Qualitative Analysis for Faults Diagnosis of a Driving System with Static Converter

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***Abstract*— Fault Diagnosis for Engineering Systems gives a complete presentation of basic essentials of fault diagnosis, and takes a look at the cutting-edge discipline of intelligent fault diagnosis for condition-based maintenance. The paper presents a defect detection system based on development the tree faults analysis for a power rectifier. The tree fault method is used for quantitative and qualitative analysis of system reliability. For the qualitative analysis of the faults, the tree of faults is developed, based on symptoms, considered to be the most frequent ones during the operation of the power rectifiers. The paper describes the steps of the diagnostics system and the results obtained after the quantitative and qualitative analysis with the tree fault method for the three phase power rectifier. For the quantitative analysis, the reliability of the drive system is determined based on the values of the operating probabilities of the component elements. The reliability of a product can be provided in the design stage, controlled during the manufacturing process, measured during the test and maintained during the operation. The life of a product is influenced by the characteristics of the working environment. Specific information about the product's working environment includes temperature, vibration strains, chemically or inert aggressive environments, electromagnetic conditions.**

Cuvinte cheie: *defect, diagnoza, convertoare, model*

Keywords: *fault, diagnosis, converters, model*

I. BASIS OF FAULT DIAGNOSIS TECHNIQUES

There are three basic tasks which must be completed in fault diagnosis:

- Fault detection consists in detection of occurrence of a fault within equipment, which determines undesired or intolerable operation of the entire system;

- Fault isolation consists in localization of the occurred fault;

- Fault analysis and/or identification consist in identification of the type, significance and, most important origin of the fault.

The simplest fault diagnosis systems are the fault detection systems. This system activates alarm signals in order to announce the occurrence of a fault. More complex are the fault detection and isolation systems and fault detection, isolation and analysis systems. They are able to send classified alarm signals in order to indicate which fault has occurred. They are also able to transmit data of predefined types containing information about the type or the significance of the detected fault.

The fault diagnosis based on model is a procedure relatively new as research in the engineering domain of fault diagnosis. The recent researches determined by the increased attention lead to fast development. Fig. 1 depicts a classification of the fault diagnosis techniques. Based on it, some traditional fault diagnosis techniques will be reviewed, with emphasis on their relationships with the model-based procedure.

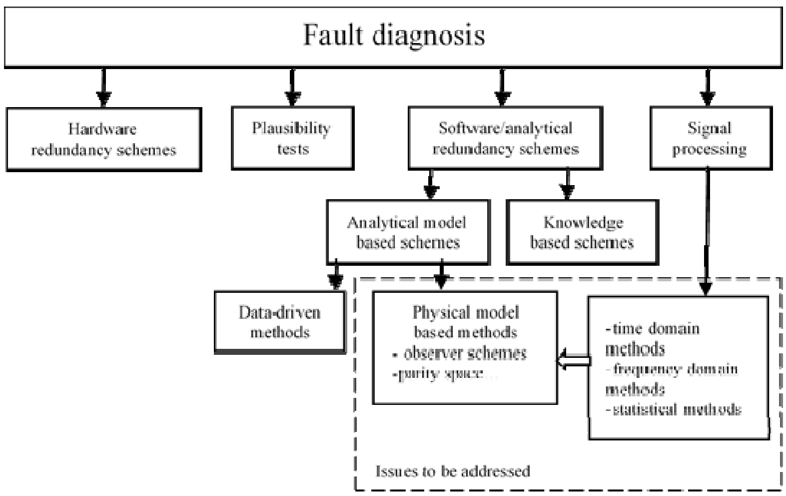

Fig. 1. Fault diagnosis techniques.

- Fault diagnosis based on hardware redundancy. The principle, Fig. 2, is to reconstruct the equipment components by using identical hardware components (redundant). The potential fault in the equipment component is detected when the output of the equipment differs by the one of the redundant one. This technique has the advantage of a high reliability. Besides this, and the fault isolation is direct. On the other hand, this technique implies higher costs. This why, this technique can be applied only for the crucial components of the equipment.

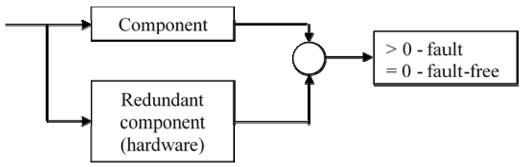

Fig. 2. Hardware redundancy technique.

