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КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ АСИНХРОННОГО ГЕНЕРАТОРА ДЛЯ ВІТРОЕЛЕКТРОСТАНЦІЇ

Актуальною проблемою сучасної економіки все ще залишається проблема вироблення достатньої кількості електроенергії. Ситуація погіршується екологічними проблемами при використанні так званої вуглецевої енергетики, а також при використанні гідро- та атомної енергетики. Розвиток альтернативних джерел електроенергії неможливо зараз уявити без використання вітроелектростанцій. Енергія вітру практично дармова енергія, проте її використання передбачає застосування електрогенераторів. В даний час це переважно синхронні генератори, але також використовуються і асинхронні генератори. Незважаючи на відносну дешевизну та надійність, проте, асинхронні генератори займають дуже скромне місце у відсотковому відношенні серед вітрогенераторів. Однією з проблем використання асинхронних вітрогенераторів є те, що їм потрібна при роботі дуже значна реактивна потужність, яка надходить з мережі або компенсується батареєю конденсаторів. Останнє й у автономних асинхронних генераторів. Комп'ютерне моделювання асинхронних вітрогенераторів ускладнюється суттєвою нелінійністю, яка обумовлена кривою намагнічування або, що, те саме, характеристикою холостого ходу генератора. Як правило, при комп'ютерному моделюванні індуктивний опір вітки намагнічування приймається постійним, що є не зовсім коректним, оскільки достовірно відомо, що воно залежить від частоти обертання ротора. Відомий ряд моделей асинхронного генератора, але поки що не існує однієї найбільш достовірної математичної моделі, що дозволяє проводити комп'ютерні дослідження асинхронного генератора з короткозамкненим ротором з урахуванням усіх його особливостей. У програмному пакеті MATLAB 2023б є математична модель асинхронного вітрогенератора, яка представляє науковий та практичний інтерес. У статті досліджено можливості даної моделі, її переваги та недоліки. Отримано залежності впливу параметрів машини на активну і реактивну потужність, що виробляється та споживається відповідно, оцінено вплив індуктивного опору гілки намагнічування і вплив характеру навантаження на вироблювану енергію генератором.

Ключові слова: вітроелектростанція, асинхронний генератор, моделювання асинхронного генератора.

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SIMULATION OF AN INDUCTION GENERATOR FOR A WIND FARM

A pressing problem in the modern economy is still the problem of generating a sufficient amount of electricity. The situation is aggravated by environmental problems when using so-called carbon energy, as well as when using hydro and nuclear energy. The development of alternative sources of electricity is now impossible to imagine without the use of wind power plants. Wind energy is practically free energy, but its use involves the use of electric generators. Currently these are mainly synchronous generators, but induction (asynchronous) generators are also used. Despite the relative cheapness and reliability, however, induction generators occupy a very modest place in percentage terms among wind generators. One of the problems with using induction wind generators is that they require very significant reactive power during operation, which either comes from the network or is compensated by a capacitor bank. The latter is typical for autonomous induction generators. Computer modeling of induction wind generators is complicated by significant nonlinearity, which is caused by the magnetization curve or, what is the same, the no-load characteristics of the generator. As a rule, in computer modeling or simulation the inductive reactance of the magnetization branch is assumed to be constant, which is not entirely correct, since it is reliably known that it depends on the rotor rotation speed. A number of models of an induction generator are known, but so far there is no one most reliable mathematical model that allows computer studies of an induction generator with a squirrel-cage rotor, taking into account all its features. The MATLAB 2023b software package contains a mathematical model of an induction wind generator, which is of scientific and practical interest. The article examines the capabilities of this model, its advantages and disadvantages. The dependences of the influence of machine parameters on the generated active power and consumed reactive power were obtained, the influence of the inductive resistance of the magnetization branch and the influence of the nature of the load on the generated energy by the generator were assessed.

Keywords: wind farm, induction (asynchronous) generator, simulation of induction generator.

Introduction. A pressing problem in the modern economy is still the problem of generating a sufficient amount of electricity. The situation is aggravated by environmental problems when using so-called carbon energy, as well as when using hydro and nuclear energy. The development of alternative sources of electricity is now impossible to imagine without the use of wind power plants. Wind energy is practically free energy, but its use involves the use of electric generators.

