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Harmonic Effects Analysis of Electronic Loads Controller on Self Excited Induction Generator (SEIG) Operations

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Abstract

The aplication of Electonic Load Controller (ELC) on Self-Excited Induction Generator (SEIG) driven by renewable energy sources creates harmonic issues. This paper has analyzed the propagation of the harmonic current generated by the ELC in the generator system. Mathematical modeling and computer simulation is used to analyze the propagation of harmonic currents generated by ELC on the generator system. Laboratory testing has also been conducted to justify the simulation results. The study results showed that the propagation harmonic currents created by ELC on the stator widings of SEIG and main load side are rejected for high order components, and attenuated for lower order components. Consequently, the THDI of stator and main load current will be reduced significantly

Keywords: *SEIG, ELC, Harmonics, Total Harmonic Distortion (THD), Dummy Load*

1. Introduction

At the moment, Self-Excited Induction Generator (SEIG) is increasingly popular used for small-scale power plants driven by renewable energy sources, including: wind, mini/microhydro, tidal wave, biomass, biogas, etc. [1]. The popularity of induction generator mainly is due to a number of advantages compared to the synchronous generators, such as: low cost, high reliability, rugged construction, maintenance and operational simplicity, self-protection against faults and overload, not needed dc supply for excitation, etc. [1, 2]. In the previous study, analysis of harmonic propagation on SEIG loaded by non-linear load [3]. The results showed that SEIG rejects the high order harmonics and attenuates low order harmonics currents on its stator windings; consequently THD_I is low relatively on the stator windings. For loading with the same non-linear load, the harmonics distortion on the stator windings of SEIG was smaller than compare the isolated synchronous generator [4].

The application of induction generators in commercial biogas power plant driven power has been successfully analyzed [1]. Some experts have successfully designed the induction generator controller (IGC) or Electronic Load Controller; consequently this generator can be used commercially on a micro hydro power plant [5-7]. In the meantime, the minimum excitation capacitor connected auxiliary windings of a single phase Self-Excited Induction Generator (SEIG) have been successfully calculated for suitable for standby power system [6].

However, the operation of SEIG with ELC or IGC can be creates the power quality problems. The utilization of power electronics components on the IGC/ELC will generate harmonics current and voltage on the generator output. The harmonics distortion can give the effect of a decrease in efficiency, heating and reducing the lifetime of the machine [8]. In this paper, the effect of ELC mounting on SEIG against propogation of harmonic disturbance on SEIG system is analyzed. The analysis will be focused on propagating the harmonic currents from the ELC to the load and to the stator windings of SEIG.

2. Description of Studied System

The configuration of studied system consists of SEIG, main loads, and Electronic Load Controller (ELC), as shown by Figure 1. ELC is built by step-down transformer, three-phase

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rectifier, DC Chopper, and dummy load. As a dummy load can be used resistive loads, batteries, or other forms of load. As shown in figure 1, in this study as a dummy load is used batteries. ELC serves as a power balance controller between the output power of the generator and load power, by controlling the value of duty cyle (δ) of DC Chopper. Because the ELC consists of non-linear components, it will be the harmonic current source for the SEIG system. The harmonic currents generated by ELC , $I_{h(ELC)}$, will propagate to the generator coils, $I_{h(IM)}$, and main loads, $I_{h(Load)}$. In addition, the hamonic effects of ELC will also have an impact on harmonic distortion on the output voltage of the generator.

