Универзитет у Београду - Електротехнички факултет

1. Изборном и Наставно-научном већу
2. Др Жељку Ђуровићу, редовном професору, Председнику Комисије за избор у звање редовног професора за ужу научну област Аутоматика, бр. 135/6 од 10.03.2022.
3. Архиви

ПРЕДМЕТ: Приговор на Извештај и предлог Комисије о пријављеним кандидатима за избор у звање редовног професора за ужу научну област Аутоматика бр. 135/6 од 10.03.2022.

Приговор: Повреда начела Кодекса професионалне етике Универзитета у Београду

Приговор се односи на референцу кандидата под ознаком М20.10. - Blagoje M. Babić, Saša D. Milić, Aleksandar Ž. Rakić, „Fault Detection Algorithm Used in a Magnetic Monitoring System of the Hydrogenerator", *IET Electric Power Applications*, 11 (2017), pp. 63-71, IET Electric Power Applications, DOI: 10.1049/iet-epa.2016.0232, Print ISSN: 1751-8660, Online ISSN: 1751-8679.

Кандидат је као коаутор наведеног рада (прилженог као доказ 1), повредио следећа начела Кодекса професионалне етике Универзитета у Београду *(година LIV, број 193, 10. јул 2016.)*:

- члан 6. (*Интегритет*) и члан 11. (*Академска честитост*);
- члан 21., члан 22., члан 24. и члан 25. под заједничким насловом „*Плагирање, лажно ауторство, измишљање и кривотворење резултата и аутоплагирање*";
- члан 26. (*Заштита ауторских права и права интелектуалне својине*).

Образложење

Поводом процедуре пријаве теме за докторску дисертацију колеге Благоја Бабића са предложеним ментором проф. др А. Ракићем, Комисија трећег степена (проф. др А. Ракић) је упутила допис Институту Никола Тесла (даље ИНТ) за изјашњење поводом оспорених права на коришћење ресурса ИНТ и резултатата рада других колега. Тим поводом спроведена је интерна провера у ИНТ чији резултати су дати у документу упућеном Електротехничком факултету (даље ЕТФ), а приложен је као доказ 2. Резултат је тај да је обустављена процедура пријаве теме кандидата Благоја Бабића.

У документу је од стране ИНТ констатовано да тема рада делом спада у делатност ИНТ, да су у раду неовлашћено коришћени подаци ИНТ али да су у раду коришћени и резултати мерења који не припадају ИНТ а за које није наведено порекло, власник те начин прибављања и да је основана сумња на злоупотребу. Такође се наводи да коаутори С. Милић и А. Ракић никада нису били чланови тимова ИНТ који су се бавили магнетним флуксом генератора а да је аутор Благоје Бабић би задужен само за аквизицију (LabView и NI модули).

Током интерне провере интервјуисан је наведени први аутор рада М20.10. Благоје Бабић. На питања које је порекло података, где су вршена мерења, ко је вршио мерења, како и чиме су вршена мерења аутор није хтео да одговори.

Доказ 3 је рад који промовише идеју о корелацији вибрација и магнетних сила са конкретним резултатима мерења и анализа. Први аутор рада је Благоје Бавић али аутор идеје је Ненад Карталовић који је са компанијама Север и Виброакустика истраживао овај проблем на генерторима ХЕ Пирот (где Благоје Бавић није учествовао). У раду је искоришћен један врло ограничени део података, уз сагласност власника. Колеге Милић и Ракић нису ни учесници истраживања ни коаутори предметног рада. Колеге нису нашле за сходно да цитирају овај рад (доказ 3) у свом раду (доказ 1).

Круцијални Доказ 4 је поверљиви документ из кога је издвојено 6 страница одакле се може видети следеће: наручилац испитивања и власник свих резултата је ХЕ Пирот (ЈП ЕПС), извршилац испитивања је компанија Виброакустика, са искључиво својим извршиоцима. Ни колеге Бабић, Милић и Ракић, нити Институт Никола Тесла нису учествовали у овим испитивањима. Из овог документа колеге су неовлшћено преузеле велики број података.

Из наведеног, и увидом у доказе, може се закључити да је колега проф. др. А. Ракић нарушио Кодес у смислу чланова 6 и 11, нарушивши интегритет Универзитета и академску честитост члана академске заједнице. Члан 11. Кодекса (*Академска честитост*) подразумева спровођење оригиналних научних истраживања те строго поштовање ауторских права других. У раду нису спроведена никаква оригинална научна истраживања већ је већи део резултата, основне идеје, формуле, слике и друго, неовлашћено преузет из ранијих радова и поверљивих докумената. Такође се може закључити да је колега Ракић прекршио све норме Кодекса под насловом *„Плагирање, лажно ауторство, измишљање и кривотворење резултата и аутоплагирање“* и *„Заштита ауторских права и права интелектуалне својине“*. Због тога ће се случај предати Етичкој комисији на даље поступање.

Списак доказа:

- ***Доказ 1.*** Blagoje M. Babić, Saša D. Milić, Aleksandar Ž. Rakić, „Fault Detection Algorithm Used in a Magnetic Monitoring System of the Hydrogenerator“, *IET Electric Power Applications*, 11 (2017), pp. 63-71, IET Electric Power Applications, DOI: 10.1049/iet-epa.2016.0232, Print ISSN: 1751-8660, Online ISSN: 1751-8679.
- ***Доказ 2.*** *Предмет: Информација (веза Ваш акт бр. 82 од 20.01.2021.), ЕТФ број 1295, од 27.09.2021.*
- ***Доказ 3.*** Blagoje Babic , Nenad Kartalovic, Savo Marinkovic, Dejan Misovic, Dragan Teslic, Zorica Milosavljevic, Aleksandar Nikolic, Correlations between Magnetic and Vibration Measurements on Hydro Generators, Proceedings of the 2nd International Conference on Intelligent Control, Modelling and Systems Engineering (ICMS '14), Cambridge, MA, USA, January 29-31, 2014, pp 171-175, ISBN: 978-960-474-365-0 www.wseas.org
- ***Доказ 4.*** "Vibroakustika doo, V*ibroacoustic company* , Rezultati ispitivanja vibracionog stanja agregata - HE "Pirot", Dinamicko balansiranje agregata A1 i A2, Sveska -1, 2012.g. izvedenog po ugovoru sa HE Pirot, br 10-6/633-12 od 07.08.2012.god. (Rukovodilac ispitivanja: mr Radomir Albijanic, dipl.inz.; Ispitivanje izveli: mr Radomir Albijanic, dipl.inz., dr Aleksandar Ratkovic, dipl.inz., Dragmio Vojnovic, dipl. inz., Milan Đordevic, teh.) – првих 5 страна + П128

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Подносилац захтева:

Ненад Карталовић,

Fault Detection Algorithm Used in a Magnetic Monitoring System of the Hydrogenerator

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Abstract: In this paper, we propose a fault detection algorithm used in an on-line magnetic monitoring system in the hydropower plant. The proposed algorithm is based on two magnetic measuring methods: measurement of (inner) flux within generator in air gap and measurement of stator leakage (outer) flux outside of the generator. The system has to ensure, in situ and real time, magnetic monitoring and fault detection of hydrogenerator. The monitoring system is also useful for modern maintenance approach such as a condition based maintenance without generators' work interruption and better planned and preventive maintenance in the power plant. The proposed system successfully detects the presence of magnetic unbalance of hydrogenerator, occurring as a consequence of shorted turns in the windings of the rotor poles or air gap asymmetry. The presented measurement results are achieved in real exploitation conditions.

1. Introduction

Hydrogenerators, as basic production units of the power system, belong to a group of the capital equipment, which in its operating life is exposed to severe stresses and loads of electrical, mechanical, hydraulic and thermal nature, resulting in a large number of potential failures [1]. Modern strategies of maintenance are based on a number of integrated concepts, starting from the planned periodic maintenance, over the condition-based maintenance, through the introduction of multi-parameter monitoring systems [2-6].

This paper describes a fault detection algorithm that has been developed with the aim to combine the advantages of several measurement methods. The proposed algorithm is based on measurement of the main radial magnetic flux in the air gap, leakage radial magnetic flux on the stator housing and mechanical vibrations on the upper and lower guide bearings of hydrogenerators. These three concepts are combined and used to complement each other.

There are two key advantages of the presented algorithm and realized monitoring system. The first advantage is the integration of the two methods for the measurement of magnetic flux. The applied measuring procedure includes a comparative analysis of the results of magnetic flux measurements, with the results obtained with the system for measuring mechanical vibrations in order to comprehensive approach to fault detection. The second advantage is the mobility of the monitoring system and its use without requiring generators' work interruption (the case when the leakage stator flux is measured or when the system is connected with the previously built-in sensors in the air gap of generator).

The monitoring system has been developed with the aim to detect the presence and cause of the magnetic unbalance of the hydrogenerator. There are two main reasons for the existence of magnetic unbalance: shorted turns in the windings of the rotor poles and geometric asymmetry of the air gap. Magnetic unbalance will at least reduce operating efficiency and in more severe cases can lead to damage from magnetically induced heating or a rotor-to-stator rub [7].

2.Magnetic Unbalance of Hydrogenerators

Three types of unbalances (mechanical, hydraulic and magnetic) can occur in hydrogenerators. Each of these unbalances is a potential source of vibrations. Mechanical unbalance is easier to eliminate or reduce its impact on vibrations. This is achieved by dynamic balancing of the generator rotors. More complicated is the situation with the magnetic unbalance. In practice, mechanical unbalance is often placed on the opposite side of magnetic unbalance, in order to reduce its impact.

2.1. Shorted Turns

Numerous cases of increased vibrations were recorded, despite the proper shape of rotor/stator. The literature [8-9], showed that the presence of shorted turns in the windings of the rotor poles can lead to increased mechanical vibrations, that are the result of the magnetic unbalance, caused by changing magnetic flux in the generator air gap.

The magnetic flux in the air gap, corresponding to the pole with the shorted turns, is smaller in comparison with the magnetic flux of other poles. The literature [7], [10], provides the simulation of changes in magnetic flux (or magnetic flux density), which is a consequence of the occurrence of shorted turns in the windings of the rotor poles.

The shorted turns are caused by deterioration of insulation material over time. Insulating materials, which are used for insulation of the rotor windings, are exposed to thermal, electrical, mechanical, and environmental stresses. The aging of the generator, among other things, is reflected in the aging of the insulation, which may lead to shorted turns, and then to ground faults [11-13].

2.2. Air gap Asymmetry

Oscillations of the magnetic flux in the air gap can also be caused by the air gap asymmetry, which is most often the consequence either of the eccentricity of the rotor (occurred due to errors in the design, installation, thermal distortion of the rotor, wear of the rotor bearing or its displacement while the machine is working) or irregularly shaped rotor/stator.

The impact of variable degrees of eccentricity (on the unbalanced magnetic pull) was analyzed in the literature [14]. Due to changes in length of air gap, the magnetic flux in hydrogenerator also changes. The change in the magnetic flux density in the air gap (with generators which have a different degree of rotor eccentricity) was discussed in [15].

3.Shorted Turns Detection and Air Gap Monitoring

It is considered that the simplest way of determining the existence of shorted turns on the rotor pole windings is to measure the voltage drop across each pole (pole drop test) [16]. Disadvantages of this method are the following: the generator must be stopped and the partially disassembled, and preparation and measuring time is long, and since the rotor is not moving, there is no centrifugal force, so that it can happen that some shorted turns are not detected, because they are present only with the effect of centrifugal forces.

