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The Harmonics Effect of Variable Speed Drives on Generator Performance

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ABSTRACT

Large motors often burden synchronous generators as power plants in factories. This motor is commonly using to regulate rotation using Variable Speed Drive (VSD). From the load side, VSD, as a regulator of motor rotation, can reduce power loss. On the generator side as a power plant, this load with VSD affects the waveform of the generator. The experiments on a small capacity generator (6 kVA) with a VSD as regulating the motor rotation with a load of about 1.1 kW shows effectiveness power transfer is about 40.7% with VSD, and without VSD, efficiency is approximately 39.6%. The motor losses by installing VSD interpreted as transferring losses to the generator with savings is about 1 %. The experiments also showed that generator performance decreases when loaded with VSD at around 6%, and a generator temperature increases at 20 oC higher than without VSD.

KEYWORDS

Variable speed drives
Motor losses
Generator losses

INTRODUCTION

The use of power electronic devices for the industry is becoming more intense nowadays (Ortmeyer et al., 1995). Power electronic devices, variable speed drives (VSD), have been widely used for controlling motor rotational speed. In large factories with their power plants, the motor load with the VSD is often connected directly to the power generator. This direct connection causes power generators to get non-linear loads. It is necessary to study to see the effect of VSD as a non-linear load on the power generator. This research intended to get a clear picture of the impact of VSD on the electric generator.

Harmonic loads due to the influence of VSD are likely to increase power losses in the electric generator on power plants. The increased loss of power generation can affect generator performance (Quang, 1998). This condition exists due to the current load harmonic directly exposed to the generator. Therefore, the current load harmonic affects the generator stator winding losses. Besides, harmonic currents also affect eddy currents in the stator generator core (Jha et al., 2013).

Renewable energy-based power plants also often use inverters to maintain their output frequency; this results in non-linear loads on the generator (Zoghlami et al., 2016). The synchronous generator uses a back to back converter to get the voltage and frequency by the

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standard grid value (Nam, 2019) so that the synchronous AC generator causes non-linear load. Non-linear load types from synchronous generators as power plants were also increasingly found, as found in the end-user of the electrical system (Teitel et al., 2004). This non-linear load will generate harmonics in the synchronous generator as an energy conversion machine into electricity in the power plant. The effect of non-linear generator load on plant performance is becoming necessary to investigate.

This research intended to get a picture of the harmonic load due to the increase in generator temperature. Sebaay has conducted a study of non-linear loads associated with generator losses. (Sebaay et al., 2017). In this study, the measurement of changes in the working temperature of generators is connected directly to the harmonic load due to the VSD regulating motor rotation. The measure of changes in working temperature intended to find out how many harmonics for the generator load affects changes in operating temperature. This research conducted using a synchronous generator device with a VSD load to drive a 3-phase asynchronous motor. It gave the asynchronous motor load with a DC generator, and subsequently, the DC generator gave a resistive load.

RESEARCH METHODS

This experiment is carrying out by measuring the change in the working temperature of the synchronous generator with an asynchronous motor load. It used the asynchronous motor, which is controlled by VSD and without VSD. The temperature difference is expecting to describe losses due to the effects of non-linear loads on the generator. As a hypothesis, the non-linear load effect is due to voltage and current harmonics on the upstream side of the VSD that goes to the generator. Harmonics of the currents and the voltages on the upstream side provide an additional loading effect on the generator. Voltage and current on VSD were measures to get a picture of the harmonics due to switching from VSD. This loading effect, according to Ortmeyer, was the quadratic proportional to the voltage harmonic and the negative sequence of the generator resistance. Calculation of copper losses, it was undertaken using the estimate of sufficient harmonic currents flowing on the conduit wire (Milardovich et al., 2014).

Similarly, the calculation of the core iron losses is proportional to the quadratic of the harmonic voltage that reached the generator (Liu et al., 2013). The increase in harmonic losses on the generator is showing by an increase in the temperature of the generator. Non-linear loads burdened this temperature increase; in this case, the motor load adjusted its rotation using VSD. The configuration of the electric power circuit described the pre-mover of the generator using a 6 kW DC motor with a rotation of around 3000 rpm.

