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Stochastic Nature Electrical Energy Conversion Processes Experimental Research of Wind Micro Power Plant

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Introduction

Wind energy nature is stochastic and its potential is not forecasted precisely. Therefore wind micro power plant generated electrical energy parameters are stochastic nature and electrical energy conversion equipments are necessary to convert wind micro power plant generated varying parameters electrical energy to standard parameters (230 V, 50 Hz) electrical energy. Now days applied electrical energy conversion equipments utilization of wind micro power plant generated stochastic parameters electrical energy is problematic when wind energy potential intensity is low particularly [1–4]. Electric power system dualism method and equipment is applied for stochastic nature electrical energy conversion for such problem solution. Here is used voltage system (U=const, I=var) conversion into current system (I=const, U=var) [5, 6]. Created and manufactured wind micro power plant electric power conversion and energy storage prototype experimental research results of autonomous, autonomous stand – by and electrical network operating conditions are presented at paper.

Experimental equipment strategic research objective and methodology

Strategic research objectives of experimental equipment (prototype) are following:

- Wind micro power plant stochastic electrical energy of voltage system conversion into current system hypothesis verification;
- Stochastic electrical energy of current system effective transmission to voltage system energy storage hypothesis verification;
- Main wind micro power plant operating conditions operation hypothesis verification;
- Main dependences creation of operating conditions, evaluation of research results replication and precision.

Following problems must be solved to achieve such objectives:

- To create and manufacture electric power conversion and energy storage experimental prototype;
- To create execution program for experiment;
- To select devices with appropriate metrology characteristic for experiment execution;
- To research electric power system conversion and energy storage electromagnetic processes of experimental prototype;
- To process and analyze research results and form conclusions.

Experimental prototype structure

Created wind micro power plant electric power system conversion and energy storage equipment (prototype) structure is showed at Fig. 1 [9]. At this figure are showed: wind turbine WT, permanent magnet synchronous generator PMSG, rectifier L – 1, L –2, inverter – system converter ISC which operates at dual system concept – converts voltage system (U=const, I=var) to current system (I=const, U=var), active load R_L, electrical network EN, energy storage “redox flow battery” RFB, ISC control system CS , transformer TR [6, 7].

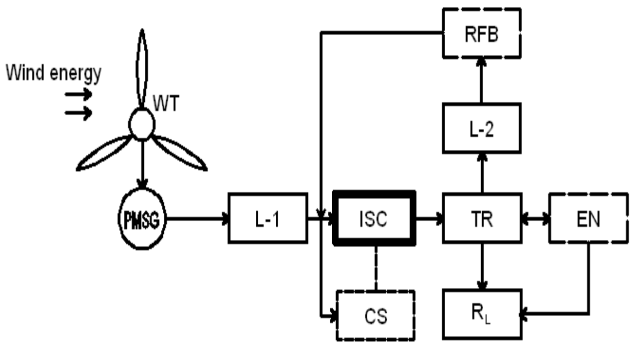

Fig. 1. Experimental prototype structure

Electromagnetic processes research results

Experimental research is performed executing four series of measurements (m = 4) and six measurements in one series (n = 6).

Wind micro power plant electric power system conversion and energy storage experimental prototype research results (Fig. 2) verified that prototype operates in inverter – system converter operating condition. Here current stability depends on ISC input voltage. When R_L varies 10 times and U_{ISCinp} = 6 V, current stability factor γ = ± 20 %, when U_{ISCinp} = 24 V, γ =±30 %.

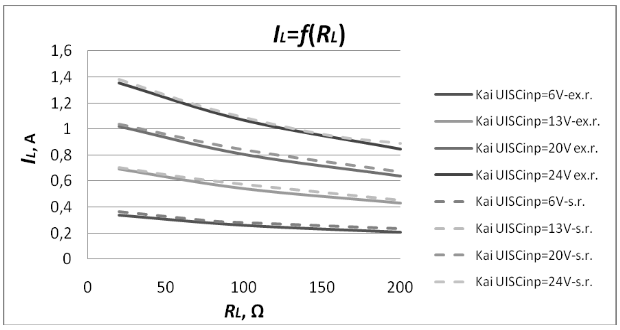

Fig. 2. Load resistance current I_L dependence on load resistance R_L when ISC input voltage U_{ISCinp} values are different, $I_L = f(R_L)$

Prototype experimental results verified that it can operate in autonomous, autonomous stand – by and electrical network operating condition.