In recent years, the implementation of on-line monitoring of flux in the air gap of the hydrogenerators has started. The measurement of the flux of each rotor poles is performed, in order to discover the rotor pole that has shorted turns and determine its impact on the existence of a magnetic unbalance of the generator [16-17]. This method is already widespread in large turbo generators [18-19]. The main disadvantage of this method is the requirement to install a flux sensor in the air gap (invasive method). These measurement systems measure only main magnetic flux in the air-gap and do not provide a comprehensive analysis of the magnetic characteristics of the hydrogenerators.

In this paper, with the desire to reduce the aforementioned shortcoming, in terms of long time for installing the sensor and dismantling parts of the generator, the presented monitoring system was developed. The system, in addition to the measurement of the main magnetic flux in the air gap, also measures the leakage magnetic flux of the stator. This measurement of leakage magnetic flux is performed with the sensors mounted on the stator housing (non invasive method - advantage). Mounting sensors on the housing does not require generators' work interruption.

Commercial systems for air gap monitoring provide information on the shape of the rotor and the stator, as well as movement of rotor during various operating conditions. Capacitive sensors are installed on the surface of the stator [20], while the inductive sensors are installed in ventilation ducts of the stator [21].

4.Monitoring System

Development of presented on-line monitoring system (see Fig. 1) was conducted on the basis of modern concepts of fault detection, condition monitoring and outage management. The purpose, using this system, is to successfully detect the most common causes of magnetic unbalance of hydrogenerator.

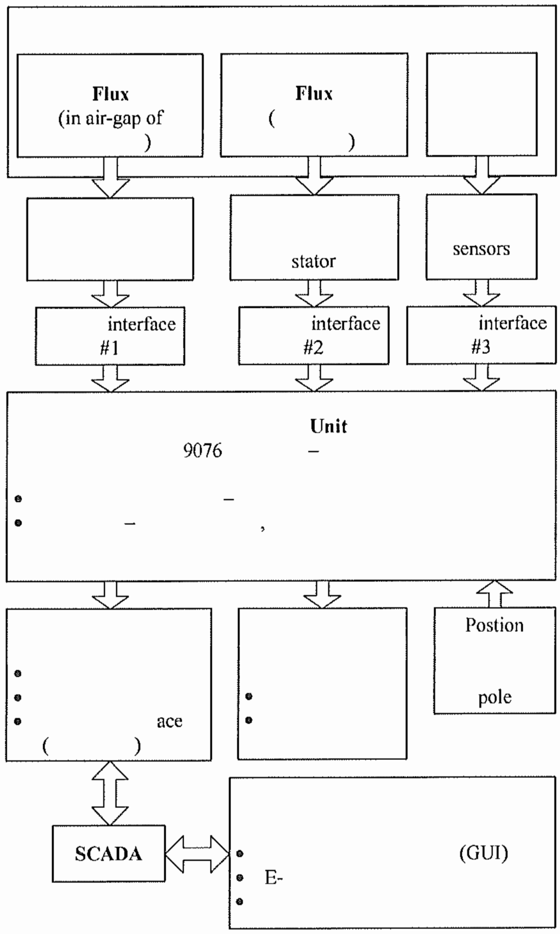


Fig. 1. Block diagram of the monitoring system

The sensor of the main flux is an air gap search coil adapted to mounting on the stator tooth, while the leakage flux sensor is adapted for mounting on the stator housing. The task of adjustable signal elements is to adapt an analog signal from the sensor for A/D conversion. The set for defining the position of the first pole serves to define the reference pole to determine the position of the measured poles with shorted turns. Data acquisition and triggering is done through the reconfigurable FPGA chip. The designed fault detection algorithm is implemented on the programmable automation controller (PAC) – NI CompactRIO 9076, which incorporate the advantages of PCs (software capability) and PLCs (robustness). CompactRIO's robust design is rated for a -20°C to 55°C temperature range, 50 g shock, and hazardous locations or potentially explosive environments [22]. Most acquisition modules feature up to 2300 Vrms isolation (withstand), and 250 Vrms isolation (continuous). A virtual instrument runs on the panel PC. Measured data collected from the PAC are shown on the front panel of the graphical user interface of the virtual instrument.

4.1. Electromagnetic Model

Monitoring system was developed on the basis of inductive sensors that measure the electromotive force (EMF) induced according to Faraday's law:

$$e = -N\frac{d\phi}{dt} \tag{1}$$

where N is the number of sensor turns and $d\phi/dt$ is the change in flux linking the coil.

A spatial magnetic flux can be assumed to flaw in flux duct. Analytical expression defining the magnetic flux $\Delta\Phi_\delta$ in air gap (in flux duct), pursuant to the Fig. 2 is [23]:

$$\Delta\Phi_\delta = \mu_0\Theta_\delta l\frac{\Delta x}{n\Delta\delta} \tag{2}$$

where μ_0 is permeability of vacuum, Θ_δ is the sum of the currents (flowing in the rotor winding) that acts upon the air gap, l is the axial length of the pole shoe, n is the number of square elements making the magnetic field diagram in the radial direction, Δx and $\Delta\delta$ are width and length of square elements and in different parts of the diagram have different sizes, but the $\Delta\Phi_\delta$ remains the same in all flux ducts.

A pole shoe creates a cosinusoidal magnetic flux density (or the approximate cosinusoidal flux density – depends on pole shoe shape) in the air gap [23]:

$$B_\delta\cos\theta = \frac{\mu_0\Theta_\delta}{n\Delta\delta} \tag{3}$$

where B_δ is the peak value of magnetic flux density in the air gap across the pole, θ is the electrical space angle (θ=0 on d-axis) and $n\Delta\delta$ is the length of the flux line from the pole shoe to the stator surface.

Since the length of the flux lines increases with closing to the q-axis (see Fig.2), the value of magnetic flux density shall reduce. In the mid pole (d-axis) where $n\Delta\delta$ is nearly constant, the value of magnetic flux density shall be nearly constant, as well.

To create a flux density B_δ, the required current of a single pole is:

$$N_f I_f = \frac{\delta_{0e} B_\delta}{\mu_0} \tag{4}$$

where N_f is the number of turns in the winding of the single pole, I_f is DC field winding current on the pole and δ_{0e} is the air-gap length in the middle of the pole, corrected with the Carter factor [23].

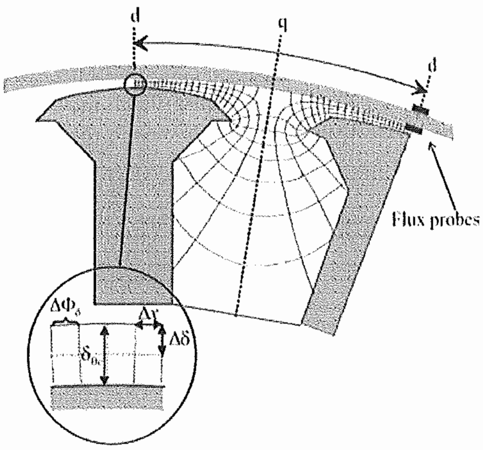


Fig. 2. Diagram of spatial distribution of magnetic flux in the air gap of hydrogenerator with the present locations of the flux probes

From (4), it can be concluded that if N_f is not changing (I_f=const) i.e. if there are no shorted turns in hydrogenerator rotor poles, every change of magnetic flux density in the air gap, from pole to pole, must be a consequence of a change in length of air gap (δ_{0e}). If the length of air gap is not changing, every change of magnetic flux density is a consequence of the presence of shorted turns.

When the shorted turns occur, the magnetomotive force (MMF) of that pole changes (the total ampere-turns of that pole reduces) and MMF as well as magnetic flux in the air gap are no longer symmetrical. Neglecting the saturation, the effect of shorted turns in generator can be presented as a sum of normal MMF and additional MMF due to a fictitious coil of the same number of turns as the shorted turns but with opposite current flow [24-26]. Fig. 3(a) shows the case of generator with six pairs of poles (*p*=6) in normal operation. If the shorted turns occur in the same generator in the first pole, the change in spatial distribution of MMF shall also occur (Fig. 3*b*). According the magnetic flux conservation law, the additional MMF by the shorted windings is presented (Fig. 3*c*).

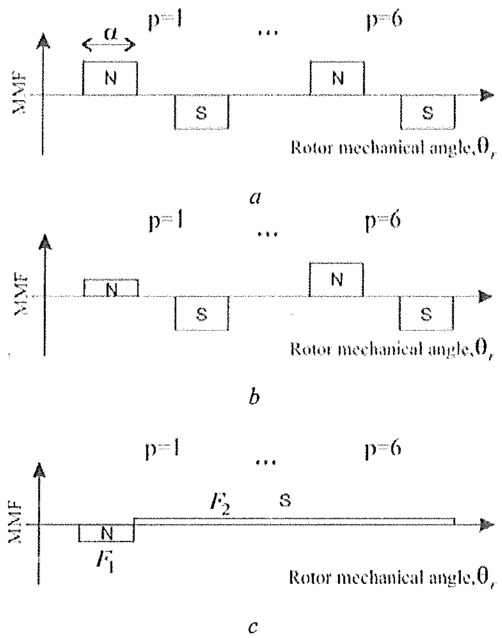


Fig. 3. *MMF distribution of the rotor.*
a Generator operates on normal condition
b Shorted turns appear on first rotor pole
c The additional MMF by shorted turns

When generator operates on normal condition, MMF (the air gap excitation MMF - $F_{m\delta}$), can be transformed into a Fourier series (5).

$$F_{m\delta}(\theta) = \sum_{k=-\infty}^{+\infty} K_k a_k e^{jk\theta} \tag{5}$$

where

$$K_k = \frac{\sin\left(k\frac{\alpha}{2}\right)}{k\frac{\alpha}{2}} \tag{6}$$

$$a_k = \frac{1}{2\pi}\int_0^{2\pi} \mathrm{F}_{m\delta}(\theta)e^{-jk\theta}d\theta = \frac{2F}{jk2\pi}\left[1-(-1)^k\right] = \begin{cases} \frac{2F}{jk\pi}, odd\ k \\ 0, even\, k \end{cases} \tag{7}$$

where F is the peak MMF of each of $2p$ poles.

Therefore MMF is:

$$\mathrm{F}_{m\delta}(\theta) = \frac{4F}{\pi}\sum_{\substack{k=1 \\ odd\,k}}^{+\infty} \frac{K_k}{k}\sin(kp\theta). \tag{8}$$

When the generator operates on normal condition, armature reaction magnetic field synchronously rotates with the rotor, and rotor winding will not induce additional harmonic current.

When the shorted turns appear on rotor poles, armature reaction magnetic field non-synchronously rotates with the rotor. So additional harmonic current is induced in the rotor winding [24]. It is necessary to analyze only the reverse MMF (Fig. 3*c*) produced by the fictitious coil.

Fourier analysis to the reverse MMF is:

$$\mathrm{F}_{m\delta}(\theta_r) = a_0 + \sum_{k=1}^{\infty} a_k\cos(k\theta_r) + \sum_{k=1}^{\infty} b_k\sin\left(k\theta_r\right) \tag{9}$$

$$a_0 = \frac{1}{2\pi}\left[-\int_0^{\frac{\pi}{12}} F_1 d\theta_r + \int_{\frac{\pi}{12}}^{2\pi} F_2 d\theta_r\right]$$

$$a_k = \frac{1}{\pi}\left[-\int_0^{\frac{\pi}{12}} F_1\cos(k\theta_r)d\theta_r + \int_{\frac{\pi}{12}}^{2\pi} F_2\cos(k\theta_r)d\theta_r\right]$$

$$b_k = \frac{1}{\pi}\left[-\int_0^{\frac{\pi}{12}} F_1\sin(k\theta_r)d\theta_r + \int_{\frac{\pi}{12}}^{2\pi} F_2\sin(k\theta_r)d\theta_r\right]$$

where:

$$F_{m\delta}(\theta_r) = \begin{cases} -F_1 & for\, 0 \le \theta_r \le \dfrac{\pi}{12} \\ F_2 & for\, \dfrac{\pi}{12} \le \theta_r \le 2\pi \end{cases} \tag{10}$$

where θ_r is rotor mechanical angle in rotor coordinate system, F_1 and F_2 are values of MMF in case of existence of shorted turns in one pole (Fig. 3*c*).