- Fault diagnosis based on signal processing. The principle of this technique is depicted in Fig. 3. In the case of this technique, the fault diagnosis can be obtained based on signals which transport information concerning potential faults. The information can bring knowledge about symptoms. By a proper signal processing, the fault diagnosis can be achieved. This technique is applied mainly to steady state systems. The symptoms are generally functions vs time or functions vs frequency. Examples: mean values, amplitudes, limits, spectral lines, spectral densities.

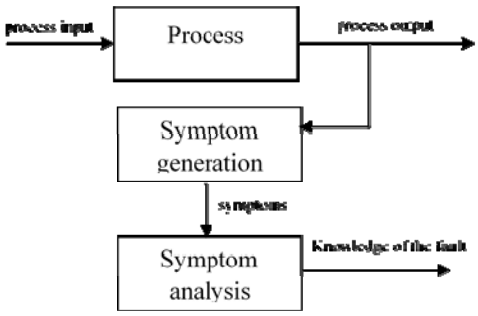

Fig. 3. Signal processing technique.

- Plausibility test. Fig. 4 depicts the principle of this technique. Some basic physical laws which govern the operation of the components are checked. If a fault occurs, the plausibility of the equipment behavior will be reduced and this behavior can give indications about the fault. Generally, this technique can be effective only for simple equipment and is limited in what concerns the faults isolation.

The faults diagnosis technique based on model is a software technique which replaces the hardware redundancy with an equipment model implemented on a computer. This model describes quantitatively and/or qualitatively both dynamic and steady state comportment. It is obtained by applying well-known modelling methods. The behavior of the equipment can be thus in real time recreated. This why, this technique is also called software or analytical redundancy technique.

Like in the hardware redundancy technique, in the software redundancy technique, the equipment model runs simultaneously with the equipment, having the same inputs as the real one.

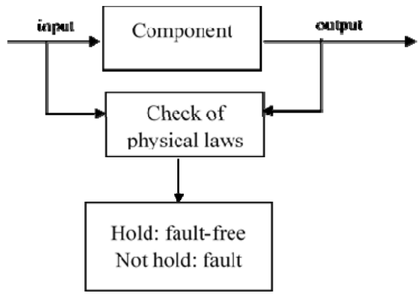

Fig. 4. Plausibility test technique.

When no faults occur, the recreated variables of the model are expected to follow with fidelity the evolution of the variables resulted from the real system. If a fault occurs, there are expected that serious deviancies will occur. The technique consists in permanent comparison of the measured real variables with their corresponding estimated variables delivered by the model. The differences between the two pairs of variables are named residual. If the residual differs from null, then the conclusion is that a fault occurred. This technique is depicted in Fig. 5.

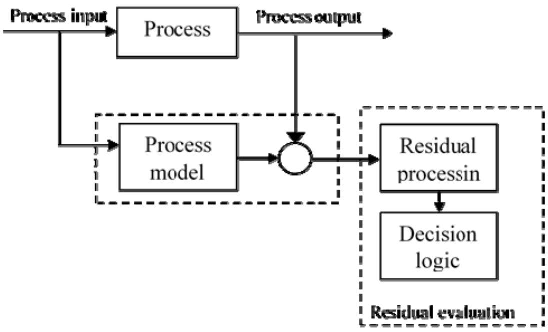

Fig. 5. Diagnosis based on model.

The model based diagnosis technique can be considered as an extended plausibility test too. As plausibility technique consist in comparison of the real input-output comportment with the input-output evolution of the modelled equipment, this process can be replaced with the comparison between the real, measured outputs and the corresponding variables obtained from the model.

It is well known that all the models are developed considering several simplification hypotheses. These lead to some differences between the real system and the model results. In addition, in the real system, some unexpected disturbances can occur. The two considerations determine reluctant residual signals that affect the fault diagnosis precision. This why, for improving the precision of the diagnosis process (identification and isolation of certain faults), more precise analysis must be performed in order to identify in the residual signal the faults and their effects. At this point must be highlighted the importance of an accurate filtering of the residual signals in order to extract with accuracy the information regarding the faults.

II. DIAGNOSIS SYSTEM FOR A RECTIFIER WITH RL LOAD

The diagnosis of the systems is used for monitoring, supervision, inspecting, modelling and design, applied in order to increasing the quality of the decisions and appropriate expertise of an analyzed system. This objective is possible if several conditions are met in each stage of the life cycle of the system.

For the power electronic equipment the models made are inaccurate and do not fully cover the evolution of the systems during the failure phenomena. The dynamics of a failure is not fully known and the influence on all the equipment in the system cannot be fully appreciated. In practice, the symptoms of manifestation of defects can be estimated based on the knowledge of the rectifier's functioning and the algorithms for detecting faults. After several simulations of the most common defects in rectifier operation, the evolution of certain sizes can be indicated as extreme values.

