Power Generator Mechanical Faults Effects On Electric Power Quality

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Abstract

The principal objective of the paper is to establish the framework for power quality assessment of hydropower generator. The suggested framework states that electric power quality is affected by mechanical faults of power generator like rotor air gap eccentricity, rotor and stator vibration characteristics and unbalance. The power quality was analysed based on harmonic components of every generator pole. The proposed framework is beneficial for diagnosis of hydropower units since it relates electrical and mechanical analysis and provides example of data acquisition program suitable for further investigations.

Keywords: *power quality, vibration, air gap.*

1. Introduction

Distorted current wastes energy, increases heat of power generation unit and causes distorted voltage, which may result into faulty operation of electrical equipment. The hypothesis states that solving mechanical problems of the hydropower generation unit could increase power quality produced. The different dynamic load conditions were used to analyze the behaviour of the rotor, and it is assumed the hydropower turbine could be described as a continuous solid material, finite element model.

The objective of the paper was to define, whether mechanical vibrations affects power quality for particular hydropower generator. Special industrial equipment and programming software for vibration and power quality analysis was used.

It was found that vibration of hydropower generator has significant effect on output power quality. It was also discovered that he opposite effect takes place and power quality disruptions as harmonics and flicker increase vibration of a generator. The framework for future similar measurements was developed.

2. Materials and methods

The air gap of the rotor should be evaluated at least once in a 5 years, as well before and after reconstruction of hydropower generation units.[1] Evaluating the air gap and rotor form helps to perform proper balancing of the unit and eliminate vibration.

Bayliss, Colin in their analysis of transmission systems suggest that one of adverse effects of harmonics include machine vibration, which could be partially caused by overstressing and heating of insulation. [2] To meet the objective of the study the set of measurements were performed on hydropower generating unit, using instrumentation like power analyser for three-phase electrical networks, laser tachometer kit, vibration measurement equipment, air gap measuring system etc. The data, acquired from the experiments, was analysed through LabVIEW, MatLAB programming tools and Microsoft Office Excel.

To evaluate both centrifugal and electromagnetic forces effects on the air gap and rotor form, the measurements were performed in different idle and loaded work conditions (regimes). Ten minutes long measurement were taken at idle regime with load 13,8 kV and nominal rotational speed, 2,5 hours at nominal load. After stator reached its normal operating temperature, measurements at reactive power at

0MVAr were taken and measurements of active power (10MW, 45MW;90 MW) followed. The duration of each measurement was ten minutes. Then 5 minutes long measurements with active power 90MW and following reactive power of +20, -10, -20, -30, -40, -50, -60, -70MVAr were performed. Finally, measurements at Synchronous Compensation with loads +20, 0, -10, -20, -30, -40, -50, -60, -70MVAr were performed.

The quantitative values of air gap for rotor were collected for the diagram of rotor form, which was calculated as follows: [1]

$$\Delta_{rot.} = \left[\left(A_{rot.max} - \delta_{rot.avg} \right) / \delta_{rot.avg} \right] \cdot 100\% \qquad (1)$$

where

$A_{rot.max}$ – maximum value of measured air gap;

$\delta_{rot.avg}$ – average value of all air gap measurements.

The similar logic was used to display stator form:

$$\Delta_{st.} = \left[\left(A_{st.max} - \delta_{st.avg} \right) / \delta_{st.avg} \right] \cdot 100\% \qquad (2)$$

where

$A_{st.max}$ – maximum value of measured air gap;

$\delta_{st.avg}$ – average value of all air gap measurements.

Such simplified analysis was applicable for measurements where no extreme air gap deviation is expected.

Typically a transformer magnetizing current will contain small third, fifth and seventh harmonic components. [2-3]

$$I_{mag} = 100 \sin(\omega t - 78) - 39 \sin(3\omega t - 83) + 18 \sin(5\omega t - 81) - 8(7\omega t - 80) \qquad (3)$$

The harmonic currents sum was obtained by root mean square (r.m.s.) value [2-3]:

$$I_{rms} = \sqrt{\frac{I_1^2}{2} + \frac{I_2^2}{2} + \frac{I_3^2}{2} + \cdots + \frac{I_n^2}{2}} \qquad (4)$$