Currently these are mainly synchronous generators, but induction (asynchronous) generators are also used [1 - 5]. Despite the relative cheapness and reliability, however, induction generators occupy a very modest place in percentage terms among wind generators. One of the problems with using induction wind generators is that they require very significant reactive power during operation, which either comes from the network or is compensated by a capacitor bank. The latter is typical for autonomous induction generators.

Problem statement. The latest version of MATLAB 2023b presents a mathematical model of an induction wind generator (Fig.1) different from the earlier model presented in MATLAB version 6.5 [6], which is of scientific and practical interest.

It is necessary to explore the capabilities of this model, its advantages and disadvantages. It is also necessary to obtain the correlations of the influence of machine parameters changing on the generated active and consumed reactive power; and it is especially important to understand how the magnetization curve affects the generated energy by the generator.

Description of model. This example shows an induction machine used as a wind turbine generator. The Simple Turbine block converts wind speed to turbine output power by a simple output power versus wind speed characteristic.

When the wind speed is below the cut-in speed or above the cut-out speed, the machine generates zero real power. The machine always consumes reactive power. The Reactive Compensation block offsets the machine's reactive power requirement.

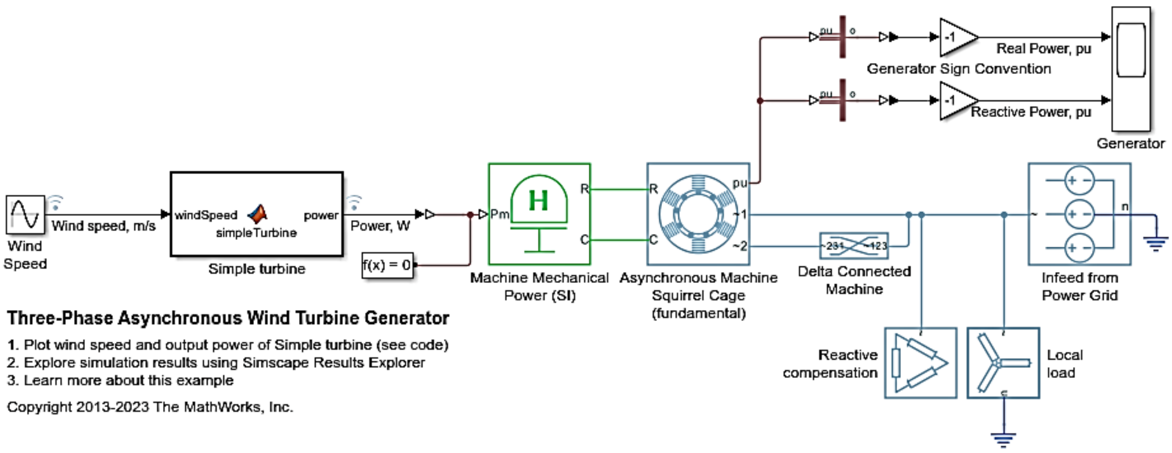

Figure 1. Simulation model presented in MATLAB-2023b

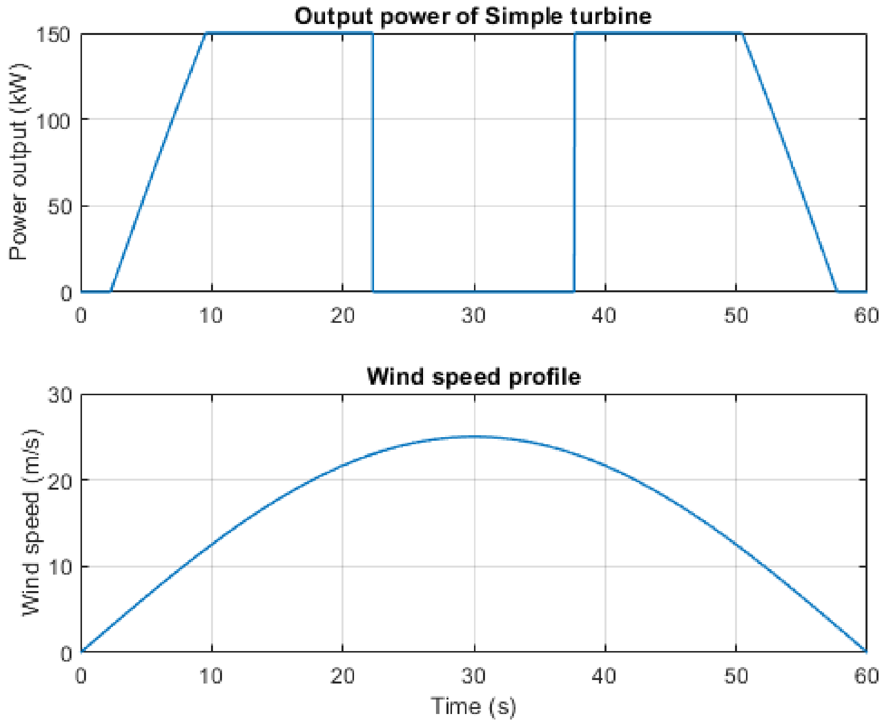

Figure 2. Output quantities of Simple Turbine and Wind Speed block respectively

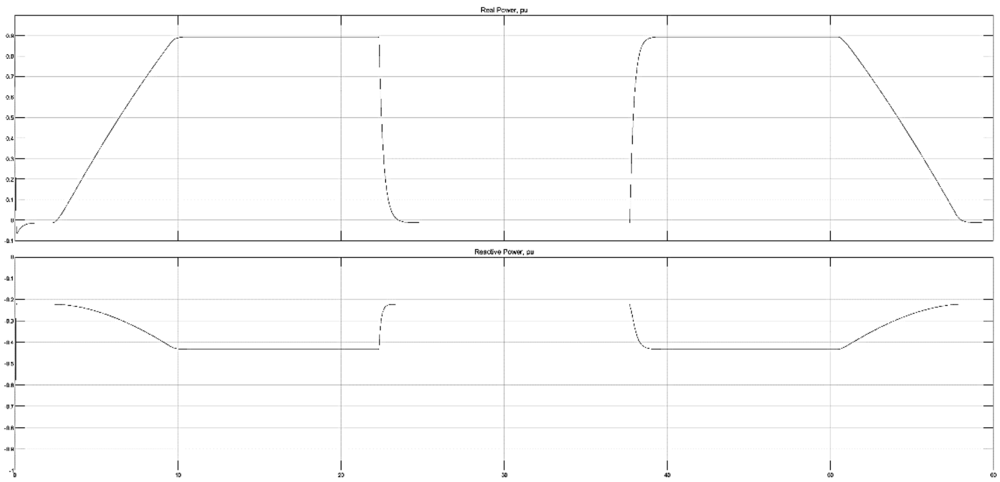

Figure 3. Graphs of real power (upper curve) and reactive power (lower curve)