The current and voltage of a motor as pre-mover were measured to get input power. Then, the electrical DC motor as pre-mover, it was used to rotate the 3 phase synchronous AC generator as generating electrical power. And then, the generator output was connected directly to VSD as the motor speed controller at load. The voltage, current, and power active of the generator output were measured using a 3-phase ammeter, voltmeter, and wattmeter. Also, the electric generator output is monitoring by using a power quality meter. The power quality meter observes the waveforms and harmonics caused by VSD as a motor speed controller at load time. The motor load with the VSD was made by assembling DC generators that given resistive loads. In other

words, the DC generator and the resistive load are called AC motor loads, which are controlled by VSD. Furthermore, the voltage and current of the AC motor load with the VSD were measured using an ammeter and voltmeter to determine the amount of power at the resistive load. VSD for speed driver was adjusted so that the motor output rotation was worth 3000 rpm.
The identification of increased power loss in electric generators could make by looking at the increase of the temperature. The increase in the heat of an electric generator is proportional to the power loss. Thus, one indicator of power losses in the generator can be seen by comparing changes in the temperature of the synchronous generator with the AC electric motor with VSD, then compared with the AC electrical motor without VSD. The difference in temperature between the two types of load expected to provide an initial picture of changes in synchronous generator performance due to the use of VSD on the load generator.

RESULT AND ANALYSIS

Data from the measurements of current, voltage, and power in each component are showing in Table 1. The table shows the value of the electrical power from the start of the pre-mover, the power generated by the synchronous generator to the active power used by the AC motor load. The electric power on the DC motor as a pre-mover is calculate using the calculation of the DC circuit. The DC motor power in the power generation is measured using a wattmeter. Then, the temperature in the synchronous generator is measured using a thermal camera imager. The measurement temperature is in the generator container or shell.

Experiments are carrying out by changing several load conditions. Load output power changed in several load conditions. The higher the load changes, the higher the generator's temperature rises; at the highest load value, the surface temperature of the generator stator increases more highly. The generator surface temperature conditions recorded at equilibrium conditions of the environment, with the initial generator surface temperature is 34 oC.

The unit of equipment is a pre-mover with a 6 kW DC motor, the 6kVA of 3 phase synchronous AC generator, a motor load device with VSD, and motor load without VSD. The VSD load device consists of 6 kVA of synchronous a 3 phase AC motor coupled to 6 kW DC generator and the DC generator loaded with a maximum power of 6 kW rheostat.

Table 1. The results of generator measurements

No	DC Motor (Premover)			AC Synchronous Generator (3 phases, delta)								AC Motor (without VSD) loaded to DC Generator		
				R		S		T		Power	Temp			
	Speed *rpm*	I *A*	V *volt*	I *A*	V *volt*	I *A*	V *volt*	I *A*	V *volt*	P *watt*	T *°C*	I *A*	V *volt*	Speed *rpm*
1	3003	2.8	363	9	219	9	219	9	219	880	34	0	220	3000
2	3000	4.8	369	9.2	219	9.6	222	9.2	219	1280	40	1.6	220	3000
3	3000	7.6	366	9.6	222	9.3	222	9.6	222	2060	47	5.6	204	3000

The experiments used the VSD, and the AC generator output fed to the VSD, which functions as an AC motor speed regulator. The AC generator output gives a VSD load to drive an AC motor coupled with a DC generator. And then, the DC generator loaded with resistive loads. AC motor speed is made equal to the speed of the AC asynchronous motor in the previous experiment. Speed regulation uses VSD. The tests' results using VSD loads direct coupled to the AC generator output are showing in Table 2.