The air gap permeance λ_r has a constant component as well as a smaller component which varies cosinusoidally with rotor angle as measures from the direct axis [27]:

$$\lambda_r = [\lambda_0 + \lambda_1 \cos(2p\theta_r)] \tag{11}$$

where λ_0 denotes the constant component of the permeance and λ_1 the peak magnitude of the rotating component of the total permeance.

The flux density distribution in rotor frame $B_r(\theta_r)$ is defined as product of (9) and (11):

$$B_r(\theta_r) = \left[a_0 + \sum_{k=1}^{\infty} [a_k \cos(k\theta_r) + b_k \sin(k\theta_r)] \right] \cdot \left[\lambda_0 + \lambda_1 \cos(2p\theta_r) \right]. \tag{12}$$

While the relative angular speed of the rotor with respect to the stator is:

$$\theta_s = \theta_r + \omega_r t \tag{13}$$

where θ_s is the stator mechanical angle and ω_r the angular velocity of the rotor.

From (14), it can be concluded that the flux density distribution, in the stator frame, has both space and time harmonics. All space harmonic components in the rotor frame exist in the stator frame.

$$B_s(\theta_s) = \left[a_0 + \sum_{k=1}^{\infty} [a_k \cos(k(\theta_s - \omega_r t)) + b_k \sin(k(\theta_s - \omega_r t))] \right] \cdot \left[\lambda_0 + \lambda_1 \cos(2p(\theta_s - \omega_r t)) \right]. \tag{14}$$

Given components exist in the spectrum of the leakage stator flux. Leakage stator flux can be easily recorded through specially developed sensors and analyzed in the frequency domain. The experimental results show that the increase of value of harmonics with frequencies kf_r (k = 1,2,3...), where f_r is rotor mechanical rotating frequency, is the consequence of existence of shorted turns. The most increase of value of harmonics in the spectrum of leakage flux, can be detected at frequencies $2f_r$ and $3f_r$, and can be selected as the symptom of rotor inter-turn short circuit fault.

4.2. Fault Detection Algorithm

The fault detection algorithm (Fig. 4) has been developed in accordance with the magnetic model. Due to the occurrence of shorted turns in the windings of the rotor poles or air gap geometric asymmetry, there is a change in main magnetic flux in air gap of hydrogenerator, while with the occurrence of shorted turns were also noticed changes in the spectrum of the leakage stator flux.

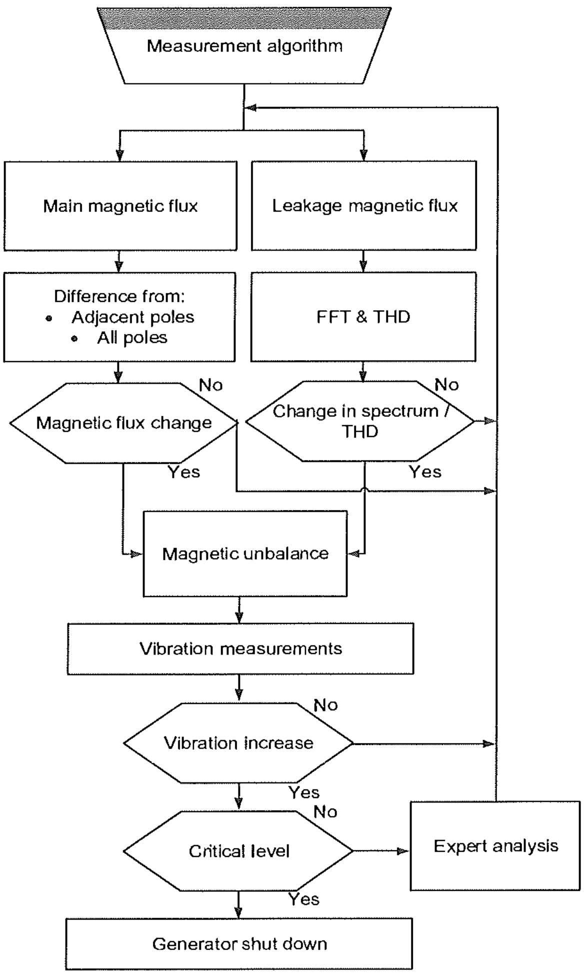


Fig. 4. *Fault detection algorithm*

The EMF is proportional to the main magnetic flux from the pole that is passing the flux sensor, during the operation of the generator. EMF (raw data) is integrated to give a value proportional to the total flux (integrated flux). The maximal value of integrated signal across the pole represents the average flux across one rotor pole and due to the presence of shorted turns this value reduces.

In order to detect shorted turns and geometric asymmetries, two auxiliary algorithms (Algorithm 1 and Algorithm 2) were developed. Algorithm 1 (for detection of shorted turns) outlines radial flux diagrams that show the difference in value of magnetic flux from adjacent poles versus pole number (see Fig. 6). Algorithm 2 which serves for detection of geometric asymmetry of air gap outlines the radial flux diagrams that show the difference in value of magnetic flux of each pole in comparison to the mean value of magnetic flux of all poles, versus pole number (see Fig. 8).

Fault detection algorithm, for detection of magnetic unbalance of hydrogenerator, also conducts analysis of leakage radial magnetic flux in the frequency domain (*Fast Fourier Transform* - FFT, *Total Harmonic Distortion* - THD). Increase of the value of certain higher harmonics in the spectrum is the consequence of the existence of shorted turns. The significant increase in higher harmonics (THD) of leakage magnetic flux, over time, indicates the occurrence of magnetic unbalance.

In addition to the magnetic parameters, the algorithm takes into account the parameters of vibration recorded on guide bearings of hydrogenerator. The air gap asymmetry easily produces increased vibration levels that can be recorded not only on the shaft, but also on the stator bars and core.

It is believed that the presence of shorted turns in the windings of the rotor poles cause excessive vibrations. The fault detection algorithm shows that usually one or more shorted turns just cause higher vibration levels, which in many cases may be tolerable. However, if more and more shorted turns occur over time, high vibrations may force a shutdown of the generator. The vibration levels (caused by the presence of shorted turns) can become excessive if the total number of rotor poles is quite low (10 to 16 poles) and/or the number of shorted turns is significant compared to the total number of turns in rotor winding. Otherwise, shorted turns (ie. variations in magnetic flux) cannot significantly affect the vibration levels.

Magnetic flux monitoring successfully detects shorted turns regardless of their number or the number of poles of the rotor. The proposed measuring method (based on measurement of the magnetic flux) better locates poles with shorted turns, particularly in cases when hydrogenerators have more poles.

Table 1 shows comparative analysis of these measurement methods.

Table 1 Comparative analysis of measurement methods

Measurement methods	Mounting of sensors	Shorted turns detection	Air-gap asymmetry detection
Main magnetic flux in the air gap	Time-consuming	Yes (from one to more shorted turns)	Yes
Leakage magnetic flux of the stator	Not time-consuming	Yes (from one to more shorted turns)	-
Vibrations of the upper and lower guide bearing	Time-consuming	Yes (if the number of shorted turns is significant/ low number of rotor poles)	Yes

5.Analysis of Operation of System in Real Exploitation

Realized monitoring system is able to simultaneously measure two types of magnetic flux, in air gap, using sensors mounted on stator tooth, and leakage magnetic flux of stator, using sensors mounted outside the stator housing. The three sets of results are presented in this section.

5.1. Model Validation

The first set (Fig. 5) shows the change in magnetic flux in the air gap of the generator and change of leakage magnetic flux of stator in real exploitation.

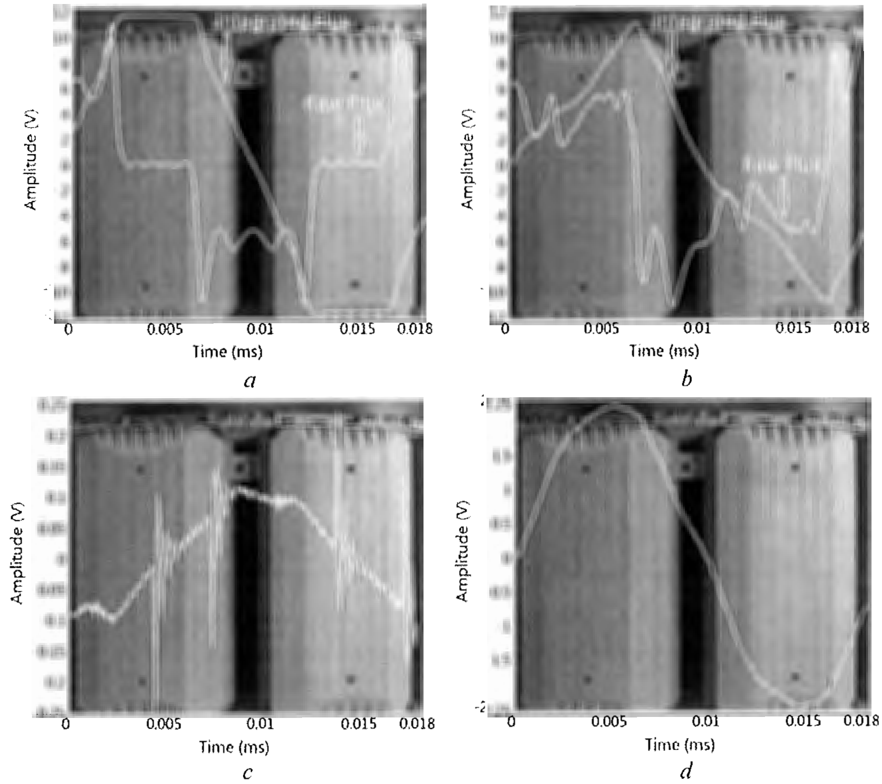


Fig. 5. *The change in magnetic flux*
a Main flux in the air gap of the generator (no-load)
b Main flux in the air gap of the generator (full-load)
c Leakage flux of stator (no-load)
d Leakage flux of stator (full-load)

In accordance with (3), it can be seen that the value of the magnetic flux does not change on the part where the air gap is constant (Fig. 5*a*), ie. in the middle of the pole (no-load operation). The change in magnetic flux occurs at the ends of the poles due to changes in the air gap.

The change in magnetic flux also occurs in regime of load operation due to armature reaction, and then flux becomes asymmetrical in relation to pole (Fig. 5*b*).

At no-load regime (Fig. 5c), the effect of commutation of converter elements in the excitation (thyristor) to a signal of leakage stator flux can be observed.

Leakage magnetic flux, on the stator housing at full load, is approximately cosinusoidal signal with a certain content of higher harmonics (Fig. 5*d*).

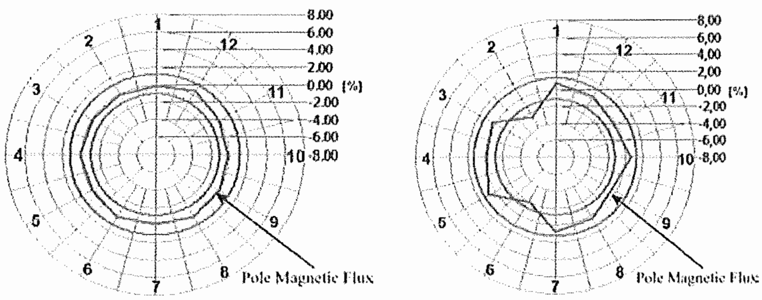
5.2. Practical Implementation of Monitoring System (Analysis for Four Hydrogenerators G1-G4)

The second set of results is obtained using the monitoring system on four hydrogenerators G1, G2, G3 and G4 (see Appendix), with the aim of analyzing their magnetic characteristics under real conditions (in situ).