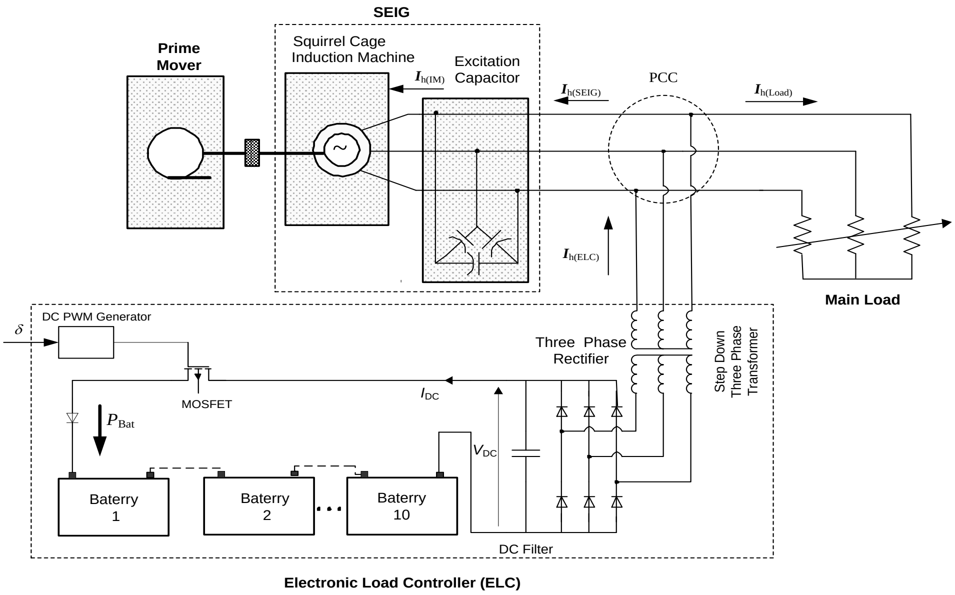


Figure 1. The configuration of studied system

3. Modelling and Simulation

3.1 SEIG Modelling

The dynamic analysis of an induction machine typically uses q-d coordinates. In the previous study, the equations of induction generators in q-d coordinates have derived [9].The flux equation in the d-q axis on the stator and rotor coils for SEIG can be written according to the following equation :

$$\begin{aligned}
\frac{d\lambda_{qs}}{dt} &= \frac{R_s L_r}{D}\lambda_{qs} - \omega\lambda_{ds} - \frac{R_s L_m}{D}\lambda_{qr} + v_{qs} \\
\frac{d\lambda_{ds}}{dt} &= \omega\lambda_{qs} + \frac{R_s L_r}{D}\lambda_{ds} - \frac{R_s L_m}{D}\lambda_{dr} + v_{ds} \\
\frac{d\lambda_{qr}}{dt} &= -\frac{R_r L_m}{D}\lambda_{qs} + \frac{R_r L_s}{D}\lambda_{qr} - (\omega-\omega_r)\lambda_{dr} \\
\frac{d\lambda_{dr}}{dt} &= -\frac{R_r L_m}{D}\lambda_{ds} + (\omega-\omega_r)\lambda_{qr} + \frac{R_r L_s}{D}\lambda_{dr}
\end{aligned} \tag{1}$$

where,

ω_{qs}, ω_{ds} = stator flux linkage in q & d axis respectively

ω_{qr}, ω_{dr} = rotor flux linkage referred to stator in q & d axis respectively

v_{qs}, v_{ds} = stator voltage in q & d axis respectively

λ_{qs}, λ_{ds} = stator flux linkage in q & d axis respectively

λ_{qr}, λ_{dr} = rotor flux linkage in q & d axis respectively

L_s = per-phase stator leakage inductance

L_r = per-phase rotor leakage inductance refereed to stator

R_s = per-phase stator windings resistance
R_r = per-phase rotor windings resistance refereed to stator
L_m = per-phase magnetising inductance
$D = L_m^2 - L_s L_r$

The voltage equation in the d-q coordinate for SEIG can be written as follows [9]:

$$\frac{dv_{qs}}{dt} = -\frac{1}{C_s} i_{ql} - \omega v_{ds} + \frac{1}{C_s} i_{qs}$$
$$\frac{dv_{ds}}{dt} = -\frac{1}{C_s} i_{dl} + \omega v_{qs} + \frac{1}{C_s} i_{ds} \tag{2}$$

where,
C_s = excitation capacitance
i_{qs}, i_{ds} = stator current in q & d axis respectively
i_{ql}, i_{dl} = load current in q & d axis respectively