Table 2. The generator measurement results are loaded with VSD to drive the motor

No	DC Motor (Premover)			Synchronous Generator (3 phases, delta) R		S		T		Power	Temp	AC Motor (with VSD) load to DC Generator		
	Speed *rpm*	I *A*	V *volt*	I *A*	V *volt*	I *A*	V *volt*	I *A*	V *volt*	P *watt*	T *°C*	I *A*	V *volt*	Speed *rpm*
1	3003	2.6	369	0.5	221	1.4	222	2	221	200	34	0	220	3000
2	3003	4.8	363	2.8	225	3.2	219	3.2	204	900	40	1.6	220	3000
3	3000	7.6	363	4.7	235	4.7	235	4.7	234	1900	49	5.5	204	3000

The harmonic current and voltage of the generator AC measured using a power quality analyzer. The voltage and current waveforms in the generator AC monitored using a power quality analyzer are shown in Figure 1. It is loaded with an asynchronous motor to rotate a DC generator with a load power of about 1142 Watt. With the same load, if the generator output is loading with VSD for motor drive, it generates waveforms containing harmonics. The voltage and current waveforms at the generator output with the AC motor load with VSD and the DC generator loaded with rheostat 1142 Watt shown in Figure 2.

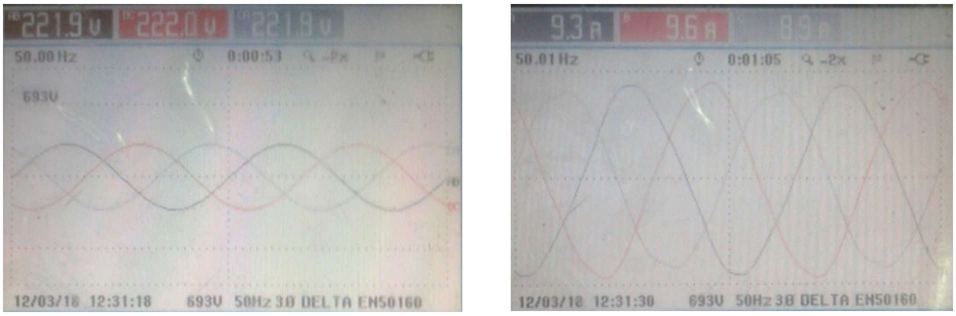

Figure 1. Voltage and current waveforms at the generator output when loaded a motor without VSD

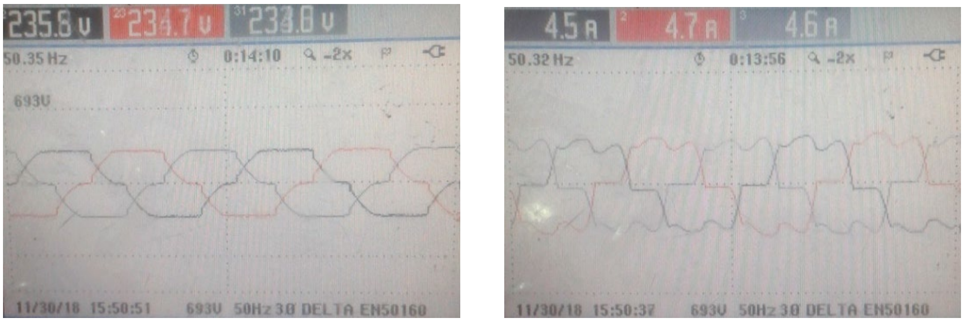

Figure 2. Voltage and current waveforms at the generator load by the DC motor with a VSD

Voltage and current harmonics in AC generators with asynchronous motor loads without VSD still look very good, Figure 3 Whereas for generators with motor loads that controlled with VSD have relatively high voltage harmonics, see Figure 4.

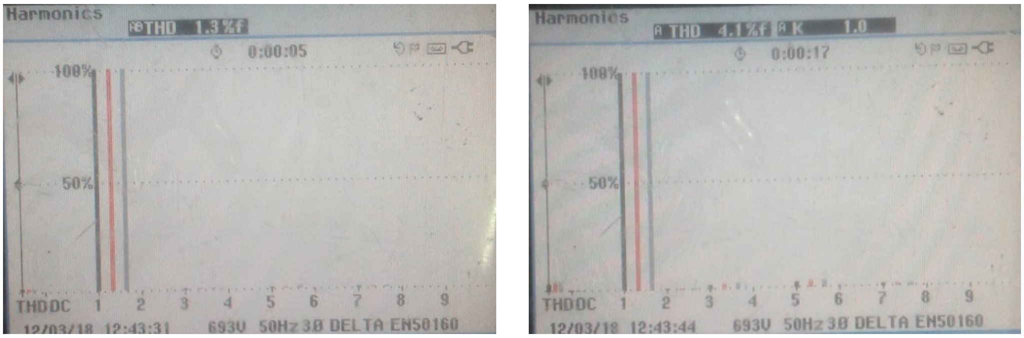

Figure 3. Harmonics of the voltage and current of the generator loaded motor without VSD