Autonomous operating condition experimental research results of wind micro power plant electric power system conversion and energy storage prototype are showed at Fig. 3, Fig. 4, and Fig. 5.

Prototype experimental research results when load resistance R_L is disconnected and RFB is connected are presented at Fig. 3. Experimental research results show that when wind micro power plant turbine and generator start up RFB charge current always is I_{RFB} > 0 A independently on wind speed value. Therefore this dependence shows when wind speed W > 0 m/s wind micro power plant generated electrical energy can be utilized and stored at RFB effectively.

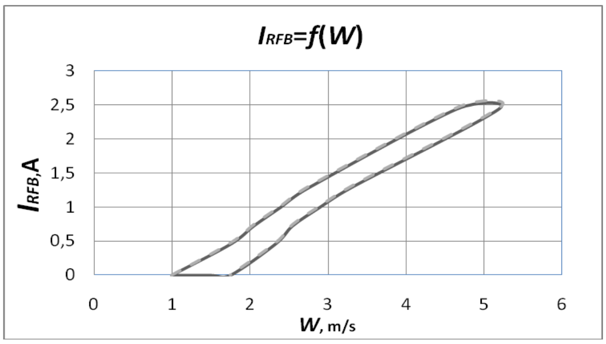

Fig. 3. RFB charge process current I_{RFB} dependence on wind speed W, I_{RFB}=f (W)

Load voltage U_L dependence on wind speed W, $U_L = f(W)$ when load resistance R_L value is constant is showed at Fig.4.

Fig. 4 shows that wind micro power plant generated stochastic nature electrical energy can be converted to standard parameters electrical energy by electric power system conversion and energy storage experimental prototype very steadily and efficiently when wind speed varies at wide range and wind energy potential intensity is low particularly.

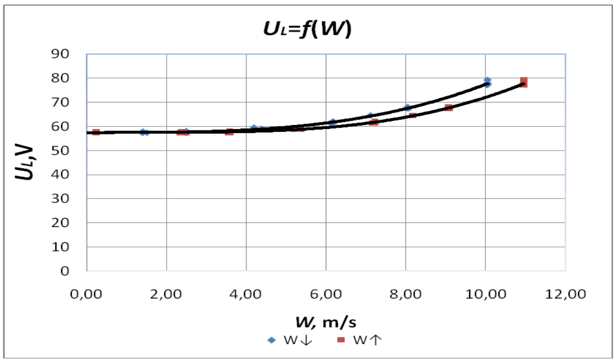

Fig. 4. Load voltage U_L dependence on wind speed W, when load resistance R_L value is constant, $U_L = f(W)$

When wind speed varies from 0 m/s to 5,21 m/s U_L (50 Hz) voltage is particularly steady and U_L stability factor γ = ±1,29 %. Wind turbine aerodynamic features, PMSG torque have influence on dependence character when wind speed value higher than 5,21 m/s. Therefore there are two values of voltage when wind speed value is the same. When wind speed is increasing wind speed value is signed W↑ and when wind speed is decreasing wind speed value is signed W↓. When wind speed is increasing from 5,21 m/s to 10,92 m/s and decreasing from 10,0 m/s to 5,21 m/s voltage varies 1,33 times. When wind speeds are higher wind micro power plant generated stochastic nature electrical energy transmitted through electric power system conversion and energy storage experimental prototype is less steady.

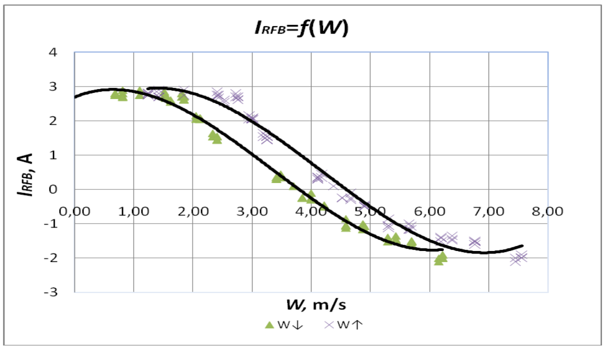

Fig. 5. RFB current I_{RFB} dependence on wind speed W, when load resistance R_L value is constant, I_{RFB}=f (W)