The MatLAB program code was developed to reduce time for future investigation calculations. Please refer to Figure 1 for the code example. The ready-to-use code also simplifies future data analysis and allows accomplishing graphical representation of data faster.

```
%Example of code for generator vibration calculation
w=100; %frequency,Hz
v=2*w; %double value of the current, vibration of main vawe;
m1=0.4; %kg, example of mass for 1 cm^2 of stator cilindrical surface
m2=0.1; %kg, example of mass for 1 cm^2 of housing cilindrical surface
H=50; %cm, stator height
R1=113; %cm, average radius of rotor;
R2=70; %cm, average radius of core;
r=2*pi*w; %mechanical resistance;
k=5; %number of elastic elements on one edge;
y=0.2*10^-4; %cm/N, relation to force applied
t=32; %cm, distance between edges
B=0.87; %Tl, induction
lambda1=(12*R1^4/(1.2*H))*(10^7*2^2+1/(2*(2^2-1)));
lambda2=(12*R2^4/(1.2*H))*(10^7*2^2+1/(2*(2^2-1)));
z1=r*4*(10^-3)-1/(r*lambda1);
z2=r*4*(10^-3)-1/(r*lambda2);
p=20*B^2*(R1/R2); %Inducing power
L=20*lg(r*(p/(z1+z2))/3*10^-2); %vibration at housing
```

Figure 1. MatLAB code.

3. Results and discussion

After actual measurements the numerical values were obtained through LabVIEW program application and for the simplicity plotted in MSC Excel. Please refer to Figure 2 and Figure 3 for illustration of the results.

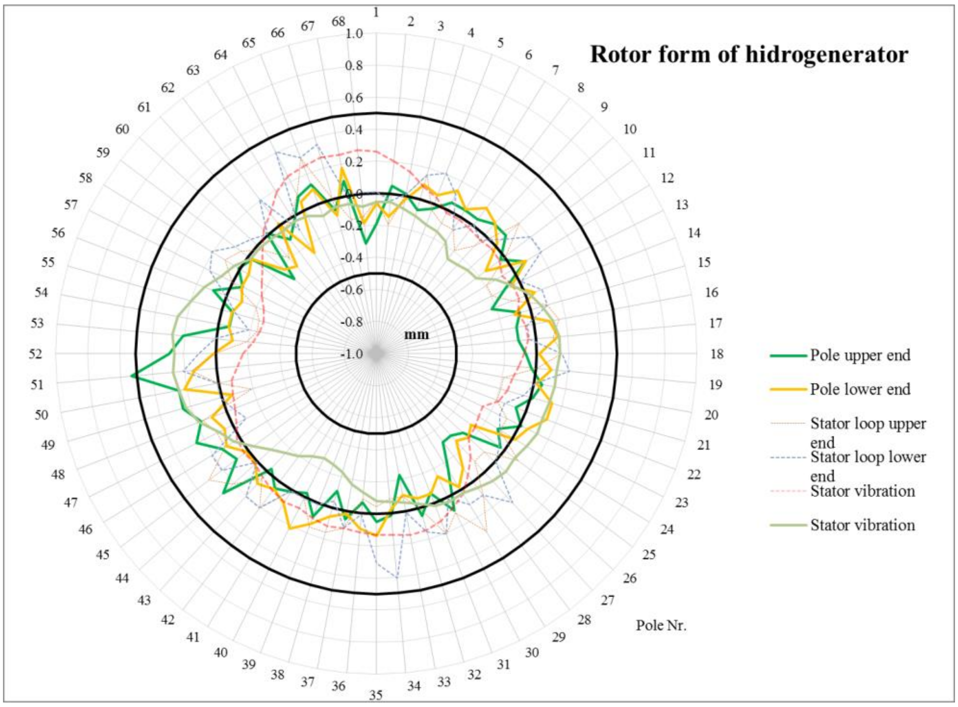

Figure 2. Plotted values of rotor air gap.

