possible symptoms of the faults are defined, the faults are located, the moment of occurrence and possible causes are identified also [3].

The methods based on knowledge are used when the complex systems must be diagnosed. In these cases, the knowledge about process can be often insufficiently. The behavior of the system is quantitatively described by using knowledge about system that is grouped in rules and facts as results of human empirical observations. For the complex systems, the qualitative models can be used for defining the relationship cause-fault-symptom by using the fault tree concept [4].

The methods based on analytic models consist in comparing the system behavior with the results of the mathematical model that reproduce the system in normal operation. If the analytic model is available, this method proves to be more efficient than the methods based on signals [5]. To make diagnosis, the system model must be developed in order to analyze the way of propagation of the specific defect into various monitoring points of system. There-fore, it is enough to elaborate the system model according to their most common defects. The diagnosis of a physical process begins with the process observation, in its normal state of operation and continues with the process analysis to point out (obviously signal) any defects. The supervision of the process is based on the consideration of acceptable or unacceptable operational limits, such as the alarm ones, at the overcoming of the measured values.

In the references from the field, many diagnosis methods based on the expert system are presented. In the paper [6] a novel diagnosis system based on the MAS and the coordination of multi agent system is presented. The method to obtain diagnosis rules from the fault tree is described in the paper [6] and the intelligent fault diagnosis knowledge base of SS7E electric locomotive is constructed and the data structure is presented also. In the paper [8] a novel distributed fault diagnosis method based on causal model has been proposed. Through the splitting entire system into several causal independent subsystems/components, the fault diagnosis can be divided. Consequently, the proper diagnosis method can be applied to each component individually, without consideration of system frame and parameters so that the proposed Method reduces the complexity of diagnosis and the reliability are increased.

The static converters are the basic equipment for adjusting of the electric energy parameters, being located between the power supply source and load. During operating it is required their monitoring and diagnosis because otherwise it can lead to the important damages at the equipment with which they interact [9].

This paper presents a diagnosis system that analyzes the behavior of static converter which supplies the electrical motors included in the ventilation auxiliary ser-vices of the electric locomotive. The auxiliary services means the facilities and aggregates which not directly participating to the traction force and speed adjustment, but are necessary for the functioning of the entire electric locomotive. The auxiliary services comprise three distinct components: supply source, adjusting installation, aggregates and the supply sources of the control, protection, ventilation, signalization and other specific facilities.

II. THE SIMULINK MODELS AUXILIARY SERVICES

The functioning of the electric motors used in the auxiliary ventilation services was simulated by means of the Matlab Simulink soft (Fig.1).

In the first part of this scheme, the DC side of the inverter input is presented. This is powered at the 640Vcc. The block with the DC source is configured as it is presented in Fig.2.

Between the DC power source and inverter it was used a current transformer to measure the current extracted from the power inverter. The inverter (Universal Bridge) consists of 6 IGBTs on 3 arms. The block for the inverter is implemented in Matlab Simulink as is shown in Fig.3.

The output voltage of the inverter is 3x400V and 6 asynchronous motors, whose parameters are presented in Fig 4, are supplied. In the simulation diagram has been put a three-phase meter that monitors the currents and voltages in the instantaneous values at the output of the inverter. Also, in addition to the static converter which supplies ventilation engines, on the locomotive there is still an identical one for the ventilation of the traction motors, one for the electric motor of the compressor and one for the ventilation of the transformer.

