Diagnosis with Analytic Model of a Rectifier for Faults of the Rectifier Control

Virginia Ivanov, Maria Brojboiu and Sergiu Ivanov
University of Craiova / Faculty of Electrical Engineering, Craiova, Romania
vivanov@elth.ucv.ro, mbrojboiu@elth.ucv.ro, sergiu.ivanov@ie.ucv.ro

Abstract **- The diagnosis of the electric systems is an actual item for the specialists in domain. Due to the variety of the measurements and multiplicity of faults which can be analyzed, the approach is motivating. The model reproduces the behavior of a system both in normal operation and fault occurrence. The procedure which uses the analytic models compares the system evolution in normal and fault conditions operation. The faults which affect the normal system operation can occur on the supplying side (grid faults), in the rectifier itself (one or more switches in fault), on the load side or in the control circuit of the rectifier. Authors had previously studied different faults within a controlled rectifier-DC motor system. The supplying side faults (broken phase, phase to ground and two phases short-circuit faults), interrupted or short-circuited switch within the rectifier and excitation disappearance were investigated. The paper deals with the analysis of different faults of the control circuit. The considered faults were the firing pulses lack for one switch or for the two switches on the same arm (phase). The effects on the rectifier operation (waveforms, major values) and on the load behavior are highlighted. As it is shown, the effects on the output waveforms of the two studied faults are quite different.**

Cuvinte cheie: *diagnoza defectelor, comanda redresor, model analitic.*

Keywords: *fault diagnosis, rectifier control, analytic model.*

I. Introduction

The systems' diagnosis consists in a compilation of investigating methods, both scientific exact and heuristic ones. For an efficient control of a system and improved decisions, diagnosis can be applied in all the stages of a product development.

This goal can be achieved only if several steps are accomplished on the whole system life cycle (Fig.1).

An important obstacle in monitoring power electronics equipment arises when no special test may be applied. From the working conditions it results that only operating signals may be used for test purposes and the diagnosis can be formulated including propagation times of the fault symptoms.

Block scheme of the rectifier state monitoring and diagnosis process is shown in Fig.2 [1].

In this case, the monitoring of the rectifier comprises the following:

• fault detection performed repeatedly;

• fault isolation;

• fault identification;

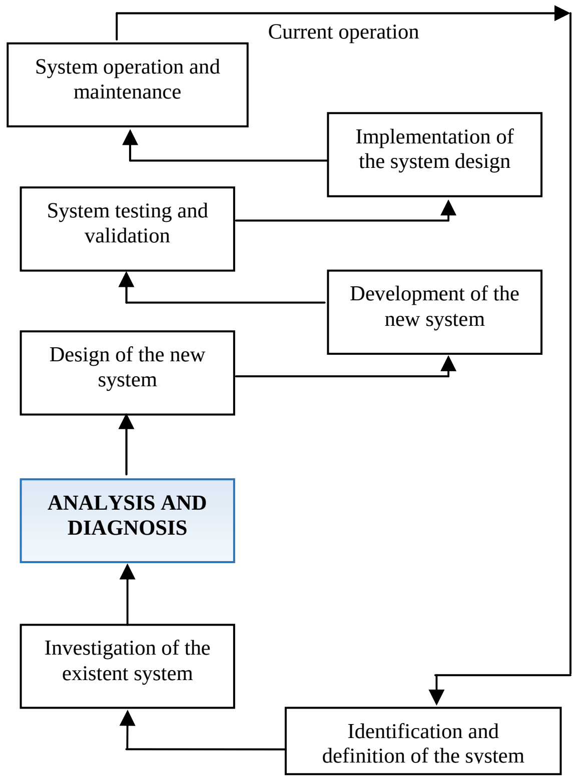

Fig. 1. The life cycle of a system

• detection of a probable recovery, return to the state of normal operation

• optional visualization and storage of the diagnoses;

• optional modification of the faults that have been considered in the monitoring process.

In the described monitoring system, two different actions are performed simultaneously:

• repeatable execution of the fault detection tests;

• all the other activities accomplishing another monitoring process.

For power electronics equipment is difficult to estimate the delays of the symptoms. This is because the models are highly inaccurate while they do not cover fully the physics of the phenomena and the dynamics of a fault is not completely known [2, 3, 4].