5.2.1 Analysis of Magnetic Flux of the Generators G1 and G2: Generators G1 and G2 have the same rated parameters. Measurements of the main and leakage magnetic flux were done under the same regime of operations of both generators.

Minor oscillations of magnetic flux in air gap can occur due to minor physical differences between poles or it can be caused because of the different pole mounting (and thus slightly different air gaps) [16]. Lower and upper alert levels, in radial flux diagrams, show allow range of oscillations of magnetic flux. Lower alert level (in %) shows what would be the decrease in magnetic flux due to one shorted turn. The generators G1 and G2 have 81 turns per pole. One shorted turn should reduce the flux density above the pole by 1.23% [(1/81)×100%=1.23%].

In Fig. 6 is possible to note, based on algorithm 1, that in G1 there are not any while in G2 there are shorted turns in two poles. Due to shorted turns in poles 2 and 6 (G2), there has been a reduction in the value of the magnetic flux of given poles in relation to the magnetic flux of the other poles.



a *b*

Fig. 6. *Radial diagram of distribution of relative differences of the pole flux compared to the average value of the flux of two adjacent poles in % (full load regime).*
a Generator G1
b Generator G2

The FFT analysis of leakage magnetic flux of stators of generators G1 and G2 (Table 2) shows the increase of value of harmonics with frequencies kf_r (k=1,2,3...), where rotor mechanical rotating frequency is:

$$f_r = \frac{f_m}{p} = 8.33\,Hz \tag{15}$$

where f_m is fundamental frequency. Frequencies of interest are 8.33, 16.66, 25, 33.33 Hz etc.

Increase of value of higher harmonics, in the spectrum of leakage flux in G2, is the consequence of existence of shorted turns (see Table 2).

Table 2 Stator Leakage Flux Harmonics

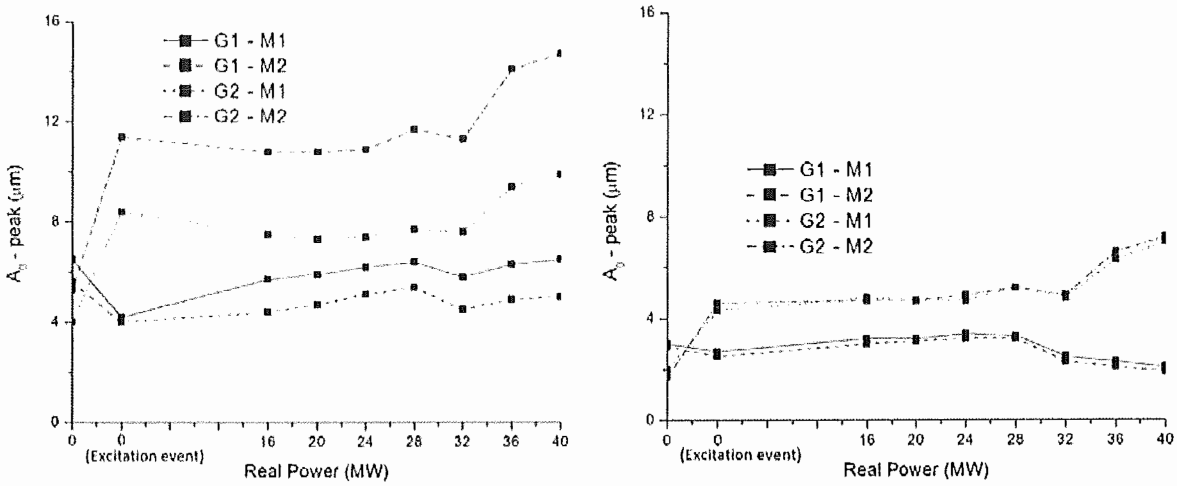
Leakage flux	Normalized amplitude (db)	
kf_r (Hz)	G1	G2
8.33	-66.37	-60.53
16.66	-67.8	-46.39
25	-57.28	-37.43
33.33	-51.53	-40.41
41.66	-50.89	-40.07
50	7.34	8.47

5.2.2 Analysis of Mechanical Vibrations of the Generators G1 and G2: With the aim of a comprehensive analysis, fault detection algorithm takes into account the value of mechanical vibrations of the upper and lower guide bearings.

Generally speaking, the mechanical vibrations recorded on the housings of guide generator bearings are indicator of the presence of mechanical and magnetic rotor unbalance. In addition, the mechanical unbalance is primarily associated with the regime of unexcited no-load operations, which is free from action of magnetic forces. In the case of present mechanical unbalance, vibration amplitude increases with increasing speed of the rotor and as a rule it is primarily expressed on the housings of guide bearings of generators [28]. Magnetic unbalance changes the vibration levels in the regimes of no-load unexcited/excited operations. Turning the excitation (excitation event – see Fig. 7), in the case of the present magnetic unbalance, vibration increase or decrease depending on the relative phase position of the vector corresponding to the mechanical and magnetic unbalance. If vectors of mechanical and magnetic unbalance are oriented in the same direction and orientation, the combined vibration vector increases and vice verse if they are of opposite direction they are subtracted. The increase in vibrations is accompanied by the increase in load in the case of the presence of magnetic unbalance.

Fig. 7 shows the comparison review of amplitude of mechanical vibrations [peak amplitude of main component per number of rotations, $A_{0\text{-}peak}$ (f_r=8.33Hz)] measured at housings of generator bearings (upper and lower guide bearing), along the measuring directions M1 and M2, which are mutually perpendicular, and regimes of operations. At G1 there was not noticed the presence of magnetic unbalance, which was expected in accordance with the magnetic measurements. Vibration amplitudes at the upper and lower guide bearings, remained almost the same before and after the excitation event.

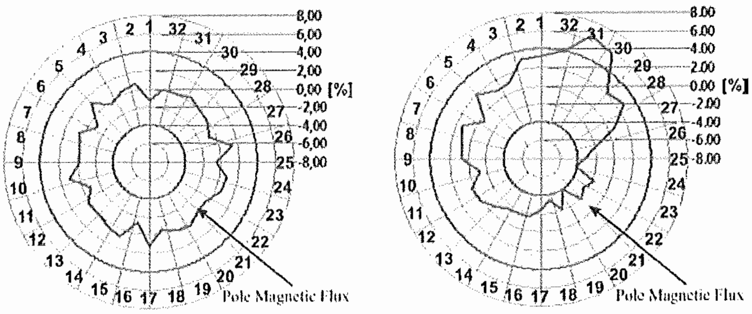
The obtained results clearly indicated the existence of magnetic unbalance in the generator G2, in which the magnetic measurements observed shorted turns in rotor pole windings. The peak value of amplitude of basic components per number of rotations ($A_{0\text{-}peak}$) reached approximately 5/12μm (no-load unexcited/excited operation) on upper generator bearing. It can be concluded that magnetic unbalance exists. In the regime of maximum load (40MW) measured value is approximately 15μm. Vibration levels at the lower guide bearing were even lower, but they were also clearly pointing to the existence of magnetic unbalance. Magnetic unbalance has been successfully detected. It can be concluded that although the two poles of the rotor (G2) had shorted turns, there has been no significant increase in vibration levels. In this case, the level of the vibrations belongs to the range of the normal operation [29].



a b

Fig. 7. Comparative review of amplitudes of mechanical vibration is given per measuring points and regimes of operation, for G1 and G2
a Upper guide bearing
b Lower guide bearing

5.2.3 Analysis of Magnetic Flux of the Generators G3 and G4: Generators G3 and G4 have the same rated parameters. Measurements of the main magnetic flux were done under the same regime of operations of both generators. Applying the algorithm 2, geometric asymmetry of the air gap in one of the generators was detected (Fig. 8).



a b

Fig. 8. Radial diagram of distribution of relative differences of the pole flux compared to the mean value of the flux of all poles in % (full load regime)
a Generator G3
b Generator G4

Generator G3 has the proper shape of the rotor and major variations in the magnetic flux in the air gap cannot be detected (Fig. 8*a*), while the trajectory of rotor of generator G4 has a pronounced misalignment in space (Fig. 8*b*), which results in a change of magnetic flux, that clearly indicates that the rotor is not round. The value of the magnetic flux increases in the area where the length of the air gap is smaller and vice versa; becoming smaller where the length of the air gap is higher.

5.3. In-Service Operating Incident

A third set of results is a display of an in-service operating incident, which occurred in the generator before installation of whole monitoring system. Generator was stopped with action of the ground fault protection of the rotor windings. During the visual inspection after stopping the generator and removing the rotor from the machine, it was established that one pole had burned (Fig. 9). The monitoring system, in regular operation, has detected the content of higher harmonics of leakage magnetic flux of THD = 4.65%. Prior to the in-service operating incident, the system has detected THD = 25.75%. THD has increased approximately five times just before the outage due to an increase in the magnetic unbalance.

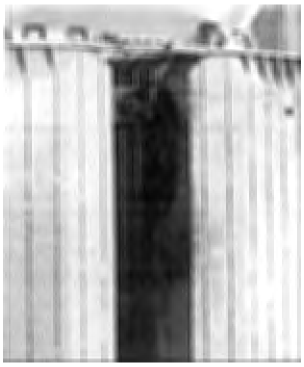


Fig. 9. *Outage of one rotor pole*

Given that the monitoring system worked only in the regime of monitoring of leakage flux of the generator, and that the alarm functions and the generator stop function were not enabled, it resulted in heavy damage.

6.Conclusion

In this paper, a fault detection algorithm and monitoring system of the hydrogenerator were presented. The main goal was to develop an adequate robust fault detection algorithm that can be used with conventional hardware and show that it works in real time applications. The developed algorithm is insensitive to different disturbances and noises. The consequences of failure (changes in magnetic flux) are present for a long time period before seriously damage or outage of generator, so that the algorithm detects them easily and avoids "false positive".

The three presented sets of results are obtained in real exploitation. One set of results, obtained by measurement of the main and leakage magnetic flux, verifies developed mathematical model of the magnetic field of the generator. The second set is obtained using the fault detection algorithm (in situ), which for the input parameters, in addition to the main and the leakage magnetic flux, takes the mechanical vibrations of the upper and lower guide bearing of the hydrogenerator. Applying a given algorithm, the magnetic unbalance was detected in two cases. In the first case it was the result of the existence of shorted turns, and in the second case, it was the result of air gap asymmetry. The third set of results is particularly significant because it indicates an increase in the magnetic unbalance during a specific time interval. The monitoring system has detected an increase in THD of the leakage stator flux, and soon after there has been an outage of hydrogenerator. The system works in fully automatic mode.

Full advantage will be achieved with the development of a number of similar standalone monitoring systems and with their interconnecting into a complex network of measurement systems.

7. Acknowledgments

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9. Appendix

Table 3 Generator parameters

Generator parameters	G1, G2	G3, G4
Year of manufacture	1983	1966
Rated Real Power (MW)	40	18
Rated Apparent Power (MVA)	44,5	20
Rated Generator Voltage (kV)	10.5	8.8
Rated Generator Current (A)	2447	1310
Rated Excitation Voltage (V)	223	130
Rated Excitation Current (A)	603	724
Rated power factor - cosφ	0,9	0,9
Rotor speed (rpm)	500	187
Frequency (Hz) - f_m	50	50
Number of poles - $2p$	12	32
Number of turns per pole - N_f	81	24

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Комисији за студије трећег степена ЕТФ-а Београд

ЕЛЕКТРОТЕХНИЧКИ ФАКУЛТЕТ
БЕОГРАД
ПРИМЉЕНО: 27-09-2021

Орг. јед.	Број	Прилог	Вредност
	1185		

ПРЕДМЕТ: Информација, веза Ваш акт бр. 82 од 20.01.2021.г.