The currents as a function of flux linkages as shown by Equation (3).

$$\begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} = \frac{1}{D} \begin{bmatrix} L_r & 0 & -L_m & 0 \\ 0 & L_r & 0 & -L_m \\ L_m & 0 & L_s & 0 \\ 0 & L_m & 0 & L_s \end{bmatrix} \cdot \begin{bmatrix} \lambda_{qs} \\ \lambda_{ds} \\ \lambda_{qr} \\ \lambda_{dr} \end{bmatrix} \tag{3}$$

3.2 Computer Simulation

The computer simulation is designed to solve the propagation of harmonic currents from ELC to the stator windings, and to main loads. The simulation process is done using SIMULINK-MATLAB software [10]. The simulation model for the proposed system is shown by Figure 2. As shown by the figure, harmonic distortion monitoring is also performed on the ELC side, main load and generator coils. Monitoring of the waveform is also done on the DC side and transmission line.

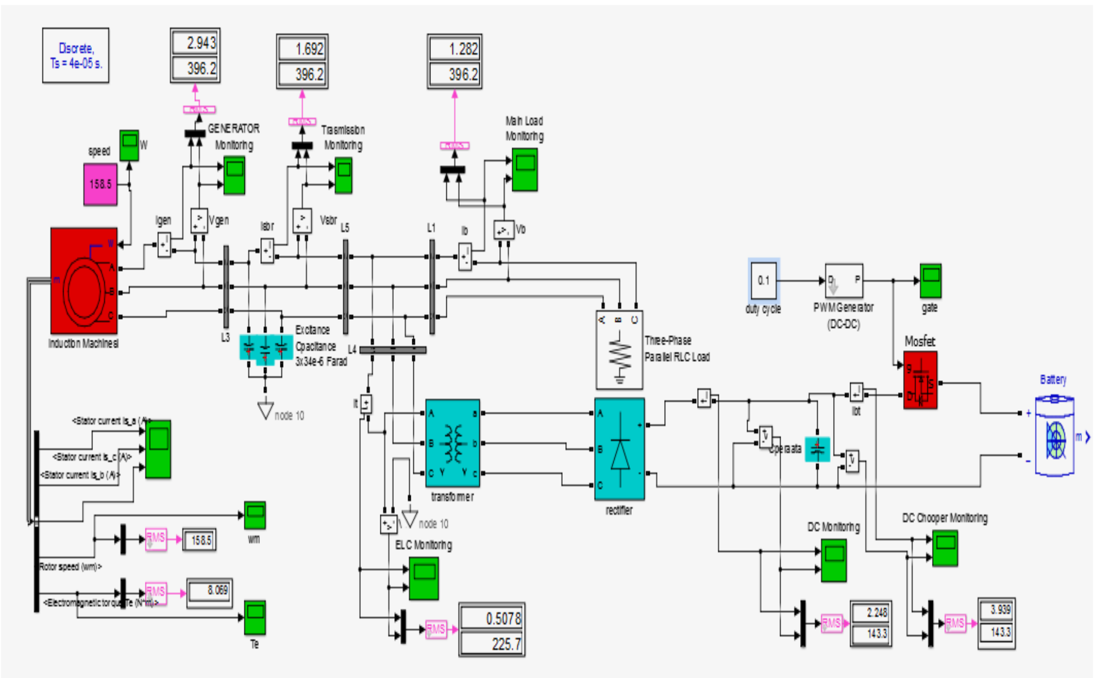


Figure 2. The simulation model for the proposed

The parameters of induction machine used this simulation, is obtained from the no-load, and the block-rotor test. The parameters obtained from the test results of the studied machine (1.5 kW, 380-420 V, 50 Hz, 3-phase, squirrel cage rotor) are listed in Table 1. To accommodate the saturation effect in the simulation model, saturation testing has been performed. The results of the saturation test are tabulated in Table 2. While the value of the excitation capacitor and parameters of the ELC completed from the calculation.