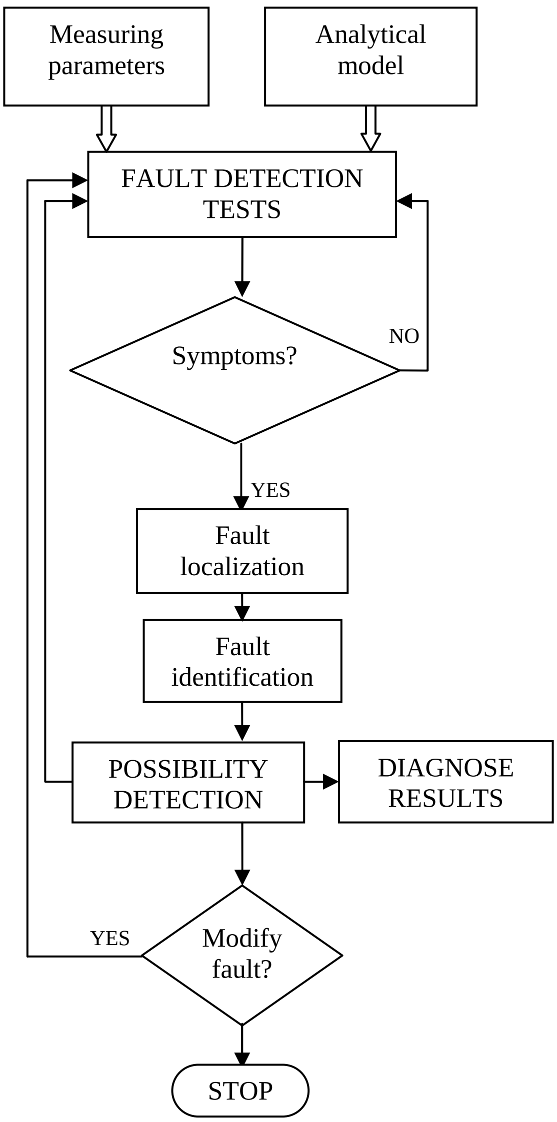

Fig. 2. General diagnosis process of a system

In practice we can try to estimate the instants of the symptoms, based on the knowledge of the rectifier's dynamics and on detection algorithms [5]. After several simulations, the instants of the symptoms can be indicated as extreme values.

In the paper, a diagnosis system for static power converters diagnosis and functional testing is developed starting from the anomalous behaviors, noticed during the operation, and the faults which determine these.

II. Diagnosis System For A Rectifier Supplying A Variable Dc Drive

By using Simulink of Matlab®, the model of a three-phase thyristor converter supplying a variable DC drive has been developed. An example of integration of the converter and DC motor equivalent circuit for obtaining the driving system model is illustrated in Fig. 3 [6, 7, 8, 9, 10].

By using the above diagram, several faults can be analyzed. These are:

- faulty supply,
- faulty thyristor in the rectifier,
- faulty motor,
- faulty rectifier control.

Some faults were deeply analyzed in previous papers [3, 4]. The mentioned fault is programmed to occur by proper parametrization of the Fault Breaker block. The dialog box is shown in Fig. 4.

It was shown that some faults caused more serious influences on the rectifier operation. As an example, the phase to ground fault on the source side is plotted in Fig. 5 and 6.

The fault occurs at the instant 0.02 s and is canceled at 0.08 s. As was shown in [11, 12], the effects are dramatic on the rectifier's output voltage and current, both as waveforms shape and as extreme values.

