

Is it Possible to Stably Manage Complexes of Unstable Aggregates? †

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Abstract: The transition to green energy is widely discussed by economists, journalists and politicians. As often happens, the engineers are almost inaudible. Meanwhile, there are problems. If green energy is based on wind turbines, as the most important and powerful power units, then the problem of sustainability in such an energy system will be extremely acute. Now it is not there, because wind energy is being added to a very stable nuclear, or carbon, one. All criteria for the stability of complex multidimensional systems begin with the words “All elements of the system must be stable in autonomous modes of operation ...”. The report proposes several provisions that analyze the conditions for the operation of wind power complexes from the point of view of ensuring their sustainability as multidimensional complex dynamic systems and proposes theoretical approaches to solving the problem.

Keywords: stability criterion; non-linear electromechanical structures; dual-fed electrical machines; frequency characteristics; equivalent circuits

1. Introduction: Formulation of the Problem

Most often, wind turbines use dual AC machines in which frequency converters on the rotor side correct the output voltage parameters. [12,13].

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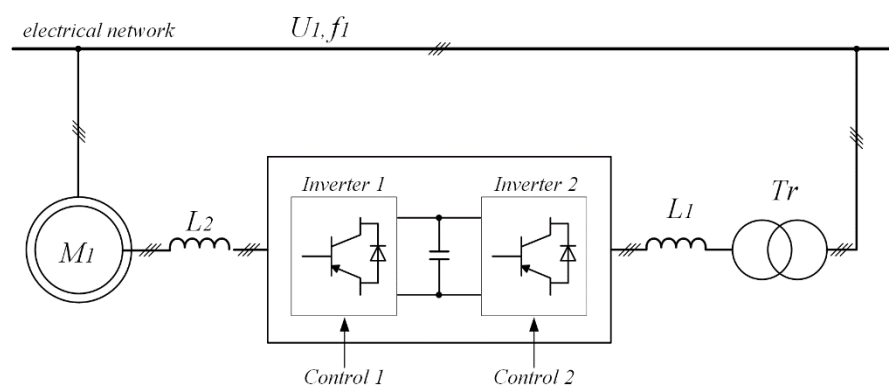


Figure 1

Since the pressure and wind speed are very unstable, the output voltages of the frequency machine do not meet the requirements of the power grids in terms of frequency and amplitude, and the control of the machine is most often not very efficient. In such modes, the electric machine is simply disconnected from the network.

At present, the basis of energy networks is formed by more stable nuclear, thermal and hydropower plants. Shutdowns of wind turbines, as a rule, do not affect the overall network, but if there is no stable part of the energy networks left after the “green turn”, the problem of building a sustainable network from some wind turbines will become relevant like no other.

Energy system sustainability problems are exacerbated by several factors.

1. Alternating current generators, which are most often used in power systems, including wind power complexes, are non-linear and very “prone” to oscillation systems [1–3,6,10].
2. Calculation methods generally accepted for such systems - vector equations, vector diagrams and equivalent circuits, arising from the equations of a generalized AC electric machine, called Park's equations, are built on a number of assumptions, which become qualitatively erroneous at a variable voltage frequency. Suffice it to mention that one of Park's main assumptions is the harmonic nature of all variable signals in an alternating current machine - voltages, EMF and currents, which, with a variable frequency of these signals, is erroneous in principle [6–9,10,11].

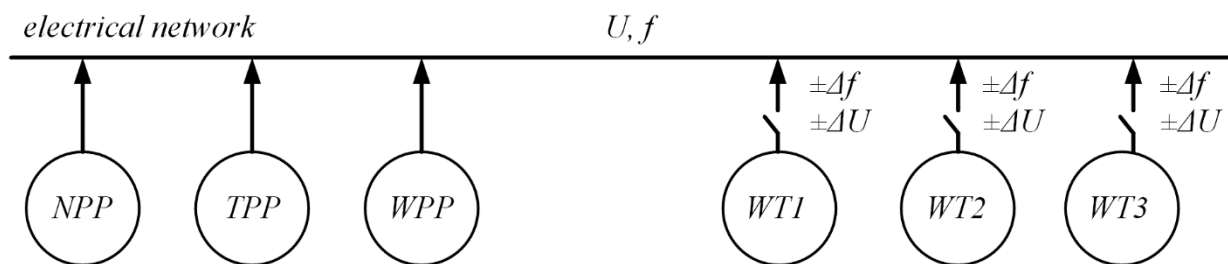


Figure 2. water-power plant (WPP), thermal power plant (TPP), nuclear power plant (NPP), wind turbines WT.

As mentioned above, at present, the connection of wind turbines to the system is built in such a way that in case of “wrong” voltage at the generator output, they are simply disconnected from the power grid. If there is no other sustainable energy network, how this algorithm will work is not very clear.

If we consider several wind turbines and their joint operation without an external network, it turns out that according to the traditional vector equations of each power unit it will not even be possible to draw up any exact general equation for their operation, since each operates at its own frequency. It is all the more difficult to formulate general conditions for stability.