Table 1. The results test of machine parameter

$R_s(\Omega)$	$X_s(\Omega)$	$R_r'(\Omega)$	$X_r'(\Omega)$	$X_m(\Omega)$
4,38	3,61	5,87	3,61	106.16

Table 2. The saturation results test

V_{LL}(V)	I_m (A)	V_{LL}(V)	I_m(A)	V_{LL}(V)	I_m (A)
420	2.620	280	1.274	140	0.607
400	2.249	260	1.176	120	0.523
380	1.997	240	1.074	100	0.432
360	1.783	220	0.976	80	0.351
340	1.635	200	0.886	60	0.297
320	1.512	180	0.795	40	0.254
300	1.374	160	0.701	20	0.420

4. Experimental Set Up

In order to validate the results of the modeling and analysis, a series of experiment are performed in thelaboratory. The experimental set up for the SEIG with ELC is implemented from Figure 1. In this test, dc PWM generating and duty cyle setting is implemented using Arduino Uno microcontroller. Furthermore, 3hp induction motor is driven by a frequency regulator is used as a prime mover of SEIG. The excitation capacitors used in this test is 3 × 34 μF, which are connected in Y-connection. The SEIG with ELC is burdened by resistive load, which are incandescent lamps of 420 Watt and 900 Watt. The harmonic measurements are performed using Power Analyzer type CA 8220 with data transfer to a PC/Laptop. The measurements were taken at three points of measurement, which are ELC side, loads side, and stator windings side.

5. Results and Discussion

In this section, the simulation and test results of the harmonic current propagation from the ELC to the main loads side and the stator coils side of SEIG are presented. The harmonic current propagation on each side are shown for the same load, i.e. 420 & 900 Watt. Then, the effect of loading on the propagation of harmonic current is also shown.

5.1 ELC Characteristics

Figure 3 shown the measurement results of the ELC output current wave, which is the charging current to the battery. As shown by figure, the output current wave of the ELC has the pulse wave form. The magnitude of the current charging average or the amount of power supplied to the battery can be adjusted through the duty cycle setting (δ). As shown in Figure 3, to maintain the voltage of the generator at a nominal value during load of 420 Watt is required a duty cycle (δ) setting of 70%.

Figure 4 shown the wave of input current and voltage for the ELC, which represents the distribution of the excess power of the generator to the ELC. As shown in Figure 4, the input current waveform of the ELC is highly distorted from the sinusoidal form. Meanwhile, the voltage waveform is still close to a pure sinusoidal waveform. This condition will generate harmonic current waves, which can propagate on the main load and the generator coils.