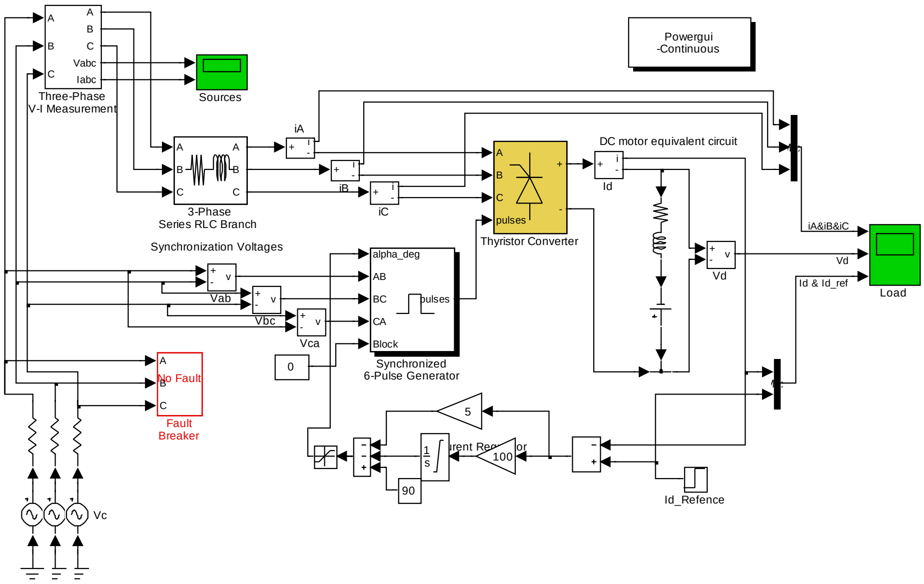

Fig. 3. The Simulink model of a three-phase thyristor converter supplying a variable DC drive

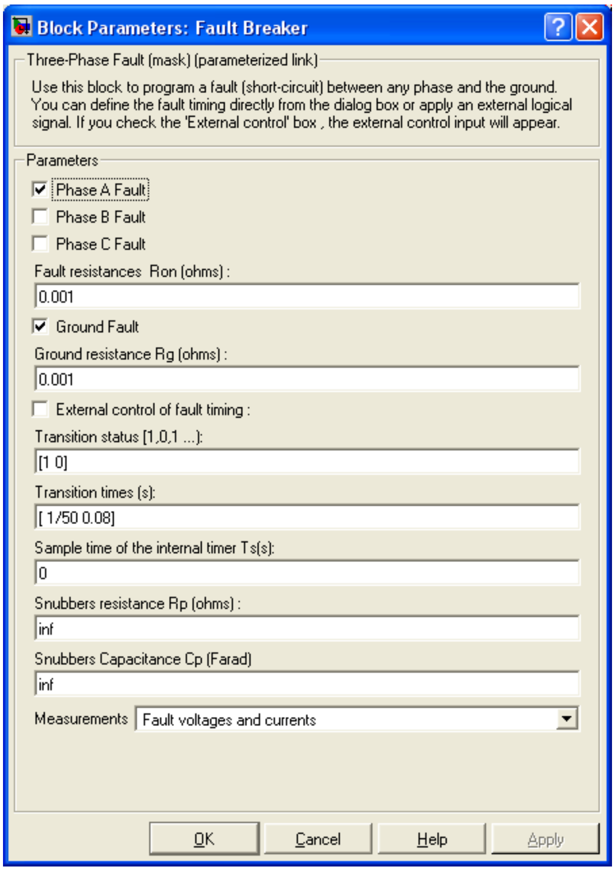

Fig. 4. Dialog box of the Fault Breaker block

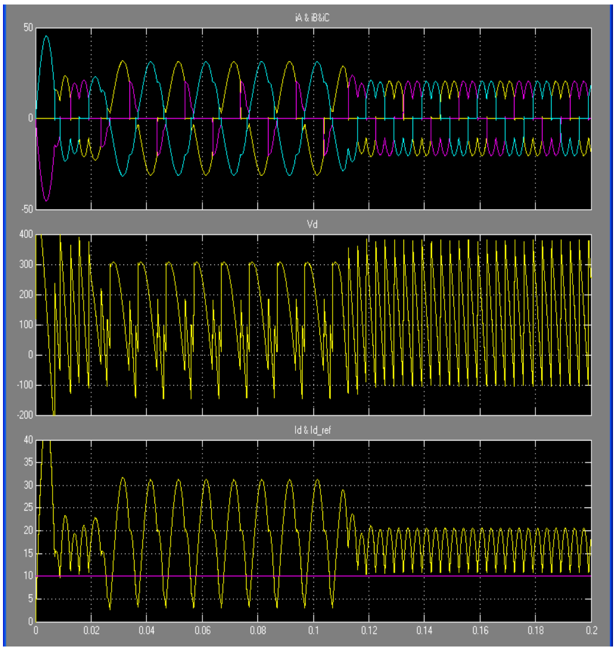

Fig. 5. Rectifier main waveforms for phase to ground fault: input currents, output voltage and output current respectively