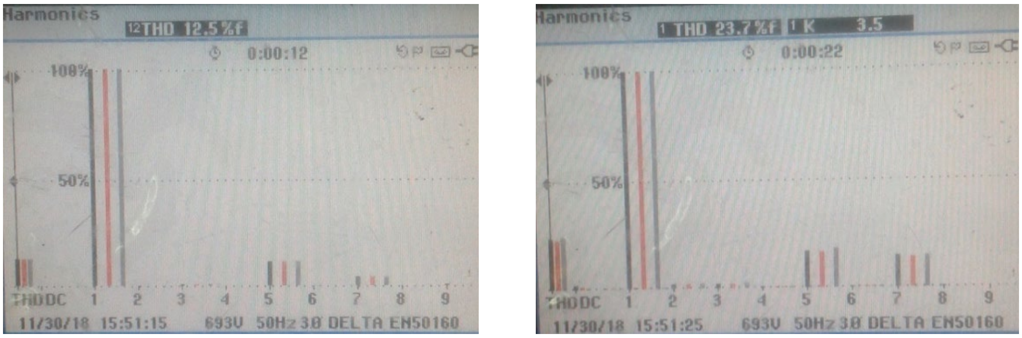

Figure 4. Harmonics voltages and current of the generator load by DC motor with VSD

Figure 3 and Figure 4 show that VSD provides increased harmonic voltages and currents. The harmonics of a voltage on the AC generator given a VSD to control an asynchronous motor with the motor load, approximately 1100 *Watt*, cause a THD of 12.5%. Whereas the current harmonics, THD, the current is 23.7%. This result is much higher than the value allowed by IEEE 519 (P519 Task Force, 1994), which is a maximum THD of 5%.

Furthermore, Table 3 shows that at low to moderate loads, it will produce sizeable apparent power. Likewise, the active power sent to the load is also quite immense. When a VSD is installing, the generator AC for apparent power sent to the AC motor reduces the losses and the AC generator's active power sent to the AC motor. This condition shows in Table 4.

Table 3. Calculation results for generator power loaded with motors without VSD

No	Premover	Pre. & Gen.	Synchronous Generator (3 phases, 6*kVA*)			Gen to Motor AC	Load
	Input Power	Losses	Apparent Power	Active Power	Temp	Power Losses	Power
	Watt	*Watt*	*VA*	*Watt*	°C	*Watt*	*Watt*
1	1016	136	3414	880	34	880	0
2	1771	491	3490	1280	40	928	352
3	2782	722	3691	2060	47	958	1102

Table 4. Results of calculations on generator power loaded with a VSD motor

No	Premover	Pre. & Gen.	Synchronous Generator (3 phases, 6*kVA*)			Gen to VSD	Load
	Input Power	Losses	Apparent Power	Active Power	Temp	Power Losses	Power
	Watt	*Watt*	*VA*	*Watt*	^oC	*Watt*	*Watt*
1	959	759	574	200	34	200	0
2	1742	842	1214	900	40	548	352
3	2758	858	1913	1900	49	778	1122

Table 5. Results of calculations on generator power loaded with a VSD motor

No	Premover	Pre & Gen.	Synch. AC Gen. (3 phases, 6*kVA*)			Gen. to VSD	Load	THD	
	Input	Losses	Apparent	Active	Temp	Losses	Power	Voltage	Current
	Watt	*Watt*	*VA*	*Watt*	^oC	*Watt*	*Watt*	%	%
1	3050	1050	2040	2000	-	790	1210	13.8	23.8

Table 3 shows that the asynchronous motor load with a small load value on the DC generator causes a small power factor. The power factor of the motor will increase when the DC generator load grows. Generator losses, column 2, also rises with the increase in generator load, as explained by Kothari (Kothari and Nagrath, 2010), and this variable loss is higher due to copper losses and stray losses. Losses on the generator side of the motor load zero value turn out to be small, i.e., around 136 *Watt*. The active power losses are initially relatively high, at about 880 *Watt* at zero loads, shown in Table 3, column 6. Although the increase of power loss is proportional to the rise of each load, the value of the rising is not too high.

