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FUNCTIONAL AND DIAGNOSTIC STRUCTURE OF THE EQUIPMENT OF A WIND POWER STATION

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Abstract: This article describes functional and diagnostic structure of the equipment of a Wind Power Station. Considering particular operational conditions of a technical object, that is a set of Wind Power Station equipment, this is a significant issue. A structural model of Wind Power Station equipment is developed. Based on that, a functional – diagnostic model of Wind Power Station equipment is elaborated. That model is a basis for determining primary elements of the object structure, as well as for interpreting a set of diagnostic signals and their reference signals.

Keywords: Artificial Intelligence, Expert Systems, Knowledge Base, Technical Diagnostics, Wind Power Plant

1. INTRODUCTION

Expert systems are programs that can help or replace human experts in a specific field. Such systems can provide pieces of advice, recommendations or diagnoses relating to problems appearing in a specific field [1, 2, 7-13, 16, 28]. Computer programs developed in that way are of great importance and use for fields that are poorly formalized (without having mathematical backgrounds, which could be created algorithms for) e.g. diagnostics, medicine, etc [4, 6, 22-23, 26-27]. Expert systems are characterized not only by their capability to solve non-algorithmically defined problems but also have other advantages e.g. collected expert knowledge can be easily transmitted and available if experts are not present at time (due to their sick health or retirement) and coded knowledge can be easily delivered (it is easier to copy a computer program than teach another human) and a response can be acquired fast, and there are no human symptoms like fatigue nor stress [8-13].

A problem of creating effective knowledge bases for expert systems to be used in a diagnostic process of safe usage of Wind Power Plant's equipment is considerably complex. One may say that this problem is of interdisciplinary character since it relates to e.g. IT (expert systems, knowledge bases), math (gathering and analyzing knowledge sets), diagnostic (creating models for technical models and organizing signals' measurements), reliability – operational (examining technical conditions of objects), artificial intelligence (processing and transferring human expertise into artificial knowledge using a computer programming languages) [2, 7, 10-13].

The article covers issues such as:

- making models for technical objects, including functional-diagnostic models,
- examining technical objects, including evaluation of technical condition, and creation of diagnostic signal sets,
- measuring diagnostic signals, including analysis of measurement results and creation of reference diagnostic signal sets,

- expert knowledge relating to gathering, analyzing, and concluding in an expert system,
- math problems, including creation of knowledge sets, analysis, and conclusions (making decisions).

The above-mentioned issues are not presented in literature clearly and comprehensively. Hence the diversity of the subject matter of publications used in the article. The authors of this article presented their approach to the development (solution) of such a complex problem. Such a full approach to the problem of presenting the issue of building an expert knowledge base for the purposes of diagnosing the state of safe use of wind farm equipment is an innovative solution [1, 7, 17, 20, 24-25].

This work presents the issues of building a diagnostic knowledge base for wind farm equipment. The development of a diagnostic knowledge base is the basis for building a set of facts and rules for the future expert knowledge base being built.

2. FUNCTIONAL AND DIAGNOSTIC STRUCTURE OF THE EQUIPMENT OF A WIND POWER STATION

The basis of the technical diagnostics of technical devices and items $\{O(e_{i,j})\}$ is the performance of a diagnostic test of the item examined. The diagnostic test of the item consists in a number of technical and technological activities as well as mental activities. The effect of these activities is the structure of the technical item in the form of its functional and diagnostic diagram based on which the set of the diagnostic signals $\{X_{i,j}\}$ is determined. The functional units of the item (units) in the functional and diagnostic diagram presented in Fig. 1 are "addressed": numbered in the following manner: (E_i) is the i -th number of the functional unit in the item [3-6].

The elements of the unit are "addressed" in the form $(e_{i,j})$, where j -th means the number of the element in the i -th unit. It is accepted that the j -th element or the basic module distinguished in the diagram of the structure of the item is such an element (module) of the item which is indivisible in its structure, and which develops its output signal. This

signal is further known as the measuring signal or the diagnostic signal. When the element develops more than one output signal, it is only one generalized signal that needs to be determined which expresses best the functional (diagnostic, reliability etc.) properties of a given j -th element [3-6].

The functional units are defined in the system as units and primary elements are defined as elements. Third level subunits perform the function of intermediate "elements" that enable the bidirectional transformation of the hierarchic form of the item into the matrix internal structure presented in (Tab. 1 and Figs. 2 and 3).