Wind speeds and pressures will also be different. That is, while remaining within the framework of the "vector" theory, it is extremely difficult to describe the operation of these generators by unified equations.

2. Methods

In the works published earlier [4,5], the author and colleagues proposed a non-linear continuous transfer function, which shows how the dynamics of AC machines depends on the frequency of the stator voltage and the slip in the MIS, which is determined by the load. Such transfer functions will make it possible to draw up a general equation for a wind generator and analyze its stability.

$$W(p) = \frac{2M_k(T_2'p + 1)S_k}{\omega_1[(1 + T_2'p)^2 S_k^2 + \beta^2]} \tag{1}$$

where, ω_1 is the stator voltage frequency, β is the relative slip, depending on the drive load.

The family of frequency characteristics of the structure at three slip values β is shown in Figure 3.

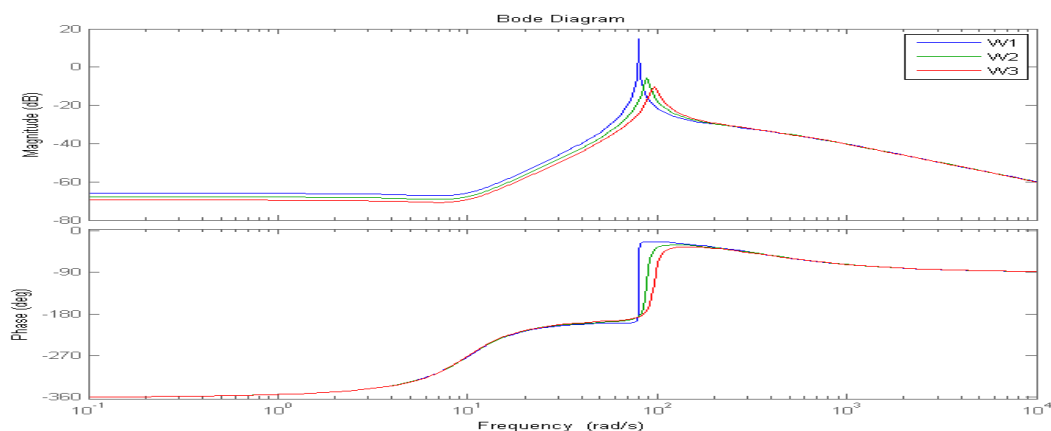


Figure 3

In the frequency zone corresponding to the peak of the amplitude characteristic, the negative phase characteristic confirms the “tendency” of the structure to oscillate.

This transfer function corresponds to the block diagram shown in Figure 4.

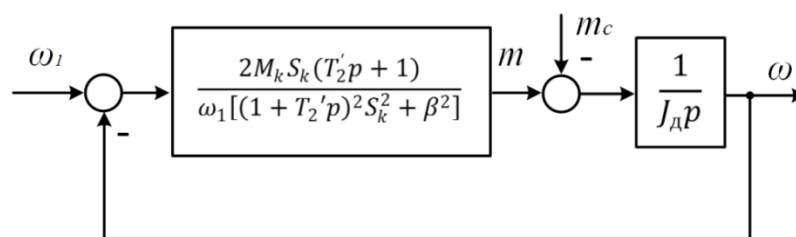


Figure 4

Unlike vector equations, which can only interact on a single carrier frequency, the transfer functions of multiple wind turbines can be subjected to any operation applied in automatic control theory (ACT).

The frequency characteristics built for asynchronous machines clearly show the frequency range with the most likely unstable processes - this is the frequency of electromagnetic processes in the machine. In machines with close parameters of the rotor and stator, the probability of oscillations is greatest, dual-feed machines for power engineering are just such machines.

However, the problem of the stability of systems with nonlinear dynamics is complicated by the fact that the methods for assessing their stability are somewhat "cumbersome" and are rarely used in engineering calculations.

It is proposed to analyze the stability of systems with nonlinear dynamics by the stability of linearized equivalent circuits.

The method of constructing equivalent circuits follows from the mathematics of stability theory.

For the stability of linearized systems, according to the conditions of the Nyquist criterion, it is sufficient that their frequency hodographs do not cover the critical point.

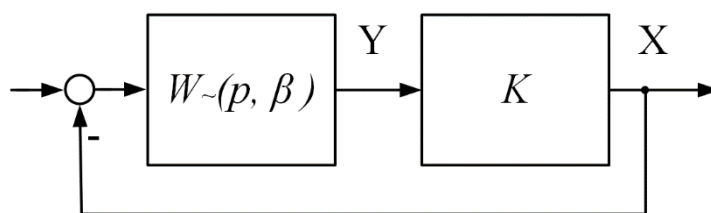


Figure 5

For the original nonlinear system, it is necessary that through this point it would be possible to draw a straight line that does not touch the hodograph (VM Popov's criterion for nonlinear systems) [1-3].