Based on the abnormal behaviors observed during operation and the faults that determine a diagnostic system for the power converters, it was developed.

Operation of the rectifier was analyzed for two typical applications:

a) with passive RL load;

b) supplying a variable DC drive.

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

The notion of “fault” of a certain device has a different significance if the fault is analyzed taking into account the effects of the fault on the other components of the system. Therewith, a complete fault of device within a bridge rectifier can be the cause of a partial fault of the subsystem which contains the device.

The system used for the diagnosis of the analyzed system is based on the faults tree method. The faults tree method was used to develop the diagnosis of the analyze system.

The analysis of the systems reliability by using the tree of faults method consists in succeeding steps:

- system description;

- construction of the fault tree with respect to the critical event considered;

- quantitative estimation of the tree of faults;

- qualitative estimation of the tree of faults.

The functional scheme of the rectifier in Fig. 6.

For the qualitative analysis of the faults, the tree of faults is constructed. It is developed based on three symptoms considered to be the most common during rectifier operation: high/low level of the output voltage, absence of the output voltage.

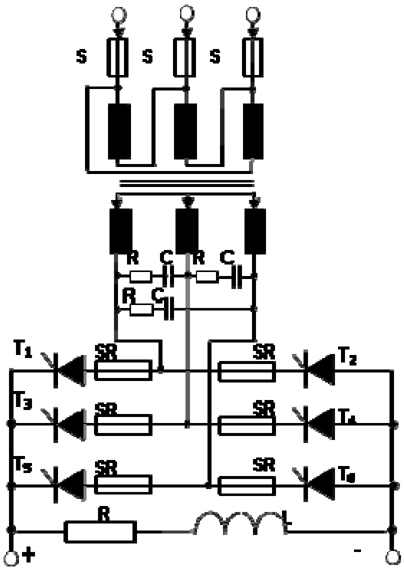

Fig. 6. The scheme of a rectifier with RL Load.

III. 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 depicted in Fig. 7 [1], [5].

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

• faulty supply;

• faulty motor;

• faulty rectifier control; one faulty thyristor.

The qualitative analysis of the faults concerning the supplying source, the semiconductors of the rectifier or the control part of the rectifier was performed in previous papers [2-4].

IV. QUANTITATIVE ANALYSIS OF THE FAULTS FOR A RECTIFIER SUPPLYING A VARIABLE DC DRIVE

In the methodology of analysis of system reliability using the tree fault method, quantitative analysis follows qualitative analysis. This analysis determines the probability of occurrence of the flaws, taking into account their propagation paths through the components of the tree.

The reliability of an “object” is defined as its capacity to fulfil the function for which it was designed, for a specified time interval and with a known probability. This concept can be applied to any product, device, system or element.

By correctly defining a number of parameters, the predicting can be achieved with some degree of confidence.