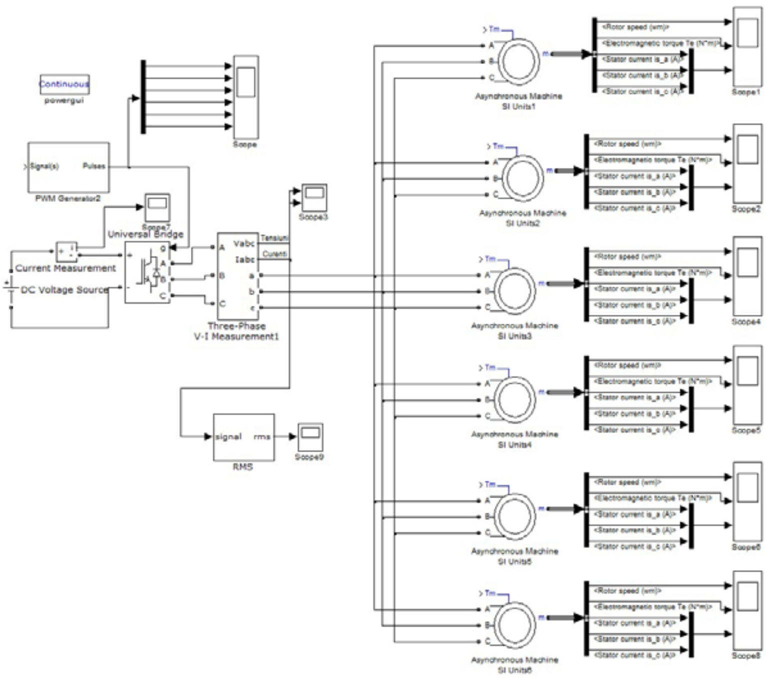


Fig. 1. The Simulink model of the auxiliary ventilation services.

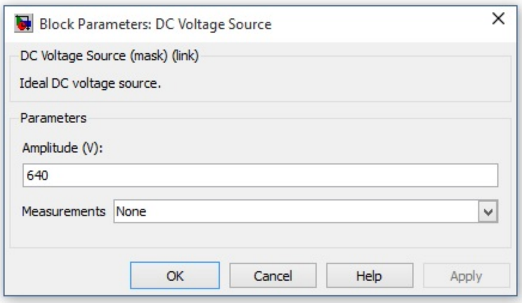


Fig. 2. The block of the DC source

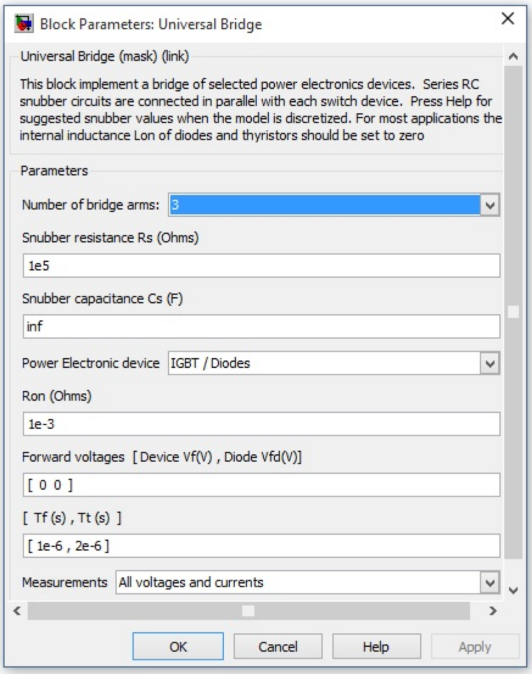


Fig. 3. The inverter block

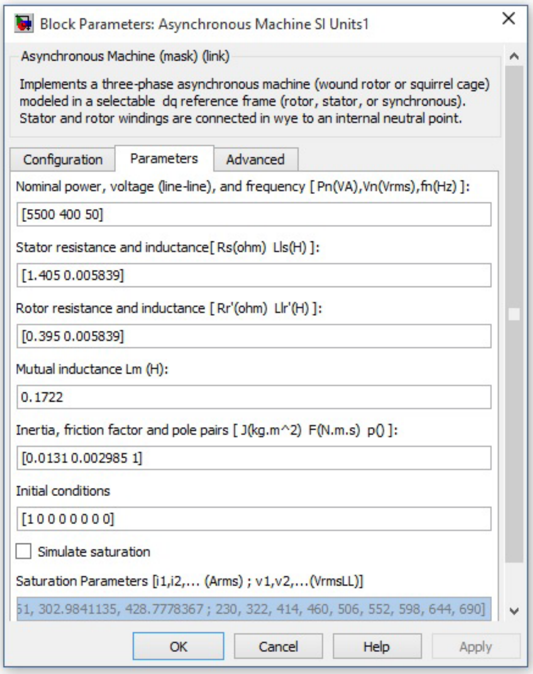


Fig. 4. The asynchronous motor parameters

A. The functioning of the static inverter in the normal operating regime

Concerning to the normal operating regime of the static inverters has been analyzed the wave shapes of the following parameters of the ventilation motors: speed, electro-magnetic torque and the current. The variations of these parameters, which have been obtained, are shown in the Fig. 5.

