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Stability of power grids with significant share of wind farms

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***Abstract*—Wind power is a promising source of energy. It has, however, its own specificity. Unpredictability and low wind conditions stability are the important problems the users of wind power are faced with. These problems are considered in the paper. The type of big wind turbine is described as well.**

***Keywords*—power grids, vertical axis wind turbines**

I. Introduction

Industrial production of electric energy has its own specifics which is caused, first of all, by the fact that, on the industrial level, electric energy cannot be stored. As a consequence, the energy either can be stored in alternative forms or it has to be transmitted to the power grid and consumed immediately. The first solution is based on hybrid systems in which a module that products electric energy is connected to the module that stores it in other form. Such systems are applied in the cases in which the possibility of the control of the energy production is limited, for instance in wind farms. To cope with this drawback, hydro pumped-storage units have been proposed in the literature as a good complement to wind generation due to their ability to manage positive and negative energy imbalances over time [1, 2, 3]. The capacity of such reservoirs of energy is, however, significantly limited. Therefore, on the national and higher levels, only tiny fraction of the produced electrical energy can be stored which means that, as it has been aforementioned, the produced energy has to be transmitted and consumed on-time. This causes a few crucial problems. Due to high inertia of the energy production in power stations in which the energy production can be controlled effectively, first of all thermal power stations, there is demand for the systems of precise prediction of electric power load on the national level in one-day time horizon – short-term load forecasting. Systems based on artificial intelligence as well as on statistical analysis give satisfactory results in such prediction – the papers [4, 5, 6, 7, 8, 9, 10, 11] can be put as examples. Long-term load forecasting is also done for long-term power systems management [12, 13, 10, 14, 11]. The aforementioned fact that electric power cannot be economically stored results in direct translation of the load fluctuations into variations in electricity process [11]. As a result the price of electricity is extremely volatile which can be even two orders of magnitude higher than for other commodities or financial instruments [11, 15]. The great environment pollution that takes place during the most common ways of electricity production, especially by thermal power station, is an additional problem [16, 17, 18, 19]. This is the reason for support for using clean energy sources, even if their usage is troublesome.

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II. Specificity of wind power industry

According to international forecasts, in the next 15 years the generating capacity installed globally will rise by approx.. 100%, reaching 10 500 GW in 2030. Additionally, by the year 2035 over 25% of total electricity will come from renewable sources. It is estimated that the wind power will account for 25% of this [20]. The financial crisis has affected mostly the growth rates in Europe, but the sector still experiences growth, though its rate has decreased from 21% to 10% per year. Recent years changed the high expectations on quick growth of the offshore wind farms. Still, there is a significant price gap between the onshore and offshore farms. The industry needs a decade to develop offshore wind generation technologies to match onshore ones. Thus, it is expected that in next two decades wind energy will still be an important part of the global power generation system, enjoying high growth rates.

The key consideration in the development of power generation industry are its costs. In the case of wind energy, there are several additional cost factors which need to be taken into account.

The wind power generation is **subsidized** in most of the countries. The industry goal is to decrease its dependence on this factor, but one need to keep in mind that other energy sources receive state subsidies as well. In Poland, for example the dominating coal plants are subsidized by high pension benefits for coal mines workers.

Wind power is generated in much more dispersed architecture that traditional star model with a few large power plants into one with many producers of different size. This requires significant reinforcement of **power grids**.

As we wrote earlier, there is no system-level energy storage technology available. Therefore, in order to keep the power system in a case of weaker winds there must be maintained a reserve of – in most cases – gas plants, which need to run on **stand-by** and are able to replace wind farms when needed.

There are also factors, which are usually not taken into account, but work in favour of wind power generation.

Wind power carries much less **social risks** than fossil or nuclear. Exploitation of fossil fuels (including mining or drilling, transportation and finally burning) on each stage increases the health risks. In the case of nuclear, there are claims that the whole process has less health impact, but societies are very hesitant about unlikely, but devastating risk of potential failures.

Wind power has very large potential for the **social impact**. The wind farms are more labor intensive during the construction phase (on par with nuclear). The impact is not only limited to manufacturing, because there is also significant amount of jobs created in installation and maintenance.

Finally, there is also **geopolitical impact**, which gains weight during tensions in Eastern Europe and Middle East. This risk is high for oil and is doubled in the case of natural gas. There is no such risk for wind energy.

There are also significant specific technical aspects of wind turbines. Initial technologies of conversion of the wind energy into mechanical energy were known for several thousand years. However, efficient conversion into the electrical energy has been introduced for last three decades. This area became well established business, with clear market leaders (i.e. Vestas from Denmark), followed by several companies, which rose to a very high position on this market. These were first of all companies from Germany (e.g. Nordex, Repower, Siemens) and Spain (e.g. Acciona, Gamesa). Next years brought next companies from all over the world into this field.