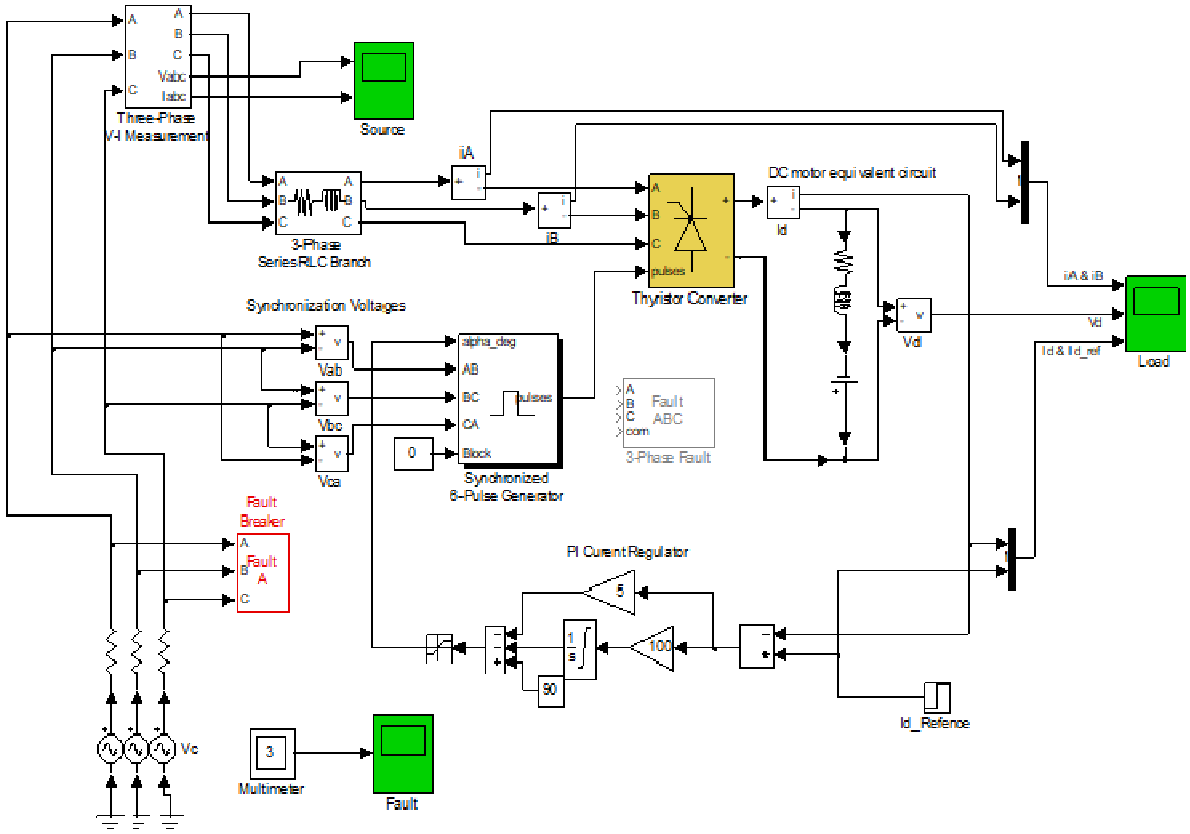

Fig. 7. The Simulink model of a three-phase thyristor converter supplying a variable DC drive

The most important is to choose the distribution that corresponds to the data. The results will not be credible if a correct distribution is not chosen. The failure rates of the single components must be based on a big enough number of examples and relevant for reflecting the daily normal usages. There are empirical considerations, such as determining the slope of the failure rate and calculating the activation energy, as well as environmental factors, such as temperature, humidity, and vibration.

Reliability of systems can be abstract in that it implicates much statistics. The design must fulfill its intended mission Product reliability is seen as a testament to the robustness of the design as well as the integrity of the quality and manufacturing commitments of an organization.

The life of a product categories can be divided into three distinct periods. Figure 8 shows the reliability curve which models to instantaneous failure rates vs. time. If we follow the slope from the start to where it begins to flatten out this can be considered the first period. The first period is characterized by a decreasing failure rate. It is what occurs during the early life of a product categories. The weaker units die off leaving a product that is more rigorous. The next period is the horizontal portion of the graph. It is called the normal life. Failures occur more in a random sequence during this time. It is difficult to predict which failure mode will manifest, but the rate of failures is predictable. Notice the constant slope. The third period begins at the point where the slope begins to increase and extends to the end of the graph. This is what happens when units become old and begin to fail at an increasing rate.

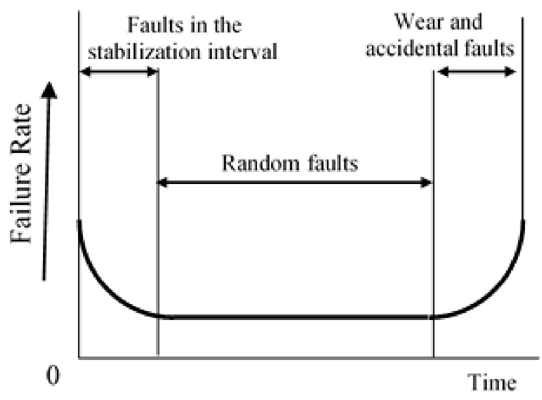

Fig. 8. Reliability Curve

As the product matures, the weaker units die off, the failure rate becomes nearly constant, and modules have entered what is considered the normal life period. This period is characterized by a relatively constant failure rate. The length of this period is referred to as the system life of a product or component. It is during this period of time that the lowest failure rate occurs. Notice how the amplitude on the bathtub curve is at its lowest during this time. The useful life period is the most common time frame for making reliability predictions.

Weibull analysis can be used as a method of determining where a population of modules is on the bathtub curve. The Weibull distribution is a 3-parameter distribution. The three parameters that make up the Weibull distribution are α, β and time. The Weibull distribution is given by:

$$f(t) = \alpha \cdot \beta \cdot t^{\beta-1} \cdot e^{-\alpha \cdot t^{\beta}} \quad (1)$$

The Weibull parameter β is the slope. It signifies the rate of failure. When $\beta < 1$, the Weibull distribution models early failures of parts. When $\beta = 1$, the Weibull distribution models the exponential distribution. The exponential distribution is the model for the useful life period, signifying that random failures are occurring. When $\beta = 3$, the Weibull distribution models the normal distribution. This is the early wear out time. When $\beta = 10$, rapid wear out is occurring.

