Proceeding Paper

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

Vladimir Kodkin

Department of Electric Drive and Mechatronics, South Ural State University, 454080 Chelyabinsk, Russia; kodkina2@mail.ru

† Presented at the 1st International Electronic Conference on Processes: Processes System Innovation, 17–31 May 2022; Available online: https://sciforum.net/event/ECP2022.

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 sustaining such an energy system will be extremely acute, especially now that wind energy is being used as a substitute for the more stable nuclear and carbon energy. 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 (Figure 1) [1,2].
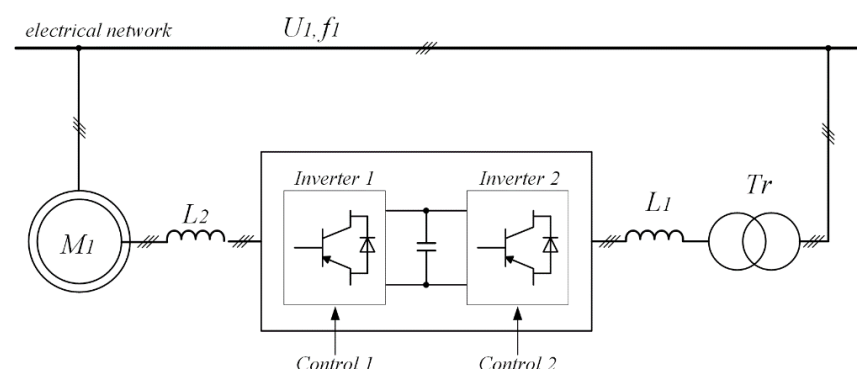

Figure 1. Scheme for connecting a dual AC machines (M_1) to an electrical network with voltage amplitude U and frequency.

Since 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 often not very efficient. In such modes, the electric machine is simply disconnected from the network.

Present energy networks consist of nuclear, thermal and hydropower plants (Figure 2), which are more stable. If wind turbines shut down, as a rule, it will not affect the overall

network, but if there are no remaining stable energy networks following the "green turn", the problem of building a sustainable network from wind turbines will become significant.
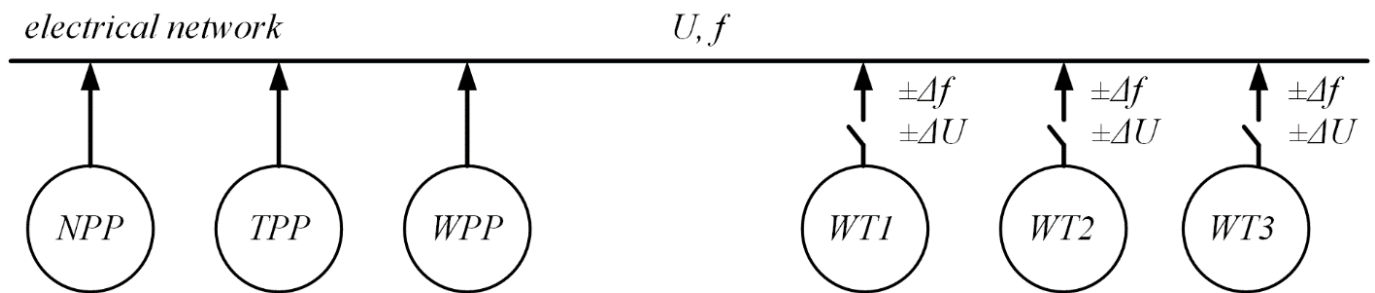

Figure 2. Scheme of a power grid with voltage amplitude U, frequency f and various energy sources with other voltage parameters. These sources -water-power plant (WPP), thermal power plant (TPP), nuclear power plant (NPP), wind turbines WT.

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 [3–7].
2. Calculation methods generally accepted for such systems, such as 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 [7–11].