Throughout this time, numerous configurations of wind turbines were investigated. Many of these were actually built and its performance was tested in practice. Currently the vast majority of wind turbines follow the same layout. Currently available machines are of 2 – 3 MW power output. They all have horizontal main rotor axis with rotors having three blades. Such a turbine has the rotor of a diameter of more than 120m (compared to 18m in 1980).

There are two distinct subtypes of such a configuration: and the geared design and the direct drive (gearless) design. The first type uses a heavy duty gearbox to increase the rotational speed of the main rotor (12 … 30 rpm) about 100 times to the level required by the electric generator. The key cost factors of such a design are: tower (26%), rotor with hub and blades (25%), gearbox (13%), generator (3.5%) and power converter with transformer (8%). The components are available on the industrial market in large quantities, so the overall price enjoys the economy of scale. The key disadvantage of this type is unsufficient reliability of the gearbox. Despite of estimated lifetime of 20 years, many gearboxes experience failures after 6-7 years. This situation is mostly caused by the varying operational conditions of the drivetrain.

The other type (direct drive turbines), has a large diameter multi-pole generator, installed directly on the rotor. It is less popular, because it is more expensive as it requires heavy generator with permanent magnets. Since rare earth metals prices are rising, this design does not gain on popularity. The important advantage of this design is its robustness. The drivetrain is much simpler and does not include the gearbox, which may cause significant lossess.

III. Big wind turbine with vertical axis

A significant difficulty in the development of wind energy in some countries, including Poland, is the fact that in large areas of the country the average wind speeds are too small to make the exploitation of large, conventional turbines having a horizontal axis of rotation profitable. An interesting, innovative proposal developed in Poland is a kind of turbine that has a vertical axis of rotation, what significantly extends the wind window for low wind speeds. Some prototypes with 20 meters high masts have been already constructed (see Fig.1.). Currently, there is realized a project of a prototype wind turbine with 50 meters high mast construction and tests as well as of designing and testing computer systems for its intelligent monitoring and for its energy production capabilities predicting.

All activities that increase the predictability of the energy production by a large wind farm are especially valuable due to the fact that, as mentioned in the first chapter, the predictability is a really important problem that the wind energetic encounters.

A. *Characterisation of a vertical axis wind turbine*

The ANew Institute that introduced aforementioned prototypes conducted some research and experiments resulting in a proper comparison between the wind turbines with a vertical axis and the one with a horizontal axis of rotation. According to it, the vertical axis turbines as opposed to the ones with horizontal rotation axis, have the following features:

- wider wind window for small wind speeds,
- higher efficiency,
- no dependency on direction of wind,
- optimization for operation at low wind speeds,
- significantly lower level of noise emitted by the turbine,
- no interference with radars.

Fig.1. 20 meters high vertical axis wind turbine prototype

B. *Market potential and competitive advantages*

Wind turbine with a vertical axis of rotation, in addition to aforementioned features, acquires some other advantages related to the operation in industrial assemblies - wind farms. The main advantages are related to the possible locations of these types of wind turbines.

As it was mentioned before, the turbine with a vertical axis of rotation can even be used in areas of low wind conditions. This means that it can be installed in areas where the average wind speeds are low - even average wind speeds ranging 3-5 m/s are admissible. For a classical turbine with horizontal rotation axes this would not be recommended.

Due to wider wind window turbines with vertical axes of rotation can be located on many urban areas, particularly in the industrial zones. Low-value land, like heaps, may be exploited, what firmly reduces industrial losses. Also terrain of the high roughness is acceptable, as well as all other places of highly volatile wind conditions.

Another advantage of turbines with vertical axes of rotation is the possibility of installing them several times more densely than the traditional ones.

All mentioned benefits can give rise to considerations of choosing this innovative type of turbine alternatively to the classical turbine, when new wind farm investments are planned.

However, there is also one more, decisive advantage of the vertical rotation axis wind turbines. There is a possibility of installing them in existing wind farms, between conventional turbines, what solves the common problem of the location of new power stations. Such supply of an existing wind farm can increase its productivity without expanding the acreage. In the long term also the efficiency of sea wind farms can be increased in this way.

Thus, it seems that not only the turbine with a vertical axis of rotation can be a promising alternative in the energy market, but also a significant complement to existing capabilities of wind power.

C. *Cost savings*

The distribution of costs during the life-cycle of the unit for wind energy is significantly different from that of traditional, fossil fired units. First of all, initial investment costs are relatively higher, whereas in traditional units cost of fuel plays important role (usually it is the second largest cost). After commissioning, the largest cost for the wind turbine is maintenance. With proper maintenance policies, wind turbines can achieve the highest level of availability in the power generation sector - even up to 98%. The basis of proper maintenance is continuous monitoring of the transmission of the wind turbine.