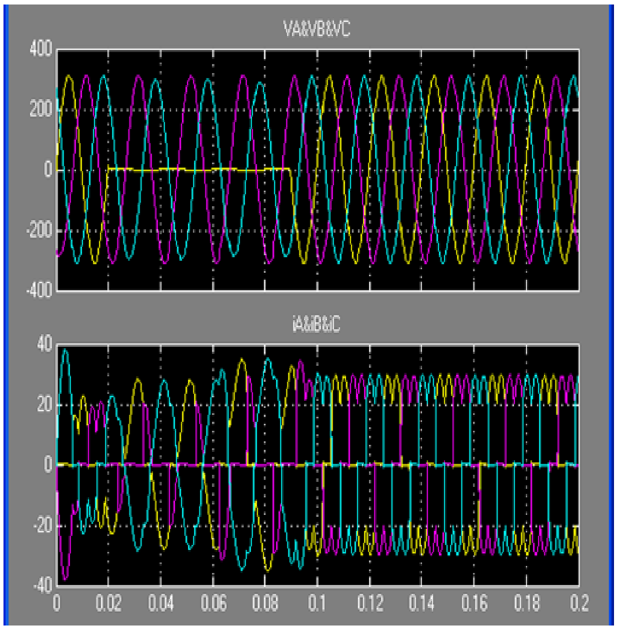

Fig. 6. Source side waveforms of the voltages and currents for phase to ground fault

Another fault analyzed is on the load side. If the load is a DC motor, a possible fault is the excitation loss. The effect of this fault is the annulation of the DC motor back electromotive force (back EMF).

If the system is without any feedback, the effects are devastating for the rectifier. The operation of the rectifier would be practically almost in short circuit. As will be shown further, if a current controller generates the fire angles of the rectifier switches, the influences of this fault are less dangerous [13].

By using the same diagram (Fig. 3), the excitation loss fault was simulated by annulation of the DC motor back electromotive force during operation [14].

The waveforms of the rectifier input currents, output voltage and output current respectively are plotted in Fig. 7. The fault occurs at the instant 0.075s and is canceled at 0.14s.

The waveforms are slightly different during the fault. In normal operation the output voltage mean value is about 120V which is the back EMF value, while during the fault is about 0 V.

Even so, the load current mean value increases from 15A to more than 18 A. The decreasing of the output voltage is due to the current controller action which increases the firing angle of the switches.

Even so, the current controller capabilities are exceeded, the load current being much greater than the reference one.

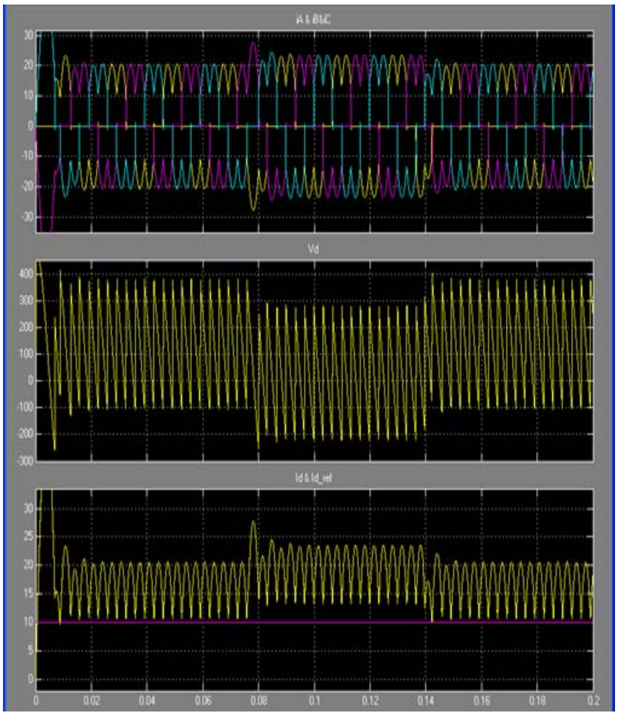

Fig. 7. Rectifier main waveforms for back EMF annulation: input currents, output voltage and output current respectively

III. Simulation Results of Firing Pulses Lacking Fault

In this paper, control block faults are analyzed. The considered faults consist in the lack of the firing pulses of one or two thyristors. This fault can occur even due to the defect of the electronic control circuit itself, even due to the defect of the galvanic separation stage.

These types of faults have similar effects with the semiconductors' interruption fault, but generally when a semiconductor falls in fault it is in short-circuit not interrupted [15].

In order to simulate the proposed faults, the "Synchronized 6-Pulse Generator" block of SimPowerSystems library of Simulink was changed as is shown in Fig. 8.

The final Manual Switch allows the commutation during the simulation between normal and fault operation at desired instants.

In all the cases double pulse control was considered.

When the single switch does not receive its firing pulses, only two of six topologies of the rectifier are affected, corresponding to the conduction of the semiconductor in fault with the two the semiconductors on the opposite side and different phases.

