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MACHINERY LIFE CYCLE EFFICIENCY MODELS FOR THEIR SUSTAINABLE DEVELOPMENT

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Abstract: The work describes the components of efficiency in the form of energy, economic and ecological benefits and outlays in the life cycle, i.e. construction and operation of machinery, equipment and power systems, on the example of wind farms and the most important models useful in designing their construction and operation for increasing system safety in three areas: environment, technical system, and human health. Technical conditions (ideas, constructions and processes) necessary to increase the benefits and / or reduce energy, economic and ecological expenditure of the operation and the prospects for effective development of the global, European and national wind energy market are characterized. A preliminary analysis of the relations of operators, workpieces, live and artificial objects of the 2-MW wind farm environment was carried out, for the possibility of increasing the benefits and reduction of outlays as a result of compensating for the destructiveness of the system, the environment and man.
Keywords: energy, economic and ecological efficiency, wind farms

1. INTRODUCTION

Intelligent development of energy, economic and ecological efficiency in the field of safer construction and maintenance of a power plant machinery, including wind farm equipment such as: machines and devices of systems used for generation, transfer and utilization of electric power and energy, involves being familiar with electrical engineering, especially, the equipment best performance states and innovative technical solutions (including modernization and optimization) (Caiado et.al., 2017; Ackermann, 2005; Niu et al., 2018; Yin et al., 2018).
The states of a technical system best performance, its goals, functional qualities; benefits for people and/or intelligent development of energy, economic and ecological efficiency in construction and maintenance of a power plant machinery, including wind farms; machines and devices of systems for generation, transfer and utilization of

power and energy, involves familiarity with electrical engineering, particularly, the equipment best performance states and innovative technical solutions (including modernization and optimization) (Flizikowski and Bielinski, 2012; Song et al., 2018; Tomporowski et al., 2017a; Tomporowski et al., 2017c).

The assumed best states of a technical system performance, its goals, functional characteristics; benefits for humans and/or the environment are closely related to high, higher and the highest quality of the product (Tomporowski et al., 2017b):

- Quality of the product of construction and maintenance of machines and systems for energy generation (structure, power, energy, waste dissipation);
- Energy, economic and ecological efficiency of operation, transformation, transfer and utilization of power and energy; respective devices, systems, production lines;
- The product, process, technological solutions impact harmlessness on humans, the environment and internal relations (including safety);
- Knowledge of the man, goals and assumed best states of machine performance as well as the environment and resources; of technical, organic and boundary conditions as well as power and energy processes.

The major goal of the study is to develop and verify a rational method for description, analysis, assessment between a logical connection of a machine construction and maintenance overall efficiency with reduction of costs and increase in benefits involved in a wind farm operation as well as provide a research methodology and economic, ecological and energy related implications for: operators' ergonomics, functionality of workpieces, harmlessness of the natural environment including living creatures, wear intensity (fatigue) of manmade objects of the environment - elements, subsets, working units of a selected wind farm.

2. MODELS OF LIFE CYCLE

A life cycle of machines, devices and technical systems starts with formulation of the need (stage I), and finishes with management of the post life potentials (stage VI). Design of technical conditions (Wt) for machines, devices and technical systems of a power plant in general, particularly wind power ones, both onshore and offshore wind farms (Fig.1), involves, first of all, social agreement for the wind farm to be constructed, maintained and utilized (Tomporowski et al., 2018a).