Fig. 5 shows stochastic electrical energy storage (charge, discharge) processes. $I_{RFB} = f(W)$ shows that RFB is charged and discharged dependently on wind speed value. When wind speed decreases W↓ and wind speed increases W↑ I_{RFB} value is different. Here wind turbine aerodynamic features, PMSG torque have influence on dependence character. When wind speed increases from 0 m/s to 4,35 m/s and wind speed decreases from 3,84 m/s to 0 m/s. RFB DC electrical energy controls prototype ISC input voltage and I_{RFB} value is positive, RFB is discharged. When wind speed value is higher wind micro power plant generated stochastic, excess electrical energy through electrical power conversion and energy storage equipment is supplied to RFB. Therefore RFB is charged and I_{RFB} value is negative.

Fig. 6 shows that load voltage U_L dependence on load resistance R_L, $U_L = f(R_L)$. Here wind micro power plant electric power system conversion and energy storage prototype are disconnected from PMSG and operates in autonomous stand – by operating condition. Experimental research results verified that prototype operates in autonomous stand – by operating condition. Dependence $U_L = f(R_L)$ has two voltage U_L stability zones. When R_L < 210 Ω voltage stability factor γ is high, $\gamma = \pm 9,1$ %. When R_L= 210 – 400 Ω, $\gamma = \pm 4,4$ %.

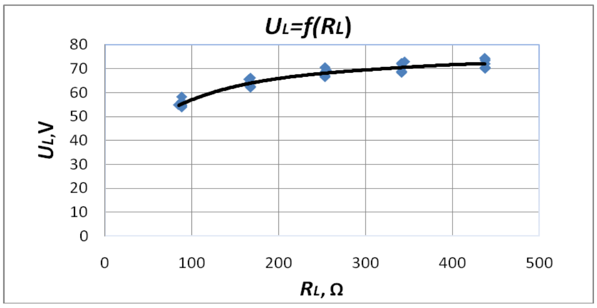

Fig. 6. Load voltage U_L dependence on load resistance R_L, $U_L = f(R_L)$

At Fig. 7 is showed electrical network current I_{EN} dependence on wind speed W, when load resistance R_L value is constant, $I_{EN} = f(W)$. Experimental research results verified that prototype operates in electrical network operating condition. When wind speed increases from 0 m/s to 5,72 m/s and wind speed decreases from 4,86 m/s to 0 m/s I_{EN} value is positive. Here electrical energy is transmitted from electrical network and wind micro power plant to load resistance R_L. When wind speed increases from 5,72 m/s to 7,51 m/s and wind speed decreases from 6,22 m/s to 4,86 m/s I_{EN} value is negative. Here wind micro power plant generated stochastic nature excess electrical energy is transmitted through electric power system conversion and energy storage experimental prototype to electrical network steadily.

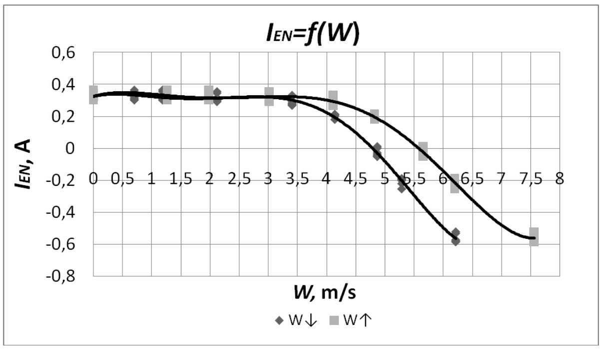

Fig. 7. Electrical network current I_{EN} dependence on wind speed W, when load resistance R_L value is constant, I_{EN}= f(W)

Replication, precision methodology and results of experimental research

Replication of experimental research results is evaluated by Kohren criterion. Results are acceptable when [8]

$$G_c \leq G_m \,, \quad (1)$$

here G_c – calculated Kohren criteria; G_m – Kohren criteria value, when obtained results reliability probability is equal to 0,95. When $m = 4$, $n = 6$ then $G_m = 0{,}59$ [8].

A Kohren criterion is calculated

$$G_c = \frac{\max(D_i)}{\sum_{i=1}^{m} D_i} \,, \quad (2)$$

here D_i – dispersion value of each measurements series; max(Di) – maximum dispersion value of each measurement series.