As mentioned above, at present, the connection of wind turbines to the system is built in such a way that cases where there is a "wrong" voltage at the generator output, they will simply disconnect 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 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 early studies presented in [12,13], the author and colleagues propose 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.
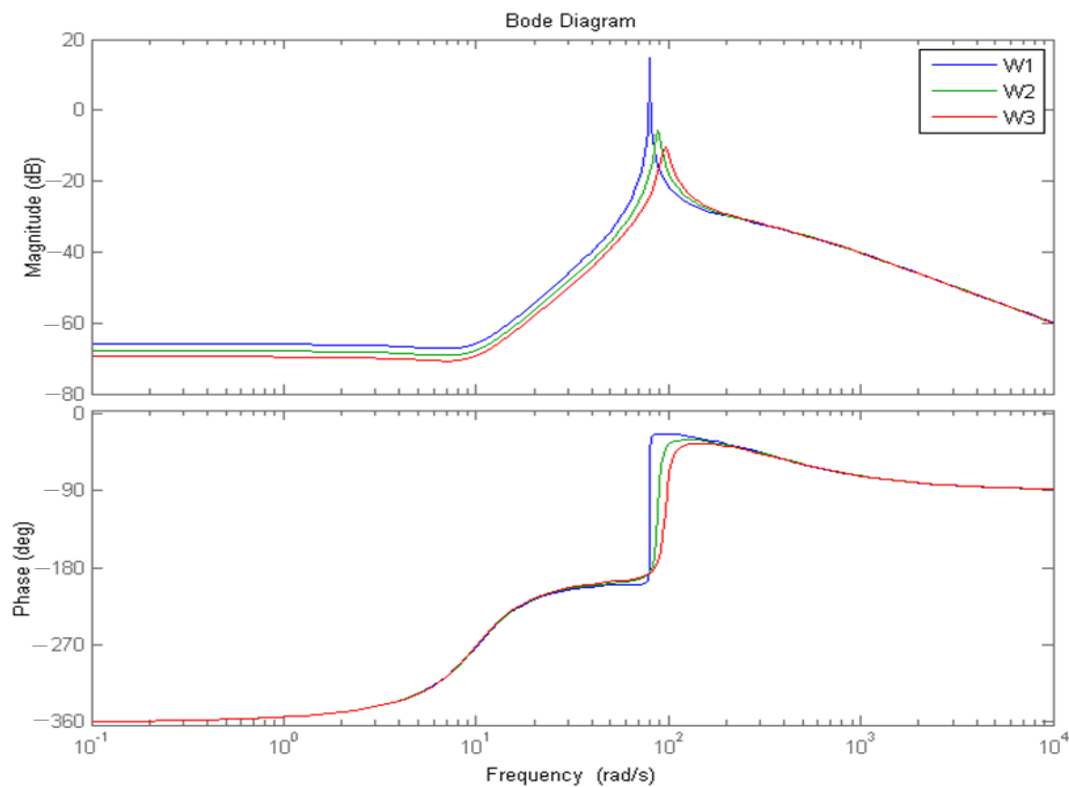
Figure 3. Frequency characteristics dual AC machines for slip (*β*) variations.

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

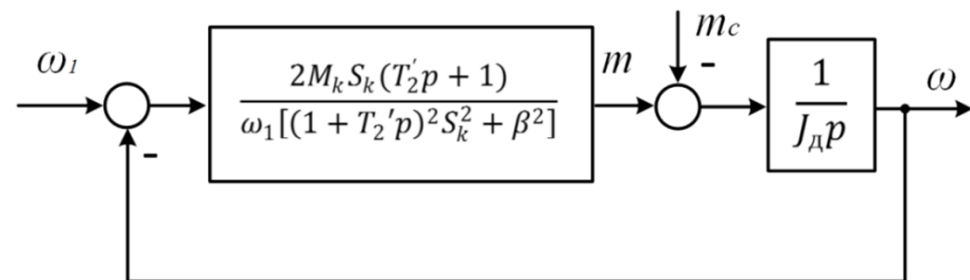This transfer function corresponds to the block diagram shown in Figure 4.

Figure 4. Structure with nonlinear transfer function.

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 the greatest; dual-feed machines for power engineering are just such machines.

However, problems regarding the stability of systems with nonlinear dynamics are 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 the 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.