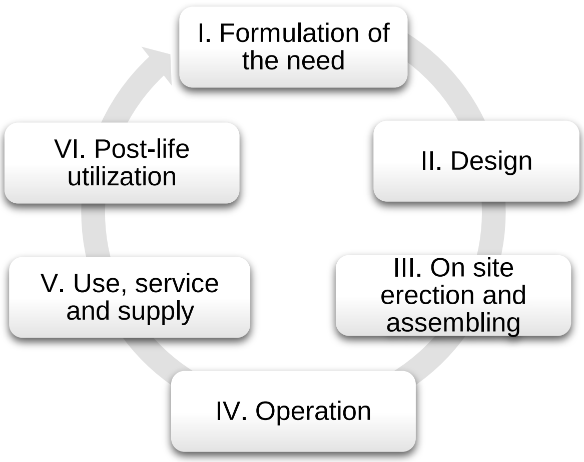

Fig.1. Processes, life cycle and stages of onshore wind farm technological systems existence, offshore (own study)

Technical conditions need to be designed created and maintained, they are variable in the lifecycle of *machines, devices and systems* of a wind farm. Outlays (N), benefits (K) and their relations are variable as well, e.g. efficiency index (e) of technological processes connected with formulation of the need, design, construction, manufacturing, investing, utilization and liquidation, that is, all stages of energy producing technical facility life cycle (Fig.1) (Flizikowski et al., 2018; Tomporowski et al., 2018b).

Exploitation of resources involves acquisition of: natural resources, industrial resources, knowledge, environmental means and human resources - people (engineers) (Klinglmair et al., 2014; Zastempowski et al., 2013).

The acquired resources undergo further utilization to become technical means, methods, states and transformations of their: creation, utilization, service, wear, power supply, liquidation of machines, use of resources, recycling, regeneration, waste storage or its total utilization (Cherrington et al., 2012; Choi et al., 2016).

A model of a machine life cycle, its construction and maintenance enables description, analysis and assessment of its operation efficiency. Operation efficiency depends on functional characteristics and time related operation potentials, that is, its own models.

3. OPERATION EFFICIENCY MODELS

The term efficiency is commonly used in different disciplines of science and technology and everyday life. Despite some specific aspects, due to diversity of objects, the core meaning of this term refers to: effectiveness, functionality, cost efficiency, effective use of outlays to achieve expected benefits.

Three models of technical object structural and operational efficiency have been developed (Flizikowski et al., 2018):

- Formal;
- Index;
- Integrated (destructive).

Formal efficiency, is a feature which represents rational capability of systems to meet given needs and desires of people, their functional qualities, the product value, its harmlessness and harmlessness of the operation process (achieving intended goals, operation consistent with destination and requirements).

Index efficiency is based on inflows and outflows of energy, finances, emissions; It is efficiency connected with costs incurred and benefits obtained from the operation.

Integrated efficiency means efficiency of useful, useless dissipation and final recovery of potentials for the environment and socially justified benefits from operation of: humans, technology, energy-matter and control.

Basing on the descriptive definition of efficiency given above, its substantial and index forms can be given as a ratio of benefits (U(t)) to direct outlays (N(t)) during operation:

$$E(t) = \frac{U(t)}{N(t)} \tag{1}$$

Quantities U(t) and N(t) mean the values of benefits and outlays until time t from the beginning of operation (t = 0).

Modeling of efficiency included three areas: energy e_{en}, economic e_{eko} and ecological e_{EKO}, which depend on single named benefits ($K_{en,eko,EKO}$) and outlays ($N_{en,eko,EKO}$), on destructiveness ($D_{s\text{-}o\text{-}c}$) and operation time (t_e):

$$SP(e_{en,eko\ EKO})_{zEW} = f(K_{en,eko,EKO},\ N_{en,eko,EKO},\ D_{s\text{-}o\text{-}c},\ t_e)_{zEW} \quad (2)$$

$$(K_{en,eko,EKO},\ N_{en,eko,EKO})_{zEW} = f\,(D_{s\text{-}o\text{-}c},\ D_o,\ D_f,\ D_{Eko},\ D_s,\ t_e) \quad (3)$$