Поштовани,

У вези са актом број и датум горњи, обавештавам Вас да је окончана процедура за утврђивања чињеничног стања у вези са пријавом теме докторске дисертације запосленог Благоја Бабића.

У прилогу Вам достављам:

1. Ваш акт бр. 82 од 20.01.2021.г., запримљен у Институту 25.01.2021.г.
2. Допис директора Института упућен директору Центра за електомерења и руководиоцу радног налога за испитивање и развој техника магнетног мониторинга и члану Научног већа, бр. 06/170 од 26.01.2021.г.
3. Обавештење Електротехничког института Никола Тесла ад Београд, упућено ЕТФ-у, бр. 06/299 од 08.02.2021.г.
4. Одговор руководиоца радног налога за испитивање и развој техника магнетног мониторинга и члана Научног већа од 22.03.2021.г.
5. Обавештење о предузетим активностима директора Центра за електромерења, бр 06/2351 од 03.09.2021.г.

Срдачно, са уважавањем

ДИРЕКТОР

др Драган Ковачевић, научни саветник

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Пословодству
Електротехничког института Никола Тесла
Београд

Поштоване колеге,

У току је процедура за пријаву теме докторске дисертације и оцену подобности студента Благоја Бабића да се бави темом, која је у вези са техникама мониторинга и детекције отказа на хидрогенераторима. У току ове процедуре је, на адресу Електротехничког факултета у Београду, стигао допис др Ненада Карталовића, научног сарадника, запосленог на Вашем Институту, у коме се указује на потенцијалне проблеме, који се током пријаве теме и израде дисертације могу појавити (допис бр. 897 од 31.8.2020. године, који је дат у прилогу).

Предложени ментор, др Александар Ракић, ванредни професор, упутио је допис Научном већу Вашег Института са конкретним питањима (допис бр. 1414 од 10.11.2020. године, који је дат у прилогу), на који је добио одговор у ком се указује да је за одговорре на постављена питања надлежно пословодство Института (допис бр. 06/34 од 11.1.2021. године, који је дат у прилогу).

Стога је, на редовној седници одржаној 12.1.2021. године, Комисија за студије трећег степена Електротехничког факултета у Београду донела одлуку да питања, претходно постављена Научном већу Института, упути пословодству Института, и то:

1. Да ли постоји лабораторијска опрема, коју је Благоје Бабић користио, или научни резултати Вашег Института, у чијем је добијању Благоје Бабић учествовао, а да нема Вашу сагласност да их у својој докторској дисертацији прикаже?
2. Колега Благоје Бабић је, заједно са коауторима, објавио радове [1] и [2] у међународним научним часописима, где се између осталог налазе и научни доприноси које он намерава да прикаже у својој докторској дисертацији. Да ли Ваша институција, по било којој основи, њему ускраћује то право?
3. Да ли сматрате да крајњи корисник пројеката, за чије потребе је наведено да су истраживања вршена, може оспорити право приказа резултата истраживања, предвиђених пријавом теме за израду докторске дисертације Благоја Бабића? Ако је тако, молимо Вас за савет на коју адресу треба да се обратимо и такву сагласност тражимо.

Референце

[1] B. Babić, S. Milić and A. Rakić, "Fault detection algorithm used in a magnetic monitoring system of the hydrogenerator", *IET Electric Power Applications*, vol. 11, no. 1, pp. 63-71, 2017. doi: 10.1049/iet-epa.2016.0232

[2] S. Milić and B. Babić, "Towards the Future - Upgrading Existing Remote Monitoring Concepts to IIoT Concepts", *IEEE Internet of Things Journal*, 2020. doi: 10.1109/jiot.2020.2999196.

У прилогу достављамо сву релевантну документацију и кореспонденцију у вези са пријавом теме докторске дисертације Благоја Бабића, и то:

1. допис бр. 897 од 31.8.2020. године,
2. допис бр. 1414 од 10.11.2020. године,
3. допис бр. 06/34 од 11.1.2021. године,
4. образложење пријаве теме докторске дисертације Благоја Бабића.

Имајући у виду да студенту истичу рокови за пријаву теме и реализацију докторске дисертације, Комисија за студије трећег степена Вас моли за хитан одговор, где би за све актере у процесу било добро да подговор на ЕТФ стигне пре наредне седнице Комисије за студије трећег степена, која ће бити одржана 2.2.2021. године.

Комисија за студије трећег степена ЕТФ-а Београд
У име Комисије председник

др Александар Ракић, ванредни професор

ЕЛЕКТРОТЕХНИЧКИ ИНСТИТУТ
НИКОЛА ТЕСЛА
Број: 06/170
26. 01. 2021. 20__ год
БЕОГРАД, Косте Главинића 8 А

ДИРЕКТОРУ Центра за електромерења

др Ненаду Карталовићу, члану Научног већа

ПРЕДМЕТ: Допис ЕТФ, молим Ваше поступање.-

Поштовани,

у прилогу акта је допис Електротехничког факултета Универзитета у Београду, бр. 82 од 20.01.2021.г., примљен 25.01.2021. г., којим се траже конкретна изјашњења у вези са темом докторске дисертације запосленог Благоја Бабића.

Молим да у писаној форми одговорите на упите из дописа.

Срдачан поздрав,

Директор

др Драган Ковачевић, дипл.инж., научни саветник

ELEKTROTEHNIČKI INSTITUT
NIKOLA TESLA A.D.
BEOGRAD

ELECTRICAL ENGINEERING INSTITUTE
NIKOLA TESLA A.D. BELGRADE
ЕЛЕКТРОТЕХНИЧЕСКИЙ ИНСТИТУТ ИМ
NIKOLA TESLA А. Д. БЕЛГРАД

11000 Beograd, Koste Glavinića 8a, Poštanski fah 139, Tel. centrale: 39-52-000; fax: 36-90-823
direktni: 36-90-487, 36-90-786, 36-90-548, 36-90-359, 36-90-674

Beograd: 08. 0...

Naš znak: 06/299

Vaš znak:

УНИВЕРЗИТЕТ У БЕОГРАДУ

ЕЛЕКТРОТЕХНИЧКИ ФАКУЛТЕТ

БЕОГРАД

Комисији за студије трећег степена

ПРЕДМЕТ: Обавештење, веза Ваш акт бр. 82 од 20.01.2021.г.

Поштовани,

У вези са Вашим актом, број и датум горњи, обавештавамо Вас да је у Електротехничком институту Никола Тесла ад Београд покренута процедура за утврђивање чињеничног стања у вези са пријавом теме докторске дисертације запосленог Благоја Бабића, у свему у делу на који се односе Ваша питања.

По окончању процедуре обавестићемо Вас о утврђеном чињеничном стању, без одлагања.

Срдачно, са уважавањем,

ДИРЕКТОР

др Драган Ковачевић, дипл.инж.

научни саветник

ELEKTROTEHNIČKI INSTITUT NIKOLA TESLA

Nenad Kartalović

Odgovor na dopis direktora Dragana Kovačevića u vezi prijave teme za doktorsku disertaciju na ETF kolege Blagoja Babića

Uvodne napomene

Elektrotehniči institut Nikola Tesla ima na raspolaganju veliki broj podataka dobijenih ispitivanjima visokonaponskih objekata tokom više decenija. Međutim, ti podaci su u najvećoj meri vlasništvo investitora, a najvećim delom JP EPS, EMS, NIS i drugih. U nekim slučajevima su to podaci partnerskih kompanija kao što su Sever Subotica, Vibroakustika doo (Radomir Albijanić), NORTH Control d.o.o. NORTH Lab i niza drugih. U ranijem periodu Institut je dobijao oštra upozorenja od kompanija HE Đerdap i Vibroakustika o neovlašćenom korišćenju njihovih podataka u publikacijama Instituta.

U duhu navedenog izvršena je analiza dva publikovana rada kolege Blagoja Babića.

I. **Analiza objavljenog rada:** „Fault Detection Algorithm Used in a Magnetic Monitoring System of the Hydrogenerator", DOI: 10.1049/iet-epa.2016.0232, autori Blagoje M. Babić, Saša D. Milić, Aleksandar Ž. Rakić.

U radu se navodi sledeće: "This research was funded by grant (Project No. TR 33024) from the Ministry of Education, Science and Technological Development of Serbia." Istraživanja koja su prezentovana u radu se odnose na period u kome je Nenad Kartalović bio rukovodilac teme za magnetni monitoring i jedini prijavljeni istraživač u vezi predmetne teme magnetnog monitoringa, što se može videti iz prijave projekta kao i iz kasnijih izveštaja. Takođe, u posmatranom periodu bio je rukovodilac inovacionog projekta 2009-02/42 „Magnetni monitoring turbogeneratora i hidrogeneratora" gde niko od pomenutih autora nije participirao. Dalje, u pomenutom periodu rukovodio je istraživačkim studijama „Implementacija magnetnog monitoringa obrtnih električnih mašina u elektranama EPS u jedinstveni dijagnostički centar" (INT, JP EPS) i "Magnetni monitoring obrtnih električnih mašina u elektranama Elektoprivrede Srbije" (INT, JP EPS) u kojima je od pomenutih autora participaro samo Blagoje Babić.

U analiziranom radu, u poglavlju „5.2.1 Analysis of Magnetic Flux of the Generators G1 and G2" se nedvosmisleno vidi da su u pitanju generatori HE Pirot, a podaci su korišćeni iz internih (ne javnih) studija. Nisu navedeni izvori podataka koje autori koriste u radu, što je poseban problem vlasništva podataka i prava korišćenja podataka.

Takođe, u analiziranom radu, u poglavlju „5.2.2 Analysis of Mechanical Vibrations of the Generators G1 and G2" se navode rezultati merenja i analiza vibracija. Jasno je da autori nisu ličnim ispitivanjima dobili obrađivane podatke. Naime, podaci ispitivanja su preuzeti iz Internog dokumenta koji je za potrebe HE Pirot radila kompanija Vibroakustika. Tada je utvrđen debalans generatora G1 i izvršeno balansiranje. Kasnija istraživanja (Institut Nikola

Tesla – Nenad Kartalović i Sever Subotica – Radisav Pantić) su pokazala da vibracije pobuđenog generator potiču od magnetnog debalansa. Do debalansa u iznosu do 10% je došlo zbog zamene (remonta) dva susedna pola rotora za koje su korišćeni novi (bolji) magnetni materijali. Deo tih rezultata je napisan u internoj studiji i nije dozvoljeno njihovo objavljivanje. Postavlja se pitanje kako su autori došli do podataka.

Može se zaključiti da su autori neovašćeno koristili prezentovane rezultate, da nisu naveli niti su imali ovlašćenje da navedu prave izvore podataka, da nisu konsultovali rukovodioca pomenutih istraživanja niti nekog od poslovodstva Instituta ili kompanije HE Đerdap.

II. Analiza objavljenog rada: „Towards the Future - Upgrading Existing Remote Monitoring Concepts to IIoT Concepts" DOI 10.1109/JIOT.2020.2999196, autori S. D. Milić, B. M. Babić.

Predmetni rad ima temu sadržanu u predlogu projekta u okviru programa Fonda za nauku pod nazivom Ideje. Naslov projekta je „Digital Power System with Artificial Intelligence" . U predlogu projekta participiraju Elektrotehnički institute Nikola Tesla, Elektrotehnički fakultet u Beogradu i Inovacioni centar Mašinskog fakulteta u Beogradu. Za rukovodioca je predložen Nenad Kartalović, a među preloženim istraživačima nema nijednog autora rada.