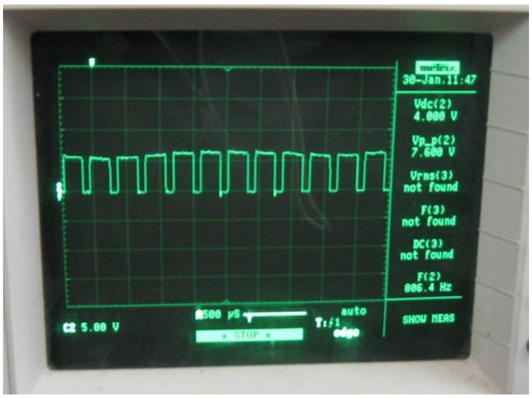


Figure 3. Output wave of ELC

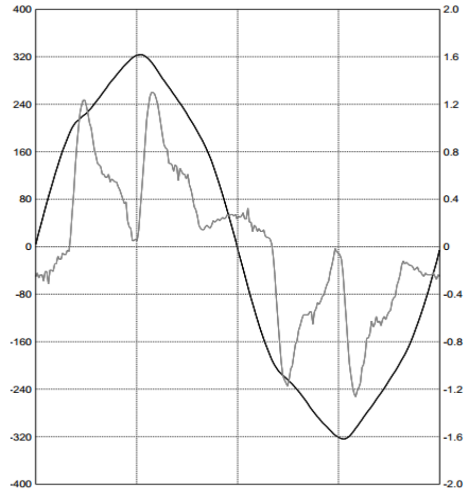
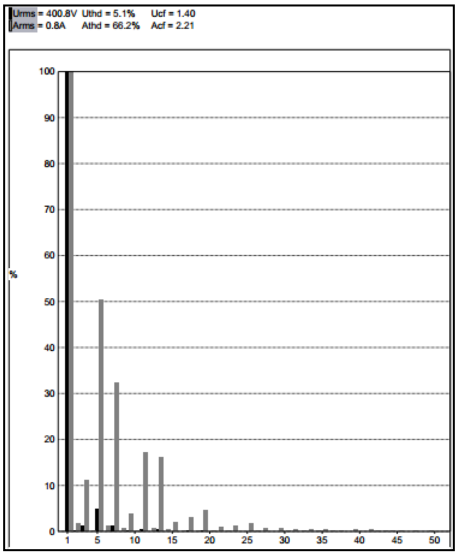


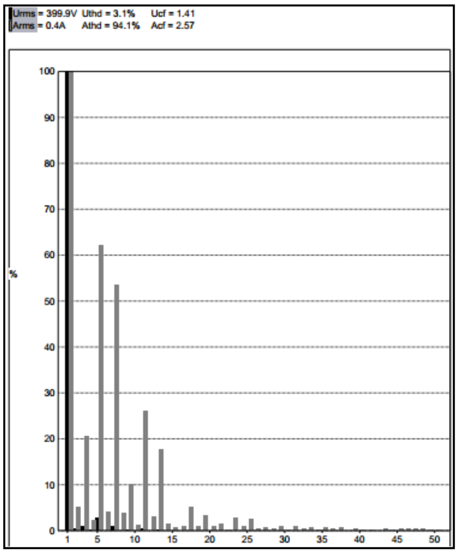
Figure 4. Input wave of ELC

5.2 Current Harmonics Generated by ELC

Figure 5 shown the measurement results for the harmonics spectrum of ELC input current and voltage for different load. As shown in Figure 5, the ELC has generated a relatively large amount of harmonic current, with Total Harmonic Distortion (THD_I) of 65.1% for load of 420 Watt, and 94.1% for load of 900 Watt. Here, it can be shown that increasing the main load will increase the value of THD_I. This may be the case because increasing the load will reduce the duty cycle of ELC, which will worsen the harmonic deviation of the input current wave. Meanwhile, the harmonic deviation of the voltage wave for each loading is still within the allowed standard. Figure 6 shown the simulation results for the harmonics spectrum of ELC input current and voltage for different load. As shown in Figure 5 & 6, simulation and experimental results support each other.



a. load of 645 Watt



b. load of 900 Watt

Figure 5. The measurement results for harmonic generated by ELC

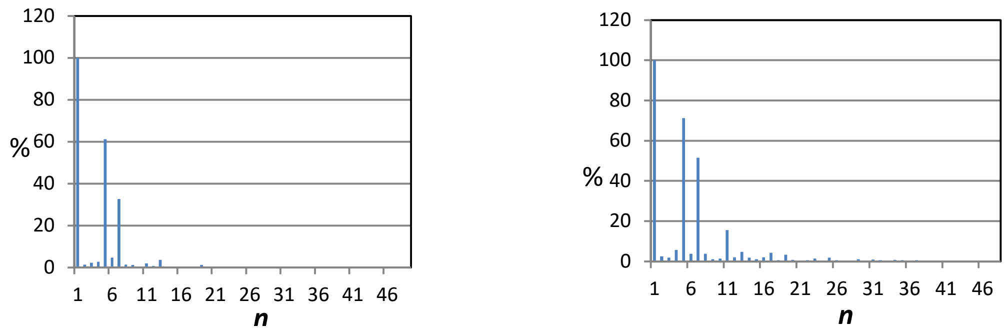
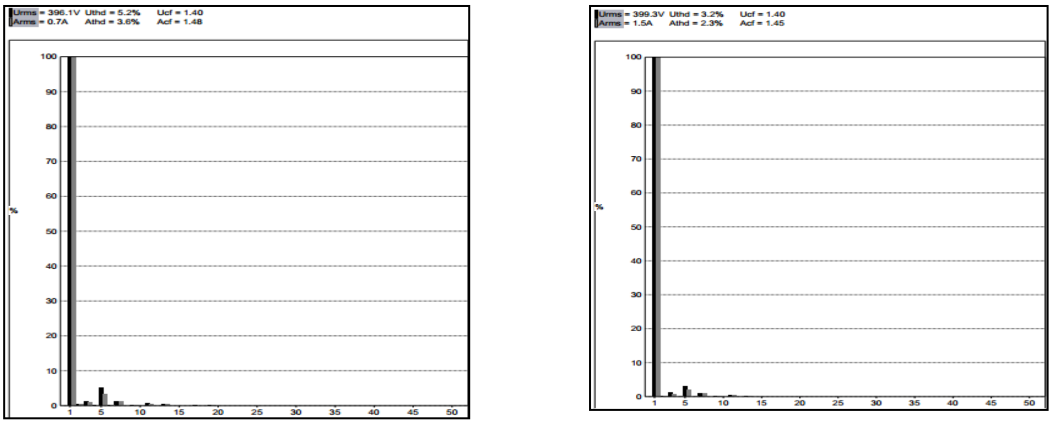