where:
$SP(e_{en,eko\ EKO})_{zEW}$ – goals*,* assumed states of good performance: energy, economic and ecological efficiency of a wind farm operation - its systems,
$e_{en,eko,EKO}$ – energy, economic and ecological efficiency of a wind farm operation, e.g. in an offshore natural environment,
$K_{en,eko,EKO}$ – energy, economic, ecological benefits of an offshore wind farm operation,
$N_{en,eko,EKO}$ – energy, economic, ecological outlays of an offshore wind farm operation,
$D_{s\text{-}o\text{-}c}$ – destructiveness of the system, environment, humans,
D_o – non ergonomics of the technical system operation and the environment,
D_f – non-functionality of the technical system variables processing,
D_{Eko} – non-sustainability of the environment living organisms,
D_s – non-sozological of the system/object manmade systems/ objects,
t_e – operation time.
Mathematical models belonging to the index efficiency class (dependence type (1), which enable adequately precise prediction of values of benefits, outlays, effects of an identified life cycle of e.g. offshore system environment, on the basis of (familiarity with) values of their input quantities, are presented in table 1 where dependencies (4)-(6b) include:
e – energy, economic, ecological efficiency index of a life cycle ,
K – energy, economic, ecological benefits of stages and a life cycle,
N – energy, finances, environmental resources of a life cycle stages,
Δ – increase in energy economic, ecological benefits in a life cycle.

Table 1
Models of benefits, outlays and efficiency of creation, operation and maintenance in a life cycle of an offshore wind farm.

Index	Dependence	No.
Benefit	$\Delta E_{En} = K_{f-p} + K_p + K_k + K_w + K_{in} + K_{u-o-z} + K_{re+skl}$	(4)
Outlay	$N_{En} = N_{f-p} + N_p + N_k + N_w + N_{in} + N_{u-o-z} + N_{re+skł}$	(5)
Efficiency	$e_{En} = f\left(D_{o-s-c}\right) = \frac{\Delta E_{En}}{N_{En}}$	(6a)
	$e_{En} = \frac{\Delta E_{En}}{N_{En}} = \frac{K_{f-p} + K_p + K_k + K_w + K_{in} + K_{u-o-z} + K_{re+skl}}{N_{f-p} + N_p + N_k + N_w + N_{in} + N_{u-o-z} + N_{re+skł}}$	(6b)

Source: own research

4. RESULTS AND DISCUSSION

Verification of the model was carried out for a 2 MV Vestas V90 wind farm in Błaszki commune. The analysis included energy related aspects of the analyzed wind power plant, particularly determination of energy efficiency of the considered wind farm.
Energy efficiency is referred to as a ratio of a benefit obtained from operation of a given object, technical device or system, under typical service conditions to the amount of energy (outlays), used by the object, technical device or system, or

involved in its service needed for the effect to be obtained (art. 2 p. 3 of Energy Efficiency Act, acc. to URE). The calculation procedure is based on the proposed methodology and covers data, models, results and graphic interpretations. Details regarding benefits and outlays refer to the life cycle stages. The values of benefits and outlays, e.g. connected with energy use in particular life cycle stages, are variable and diversified. It is often difficult to identify these values for a single machine, system of a wind farm and its life cycle stages, especially as regards its creation (formulation of the need, design, construction, etc.).

The obtained results of the life cycle model variables are presented in table 2, table 3 and calculated efficiencies, respectively, in tab.4 and tab.5.

Table 2

Energy benefits in 2013-2015, from Vestas V90, MWh wind power life cycle stages

Energy benefits from VESTAS V90, 2.0 MW wind farm life cycle phases							
Year	**Kf-p**	**Kp**	**Kk**	**Kw***	**Kin**	**Ku-o-z**	**Kre+skł**
2013	0.2	0.2	0.2	259.29	0.1	5195	0.1
2014	0.05	0.05	0.1	259.29	0.3	4139	0.1
2015	0.1	0.1	0.05	259.29	0.3	5628	0.1

Source: own research, *-referred to a period of 25 years of a wind farm construction and operation

Table 3

Energy outlays in the period 2013-2015, from Vestas V90, MWh wind farm life cycle stages