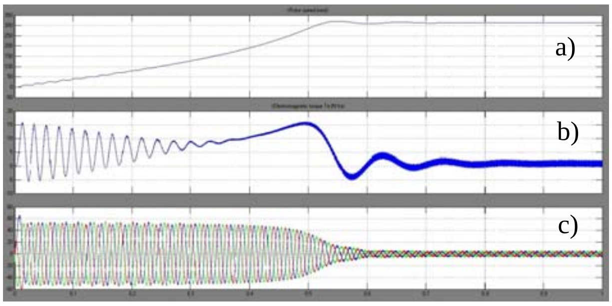


Fig. 5. The rotation speed (a), electromagnetic torque (b) and the currents (c) vs. time for a motor

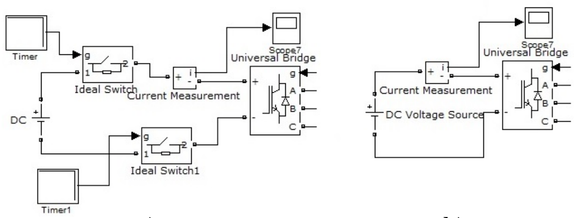
It can be noticed that the rotor speed increases and are stabilizing at 300 rpm. As long as the speed increases, the torque oscillates amortized in the range 15… -5 [Nm]. When the speed is stabilizing, when the speed is stabilizing, the torque shows small oscillations between 0 and 2 [Nm]. The current is higher at the motor starting. During the increasing of the speed, the current is kept constant and then, after the reaching of the nominal regime, the current stabilizes at 5A.

III. FAULTS SIMULATION RESULTS

In this paper, tree situations of defect, which may appear during the operation, are considered: losing the inverter supply; an interrupted output phase of the inverter and Biphasic shortcircuit at inverter output.

A. The analyze of the defect: losing the inverter supply

The Simulink model used to simulate this fault is presented in Fig.1. The only difference appears to the nominal operating model is the inverter supply (Fig. 6).



a) b)

Fig. 6. The difference between the original model (b) and the model of the simulated fault (a)

It is considered normal operation regime and at the moment of time 0.6 seconds the inverter no longer receives an input signal. In the Fig. 7 it can be observed that in the moment when the inverter loses the supply, the current greatly increases to maintain constant the power. In the moment of loosing of the power, the output voltage of the inverter suddenly decreases at zero. At the beginning the current greatly increases and then becomes zero. The wave shape of the current on the entire duration of the simulation is shown in Fig. 8.

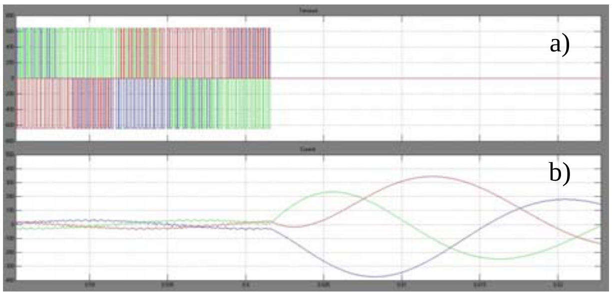


Fig. 7. The instantaneous values of voltages (a) and currents (b) vs. time at the inverter output

In Fig. 8 are presented the variations of the speed, electromagnetic torque and the stator currents for one of the ventilation motors. It is noticed that after the disconnecting of the inverter from the power source occurs a strong braking of the motor after which the electromagnetic torque becomes zero. In the moment of the supply interrupting it is observed the increasing of the motor currents (approximately 10 times); this fact makes possible the breaking after which the currents become zero. In this diagram, the motor speed is quasi stationary, but having a tendency to decrease. The rotor inertia helps to keep constant of the speed corresponding to the normal operation regime of the circuit.

