Determination of Cost of Contra-Rotating Wind Turbine with Transformer with Rotating Half

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Abstract – For effective use of low-speed potential of a wind use low-power wind turbines with vertical axis of rotation (VAWT). A new design of contra-rotating noncontact VAWT in which two wind rotors rotate in opposite directions is proposed. The contactless transmission of generated power from the multipole permanent magnet synchronous generator (PMSG) and the regulation of electric power carries a special device – a transformer with rotating half (TRH). The cost of VAWT of the classical and offered sample is determined. The offered design of contra-rotating VAWT has till 42 % lower cost than a traditional design of wind turbine with vertical axis of rotation, and this cost advantage grows with reduction of power.

Key words – contra-rotating wind turbine, wind turbine with a vertical axis of rotation, a transformer with rotating half.

I. Introduction

In different territories of Ukraine the potential of wind power is characterized by low average annual speeds of a wind which makes 4 – 5 m/s. low-power wind turbines with vertical axis of rotation (VAWT) which are installed directly at consumers [1] can use this potential. Because of simplicity and reliability of a design, possibility of installation directly on houses, and also low noise level, expedient is use of VAWT. For maximum efficiency in VAWT is used synchronous generators with excitement from permanent magnets (PMSG).

Use of VAWT in which the inductor PMSG is connected to a rotor and an anchor with a contra-rotating part, which are rotating diversely, allows to reduce the sizes and cost of the generator [2]. However there is a problem in transfer of the made electric energy from a mobile anchor of PMSG.

The new design of contra-rotating VAWT in which for transfer of the made electric power from mobile part of PMSG the transformer with the rotating half (TRH) is offered. In TRH a half of the core rotates together with a mobile anchor of PMSG, and other part is motionless. Also TRH carries out regulations of output voltage of VAWT by switching of branches on its secondary winding. It gives the chance to get from a wind the maximum quantity of energy [3].

II. Material and Results of Researches

To be convinced of prospects of application of a contra-rotating design of VAWT, it is necessary to carry out comparison of cost of a traditional design (a wind a rotor, the generator, the active rectifier, the battery) and offered (two wind-rotors, the generator, TRH, the electronic control unit and the battery).

The cost of mechanical part of classical VAWT is determined on the basis of the VAWT market analysis. For the contra-rotating VAWT the cost of mechanical part is increased by 20 % because of complication of the rotating parts.

For generation of electric energy in VAWT much polar axial PMSG is used. Design data of such generators for a number of capacities is specified in the Table 1. It is determined by results of the carried-out design calculations according to the developed technique. On the basis of the received electric, magnetic and mass-dimensional results of determination of cost of active materials of a designed generator. Costs of generators in general is determined by equation

$$C_G = k_p k_m (m_{Cu} c_{Cu} + m_{Fe} c_{Fe}) + m_{pm} c_{pm}, \qquad (1)$$

where:

k_p = 1.4 – the coefficient considering production cost;

k_m = 1.3 – the coefficient considering the cost of the materials necessary for production of the basic and rotary device;

m_{Cu}, m_{Fe}, m_{pm} – the mass of copper, steel and magnets with NdFeB;

c_{Cu}, c_{Fe}, c_{pm} – prices of copper, steel and magnets.

Coefficients k_p and k_m in equation (1) do not include parameters of magnets because of their high cost and rather small work which is needed for installation. Angular speed of the generator of contra-rotating VAWT is twice above, than in a classical design. It means that it has twice smaller number of couples of poles p. As values of capacities and currents of an anchor of PMSG in traditional and contra-rotating VAWT have to be identical, a ratio between their angular speeds and the moments have to be the following:

$$\omega_{cr} = p\omega_{cl};\ M_{cr} = \frac{M_{cl}}{p}, \qquad (2)$$

Indexes "cr" and "cl" are for contra-rotating and classical options. Dimensions of the generator will decrease with reduction of the number of couples of poles in contra-rotating VAWT in comparison with the classical. For the purpose of receiving good technical and economic results of the generator it is necessary to leave in both designs invariable value of the amplitude of induction in an air interval $B_\delta = const$.