Table 4 shows synchronous generators loaded by synchronous motors mounted on VSD as regulators of rotation. If the VSD turns in, the motor losses reduce. Therefore, at zero load losses, the active power of the generator output is worth 200 *Watt*, compared with Table 3 at the same load having 880 *Watt* losses. The generator load power losses reduce if the motor load is installing with VSD. Loss of active power on the motor when the zero power load turns out to be quite large, i.e., 759 Watt is shown in Table 4, column 2. If the power load for the synchronous generator is an electric motor without VSD, the power loss at the electric motor becomes smaller. Still, the power loss of the generator becomes large enough. Table 3, column 2, and Table 4, column two, and in the first row show that the loss of power from the generator increases if loaded with VSD. This condition is like moving losses from an AC motor to a generator if an AC motor installs a VSD.

Comparison of Table 3 and Table 4 on the improvement of motor power as a load, it can be said that using VSD will cause less power loss than without VSD. By using VSD, the motor losses are around 39%, whereas, without VSD, the motor losses are about 46%. So it can be said if the VSD will decrease the power losses compared with a motor without VSD in which the reduction in power losses is around 7%.

Comparison of Table 3 and Table 4 in the temperature rise value column shows that the difference in temperature rise in the generator is not too significant; except for the relatively high load of the 1,100 Watt motor load with VSD, it turns out the generator temperature is slightly higher. The power losses to the generator without VSD are around 25%, whereas if using VSD, the power losses become 31%.

Next, the harmonic effect on the increase in generator losses seen in Table 4 number 3, i.e., when the power factor approaches one, the harmonic current is relatively large. The rise of power losses on the generator due to the effect of VSD is around 6%. So it can be said that because the harmonics cause an increase in generator losses. Thus, the increase in power losses causes an increase in generator temperature. On the generator side, the rise in temperature shows an increase in the value of power loss, i.e., the temperature difference of the generator is 2°C lower with the motor load without VSD.

Further studies by increasing the VSD load show that the power factor at the VSD load greater than 0.95 turns out to be a significant value of generator losses. The measurement results from experiments about the system shown in Table 5.

In terms of generating unit, it appears that the power used by the pre-mover at the same load is not far different between the motor load with VSD and without VSD. This difference is obtaining by comparing Table 3 and Table 4 in column 1. Based on these tables, it could say that the non-linear load causes the generator loss to increase. However, overall, the improvement in loss factors occurs when the system load uses VSD.

Table 5 shows that the power losses in the generator increase with the increase in harmonics current. Table 5 above also shows that the power factor due to VSD is almost close to one, meaning that the effect of the power factor on power quality is not significant. From Table 5, it could say that the increase of power losses with VSD loads when compared to motor loads without VSD, i.e., when the current harmonics more influences the conversion of pre-mover to electric power generators. Furthermore, this shows that improving the quality of VSD input power can be done by installing a current filter so that the THD current becomes smaller than without the filter. With the current filters on the VSD input side, harmonic currents do not burden the generator due to the VSD.

CONCLUSION

Based on the experiments on comparing the generator performance using motor loads driven with VSD and without VSD, the losses are higher when the motor loads are without VSD. The overall efficiency of a system load with VSD or without VSD does not change significantly. However, it is a bit more effective when using VSD. The effectiveness of power transfer is about 40.7% with VSD, and without VSD, efficiency is approximately 39.6%. The motor losses by installing VSD are interpreting as transferring losses to the generator with little savings, which is about 1 %.

The quality of the waves at the generator using VSD, which tested, turns out to increase both current and voltage harmonics. Therefore the quality of the waves on the generator becomes worse. Likewise, the generator losses are more potent if they are loading with VSD, which is about 6 %, and the generator temperature slightly increases when loaded with VSD, which is 2°C higher when without VSD.

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