When the switches on the same arm are affected, the rectifier operates during only of two of six topologies, when are in conduction the opposite elements on the other phases.

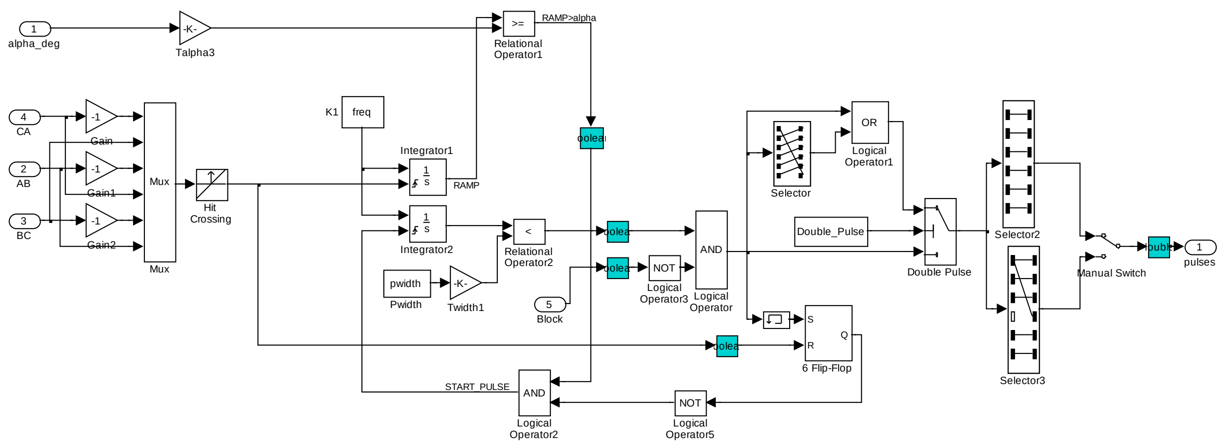

Fig. 8. The modified "Synchronized 6-Pulse Generator" block

In Fig. 9 and 10 are plotted the waveforms of the most important signals corresponding to the two considered faults, input currents, output voltage and output current respectively.

In Fig. 9 the firing pulse of one thyristor is canceled at about 0.055 s from the beginning of the simulation. The reaction of the current controller determines the change of the firing angle mostly for the next thyristor on the same side. This is normal, as during the non-conduction of the affected switch, the load current falls near zero, as can be seen in the third plot of Fig. 9. This determines higher output voltage ripple, from less ten 500V in normal operation to almost 700V during the fault.

During the fault, the most affected is the load current which falls to zero during the non-conduction intervals. Its ripple increases from 10A during normal operation to more than 40A when one thyristor is not fired.

The effects are more pronounced when the two thyristors of the same arm are not fired. The results of the simulation for this fault are plotted in Fig. 10.

All the waveforms are deeply affected both quantitatively and qualitatively, being closer by the single-phase rectifier ones.

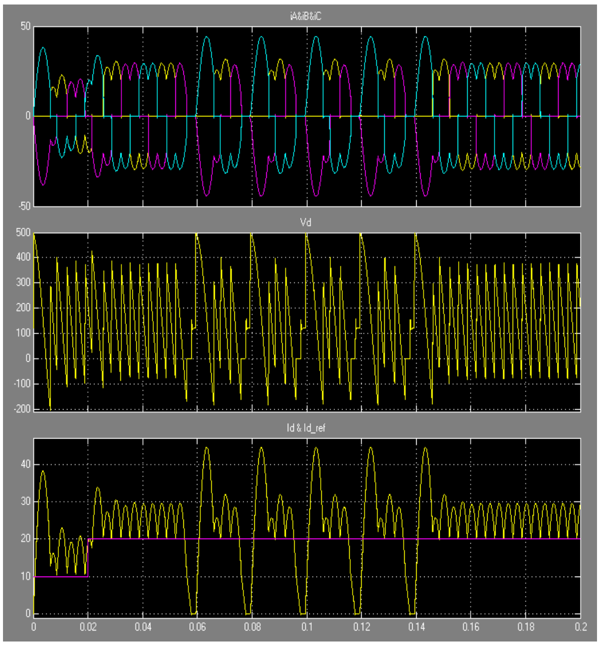

Fig. 9. Rectifier main waveforms for one thyristor firing pulses annulation: input currents, output voltage and output current respectively