Pomenuta tema istraživanja je od izuzetnog poslovnog interesa Instituta i zahteva da se u daljem radu internim dokumentima Instituta urede odnosi istraživača.

III. Analiza prijave teme kandidata Blagoja Babića

Predložena je tema pod nazivom "Magnetni monitoring i detekcija kvarova hidrogeneratora". Tema je od izuzetnog poslovnog interesa za Institut, i dalji rad istraživača Instituta na ovoj temi mora biti uređen internim aktima. Sa druge strane vlasnici podataka koji su ili bi bili korišćeni u radovima i disertaciji nisu dali saglasnost za njihovo korišćenje.

Zaključak

Analizom radova Blagoja Babića i Saše Milića se nedvosmisleno zaključuje da su neovlašćeno korišćeni podaci čiji su vlasnici kompanije sa kojima Institut sarađuje. Takođe, povređena su prava intelektualne svojine kolega iz Instituta i iz drugih kompanija (JP EPS, Vibroakustika i dr.). Dalji rad na predloženim istraživanjima moguć je samo ako se institucionalno razreše nastali problemi oko vlasništva i prava.

Sa poštovanjem,
Nenad Kartalović

Beograd, 22.03.2021.

ЕЛЕКТРОТЕХНИЧКИ ИНСТИТУТ
НИКОЛА ТЕСЛА
Број: 01/2351
03. 09. 2021 20___ год.
БЕОГРАД, Косте Главинића 8 А

Центар за електромерења

Директор Центра за електромерења

ДИРЕКТОРУ

Електротехничког института Никола Тесла ад Београд

Предмет: Обавештење о предузетим активностима по Вашем допису бр. 06/170 од 26.01.2021.г.

Поштовани директоре,

У вези са дописом Електротехничког факултета Универзитета у Београду, пријемни бр. 06-160 од 25.01.2021.г., у којем се од пословодства Института тражи изјашњење по предмету пријаве теме докторске дисератције запосленог Благоја Бабића, као и о објављеним радовима и праву крајњих корисника на оспоравање приказа резултата истраживања, обавештавам Вас да сам спровео одговарајући поступак, чију хронологију дајем у наставку.

25. јануара 2021. – примљен је допис Електротехничког факултета насловљен на пословодство, са молбом да се пословодство изјасни о спорним питањима око пријаве теме докторске тезе Благоја Бабића, о објављеним радовима и праву крајњих корисника на оспоравање приказа резултата истраживања, са прилозима:

1. Образложење теме докторске дисертације Благоја Бабића од 03.07.2020.г.;

2. Допис др Ненада Карталовића упућен Комисији за студије трећег степена ЕТФ-а од 31.08.2020.г.;

3. Допис ЕТФ-а упућен Научном већу Института од 10.11.2020.г.;

4.Одговор Научног већа Института од 11.01.2021.г. (допис у прилогу).

26. јануара 2021. – достављен ми је допис директора Института, са захтевом да се доставе одговори на питања из дописа ЕТФ-а (допис у прилогу).

05. фебруара 2021. – упутио сам допис Благоју Бабићу са захтевом да се изјасни на спорна питања око пријаве теме докторске тезе (допис у прилогу).

08. фебруара 2021. – Благоје Бабић је доставио писано изјашњење (допис у прилогу).

08. фебруар 2021.г. – ЕТФ-у је упућен допис, са одговором да је покренута процедура за утврђивање чињеничног стања у вези са пријавом теме докторске тезе Благоја Бабића (допис у прилогу).

22. марта 2021. – допис Ненада Карталовића – одговор директору у вези са спорним питањима око теме докторске тезе Благоја Бабића (допис у прилогу).

29. марта 2021. - ЕТФ-у је упућен допис, у којем се истиче да Благоје Бабић нема сагласност Института да резултате истраживања прикаже у докторској дисертације пре него што се односи између њега и Института уреде посебним актом; да је у току детаљна анализа радова Благоја Бабића у смислу да ли су неовлашћено коришћени подаци трећих лица, и назнака да ће их Институт о извршеној анализи обавестити (допис у прилогу).

19. априла 2021. – упутио сам допис Благоју Бабићу са захтевом да се детаљније изјасни о теми докторске дисертације и о спорним радовима – у прилогу му је достављен допис Ненада Карталовића од 22.03.2021. (допис у прилогу).

22. априла 2021. – допис Благоја Бабића- изјашњење на постављена питања и на допис Ненада Карталовића (допис у прилогу).

10. маја 2021. – допис Благоју Бабићу са захтевом да се изјасни о наводима из дописа од 22.04.2021. који се односе на наводне притиске и претње (допис у прилогу). Благоје Бабић се није изјаснио по овом захтеву, па сам сазвао састанак.

02.јуна 2021. – одражан је састанак којем су, поред мене, присуствовали Благоје Бабић и Сандра Лучић, на околност наводних притисака и претњи које запослени наводи у допису од 22.04.2021.; сачињена је белешка са одржаног састанка (белешка у прилогу). Затражио сам од запосленог да се изјасни да ли и какве притиске и претње трпи и од кога, са напоменом да то није дозвољено и да никакви притисци ни претње неће бити толерисани. Благоје Бабић је изјавио да притиском сматра поступак Ненада Карталовића који је упутио допис ЕТФ Београд, са примедбама на тему докторске теме коју је пријавио Благоје Бабић. Изјавио је да је сарадња са Ненадом Карталовићем по текућим радним налозима коректна. Запосленом је скренута пажња да понашање колега треба бити у складу са Кодексом понашања и актима ИНТ, да се не могу износити, ни усмено ни писмено, тврдње које нису тачне, да постоји потпуна слобода сваког појединца да се изјасни о научном раду, поготову о докторском раду који ће бити изложен на јавни увид и на који комплетна научна јавност има право да изнесе запажања. Од запосленог је затражено да се о свему писмено изјасни до 4. јуна 2020.

04. јуна 2021. – допис Благоја Бабића – писмено изјашњење о наводним притисцима и претњама, у којем се запослени изјаснио да оспоравање рада који је писан пре неколико година лично доживљава као вид притиска на њега.

Увидом у сву горе наведену документацију, може се закључити следеће:

1. Запослени је поднео пријаву теме докторске дисертације 03.07.2020. у који нисам имао увид до дописа ЕТФ. У пријави докторске дисертације стоји: „Основни циљ истраживања је унапређење постојећих система магнетног мониторинга хидрогенератора и детекције кварова, укључујући побољшања постојећих и генерисање нових мерно-дијагностичких алгоритама на бази мерења магнетног флукса у међугвожђу и расутог магнетног флукса на кућишту статора хидрогенератора". С обзиром да ми није познато резултате којих истраживања је запослени у докторској

дисертацији намеравао да користи, не могу се изјаснити да ли је то у складу са пословном политиком и актима Института.

2. У раду објављеном 2016. године, на којем је запослени Благоје Бабић први аутор: „Fault Detection Algorithm Used in a Magnetic Monitoring System of the Hydrogenerator" приказани су резултати испитивања механичких вибрација (слика 7), који нису резултати Института, а није наведен извор података. Наведено изазива сумњу да су у предметном раду неовлашћено коришћени подаци трећих лица, на шта је у свом допису указао Др Ненад Карталовић, а Благоје Бабић се на наведено није изјаснио.

3. Желим да нагласим да Институт системски подржава све запослене који желе да докторирају, да у оквирима пословања развијају нове и унапреде постојеће резултате истраживања. Од запослених се очекује да поштоју процедуре и акта Инстиута..

С поштовањем,

ДИРЕКТОР ЦЕНТРА ЗА ЕЛЕКТРОМРЕЖА

мр Срђан Милосављевић, дипл.инж.

Correlations between Magnetic and Vibration Measurements on Hydro Generators

BLAGOJE BABIC , NENAD KARTALOVIC, SAVO MARINKOVIC, DEJAN MISOVIC, DRAGAN TESLIC, ZORICA MILOSAVLJEVIC, ALEKSANDAR NIKOLIC
Nikola Tesla Institute of Electrical Engineering
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Abstract: - An effective magnetic method of detecting rotor winding shorted-turns, broken damper bars and magnetic imbalance of hydro generators is described. Testing of generators vibration state was also performed. Magnetic and vibration measurements were done simultaneously, in order to find a correlation between the given measurements. This correlation will provide valuable information for understanding the causes of high measured vibration values.

Key-Words: - Magnetic monitoring, hydro generator, vibration, shorted-turns, magnetic imbalance.

1 Introduction

Magnetic monitoring is ON-LINE monitoring that involves measuring the magnetic flux in the air gap in hydro generators in order to determine if field winding shorts in the rotor poles, broken damper bars or magnetic imbalance have occurred.

In hydro generators, magnetic flux across each pole depends on the MW and MVAR loading of the machine. Any change in the magnetic flux within a pole at a given load must be due to shorted turns, magnetic imbalance or broken damper bars. If any of these faults occurs, bearing vibration level will increase. For this magnetic measurements, the National Instruments USB 6212 multifunction data acquisition module and LabVIEW application was used.

Testing of generators vibration state was performed using Brüel & Kjær PULSE system. Digital signal processing and data logging were done in time and frequency domain. The recorded waveform data was then analyzed.

2 Flux and Vibration Monitoring System for Hydro Generators

The basic elements that are part of flux monitoring system (Fig. 1) are flux probes, amplifiers, filters, acquisition system, PC and programs for signal processing and data logging.

Six air gap probes are permanently mounted to the stator tooth surface to determine if magnetic imbalance and turn-to-turn shorts have occurred.

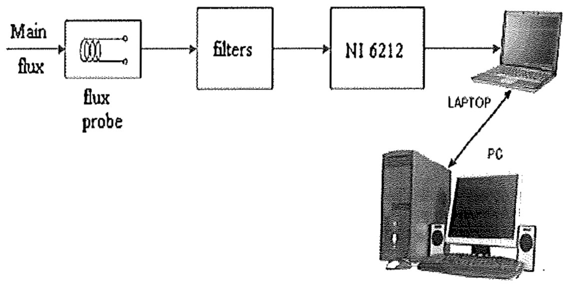


Fig.1 Flux monitoring system

Inductive sensors are placed evenly (every 60 degrees of scale, Fig. 2), where the first, third and fifth sensor are placed at the top of the stator and the second, fourth and sixth are at the bottom of the stator.