Figure 6. The simulation results for current harmonics generated by ELC

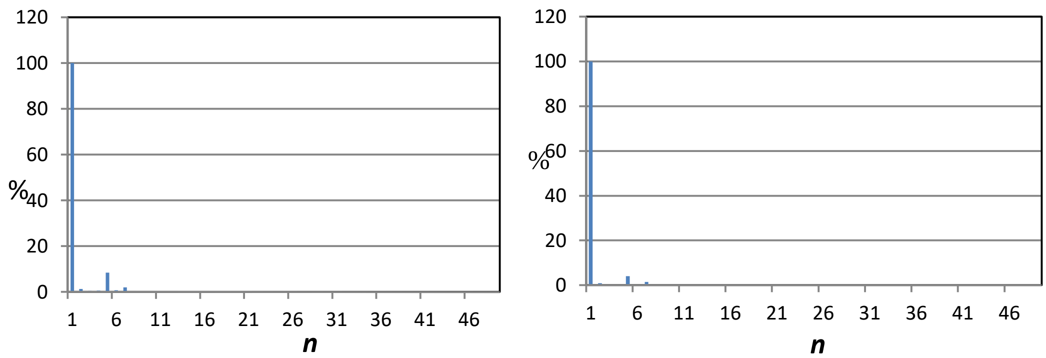
5.2 Harmonic Effect On The Main Load

Figure 7 shown the measurement results of the harmonic current and voltage spectrum on the main loads side for different load. As shown in Figure 7, the hamonic effect of ELC on the main load is very small, so this condition can be ignored. However, the decrease of main load from 900 Watt to 420 Watt will increase THD_I from 2.3% to 3.4%. This may happen because the decrease in main load will trigger an increase in ELC input current, which contains a large amount of harmonic component. Figure 8 shown the simulation results of the harmonic current and voltage spectrum on the main loads side for different loads. As shown in Figure 7 & 8, simulation and experimental results support each other.



a. load of 420 Watt b. load of 900 Watt

Figure 7. The experimental results of voltage and current harmonics on main load side for different load