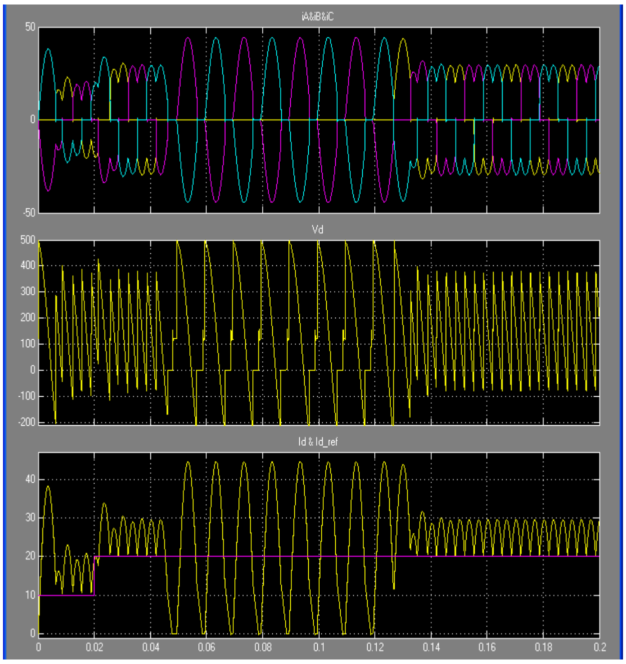

Fig. 10. Rectifier main waveforms for two thyristors on the same arm firing pulses annulation: input currents, output voltage and output current respectively

As was stated above, the lack of the firing pulses is equivalent to the corresponding interrupted semiconductor. For comparison, Fig. 11 plots the output current and voltage wave-forms when one thyristor (T_4) is interrupted during the interval (2-4) s, otherwise, the normal operation is considered [13]. The simulation is performed without any current feedback (open loop).

As can be seen, important oscillations occur, both in current and in voltage.

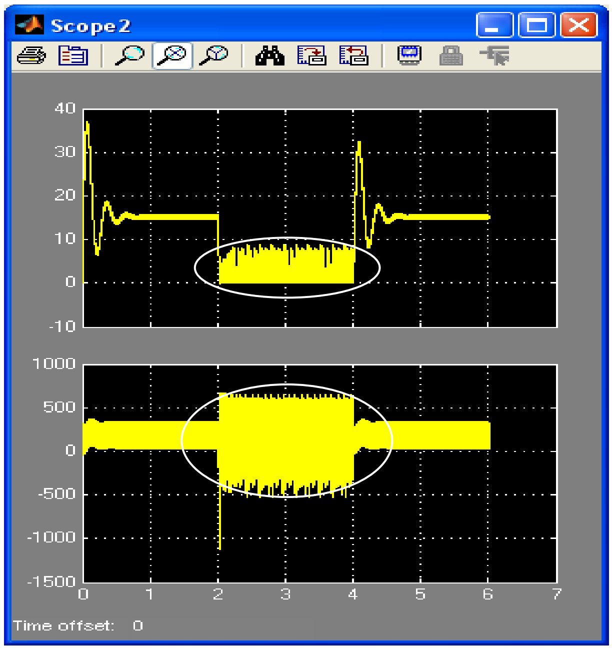

Fig. 11. Output current and voltage, with T_4 interrupted (2-4) s.

IV. Conclusions

Different faults can occur within an adjustable speed DC drive supplied by a controlled rectifier: supply fault, semiconductor fall, load fault or control circuit fault. In a series of publications, the authors have investigated the influences of some of them [16,17]. Ones are more dramatic on the system behavior, other, like load fault is less striking.

The present paper analyzed the influence of the control circuit faults on the system behavior. Two types of faults were analyzed: the lacking of the firing pulses of one or two thyristors on the same arm of the controlled rectifier.

The created Simulink model is adaptable used. It allows to obtain different waveforms for normal and faulty operation. One original block of the SimPowerSystems library of Simulink was changed in order to be able to simulate the proposed faults. The paper presented the results for the simulation of several faults, with emphasis on the control circuit defect.

Due to the current controller, the effects of some studied faults are attenuated compared with a system without feedback (load fault). In other cases (control circuit faults), the influences of the current controller are more prominent, as was highlighted in the paper.

The results of the studied faults are waveforms specific to the diverse cases and they are collected in a knowledge database. The usefulness of this collection is attained when the normal operation waveforms are compared with the fault ones and the type of fault can be quickly identified.

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Contribution of the authors:

First author – 60%

First coauthor – 10%

Second coauthor – 30%.

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