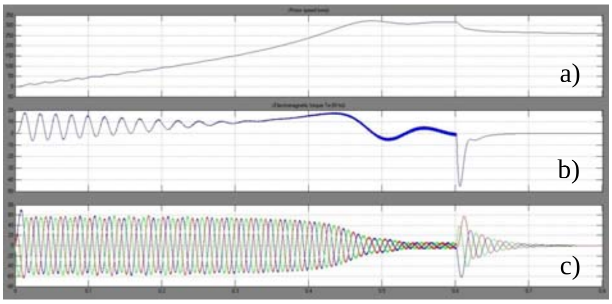
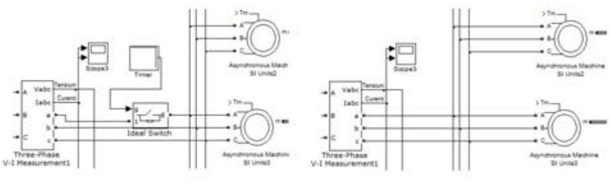


Fig. 8 The speed (a), electromagnetic torque (b) and the stator currents (c) vs. time after the appearance of defect

B. The analyze of the defect: an interrupted output phase of the inverter

The Simulink model used to simulate this fault is presented in Fig.1. In addition to the nominal operating model, between the inverter and motor it is added a switch (Fig. 9).



a) b)

Fig. 9. The difference between the original model (b) and the model simulated fault (a)

It is considered that the appearance of the defect take place at the moment of time 0.6 sec. The voltages and the currents at the inverter output are presented in Fig. 10 and more itemized in Fig 11.

On the interrupted phase the current decreases from the 23A RMS value to zero in approximately two periods of time. On the other two phases the currents values remain at 23A, being At the defect appearance, the current variations are different to the three phases. in phase opposition.

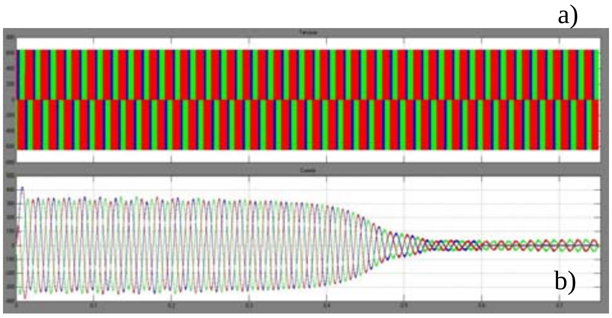


Fig. 10. Instantaneous values of voltages (a) and currents (b) vs. time at the inverter output

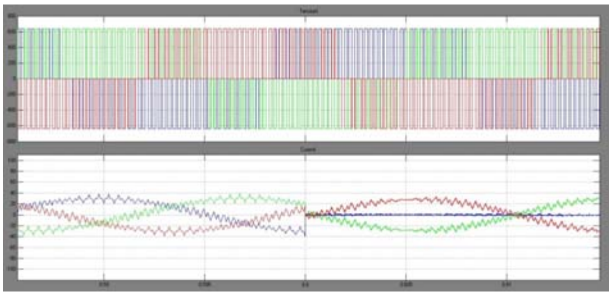


Fig. 11. Instantaneous values of voltages and currents at the inverter output - itemized

The evolution of the asynchronous motor parameters in the case of producing of this defect is shown in Fig. 12. After the one phase interruption at the inverter output (0.6sec moment of time) it is observed that the speed remain constant but the electromagnetic torque greatly oscillates. This fact is a consequence of the currents evolution.

After the interruption of the one phase, the currents passing through the other two phase are in phase opposition, being one moment when both currents are zero (Fig. 13).

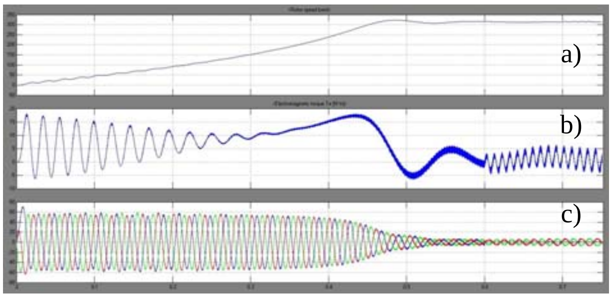


Fig. 12. The speed (a), electromagnetic torque (b) and the stator currents (c) vs. time after fault appearance (0.6s)