For the original nonlinear system (Figure 5). 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) [3–5].
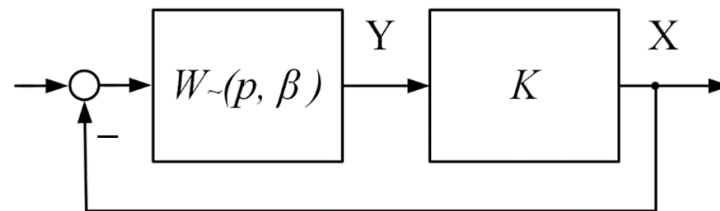

Figure 5. Generalized structure of a system with a nonlinear dynamic link $W_\sim(p, \beta)$.

That is, if the hodographs of linearized systems are supplemented, as shown in the Figure 6, 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.
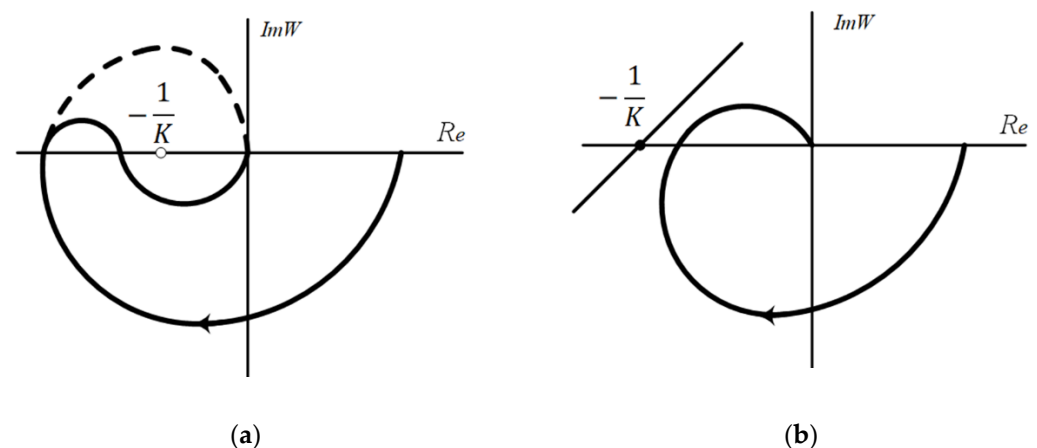

(a)   (b)

Figure 6. Illustration of the stability condition for a non-linear system presented in Figure 5, according to the Nyquist criterion (**a**), V M Popva (**b**). The dotted line in Figure 6a shows the hodograph of the "addition" to the dynamic link $W_\sim(p, \beta)$ for the connection of the criteria of V M Popov and Nyquist.

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 (Figure 7).

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 (Figures 6 and 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.
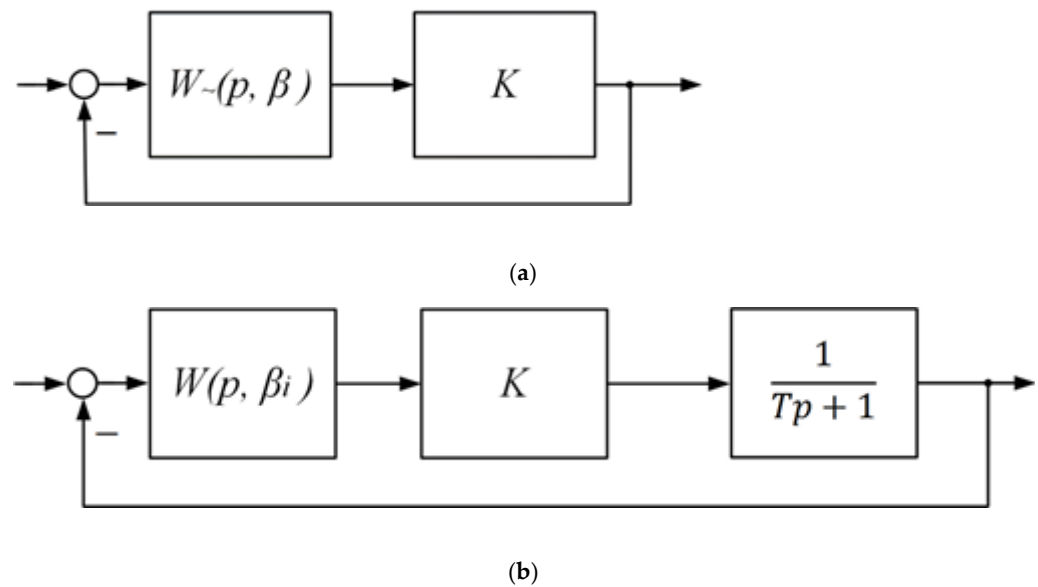
(a)

