A STUDY ON THE INFLUENCE OF AN INDUCTION MOTOR FOR ISLANDING-DETECTION POWER CONDITIONING SYSTEMS

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ABSTRACT: The power conditioner used for a generic PV system has the protection devices to connect with a utility grid. The one of the devices is an islanding detection function. There is a knowledge the islanding detection function was influenced from an induction machine load. The finding obtained by analyzing the experiment result is described. In this study, we focused attention on the power generation phenomenon of the induction machine after the power supply to the induction machine was cut off. In the beginning, our purpose is to know the phenomenon of a monadelphous induction machine. The findings obtained by analyzing the experimental results are described in this paper. As a result, we confirmed the generated electricity from the induction machine after the power supply was cut off. The external circuit condition makes changes in the duration and the electric power of the generation phenomenon. The relation between the calculated kinetic energy of the rotor and the generation phenomenon is shown by comparing each one. There is the possibility that the generated electric power by the induction machine disturbs a sudden change of other electrical equipments, furthermore the power causes that power conditioners can't detect the islanding phenomena.

1 INTRODUCTION

1.1 Background

The installation of the PV systems for houses is advancing in Japan aiming at PV2030 by NEDO. They are almost a grid-connected type. The PV systems for the commonly installed houses are connected with a utility grid. The power conditioner is a device that has both of the inverter which converts a direct-current to an alternating-current and protection functions to connect with a grid. The islanding detection function is one of the protection functions. The islanding phenomenon means the electrical power is supplied to a distribution line from the distributed generators. The islanding phenomenon causes many dangers. For example, repair or ordinary person gets an electric shock, the electronic products to be broken and so on. Therefore, we must prevent the islanding phenomenon.

However, there is knowledge [1] [2] that the islanding detection functions become difficult to detect the islanding phenomenon when the induction machine load exists in the same distribution line. That phenomenon was checked by comparing with the case of the RLC resonance load only. As affairs stand, the cause is not clarified. Then, authors are aiming to verify the difference between an induction machine load and a RLC resonance load, and to make the standardization model of the induction machine. Finally, the authors aim to be able to estimate the performance of the islanding detection using the model.

This paper describes the analysis about the generation phenomenon of the induction machine after the power supply was cut off. This paper's experiments didn't use a power conditioner, because of to get characteristic of the induction machine only.

1.2 Approach

The power generation phenomenon of an induction machine has experimented after the power supply was cut off. A single phase induction machine (1φIM or SPIM) was selected in experiments as follows, because of the power-conditioners which was used in houses outputs a single phase electric power.

How electricity is generated by 1φIM, after a power supply is cut off, is analyzed by measuring of power consumption by the resistance load which connected in parallel with 1φIM. The slip is also calculated to know the generation of the 1φIM. Moreover, the electrical energy and the kinetic energy of the rotor are compared to examine an origin of the generation.

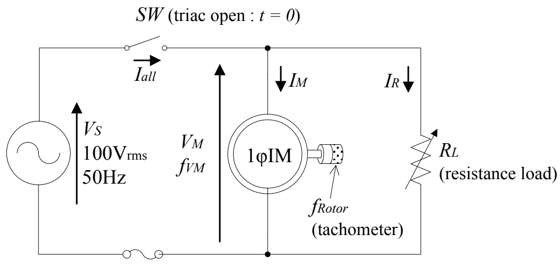

Figure 1: Experimental circuit to measure the generation

2 EXPERIMENTAL SETUP

2.1 Circuitry

Fig. 1 shows the experiment circuit. The detail of 1φIM which is used in the experiments is describe.

The power supply was decided that its voltage is $100V_{rms}$ and frequency is 50Hz. This is a general condition used in eastern Japan.

The switch *SW* was made by using triac. A triac is a three-electrode semiconductor device that will conduct in either direction when triggered by a positive or negative signal at the gate electrode. The triac switch was used to unite the cut-off timing of the power supply, and to secure a reproducibility of the experiments. The triac switch cut off the power supply from the induction machine in zero-crossing point of the current I_{all} that occurs immediately after the input of the trigger.

The rotational speed f_{Rotor} was measured by photo sensor.

To consume the generated power from the induction machine, the resistance load R_L is connected in parallel with the induction machine. The resistance load R_L was changed within the range from 0W (opened circuit) to 860W (about 12Ω).

The voltage V_M between the induction machine terminals, the current I_M of the induction machine, the resistance load current I_R, and the rotational speed f_{Rotor} are measured after the triac switch has turned off. The measuring equipment used a power analyzer "PZ4000" which was made by Yokogawa Electric Corporation.