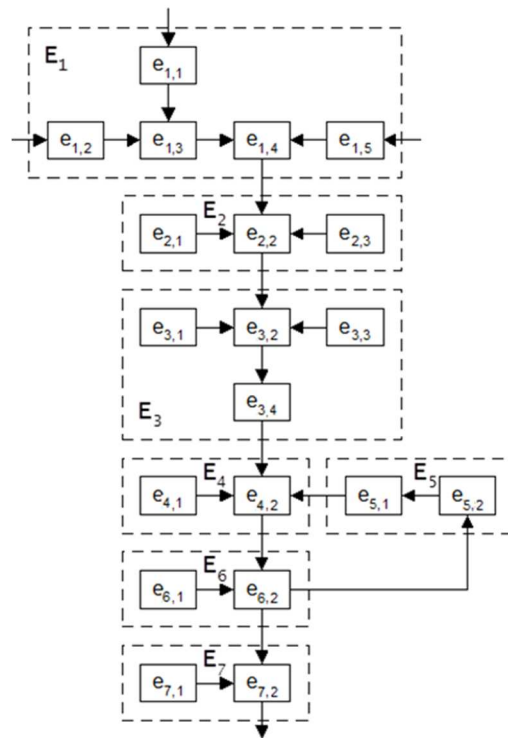


Fig. 1. Functional diagnostic diagram of a wind turbine generator, where: E1 – generator drive system, E2 – synchronous generator system, E3 – generator's magnet system, E4 – power regulator system, E5 – electric power converter system, E6 – voltage and current coordinate converter system, E7 – MV transformer assembly

Tab. 1. A set of diagnostic signals $\{X(e_{i,j})\}$ determined in a wind farm model

Object Units	A set of diagnostic signals $\{X(e_{i,j})\}$ determined in a wind farm model				
E ₁	e _{1,1}	e _{1,2}	e _{1,3}	e _{1,4}	e _{1,5}
E ₂	e _{2,1}	e _{2,2}	∅	∅	∅
E ₃	e _{3,1}	e _{3,2}	e _{3,3}	∅	∅
E ₄	e _{4,1}	e _{4,2}	∅	∅	∅
E ₅	e _{5,1}	e _{5,2}	∅	∅	∅
E ₆	e _{6,1}	e _{6,2}	∅	∅	∅
E ₇	e _{7,1}	e _{7,2}	∅	∅	∅

Where: $e_{1,1}$ – turbine shaft stabilization unit, $e_{1,2}$ – main transmission, $e_{1,3}$ – transmission temperature control system, $e_{1,4}$ – clutch, $e_{1,5}$ – generator brake, $e_{2,1}$ – synchronous generator, $e_{2,2}$ – generator temperature control system, $e_{3,1}$ – magnetic field winding, $e_{3,2}$ – system excitation voltage regulation, $e_{3,3}$ – matching system, $e_{4,1}$ – PWM inverter assembly, $e_{4,2}$ – generator power regulator, $e_{5,1}$ – controlled rectifier, $e_{5,2}$ – inverter, $e_{6,1}$ – U_A, U_B, U_C - three-phase voltage coordinate converter assembly, $e_{6,2}$ – current coordinate converter unit I_A, I_B, I_C ; $e_{7,1}$ – MV transformer temperature control system, $e_{7,2}$ – MV transformer unit.

It is assumed that the j -th basic element or basic module highlighted in the structure of the object structure is the element-module of the object that is not divisible in its structure, and which produces its output signal. The signal generated is referred to as the measuring signal or diagnostic signal. If an element generates more than one output signal, then only one generalized signal should be determined, which most closely reflects the functional (diagnostic, reliability, etc.) properties of the given j th element.

As a result of functional and diagnostic analysis, a set of measuring and reference diagnostic signals $\{X(e_i, j)\}$ was identified in the wind farm model, which are identified at the outputs of j -functional elements. The designated set of reference and measuring diagnostic signals $\{X_w(e_i, j)\}$ of a wind power plant is presented in Table 2. By analyzing

values of measurement signals, a set of reference diagnostic signals $\{X_w(e_i, j)\}$ of wind turbine generators is designated and shown in Table 2.

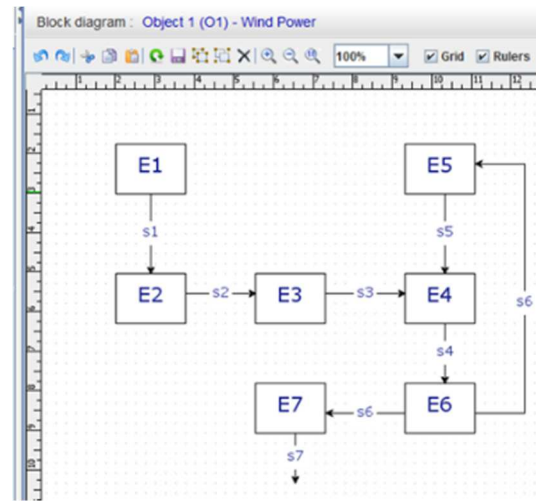


Fig. 2. Screen of (DIAG 2) programme - diagram of the functional and diagnostic structure of the wind power system, where: E1 – generator drive system, E2 – synchronous generator system, E3 – generator’s magnet system, E4 – power regulator system, E5 – electric power converter system, E6 – voltage and current coordinate converter system, E7 – MV transformer assembly

Unit	e1	e2	e3	e4	e5
E1	18	240	239	57	12,5
E2	0,0038	746	28	∅	∅
E3	38	1487	1487	1487	∅
E4	38	690	∅	∅	∅
E5	3,35	1,38	∅	∅	∅
E6	1,67	678	∅	∅	∅
E7	37	1,75	∅	∅	∅