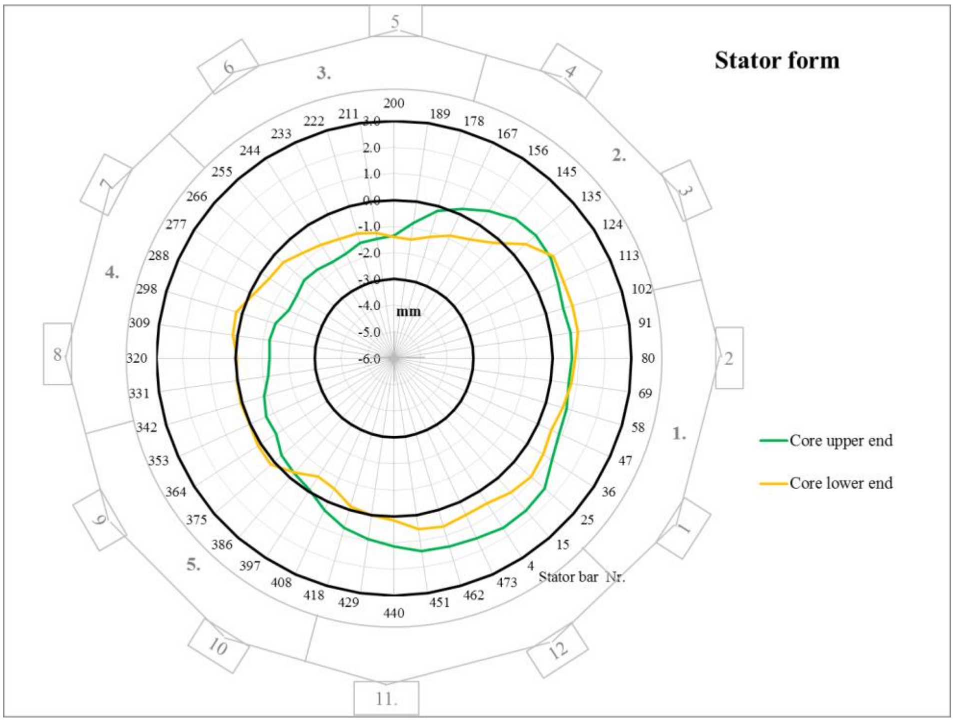

Figure 3. Plotted values of stator form.

The deviation was calculated to be 2,7%, which is less than 3% and therefore compliant to the standard. Some abnormal behaviour was observed during vibration measurements, particularly at 100 Hz rate. The data about vibration at 100 Hz rate has been collected since 1998. The data is useful material for future investigations, because it is not clear yet what mechanical faults exactly cause the flicker at the particular rotation speed.

Normally by observing increasing phase shift per harmonic, the phase shift gets greater the higher the frequency, but for particular measurements done during the study (specifically at frequency 100 Hz) the effect was just the opposite.

In the methodology section it was shown that simplified air gap analysis by equation (1) and (2) was applicable for particular measurements, because no extreme air gap deviation was expected. However, for further analysis Fourier transformation should be used. Thus, first harmonic component will describe eccentricity of rotor, second – elliptic form and higher harmonics will show if rotor has more complicated air gap deviation. [1] Harmonic analysis should be a good way to quantify non-linear load and is suggested for further investigations.

During further investigation it should be considered that the major producers of harmonics could be large converter-controlled electric motor drives. Such harmonics (as well as harmonics from miscellaneous equipment like computers) do not inject a harmful level of harmonic currents into the public electricity supply system if filtered on site. [2]

For the future measurements the following framework is suggested [2]-[4]:

- The working program with regimes similar to those listed in the materials and methods section is composed;
- The numerical values of expected vibration are obtained through MatLAB code developed in materials and methods section for the particular study[7]-[8];
- The information, which could be useful for further investigation, is collected. The suggested information is (but not limited to) the following characteristics:
    - The characteristics of the iron of the transformer core;

- The designed flux level of the transformer;
- The level of the supply voltage compared to the nominal;
- The inductance of the relevant transformer winding when saturated;
- The load on any other windings on the transformer, and the coupling between the windings.

The Total Harmonic distortion calculated and high order harmonics analysed if percentage of rotor gap deviation from the average value is larger than 3%. [1] [5]

4. Conclusion

The paper explored harmonics and phase shifts causes during vibration measurements for hydropower generation equipment.
The strong correlation between stator vibration and power quality was confirmed. The general air gap $\Delta_{rot.}$ and $\Delta_{st.}$ was found to be acceptable and within acceptable limits (3% and 5% respectively) of existing standards [1], therefore no significant mechanical fault was discovered for particular generation unit and analysis of higher order harmonics was not necessary. Still, the framework developed could be applied for measurements on other units of power plant, where some mechanical defects (like excessive low-frequency vibration or heating of metal) are observed already.
For the given hydropower generation unit further investigation and analysis of harmonics could also be performed for power quality analysis at 100 Hz rate only, since the greatest vibration with no clear causes was observed at the given rotational speed on hydro power generator for long period of time.

References

[1] Стандарт ОАО РАО «Методики оценки технического состояния основного оборудования гидроэлектростанций», 2006;
[2] Colin R. Bayliss, and Brian J. Hardy. Transmission and distribution electrical engineering. Elsevier, 2012;
[3] Arrillaga, Jos, and Neville R. Watson. Power system harmonics. John Wiley & Sons, 2004;
[4] Steed. Ferroresonance - mystery, mythology and magic! IEE Power Eng J 1996;
[5] Shmilovitz, Doron. "On the definition of total harmonic distortion and its effect on measurement interpretation." *IEEE Transactions on Power delivery* 20.1 (2005): 526-528.
[6] T. A. Buchh and A. Domijan, Jr., “Harmonic effect of electric vehicle loads,” Int. Assoc. Science Technol. Development J. Power Energy Syst., vol. 21, no. 2, pp. 62–6, 2001.
[7] В.Я.Кучер, Вибрация и шум электрических машин, письменные лекции, Санкт-Петербург,2004;
[8] Каплин, А. И., and М. Ю. Либерман. "О новых стандартах МЭК по нормированию акустического шума и вибрации электрических машин." Электротехника 5 (2009): 35-40.

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