The local load consumes 75kW. The infeed from the power grid meets any wind turbine generation shortfall. When the generator produces more than 75kW, excess power is exported to the grid.

The reactive power compensator is dimensioned to supply 90 kvar when a 440 V phase-to-phase voltage is applied across its terminals.

Parameters of an induction generator (IG) with a squirrel cage rotor:

- rated apparent power S = 15 kVA;
- rated frequency f = 60 Hz;
- stator resistance R_1 = 0,25 Ohm;
- stator leakage reactance X_1 = 0,4 Ohm;
- referred rotor resistance R_2 = 0,14 Ohm;
- referred rotor leakage reactance X_2 = 0,41 Ohm;
- magnetizing reactance X_m = 17 Ohm.

Magnetic saturation of the IG representation is in TABLE I. Here I is a no-load line current, U is terminal voltage.

TABLE I – Magnetic saturation of the IG

I, A	0	4	9	18	25	34
U,V	0	88	154	198	220	242
I, A	50	86	95	120	-	-
U,V	264	286	308	327	-	-

Turbine rated output power 150 kW, cut-in speed 3 m/s; rated output speed 12 m/s, cut-out speed 23 m/s.

Simulation. Let us simulate the processes in the generator when the parameters of the stator and rotor change by a factor of two from the nominal value, both up and down. We are interested in the maximum steady-state value of active and reactive powers.

First, we will change only one parameter, and then two parameters in pairs in the stator and rotor, then together in both the rotor and stator and for several values of the magnetization reactance from its minimum to maximum values.

We will also change the nature of the generator load. First, we will consider a purely resistive load, and then a resistive-inductive and resistive-capacitive load.

TABLE II presents experimental data on the values of real or active power P and reactive power Q in relative units when changing the parameters of the induction generator by a factor of two, both up and down. A minus sign before the reactive power value means that this power is consumed.