2.2 Specification of 1φIM

In these experiments, a grinder is used in these experiments as a split-phase induction machine. A grinder is often used in factories and houses. The phase of the current that flows to a main-winding and a sub-winding of the induction machine are divided by the capacitor. That divided phases makes a torque to rotate.

Table I: Specifications of using induction motor

Input		645 (W)
Output		400 (W)
Source	Phase	1φ
	Voltage	100 (V)
	Frequency	50 / 60 (Hz)
Rotation @ no-load		2960 (rpm)
Current @ full-load		6.5 (A)

The rotor's moment of inertia (MOI) added the MOI of an axis and each parts as a grinding stone. The MOI of each part is calculated from the equation 1. The equation 1 can calculate that the MOI of the column which has rotation axis on the center of a circle. To calculate easily, the MOI of each part which composed the rotor approximates to the column with a uniform mass distribution. Where J is the inertia moment (Kg • m^2), M is mass (kg) and D is diameter (m).

$$J = \frac{1}{8} M D^2 \qquad (1)$$

Table II: Component and inertia moment of Rotor

Parts of rotor	Mass (kg)	Diameter (m)	MOI (kg·m^2)	Percentage (%)
Left grind stone	1.37	0.205	$7.20 \cdot 10^{-3}$	48.4
Right grind stone	1.36	0.205	$7.14 \cdot 10^{-3}$	48.0
Others (axis etc)	3.52	0.035	$5.39 \cdot 10^{-4}$	3.6
TOTAL			$1.49 \cdot 10^{-2}$	100.0

Table II shows the MOI calculation results of each part. As the result, the rotor MOI is 1.49×10-2 (kg • m^2). It is understood that the MOI of the rotor consist mainly of the grind stones.

2.2 Experimental procedures

The triac switch is turned on, and waiting until the rotational speed of the induction machine became constant. The experiments are carried out in each condition of the resistance load R_L. When the gate input of the triac is turned off, the triac can pass the current until the time of I_{all} = 0, after that the triac switch is opened. In this paper, this timing is defined to be zero on the axis of time.

Transients in the circuit which has the induction machine and the resistance load R_L are measured. Following analysis are based on these measured results.

3 RESULTS AND DISCUSSION

3.1 Shift to the power generation mode

Power consumption by resistance load R_L can be calculated from the measured results of the induction machine voltage V_M and the resistance load current I_R. Figure 2 shows the power consumption by the resistance load R_L that were 0W, 335W, 505W, and 860W. Figure 2 shows that the resistance load R_L had consumed the electric power during 0.6 seconds approximately after the power supply had cut off. The electric powers observes after the power supply had cut off. It's explained that the electricity was supplied by the induction machine.

The generating durations were different depending on the condition of the resistance load. Figure 3 is a summary of the durations of the induction machine voltage V_M up to 2% of ratings. The power consumption of the resistance load R_L has been changed within the range from 0 to 860W. The attenuation of the induction machine voltage V_M means the stop of power generation.

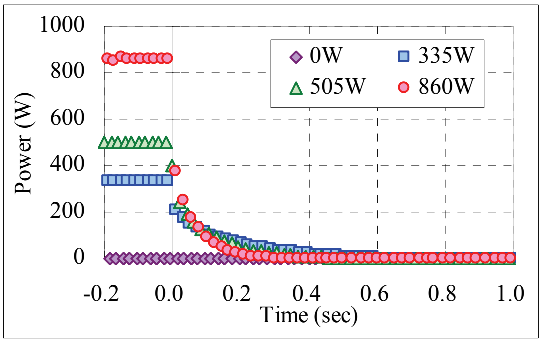

Figure 2: Transients of the electrical power (Resistance consumption were set in 0W, 335W, 505W, 860W)

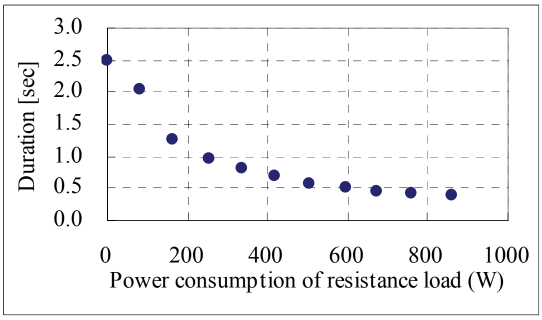

Figure 3: Duration up to 2% (2 V_{rms}) of the rating voltage (100 V_{rms})

3.2 Confirmation of power generation by a slip

The power generation of the induction machine can be understood by a "*slip*". A *slip* in these experiments is calculated from the rotational speed f_{Rotor} (1/sec) and the frequency f_{VM} (Hz) of the induction machine voltage V_M. f_{VM} isn't obtained as the voltage V_M attenuates. Therefore, a *slip* calculated within the duration dt.

$$S = \frac{f_{VM} - f_{Rotor}}{f_{VM}} \qquad (2)$$

Figure 4 shows calculated slips. The *slip* calculates from equation 2. The *slip* has changed from positive to negative at zero-second. It was shown that the induction machine was a power generation mode from the *slip*. Moreover, it became a comparable result in all the resistance load conditions.