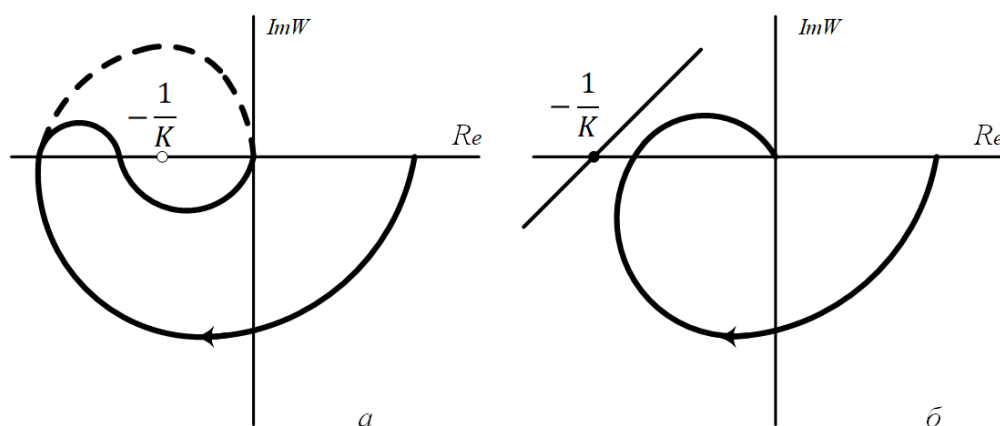


Figure 6

That is, if the hodographs of linearized systems are supplemented as shown in Fig. the stable states that exist only for linearized systems will cease to be stable, and such linearized systems with substitutions will be stable, the original nonlinear systems of which will be stable.

That is, that the original nonlinear system will be stable if the linearized system with the added dynamic link is Nyquist stable. complementing the hodograph of the original system. In the first approximation, such a link will be a first-order filter with a time constant. close to the cutoff frequency of the original system.

For the original nonlinear system, it is necessary that through this point it would be possible to draw a straight line that does not touch the hodograph.

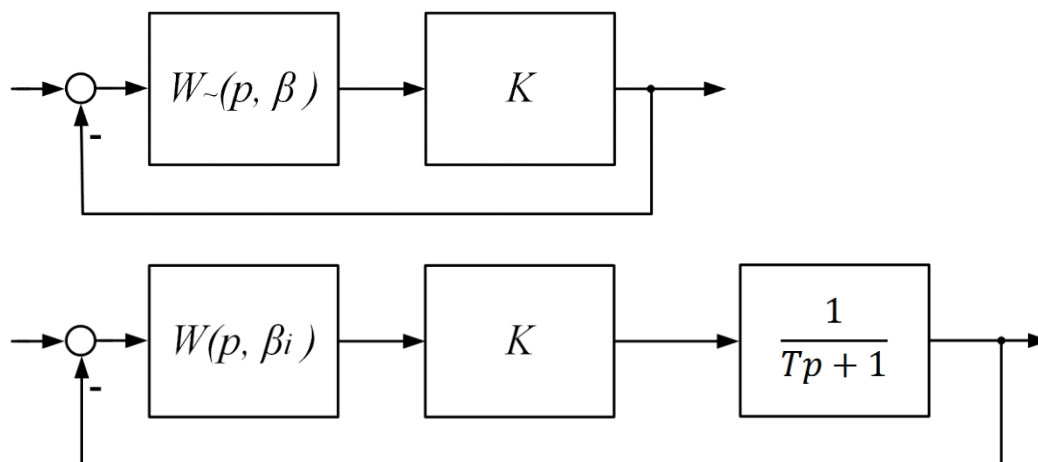


Figure 7

In this case, no initial requirements are imposed on the nonlinear continuous transfer function, except for the existence of this function and its continuity. It is possible to take into account the influence of external loads on the processes and on the transfer function itself.

This condition can be applied when designing wind power systems and when setting them up. In experiments and simulations, it is not necessary to separately investigate and stabilize all modes of operation of the generators or turn them off at the first mismatch of the output voltage parameters.

3. Results and Discussion

The existing mathematical apparatus of vector equations for considering and analyzing the stability of complexes of power units with nonlinear dynamics is extremely inefficient and leads to the inefficiency of the algorithms for their functioning in power complexes.

The proposed method for identifying asynchronous electric motors by nonlinear continuous transfer functions, which made it possible to significantly improve the quality of the operation of electromechanical nonlinear systems and select an effective correction for them, as for electromechanical complexes, will solve these problems for wind energy as well.

The formulated criterion for the stability of systems with nonlinear dynamics in terms of the stability of equivalent circuits can become a theoretical basis for design methods for dual-feed machines for wind power.

4. Conclusions

To consider stability, it is necessary to move away from vector equations and move on to continuous transfer functions and frequency responses.

In correction systems, it is necessary to take into account the dependence of dynamic characteristics (nonlinear transfer functions and families of frequency characteristics) on wind parameters and compensate this effect as much as possible.

For engineering analysis of the stability of wind turbines and their connections, it is necessary to effectively analyze the stability using the Nyquist criterion for equivalent circuits, taking into account the influence on the transfer function of various factors.

Conflicts of Interest: The authors declare no conflict of interest.

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