Energy outlays for VESTAS V90, 2.0 MW wind farm life cycle phases							
Year	**Nf-p**	**Np**	**Nk**	**Nw***	**Nin**	**Nu-o-z**	**Nre+skł**
2013	0.1	0.1	0.1	31.98	0.05	22.59	0.05
2014	0.1	0.2	0.2	31.98	0.1	18.31	0.2
2015	0.05	0.05	0.1	31.98	0.2	14.39	0.1

Source: own research, *-referred to the25 year- period of a wind farm construction and operation

Table 4

Energy efficiency in 2013-2015 of Vestas V90 wind power operation

Energy efficiency of VESTAS V90, 2.0 MW wind farm												
Year	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
2013	366	185	434	230	154	65	103	102	208	444	343	1327
2014	259	945	268	245	471	144	158	196	214	270	237	448
2015	1642	548	748	818	167	126	183	240	295	299	475	1825

Source: own research

Table 5 shows annual and three-year energy efficiency for Vestas V90 wind farm operation phase, according to a simplified dependence (6b), covering (*u*), mainly service (*o*) and supply (*z*):

$$e_{Enu} = \frac{\Delta E_{Enu}}{N_{Enu}} = \frac{K_{u-o-z}}{N_{u-o-z}} \qquad (7)$$

Annual average energy efficiency for the phases of operation, maintenance, and supply reaches the value range (321,25; 613,83), whereas, the average energy efficiency for a 3-year period is e_{Enu}=422.06. These values are rarely reported in professional power engineering or other areas of human activity.

Table 5
Annual and three-year energy efficiency in 2013-2015 of Vestas V90 wind farm operation phase

Energy efficiency of j VESTAS V90, 2.0 MW wind farm		
Year	**Annual efficiency**	**3-year efficiency**
2013	33.10	422.06
2014	31.25	
2015	613.83	

Source: own research

5. CONCLUSIONS

The major **goal** of the study involving identification and verification of a reasonable connection of destructiveness with a decrease in costs an increase in benefits for operation of an offshore wind farm operation, in terms of energy, economy and ecology, has been achieved for particular phases of its life cycle.

Two models were accepted to achieve the study goal: a model of a wind farm life cycle and a model of a wind farm operation efficiency. Mathematical models classified as operation efficiency index models (of (1) dependence type) were chosen to enable adequately precise, numerical determination and prediction of the values of benefits, outlays, life cycle effects of the identified machine construction and maintenance facility, e.g. an offshore system environment, on the basis of the input quantity values.

In the Life Cycle Approach, phases of a wind farm, dominant values occur for energy benefits ($K_{u\text{-}o\text{-}z}$) i and outlays ($N_{u\text{-}o\text{-}z}$) of the phases of operation, service and supply. (tab. 2 and tab.3). In time approach , the highest benefits from operation (utilization) of a wind farm occur in January and December (tab.4) and the highest outlays are found for operation, service and supply in June (tab.4).

It has been proven that it is possible to provide actual life cycle scenarios of wind farm working systems and their resources, materials and elements, with a special focus on available models of the post life utilization. It allows to perform further tests and assessments of life cycle phases of working systems and resources, materials and elements of wind farms, not only on the basis of manufacturer's data but also data provided by the users, and further - create structural, more ecological algorithms to be used for maintenance of working systems, resources, materials and elements withdrawn from operation.

It needs to be said that this study extends the knowledge of design, construction, operation and maintenance of machines, devices, technical systems and energy transformation processes as well as monitoring of high power wind farm functioning.

On the basis of currently available data and the authors' own research results, it was found that wind farms provide the possibility of substantial improvement upon ecological management of the world energy resources in order to comply with the rules of intelligent and sustainable development.

It is necessary to do further research in order to provide methods for intelligent processing of wind energy by means of machines. It was assumed that the author's original, model relations of benefits and outlays with operation efficiency of large wind energy generation systems, developed and presented in this study, provide the basis and inspiration for research on both wind farm systems and, widely understood, construction and operation of machines.

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