However, the duration of the induction machine voltage V_M is different as shown in Figure 4. Therefore, the generated power is different depending on the resistance load condition. It's also understood from the difference of the *slip* 's magnitude.

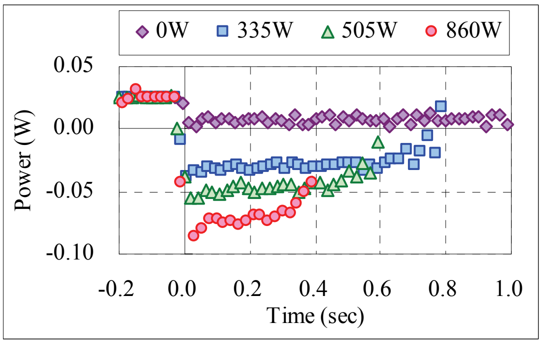

Figure 4: Transients of the slip (Resistance consumption were set in 0W, 335W, 505W, 860W)

3.3 The kinetic energies calculations

As previously stated, the energy source of power generation is thought to a kinetic energy by the inertia movement of the rotator. Then, the kinetic energy of the rotator is calculated from the change of the rotational speed, and it compared with the generated electric power.

$$\omega = 2\pi \cdot f_{Rotor} \quad (3)$$

$$T = J \cdot \dot{\omega} \quad (4)$$

$$P = \omega \cdot T \quad (5)$$

$$E_{kinetic} = P / dt \quad (6)$$

Equations (3) - (6) are used to calculate a kinetic energy of the rotor. The MOI *J* and the duration *dt* has already been shown in previous. Where ω (rad/sec) is the angular rate, $\dot{\omega}$ (rad/sec^2) is the differentiated angular rate, *T* (Nm) is the torque, *P* (W) is the kinetic power and $E_{kinetic}$ (J) is the kinetic energy. ω & $\dot{\omega}$ is calculated from the rotational speed change of the rotator.

The calculated kinetic energy is approximated by using exponential, and shown in Figure 5. It approximated to remove the superimposed periodic vibration of the calculated kinetic power and to understand its tendency. It's thought that a periodic vibration was caused by the blur of the rotor axis.

Figure 5 shows that the attenuation time and tendency of the kinetic power are similar to those of the generated electric power. The tendency of the kinetic energy of the rotor and the tendency of the generated power are similar by comparing Figure 2 and 5.

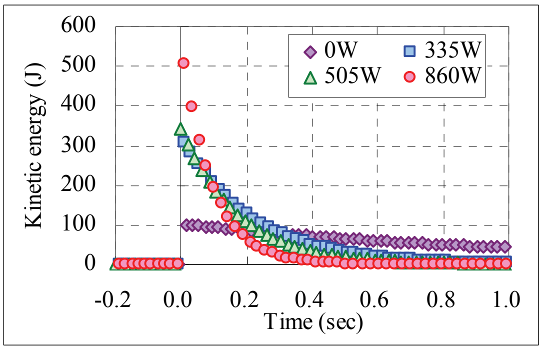

Figure 5: Transients of the kinetic power (Resistance consumption were set in 0W, 335W, 505W, 860W)

3.4 Comparison of kinetic energies of the rotor and the electrical energy

The mechanical loss that was one of the losses originated in the induction machine was measured, before the kinetic energy was compared with the electrical energy. A mechanical loss was guessed by the approximated straight line. Figure 6 shows that the mechanical loss was measured by the actual experiments in many rotation speed conditions.