Number signals 20 Number ∅ 15

Fig. 3. Screen of consolidated diagnostic information in (DIAG 2) software, where: E1 – generator drive system, E2 – synchronous generator system, E3 – generator’s magnet system, E4 – power regulator system, E5 – electric power converter system, E6 – voltage and current coordinate converter system, E7 – MV transformer assembly

Tab. 2. Set of measurement diagnostic signals and reference signals $\{Xw(e_{i,j})\}$ for one wind turbine generator in a Wind Power Plant as an example

Object Units		Signals of Basic Object Components	
Symbol	Description	Symbol	Description of example diagnostic signals
E ₁	Nacelle with drive train	X(e _{1,1})	Wind speed and direction measurement system - 18 reference value 18
		X(e _{1,2})	Yaw system - 240 reference value 240
		X(e _{1,3})	Drive train - 239 reference value 240
		X(e _{1,4})	Rotor - 57 reference value 60
		X(e _{1,5})	Pitch system – 12.5 reference value 13
E ₂	LSS	X(e _{2,1})	LSS stabilization system - 0.0038 reference value 0.0035
		X(e _{2,2})	LSS - 746 reference value 750
		X(e _{2,3})	LSS grease system - 28 reference value 30
E ₃	Gearbox	X(e _{3,1})	Gearbox temperature regulation system - 38 reference value 40
		X(e _{3,2})	Gearbox - 1487 reference value 1500
		X(e _{3,3})	Clutch - 1487 reference value 1500
		X(e _{3,4})	Mechanical brake - 1487 reference value 1500
E ₄	Generator	X(e _{4,1})	Generator temperature regulation system - 38 reference value 40
		X(e _{4,2})	Generator- 690 reference value 690
E ₅	Magnetizer	X(e _{5,1})	Magnetizer- 3.35 reference value 3.40
		X(e _{5,2})	Generator current regulation system - 1.38 reference value 1.40
E ₆	Converter	X(e _{6,1})	Power regulator system- 1.67 reference value 1.80
		X(e _{6,2})	Converter - 678 reference value 690
E ₇	MV Transformer	X(e _{7,1})	MV transformer – 1.75 reference value 1.80
		X(e _{7,2})	Output block - power grid – 1.75 reference value 1.80

3. CONCLUSIONS

The expert system described above that supports diagnosing wind farm devices works out an assessment of the working condition of its individual elements based on input data and a knowledge base created. Obtaining a diagnosis and the realization of the inference process takes place in an intuitive manner through the subsequent occurrence of panels that form the so-called diagnosing path. Owing to the use of a graphical interface, there is a quick access to the working condition of all the elements of the wind farm within the framework of a consolidated (general) assessment. In a detailed assessment, each element of the farm presents the working conditions of all the sub-assemblies (blocks) and the reasons of the occurrence of an alarm or failure signal. The database that is based on real measurements (the real values of diagnostic signals) and an extended knowledge base allow one to obtain a reliable diagnosis of the functioning condition of the wind farm devices. Owing to this, the expert system described can be successfully used as a part of an intelligent supervision and safety system in the operation of the wind farm.

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Biographical notes



Stanisław Duer was born at Latyczyn in Poland. He received the B.Sc. and M.Sc. degrees in electrical engineering from Military University of Technology, Warsaw, Poland. In 2003 he defended the Ph.D. thesis on technical diagnostic and received a PhD degree from Department of Mechatronics, Military University of Technology. Since 2003, he has been an Assistant Professor with the Applied Electrical Engineering and Electronics in Department of Mechanics, Technical University of Koszalin, Poland. He published sixteen books and more than 190 articles. Since 2013 he is working at the Department of Energy in Faculty of Mechanics of Technical University of Koszalin as the Professor. His areas of interest are: technical diagnostic, diagnostic systems with an artificial neural network, mathematical modelling, application of mathematical, expert systems, control theory, innovation in electronic applications in the wind power plants equipment, cars and others.



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Wrzesień Paweł was born in 1987 at Darłowo, Poland. He received the B.Sc. degree in power engineering in 2016 from the Technical University of Koszalin and has been expecting the M.Sc. degree in electric power engineering in 2018 from the Wrocław University of Science and Technology.

From 2012 to 2015 he worked as operations & maintenance manager of wind farms. Since 2015 he has been Head of Technical and Commercial Management of Wind and PV assets at vortex energy, managing the assets in Poland and Germany. His areas of interest are: optimization of operations and maintenance of wind and PV parks, technical diagnosis, development and application of the AI in expert systems for operational safety and reliability of wind and PV parks interconnected to respective DSOs.



Ján Valiček graduated from the Faculty of Mining and Geology, Technical University of Ostrava in 2000. He received his PhD and DSc degrees in 2004 and 2008, respectively. Currently he works as an professor in Department of Mechanical Engineering, Faculty of Technology, Institute of Technology and Business

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