(b)

Figure 7. The original system with a nonlinear dynamic link $W_{\sim}(p, \beta)$ (**a**) and an equivalent circuit (**b**) with a family of transfer functions $W(p, \beta_i)$ and an additional filter. The Nyquist stability of the equivalent circuits is sufficient for the stability of the original nonlinear structure.

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 make 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 also solve these problems for wind energy.

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 on various factors.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Doncker, R.D.; Pulle, D.W.J.; Veltman, A. Advanced Electrical Drives: Analysis, Modeling, Control. In *Advanced Electrical Drives: Analysis, Modeling, Control*; Springer: Berlin/Heidelberg, Germany, 2011; p. 474. [CrossRef]
2. German-Galkin, S.G. An Analytic and Simulation Study of a Wound-Rotor Asynchronous Machine at Positive Slides. *Russ. Electr. Eng.* **2015**, *86*, 418–424. [CrossRef]
3. Meerov, M.V.; Mikhailov, Y.N.; Fridman, V.G. *Fundamentals of Automatic Control*; Nedra: Moscow, Russia, 1972.
4. Rush, N.; Abets, P.; Lalua, M. *Direct Lyapunov Method in the Theory of Stability*; Mir: Moscow, Russia, 1980; p. 300.
5. Popov, V.M. *Hyper-Stability of Automatic Systems*; Nedra: Moscow, Russia, 1970; p. 456.
6. Usoltsev, A.A. *Vector Control of Asynchronous Motors*; ITMO: St. Petersburg, Russia, 2002; p. 120.
7. Alekseev, V.V.; Emel'yanov, A.P.; Kozyaruk, A.E. Analysis of the dynamic performance of a variable-frequency induction motor drive using various control structures and algorithms. *Russ. Electr. Eng.* **2016**, *87*, 181–188. Available online: https://link.springer.com/article/10.3103/S1068371216040027 (accessed on 23 May 2021). [CrossRef]
8. Yuhendri, M.; Ahyanuardi, A.; Aswardi, A. Direct Torque Control Strategy of PMSM Employing Ultra Sparse Matrix Converter. *Int. J. Power Electron. Drive Syst.* **2018**, *9*, 64–72. Available online: http://ijpeds.iaescore.com/index.php/IJPEDS/article/view/9696/11112 (accessed on 22 January 2022). [CrossRef]
9. Zair, M.; Hazzab, A. MRAS Speed Sensorless Vector Control of Induction Motor Drives Using Predictive Adaptation Mechanism. *Int. J. Power Electron. Drive Syst.* **2018**, *9*, 1523–1533. Available online: http://ijpeds.iaescore.com/index.php/IJPEDS/article/view/13084/11455 (accessed on 23 June 2021). [CrossRef]
10. Firago, B.I. *Pavlyachik, L.B. Regulating Electrical Drives of Alternating-Current*; Technoperspectiva: Minsk, Belarus, 2006; 363p.
11. Alekseev, V.V.; Kozyaruk, A.E. Comparative analysis of models for systems of an automated asynchronous drive with vector control. *Russ. Electr. Eng.* **2013**, *84*, 702. Available online: https://link.springer.com/article/10.3103/S106837121312002X (accessed on 24 May 2015). [CrossRef]
12. Kodkin, V.L.; Anikin, A.; Baldenkov, A. *Nonlinear Dynamics of Asynchronous Drive: Engineering Interpretation and Correction Techniques*; IntechOpen: London, UK, 2020.
13. Kodkin, V.; Anikin, A. On the physical nature of frequency control problems of induction motor drives. *Energies* **2021**, *14*, 4246. [CrossRef]