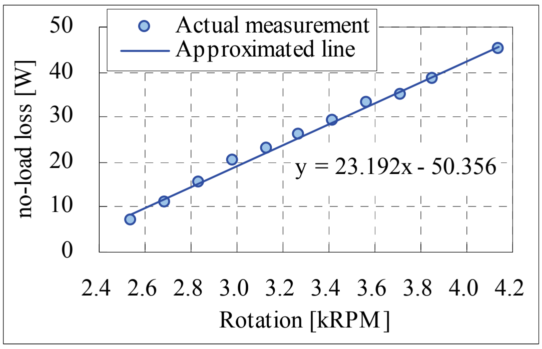

Figure 6: Actual mechanical loss and approximated line

The equation (7) was obtained from the result. Where *ML* (W) is the mechanical loss, and *x* (kRPM) is the rotational speed. Needed mechanical losses were calculated by substituting the adequate rotational speed.

$$ML = 23.2 \cdot x + 50.4 \quad (7)$$

Table III: Comparison of kinetic energies and electrical energies

Resistance load condition (W)	(1) Power consumption by resistance load (J)	(2) Power consumption by mechanical loss (J)	(3) Sum of (1) & (2) (J)	(4)Kinetic energy (J)	(5) Ratio (3) / (4)
0	0.00	0.71	0.71	1.94	0.37
80	0.61	0.70	1.32	2.27	0.58
160	1.26	0.73	2.01	3.07	0.65
250	1.84	0.74	2.62	3.65	0.72
330	2.07	0.73	2.87	3.93	0.73
420	2.31	0.73	3.15	4.09	0.77
505	2.98	0.75	3.87	4.62	0.84
590	3.40	0.77	4.35	5.06	0.86
670	2.98	0.77	3.96	5.06	0.78
760	3.13	0.75	4.13	5.32	0.78
860	3.32	0.78	4.39	5.68	0.77

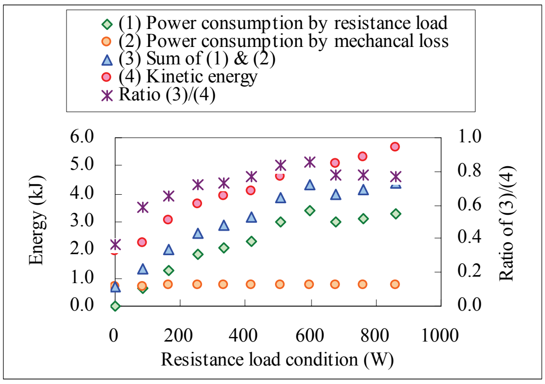

Figure 7: Comparison of kinetic energies and electrical energies

Table III and figure 7 shows results of the comparison by energy. The calculated kinetic energy of the rotor was always bigger than the amount of the electric energy and the mechanical loss. Because of the power consumption includes the iron loss and the excitation reactance. However, they were not considered in this time. Because of the iron loss and the excitation reactance has the frequency characteristic which was confirmed by the experiments. To calculate those things, it is necessary to use the moment changed V_M and I_M, and its difficult now. This issue is future tasks. Moreover, when the MOI was calculated, the mass of each part was approximated as it distribute uniformly. It can be thought that the error margin influence to the result.

The calculated value was not corresponding accurately, because of some losses. But, the electric energy takes almost its 70% or more of the kinetic energy when the resistance load is 250W or more.

If other induction machine which isn't used in this paper has a similar phenomenon, the induction machine generates the electric power by the influence of the MOI, and there is a possibility of supplying the electric power to the load on the same line. There is possibility that the phenomena interferes the islanding detection of power conditioner.

4 CONCLUSIONS

From the both "Power consumption in the parallel resistance load" and "Calculated slip from the V_M's frequency f_{VM} (Correspond at a synchronous speed in the usage usually) and the rotational speed f_{Rotor}", the generated electricity was confirmed. The 1φIM generated electricity in a short time, when the power supply had cut off.

As for the power generation phenomenon, the correlation with the kinetic energy of the rotor is seen. It is understood that the kinetic energy of the rotor contributes to the power generation phenomenon of 1φIM. However, the calculated value was not corresponding accurately. Because of there are some loss, such as the iron loss, the excitation reactance and the error of calculation. These will be examined in the future.

The phenomenon that the induction machine supplies the electric power to outside influences the equipment of the same distribution line. This will have some influences on the islanding detection devices.

One induction machine is only analyzed in this paper. A similar examination will be requested to be done about other induction machines in the future.

Future tasks in this research, the model which is enable to simulate the generation phenomena of the induction machine will be made. Definitely, the influence that the induction machine gives to the islanding detection devices will be estimated by the model.

5 REFERENCES

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[2] H Igarashi, K Kurokawa, S Suenaga, T Sato, "About the Influence on the Islanding Detection Device by the Difference in the Motor Load ", *TECHNICAL DIGEST of PVSEC-15,* pp. 1234-1235, Oct. 2005.