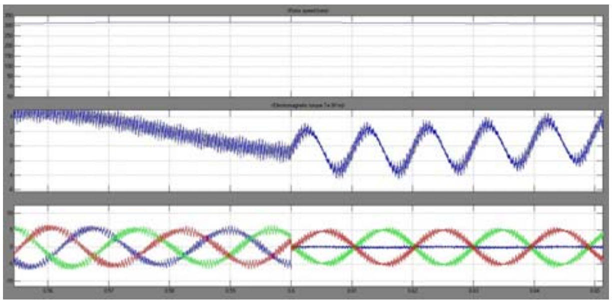


Fig. 13. The speed, electromagnetic torque and motor currents - itemized

C. Biphasic shortcircuit at inverter output

To simulate the biphasic shortcircuit, one switch was installed between two phases at the inverter output. The switch shuts down after the 0.6 seconds when the motors reach the rated speed. This situation is purely theoretical. Actually, any inverter instantly disconnects in almost all cases, each motor is powered by means electrical equipment having the purpose to make the protection both overload and short circuit; the thermal protection is carried out by the bimetal device or electromagnetic protection. Therefore, if a short circuit occurs, the electromagnetic protection triggers and consequently, the other motors are still working. However, if these protection devices are lacking, the inverter disconnects the power circuit.

The Simulink model for "biphasic shortcircuit at inverter output" fault is present in Fig. 14.

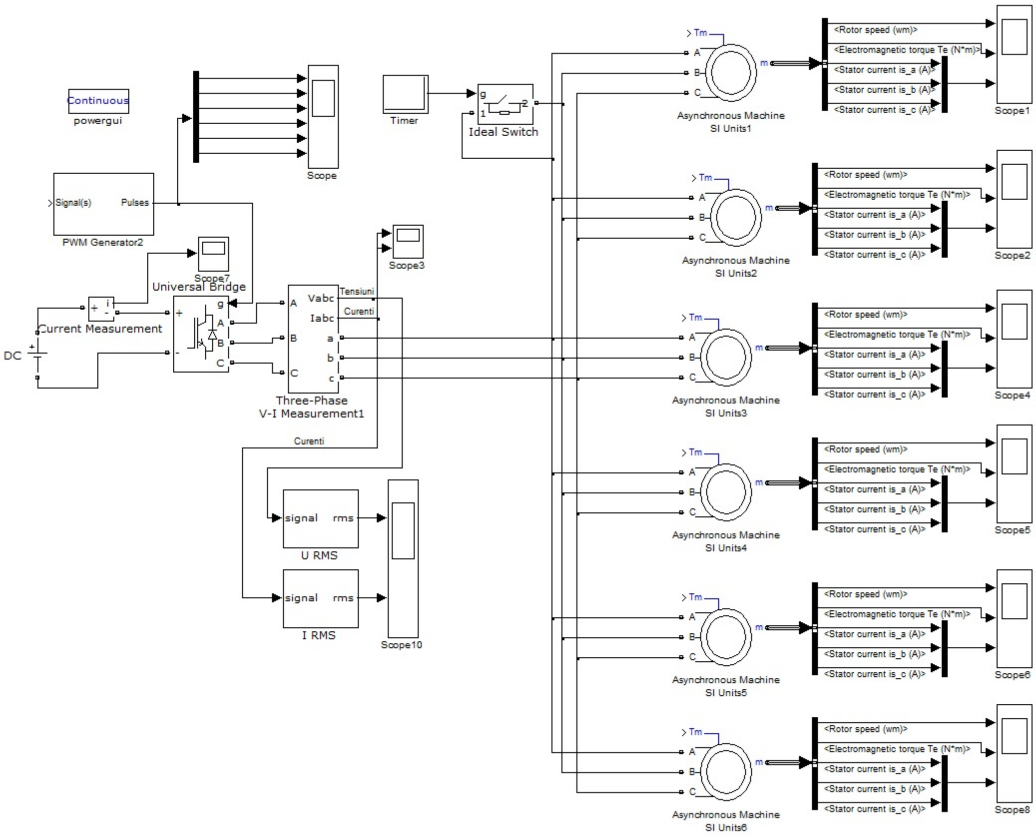


Fig. 14. The Simulink model for "biphasic shortcircuit at inverter output" fault

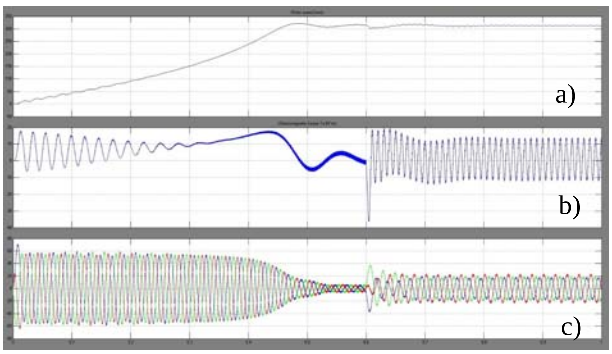


Fig. 15 – The waveforms of motor speed (a), electromagnetic torque (b) and currents (c) in the fault regime

The Figure 15 shows the waveforms for the motor which is in the fault regime.