In recent years large development of monitoring and diagnostic technologies for wind turbines has taken place. The growing number of installed systems causes the need for analysis of gigabytes of data created every day by these systems. Apart from the development of several advanced diagnostic methods for this type of machinery there is a group of methods, which act as an ”early warning”. They are based on data driven algorithms, which decide on a similarity of current data to the data already known. In other words, the data from the turbine are assigned to one of known states. If this is a state describing a failure, the human expert should be alarmed. If this is an unknown state, the expert should be informed about the situation and asked for a definition of such a new state. This kind of intelligent monitoring tracks wind turbine condition as well as detects faults and failures, what optimizes the cost of servicing and conservation.

There are several methods which have been developed as such a tool, in most cases based on various classification methods [21, 22]. Also authors of this paper have made the research on using artificial intelligence systems to develop this kind of tool, what have gave positive results [23, 24, 25, 26]. An innovative monitoring system based on the ART-2 neural network has been created to perform a classification of operational states of a horizontal axis wind turbine.

As far as the classification of a vertical axis wind turbine operational states is concerned, a new research related to this subject has already started. The idea of using the ART-2 network has been applied to data from wind turbines with a vertical axis of rotation. However, this kind of data have a different characteristic than data from horizontal axis turbines, what makes the classification of turbine operational states more difficult. It has been remarked that the ART-2 network is not able to work on this kind of data due to the network architecture limits. That is why the additional signal normalization procedure, based on an idea of a stereographic projection, has been introduced. A prototype monitoring system, composed using this normalization procedure and the ART-2 network unit, has been implemented and initially tested. System operation simulations results have been analyzed. Fig.2 presents one of test scenarios where turbine operational states have been correctly classified, as well as where data clusters have not been destabilized after a large data set had been processed. Therefore, the proposed

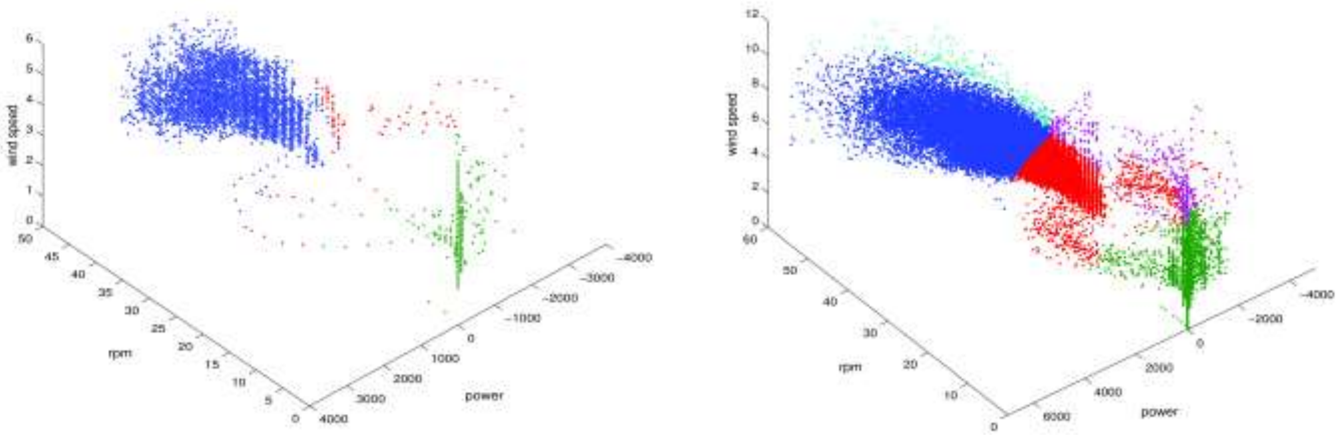

Fig.2. Operational states classification of the vertical axis wind turbine data by the system of the ART-2 neural network and the stereographic projection normalization. The left plot shows starting 10.000 data points of a full data set (500.000 points) placed in the right plot.

monitoring system is considered to be capable to perform an efficient classification and identification of new classes of operational states in real-time. Thus there is a possibility to perform this intelligent monitoring as an early warning tool optimizing a risk and costs of vertical axis wind turbines operations.

IV. Summary

A production of electricity on the industrial level encounters several significant problems. These include a prospect of depletion of conventional energy sources, an environmental pollution caused by electric energy production, an inability to store electric energy on the industrial level and some limitations in the usage of renewable energy sources. Problems with an access to fossil fuels and the prospect of their depletion cause the growing importance of renewable energy sources. In European countries, due to the climatic conditions, wind power offer the greatest potential among clean renewable energy sources. However, its major drawback is a relatively high unpredictability of production capabilities. In order to reduce that unpredictability, the predictive systems are developed. Another significant element reducing a risk in the wind energy production is a development of the intelligent monitoring systems, which allows to optimize the operating costs of wind farms. What is specific to the wind energy in Poland, the big part of the wind resources operates at low wind speeds. That, in large areas of the country, makes the operation of large turbines with horizontal axes of rotation unviable. The proposed solution to this problem is a Polish innovative turbine with a vertical axis of rotation.

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