“Accelerated life testing” employs a variety of high stress test methods that shorten the life of a product or quicken the degradation of the product’s performance. The goal of such testing is to efficiently obtain performance data that, when properly analyzed, yields reasonable estimates of the product’s life or performance under normal conditions.

This induces early failures that would sometimes manifest themselves in the early years of a product’s life, and also allows issued related to design tolerances to be discovered before volume manufacturing. Both the type of stressor and the time under test are used to determine the normal lifetime. There are various stressors including, but not limited to, heat, humidity, temperature, vibration, and load. The effect of these stressors can be mathematically determined.

The equation below is used to model acceleration due to temperature and is referred to as the Arrhenius equation. The Arrhenius equation relates how increased temperature accelerates the age of a product as compared to its normal operating temperature [7]:

$$A_f = e^{\frac{E_a}{k}\left(\frac{1}{T_u}-\frac{1}{T_t}\right)} \quad (2)$$

Where,

A_f - acceleration factor;

E_a - activation energy [eV];

k - Boltzmann’s constant;

T_u - reference junction temperature [K];

T_t = junction temperature during test [K].

Humidity is also a stressor.

The equation below (Hallberg – Peck) models the effect of temperature and humidity combined on product life [7]:

$$A_f = \left(\frac{RH_t}{RH_u}\right)^3 \cdot e^{\frac{E_a}{k}\left(\frac{1}{T_u}-\frac{1}{T_t}\right)} \quad (3)$$

RH_u – use environment relative humidity;

RH_t – test environment relative humidity.

The stressor that has the most profound effect on product life is thermal cycling. The acceleration factor due to thermal cycling is given by the Coffin-Manson equation below [7]:

$$A_f = \left(\frac{\Delta T_l}{\Delta T_f}\right)^9 \cdot \left(\frac{f_f}{f_l}\right)^9 \cdot e^{\frac{E_a}{k}\left(\frac{1}{T_{maxf}}-\frac{1}{T_{maxl}}\right)} \quad (4)$$

Where:

ΔT_l = lab temperature difference between highest and lowest operating temperature;

ΔT_f = field temperature difference between on and off state;

f_f = cycle frequency in the field;

f_l = cycle frequency in the lab.

Activation energy is derived from empirical data gathered during accelerated testing and is the slope of the failure rate at two different stressors. Activation energy represents the effect that the applied stress will have on the product under test — the stress factor being heat, voltage, current, or vibration. Large activation energy indicates that the applied stress will have a large effect on the life of the product.

The reliability function of an exponential distribution that a system will operate without faults for a time interval (0, t) is denoted [8-10]:

$$p(t) = e^{-\lambda t} \quad (5)$$

where λ is the failure rate expressed in p.u.

When determining the reliability of a product, the exact failure time can never be known. The Chi2 distribution can be used because it is a probability distribution by which the observed data resolve the expected values. The relationship between failure rate and the Chi distribution is as follows [15]:

$$\lambda = \frac{\chi^2_{CL,2\cdot(r+1)}}{2 \cdot t \cdot A_f} \quad (6)$$

Where, r is the number of failures;

CL is the confidence level;

t is the accumulated test time.

The reliability of the system from n components in series [3]:

$$p(t) = \prod_{i=1}^{n} p_i(t) \tag{7}$$

where $p_1(t)$ is the transformer reliability function, $p_2(t)$ is the rectifier reliability function and $p_3(t)$ is the DC motor reliability function. It results the reliability of the system expressed as [faults/year] [11]:

$$p(t) = 0.00899 \cdot 0.0216 \cdot 0.189 = 0.000036 \tag{8}$$

The acceleration factor for stress-dependent models is: $A_f=0.4129$ [14]. If we consider the acceleration factor the reliability of the analyzed system is (6):

$$p(t) = 0.00766 \cdot 0.0145 \cdot 0.0155 = 0.00000172 \tag{9}$$

CONCLUSIONS

The paper presents a defect detection system based on development the tree faults analysis for a power rectifier. For the qualitative analysis of the faults, the tree of faults is developed, based on symptoms, considered to be the most frequent ones during the operation of the power rectifiers.

The quantitative analysis of the fault tree is the last step in the methodology of reliability analysis of the systems by using the fault tree method.

The reliability model of the analyzed system is a series one. The reliability of the system is determined by accelerated life testing.

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