For this purpose, at preservation of invariable axial length l_δ of the generators, between their diameters D and number of conductors per unit of length of boring of the stator *N* following conditions should be executed:

$$D_{cr} = \frac{D_{cl}}{p^{\alpha}};\ N_{cr} = \frac{N_{cl}}{p^{-\alpha}}, \qquad (3)$$

α – coefficient which value lies in limits $0 \le \alpha \le 1$.

$$C_A = \frac{D_{cr}^2 l_\delta \omega_{cr}}{P_e}, \qquad (4)$$

P_e – electromagnetic power.

TABLE 1

THE COST OF AUTONOMOUS ELECTROMECHANICAL SYSTEM OF VAWT

The elements of VAWT	Typ of VAWT					
	Classical with 1 windwheel and the uncontrollable rectifier			The contra-rotating noncontact TRH		
Power of VAWT, kW	0.4	1	2	0.4	1	2
Mechanical part	3730	8930	17040	4480	10720	20450
Generator	7810	10320	12960	5550	7330	9200
Active rectifier	9830	12180	14680	-	-	-
TRH	-	-	-	1820	3580	5650
Electronic control unit	-	-	-	480	480	480
VAWT in general	21370	31430	44680	12330	22110	35780

Having substituted expressions (2) and (3) in (4) we will receive the final equation:

$$C_A = \frac{D_{cl}^2 l_\delta p \omega_{cl}}{p^{2\alpha} P_e} \quad (5)$$

From expression (5) it turns out that Arnold's constant remains to a constant, when $\alpha = 0.5$. This value was also used for calculation of mass of active materials of designs of generators for the contra-rotating VAWT proceeding from the corresponding masses for generators of the same capacities, but with biger twice value p for classical VAWT.

Using the aforesaid, it is possible to write down dependences for determination of mass of active materials of the generator of contra-rotating design of VAWT:

$$m_{Cu.cr} = p^{0.5} m_{Cu.cl} \quad (6)$$

$$m_{Fe.cr} = p^{0.5} m_{Fe.cl} \quad (7)$$

$$m_{pm.cr} = p^{0.5} m_{pm.cl} \quad (8)$$

Costs of generators for contra-rotating VAWT are specified in Table 1.

Costs of active rectifiers of voltage which are one of elements of classical VAWT which are given in Table 1, are received on the basis of the analysis of the market of such devices. In contra-rotating VAWT instead of this element the simple electronic block providing contactless switching of branches of TRH is used. The simple logical controler, simistor and the diode bridge are a part of this block. Its estimated cost is also given in Table 1.

The cost of the batteries (B) is a constant for contra-rotating and classical systems of VAWT through the identical power of these systems. Because of it, and also because of other factors which influence on B capacity they aren't included in the total cost of electromechanical system of autonomous VAWT.

Costs of active rectifiers of tension which are one of elements of classical VAWT which are given in Table 1, are received on the basis of the analysis of the market of such devices. In counter rotor system of VAWT instead of this element the simple electronic block providing contactless switching of branches of TRH is used. Simistor, the simple logical controler and the diode bridge are a part of this block. Its estimated cost is also given in Table 1.

The cost of the batteries (B) is a constant for a counter rotor and classical systems of VAWT through the identical power of these systems. Because of it, and also because of other factors which influence on capacity of B they aren't included in the total cost of electromechanical system of autonomous VAWT.

The cost of elements paid off at the hryvnia exchange rate relation to dollar exchange rate – 23:1.

Conclusion

The technical and economic assessment of a new design of contra-rotating noncontact VAWT showed that it is competitive with classical system of VAWT with one vertically focused rotor. Its cost is up to 42 % lower, than the cost of a traditional design of VAWT with VAR in a power range from 0.4 to 2 kW, and this cost advantage grows with reduction of power.

References

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