An increase in the resistance of the stator R_1 and rotor leads to a decrease in active power, which is explained by a decrease in currents in the stator and rotor windings. If we reduce the resistance of the stator winding, the active power increases and the reactive power decreases. It would seem that the power factor of the stator winding decreases, which should reduce active power and increase reactive power, but an increase in the current in the stator winding leads to a decrease in reactive power consumption.

If you increase the resistance of the rotor R_2, the active power decreases, and the reactive power also decreases. If you reduce the resistance of the rotor, the active power increases and the reactive power also increases.

A change in the reactance of the stator X_1 and rotor X_2 windings leads to the same changes in active and reactive power, exactly like changes in the resistance of the stator winding.

Despite the magnetization curve presented in the model, in reality the model only works with one value of X_m. Moreover, the maximum value X_m, which is the default in the model, corresponds to the minimum value of current and voltage on the magnetization curve, (see TABLE I) which is not clear.

TABLE II – Experimental data

IG Parameters		*P*	*Q*
R_1, Ohm	0,25	0,895	- 0,433
	0,5	0,843	- 0,441
	0,125	0,922	- 0,430
X_1, Ohm	0,4	0,895	- 0,433
	0,8	0,885	- 0,530
	0,2	0,897	- 0,369
R_2, Ohm	0,14	0,895	- 0,433
	0,28	0,868	- 0,421
	0,07	0,907	- 0,439
X_2, Ohm	0,41	0,895	- 0,433
	0,8	0,886	- 0,535
	0,2	0,896	- 0,383
X_m, Ohm	17	0,895	- 0,433
	2,725	0,761	-1,531
	5,28	0,848	- 0,960
	11	0,885	- 0,568
	22	0,887	- 0,376
R_1, Ohm and X_1, Ohm	0,25 and 0,4	0,895	- 0,433
	0,5 and 0,8	0,838	- 0,4825
	0,125 and 0,2	0,926	- 0,331
R_2, Ohm and X_2, Ohm	0,14 and 0,41	0,895	- 0,433
	0,28 and 0,8	0,86	- 0,500
	0,07 and 0,2	0,92	- 0,387
R_1, Ohm and X_1,Ohm; R_2, Ohm and X_2, Ohm	0,25 and 0,4 0,14 and 0,41	0,895	-0,433
	0,5 and 0,8 0,28 and 0,8	0,794	- 0,622
	0,125 and 0,2 0,07 and 0,2	0,941	- 0,334
load	resistive	0,895	- 0,433
	RL	0,893	- 0,433
	RC	0,894	- 0,433

From the point of view of changes in power factor, varying the reactance of the stator and rotor windings well explains the change in active and reactive powers.

In the IG with a squirrel-cage rotor, control goes through the stator circuit and the load is connected to the stator circuit. An increase of the resistance and inductive resistance in the stator winding leads to a decrease in active power and an increase in reactive power consumption.

A simultaneous increase in the resistance and reactance of the stator and rotor leads to a decrease in active power and an increase in reactive power. When these resistances and reactance are simultaneously reduced, the situation is reversed.

The presented model in the MATLAB program has a number of advantages and disadvantages.

The undoubted advantages of the presented model are clarity, block structure, the ability to see the output of any structural block, ease of changing any parameter in any block, especially in the structure of an induction generator.

Disadvantages: it is not possible to simulate an induction generator with a nonlinear characteristic of the magnetization branch, as mentioned before, depending on the rotor rotation speed, since it is known that such a dependence exists and is significant. In addition, the model seems to have the ability to change the nature of the load, but changing this nature during modeling does not give any change in the values of active and reactive power, which is very doubtful. There is also no way to change the *RL*-, *RC*-load values.

Conclusions.

1. This MATLAB model of an induction generator as part of a wind farm is very visual and convenient to model due to its block structure.

2. Moreover, it is convenient to change not only the parameters of the generator itself, but also the parameters of external influence, i.e. wind, as well as wind turbine parameters.

3. It is enough to simply estimate the numerical values of the quantities being studied.

4. Since in an autonomous asynchronous generator the load is connected from the side of the stator winding, the most interesting changes are the parameters of the stator winding.

5. Changes in these parameters lead to a significant change in the generated active power and consumed reactive power.

6. Additional research is required on the induction generator when changing its parameters, taking into account optimal excitation conditions and stator current values.

7. The disadvantage of the model is the impossibility of modeling while taking into account the nonlinearity of the magnetization curve. It is possible to specify only a single value.

8. It is not possible to change the load values taking into account its nature: resistive-inductive or resistive-capacitive.

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