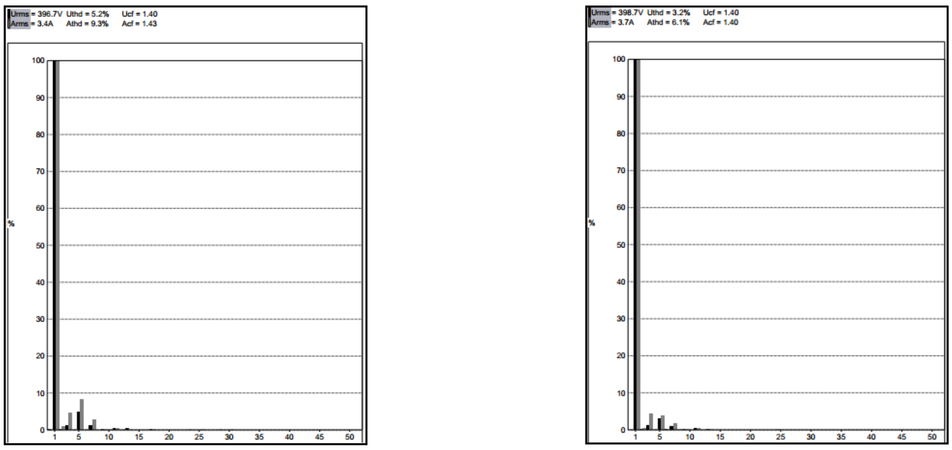


a. load of 420 Watt a. load of 900 Watt

Figure 8. The simulation results of voltage and current harmonics on main load side for different load

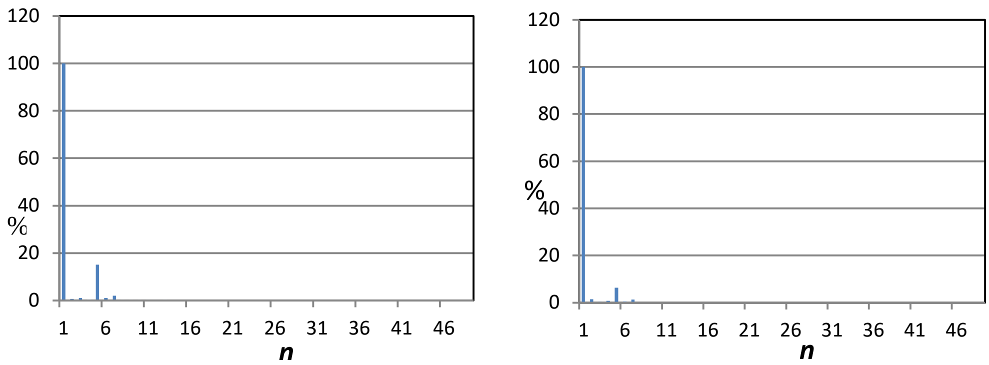
5.4 Harmonics Effect On The Stator Windings of SEIG

Figure 9 shown the experimental results of the spectrum harmonic of current and voltage on the stator windings of SEIG for different load. As shown in Figure 9, the hamonic effect of ELC on the stator windings is small relatively. This may be due to the interaction between the excitation capacitance (C_e) and the leakage inductance of stator windings can eliminate for high frequency harmonic currents and attenuate for frequency harmonic currents. In addition, the increase of main load from 420 Watt to 900 Watt resulted in a decrease of THD_I from 9.3% to 6.1%. This is possible due to a decrease in the contribution of ELC currents in the SEIG system with the increase of load. Figure 10 shown the simulation results of the harmonic current and voltage spectrum on the stator windings side for different loads. As shown in Figure 9 & 10, simulation and experimental results support each other.



a. load of 420 Watt b. load of 900 Watt

Figure 9 The experimental results of voltage and current harmonics on stator windings side for different load



a. load of 420 Watt a. load of 900 Watt

Figure 10. The simulation results of voltage and current harmonics on stator windings side for different load

6. Conclusion

The distribution of harmonic current on SEIG with ELC has been successfully analyzed in this study. Some important things need to be summarized below. The THD_I value of the harmonic current generated by the ELC is influenced by main load power, the higher the main load power the greater the THD_I value of the harmonic current generated by the ELC. The harmonic current effects generated by the ELC on the stator coil are relatively small, in which case the high frequency harmonic current component has rejected and the low-frequency harmonic components has attenuated. The reduction of the main load power can be increase the effect of ELC harmonic current on the stator windings. The effect of the harmonic current on the main load is very small. The ELC harmonic effect on the PCC voltage still revolves around the allowable value (THD_V = 5.2%). Overall it can be concluded that the use of ELC has a relatively small harmonic effect on the SEIG system.

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