It can be noticed that at the short circuit occurrence, the current value increases from 6A to 20A peak value.

In Figure 16, it can be also observed the phase shift of the current after the short circuit occurrence.

In the Figures 17 and 18 can be noticed why this simulation is only theoretically. The waveform of the voltage changes also, but it is important that the current value reaches almost 300kA (Fig. 17).

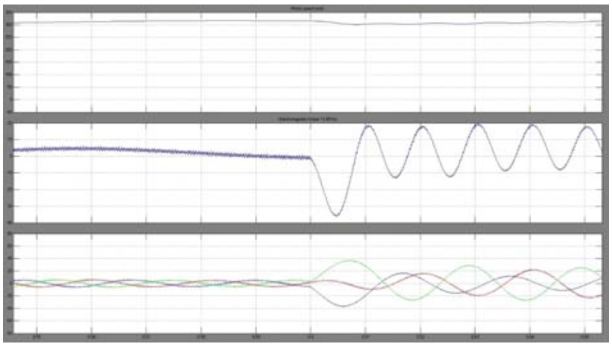


Fig.16. –The waveforms of motor speed, electromagnetic torque and currents - fault regime, itemized

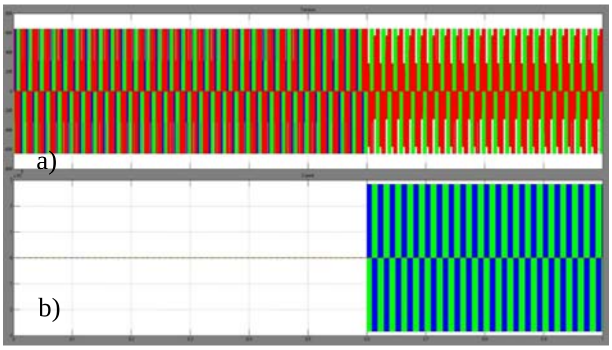


Fig. 17. –The waveforms of the voltage (a) and the current (b) vs. time on the three phases of the inverter

This fact is impeded to occur, either the internal protection of the inverter or by the device which is serially connected to the motor, through the disconnecting of the circuit, as long as the current slope is upward; consequently the current not reached the maximum value.

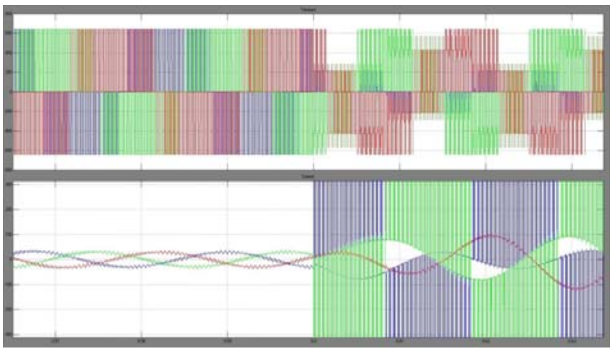


Fig. 18. – The waveforms of the voltage and the current on the three phases of the inverter- in the fault regime, itemized

The comments which have been made before about the instantaneous values are available for the evolution of the RMS values of the voltages and the currents. The voltage value of the one phase dropped at 140V, while the voltages values on the other two phases reached the 350V value and the RMS values of the shortcircuit currents reach the 135kA value.

IV. Conclusions

The static converters are equipments included in the auxiliary services of the electric locomotive. During the electric locomotive operation it is needed the monitoring and diagnosis of the static converters because they can cause serious damages to equipment with which they interact. In the diagnose process, the analytical model of the system must be carried out to analyze the propagation of a fault at different points in the system.

The diagnosis of a physical process begins with observation of the process in its normal state of operation and continuous process analysis after the defects. The surveillance of the measurements is based on the consideration of acceptable or unacceptable limits in operation, with reference to the supervised process parameters. In this paper it is carried out the monitoring and diagnosis of the motor from the auxiliary ventilation services of the electric locomotive for two types of defects: first one: losing the inverter supply and the second one: an interrupted output phase of the inverter. This purpose was possible based on the analytical model methods using Matlab Simulink.

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