Kohren criteria calculation results showed that for appropriate results of dependences: $I_{RFB} = f(W)$, $G_c = 0{,}28 - 0{,}36$, for $U_L = f(W)$, $G_c = 0{,}28 - 0{,}42$, for $U_L = f(R_L)$ $G_c = 0{,}28 - 0{,}32$, for $I_{EN} = f(W)$, $G_c = 0{,}24 - 0{,}43$.

When number of measurement is n < 30 then precision of experimental results is evaluated statistically by following equation [8]

$$x^* = \overline{x_i} \pm \frac{\sigma}{\sqrt{n}} \cdot \alpha_{CT} \,, \quad (3)$$

here $\overline{x_i}$ – arithmetic mean of measurement series; σ – root – mean – square –deviation; α_{CT} – Student coefficient.

Results showed that when data dispersion reliability probability p = 0,95 for dependences $I_{RFB} = f(W)$, $U_L = f(W)$, $U_L = f(R_L)$, $I_{EN} = f(W)$ then real value varies from 0,4 % to ± 10% from $\overline{x_i}$ value. Therefore reliability and precision of experimental measurements is sufficient.

Conclusions

Experimental research results verified hypothesis that created and manufactured electric power system conversion and energy storage prototype converts voltage system electrical energy to current system electrical energy. Current stability depends on inverters – system converter input voltage. When load resistance R_L value varies 10 times, current stability factor value varies γ =± 20 – ± 30 %.

Created and manufactured ISC transmits stochastic current system electrical energy for voltage system redox flow battery effectively. When PMSG start – up energy storage charge current I_{RFB} > 0 A and DC/DC converter is not necessary for intermediate DC current value adjustment that increase effectiveness.

Experimental research results verified that created and manufactured electric power system conversion and energy storage prototype operates in autonomous, autonomous stand – by, electrical network operating conditions.

Main electromagnetic stationary processes research results of autonomous operating condition show that generated stochastic electrical energy of wind micro power plant is transmitted to load through electric power system conversion and energy storage prototype is stabilized and stability depends on load resistance value and wind speed variation. Therefore prototype converts stochastic electrical energy to standard parameters electrical energy effectively when wind energy potential intensity is low particularly, wind speed $W > 0$ m/s.

Electromagnetic stationary processes research results of experimental prototype autonomous and electrical network operating conditions show that wind micro power plant electric power system conversion and energy storage prototype transmit generated stochastic, excess electrical energy to RFB and after synchronization to electrical network steadily.

Reproduction, measurement precision are evaluated for selected appropriate points of experimental research appropriate dependences of autonomous, autonomous stand-by and electrical network operating conditions when received results probability of reliability is equal to 0,95. Calculation results show that real value vary from mean value insignificantly and calculated Kohren criteria value G_c < 0,59. Therefore experimental research results reliability and precision are sufficient.

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Wind energy nature is stochastic therefore its potential is not forecasted precisely. However wind energy low potential resources dominate at all Lithuania and EU territory. Though wind energy low potential utilization is problematic. Electric power system dualism method and equipment is applied for stochastic nature electrical energy conversion for such problem solution. Created and manufactured wind micro power plant electric power conversion and energy storage prototype experimental research results of autonomous, autonomous stand – by and electrical network operating conditions are presented at paper. Ill. 7, bibl. 9 (in English; abstracts in English and Lithuanian).

P. Balčiūnas, P. Norkevičius. Vėjo mikroelektrinės stochastinių energijos procesų eksperimentinis tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 9(105). – P. 57–60.

Vėjo energija yra stochastinio pobūdžio, todėl jos potencialas nėra tiksliai prognozuojamas. Tačiau žinoma, kad mažo potencialo vėjo energijos ištekliai Lietuvos ir Europos Sąjungos teritorijoje yra vyraujantys. Tačiau naudojimas kelia problemų. Šiai problemai spręsti panaudotas elektros sistemų dualizmo būdas ir įrenginys stochastinei energijai konvertuoti. Straipsnyje pateikti sukurto ir pagaminto vėjo mikroelektrinės elektros sistemos keitimo ir energijos kaupimo prototipo eksperimentinio tyrimo rezultatai mikroelektrinei veikiant autonominiu, autonominiu rezerviniu ir sisteminiu režimu. Il. 7, bibl. 9 (anglų kalba; santraukos anglų ir lietuvių k.).