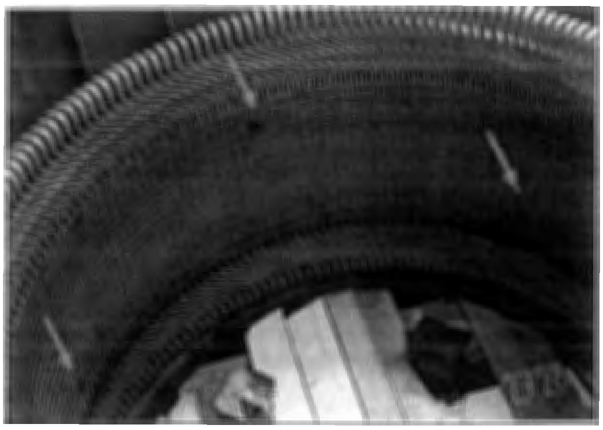
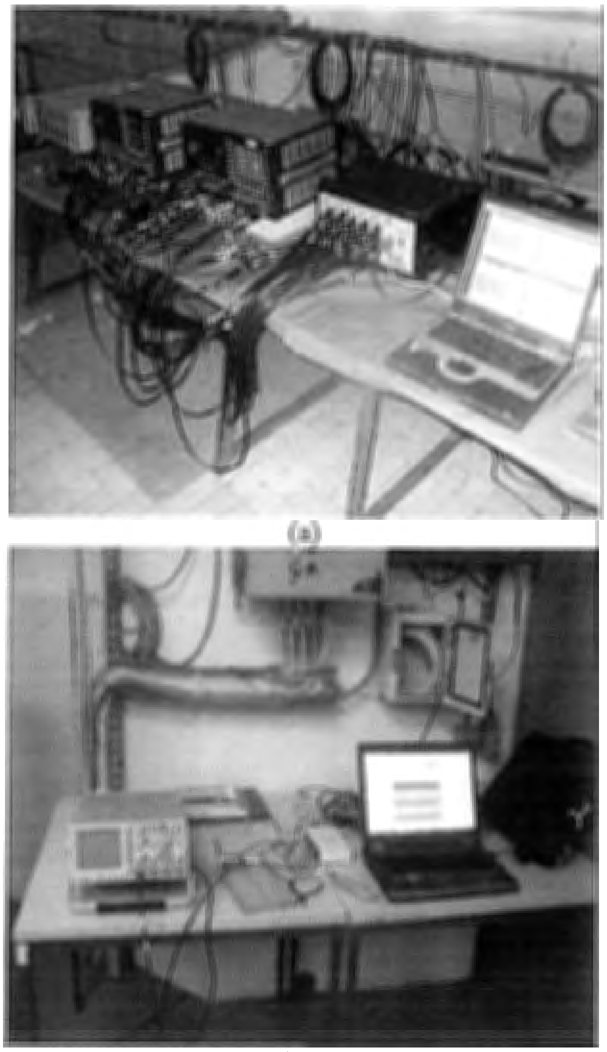


Fig.2 Detail of installed flux probes

As shown in figure 3a, testing of generators vibration state was performed using Brüel & Kjær PULSE system (30 channels). Software package that is used is PULSE Balancing Consultant 7790. Balancing is carried out in accordance with standard ISO 1940-1 and 2. Figure 3b shows flux monitoring system.



(a)

(b)

Fig. 3 Monitoring system a) vibration monitoring b) magnetic monitoring

3 Magnetic Measurements

During machine operation, the rotor flux from each pole will induce a current in the flux probe, since the rotor is moving past the flux probe. As each pole in the rotor passes, there will be a peak in the induced current caused by the magnetic flux of the pole. The peaks in the current can then be recorded and each peak of the waveform represents the "average" flux across one rotor pole. Shorted turns in a pole reduce the effective ampere turns of that pole and thus the peaks associated with that pole [1]. The recorded waveform data can then be analyzed to locate the poles containing the fault or to determine if magnetic imbalance has occurred. Presence of broken damper bars in the rotor also changes the air-gap flux.

3.1 Results of Magnetic Measurements

Data were taken under different load conditions ranging from no load to full load. Magnetic flux is proportional to induced voltage. Inductive sensors measure the electromotive force (1):

$$e = -N\frac{d\phi}{dt} \qquad (1)$$

Where e is the induced voltage, N is the number of turns and $\frac{d\phi}{dt}$ is the change in flux linking the coil.

Figure 4 shows the change in signal characteristics vs. load condition (Fig. 4a - 0MW, 3VAR and Fig. 4b - 40MW, 17MVAR). Two adjacent poles with the change in flux (red color, normalized) and the total flux (white color) are shown. 40MW is full load for this machine.

The magnitude of flux density in air gap can be defined as [2]:

$$B(x) = \frac{\Delta bo}{\Delta b(x)}\mu_o\frac{Um,\delta}{\delta_o} \qquad (2)$$

where the δ_o is minimum air gap, μ_o is permeability of vacuum, Um,δ is magnetic potential in air gap, Δbo is predefined width on stator in front of pole and $\frac{\Delta bo}{\Delta b(x)}$ is relation that defines the impact of air-gap to changes of flux density. If we define width Δbo, in front of pole (air–gap is constant), where magnetic flux has some value, then we can define width $\Delta b(x)$ in part where air-gap is not constant so that flux value is the same as in case of Δbo.

Fig. 4a shows that air-gap flux is homogeneous in the middle of the pole ($\frac{\Delta bo}{\Delta b(x)} \approx 1$). The change in flux is symmetrical from pole to pole. Fig. 4b shows that when there is armature reaction (air-gap flux component caused by the armature current), air-gap flux is no longer uniformly distributed under the poles. The peak magnitude of the change in flux and the total flux varies little.

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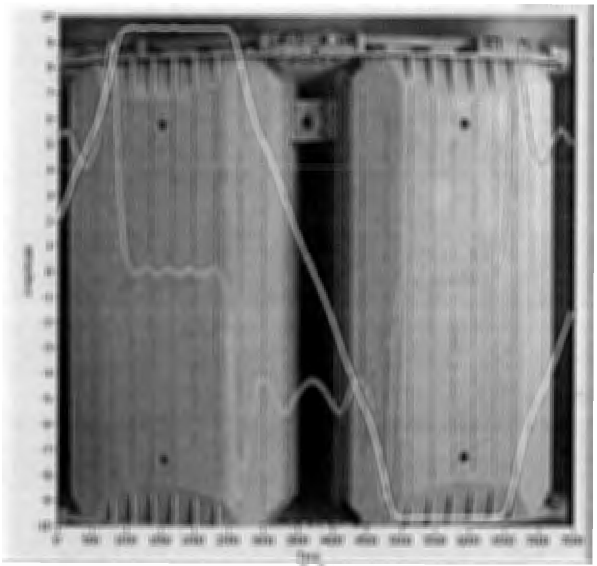
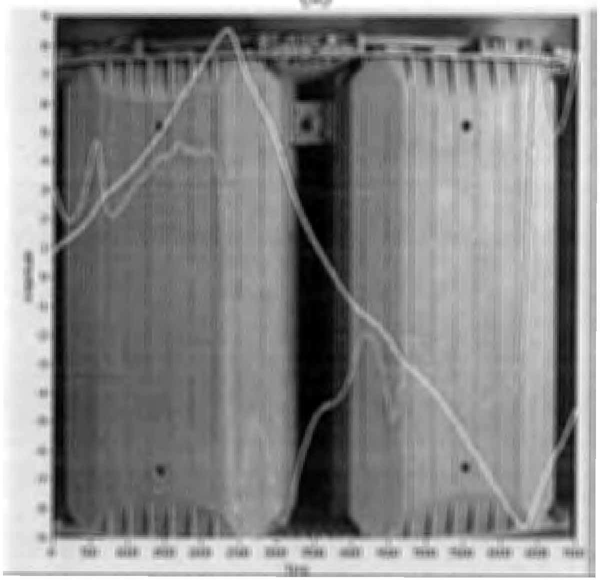


(a)



(b)

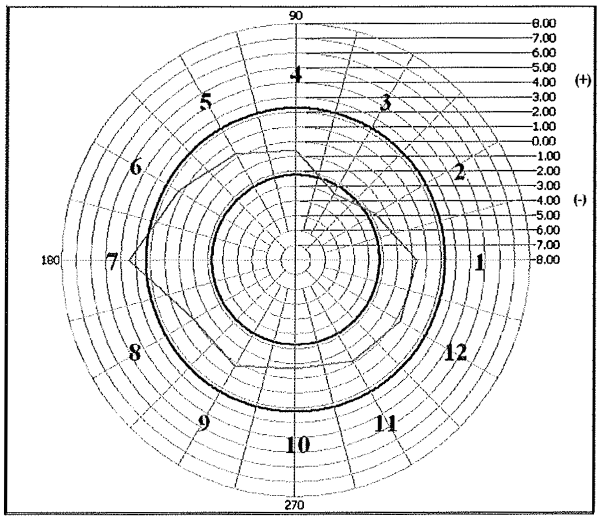
Fig. 4 Flux change (red color, normalized) and total flux (white color) a) 0MW, 3VAR b) 40MW, 17MVAR

3.2 Analysis of the Results of Magnetic Measurements

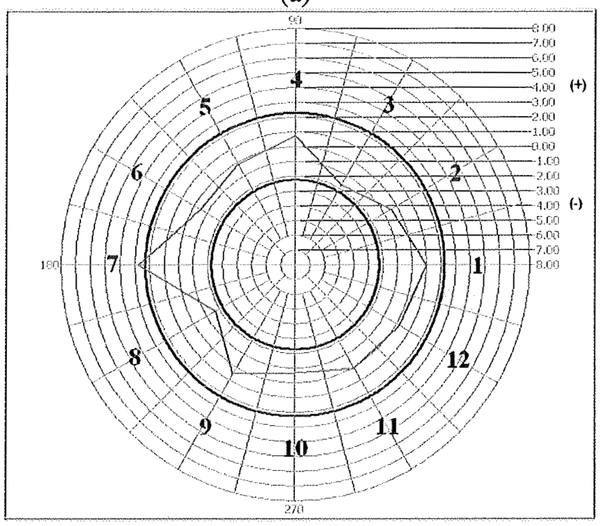
Algorithm to be used is to plot the peak integrated signal (total flux) for each pole compared with the value of the average of all the poles (Fig. 5a) and to the average of the two adjacent poles (Fig 5b) [3]. Figure 5a shows magnetic imbalance, which is not critical. This was confirmed by testing of generators vibration state.

Variations in flux (Fig. 5a) may be due to changes in gap due to an out of round rotor due to poles mounting on the rotor [4]. We can consider that in all cases of load condition the natural variation in comparison of pole to average of adjacent poles or to average of all the poles is 2.2 % or less.

The total flux is proportional to the number of turns of the pole and if one turn is short then the total flux would decrease by 1/number of turns. In our case the total flux would decrease 2.2 % (compared to the average of two adjacent poles) if there is one short turn. Figure 5b shows that there were no pole shorts in this case. Pole 7 had total flux that is little higher than the value of the average of the two adjacent poles. There are 12 poles on the rotor. The higher load and more positive VARS are most sensitive to shorted turns.



(a)



(b)

Fig.5 Radial plot of difference in peak integrated signal (40MW, 17MVAR) a) average of all the poles b) average of the two adjacent poles

Numerical data from Fig. 5 are shown in Table 1. Presence of broken damper bar will amplify the flux probe signal considerably [5].

Pole	Algorithm 1	Algorithm 2
1	0.281	1.004
2	-1.685	-0.426
3	**-2.809**	-1.719
4	-0.534	0.746
5	0.267	-0.132
6	1.334	-0.502
7	**3.425**	**2.726**
8	0.026	-1.753
9	0.199	0.526
10	-0.677	-0.712
11	-0.127	0.061
12	0.299	0.248

Table 1 Numerical data (in %) showing results of magnetic measurements

4 Testing of Generators Vibration State

Testing of generators vibration state includes testing of upper and lower generator guide bearings, and a turbine guide bearing in different measurement directions [6].

Magnetic imbalance changes vibration signals in cases of no load – not excited (Fig. 6) / excited generator (Fig. 7). Fig. 6 and fig. 7 show two different measurement directions (MM10 and MM11), which are 90 degrees apart. Component of interest is $A_{o-peak}(f_o)$, where

$$f_o = n/60 = 500/60 = 8.33Hz \qquad (3)$$

It is obvious that the magnetic imbalance was detected. Vibration amplitudes and magnetic imbalance usually increased with higher loads (Fig. 8). Vibrations that are recorded in case of no load (not excited generator) are indicators of the presence of mechanical imbalance [7]. Measured vibration values were not too high and their correcting wasn't necessary.

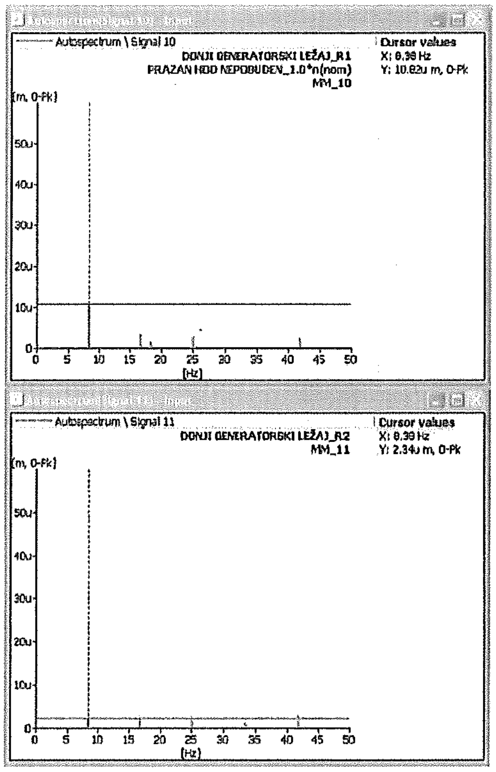


Fig. 6 Absolute bearing vibration / lower generator guide bearing / no load – not excited / frequency domain

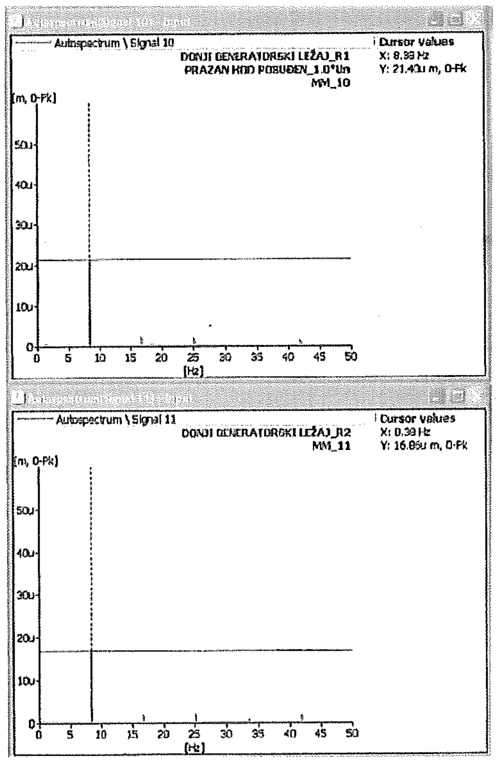


Fig. 7 Absolute bearing vibration / lower generator guide bearing / no load – excited / frequency domain

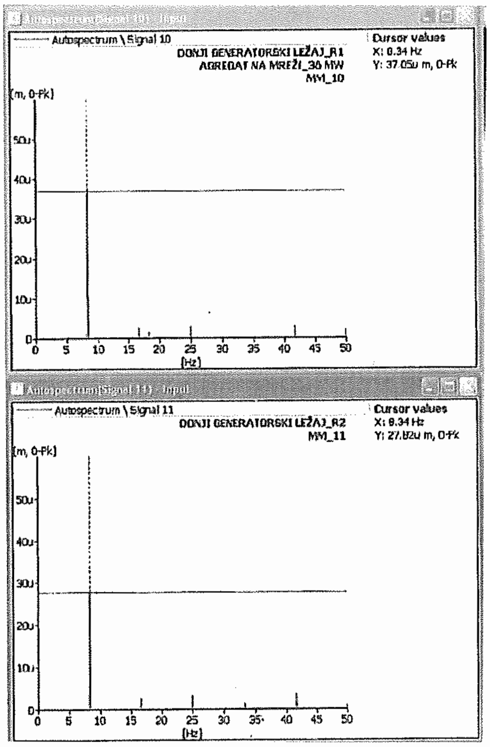


Fig. 8 Absolute bearing vibration / lower generator guide bearing / 36 MW / frequency domain

5 Conclusion

In this paper, special attention was given to detection of rotor winding shorted-turns, broken damper bars and magnetic imbalance. Magnetic and vibration measurements were done simultaneously. Results from all six sensors were similar.

There were no shorted turns and broken damper bars found on the rotor poles. Presence of magnetic imbalance, that is not critical, was detected. This is confirmed by testing of generators vibration state. Measured vibration values were not too high. Correlations between the given measurements are extremely important. Using magnetic measurements it is possible to detect the causes (changes in air gap, physical differences in the poles…) ,of the magnetic imbalance. Periodic magnetic monitoring (once or twice per year) is recommended to catch any changes in the rotor winding insulation condition and rotor balance.

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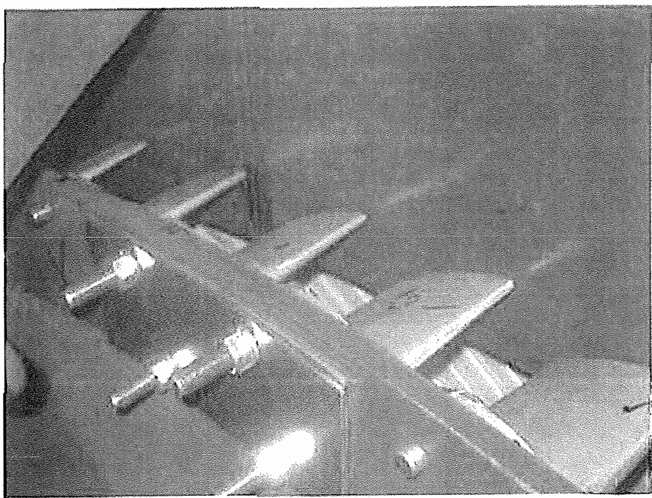

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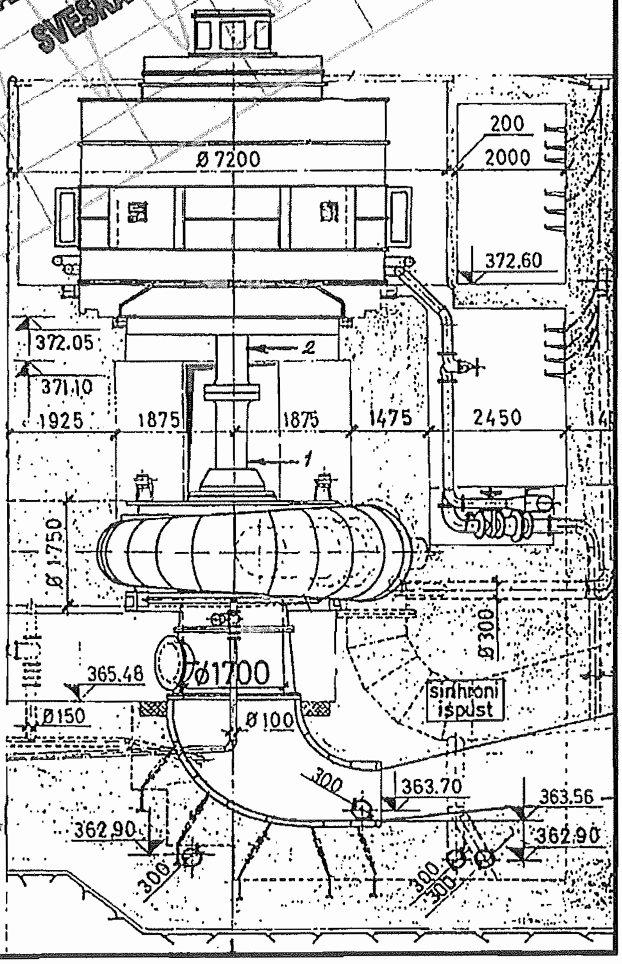

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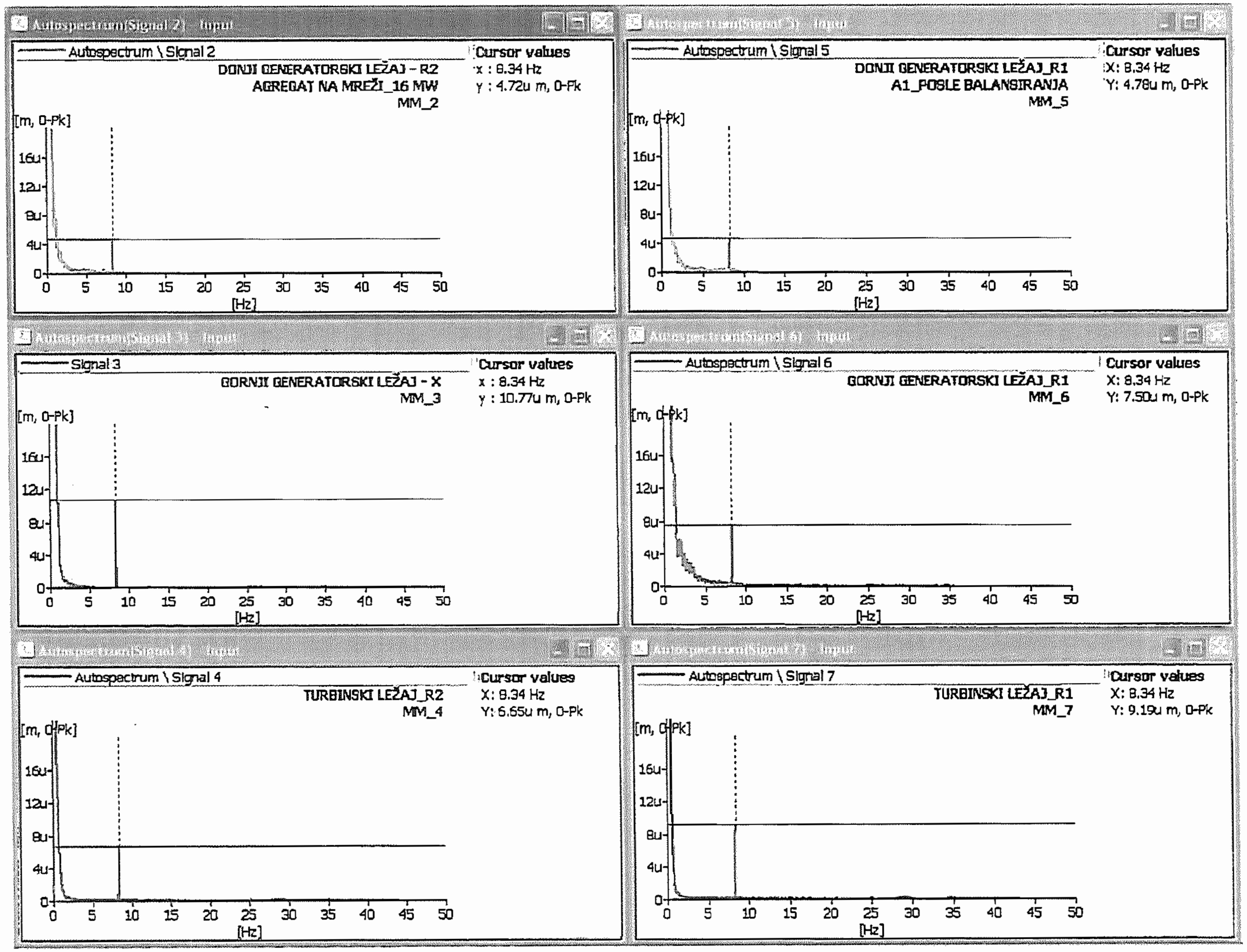

Sl. 115 Frekventni spektri apsolutnih vibracija pomeraja snimljeni u ustaljenim režimima rada

- Agregat_A1: Posle balansiranja
  - Kućište donjeg generatorskog vodećeg ležaja – MM: 2 R2 / 5 R1
  - Kućište gornjeg generatorskog vodećeg ležaja – MM: 3 X / 6 R1
  - Kućište turbinskog vodećeg ležaja – MM: 4 R2 / 7 R1

☐ Prazan hod nepobuđen – $n = 1.0 * n_{nom}$
☐ Prazan hod pobuđen – $U_g = 1.0 * U_{nom}$
☒ Agregat na mreži - P_A =16 MW