

DEVELOPING THE DUAL SYSTEM OF WIND FORCED CHILLER INTEGRATED WITH WIND GENERATOR

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ABSTRACT

The in CCT Lab successfully developed wind forced chiller directly uses the wind force to drive the refrigerating system and therefore reduces two times energy conversion between mechanical and electrical energies. Due to its larger working torque needed by the compressor than the other wind generators, the wind forced chiller needs also large wind speed for effective work. This work aims to develop a dual system of wind forced chiller integrated with wind generator, which can capture wind energy with more wide wind speed range. An integrated programmable logic controller (PLC) is applied in this wind forced dual system, to drive the wind forced chiller and the wind generator in terms of the rotational speed of the wind machine separately. The wind forced chiller will be switched on while the increasing rotational speed reaches to 80 rpm and off while the decreasing rotating speed reaches to 40 rpm. The combined wind generator is switched on while the increasing rotational speed reaches to 10 rpm or the compressor is off and off while the increasing rotational

speed reaches to 70 rpm. The two systems are not switched on at the same time.

INTRODUCTION

The human technological developments have spent extremely large energy and caused environmental pollution on the earth simultaneously. The problems of energy crisis and environmental pollution in the 21st century are very bad due to the highly developed industry in the world. Petroleum is overspent and the greenhouse effect causes the atmospheric ozone layer to be destroyed seriously more and more. A new energy solution today does not consider only the new energies seeking, but it also should be able to decrease the environmental pollution. Therefore, the green energy development is the unique solution. The green energies, which include wind energy, solar energy, etc., are suitable for replacing the petroleum and are the perfect energies [9].

Applications of wind machine are the age-old technique and their technical development is normally combined

with electric generator, which already achieves the skillful applying technique [1, 4]. In comparison with the other green energies, the wind energy development has some special features, i.e. less building time, lower cost, simple maintenance, and smaller building area. In general, building a wind generator with million watts needs time less than one year and costs much cheaper than the other thermal power plants or nuclear power stations with the same output power [3].

Procedure of energy conversion causes energy loss in accordance with the thermodynamics [14]. That means, the more the energy conversions, the larger the energy loss. In order to reduce energy conversions a study on the development of a wind forced chiller was presented in [6], which directly uses the mechanical energy of wind force to drive the compressor. The developed wind forced chiller reduces two times energy conversions between mechanical and electrical energies. It receives a higher working efficiency of ca. 20%. In comparison with a traditional closing system of refrigerator with ca. 40% working efficiency integrated with a wind generator with ca. 20% working efficiency receives a total working efficiency ca. $40\% \times 20\% = 8\%$ [6]. This result shows that the wind forced chiller has larger working efficiency without additional energy conversions.

Due to the unstability of wind and the larger working torque requirement of the wind forced chiller, the most natural wind speeds can not drive the compressor to work effectively, whereas the smaller wind speed can be used by the wind generator [6]. Figure 1 shows statistic annual wind speed distribution measured at the National Taipei University of Technology. The horizontal line is the starting wind speed of refrigeration. Figure 1 shows that the most wind speeds in this place can not drive the refrigeration to work effectively. A wind forced chiller can use only a little wind energy upon the horizontal line of refrigeration starting wind speed in this place.

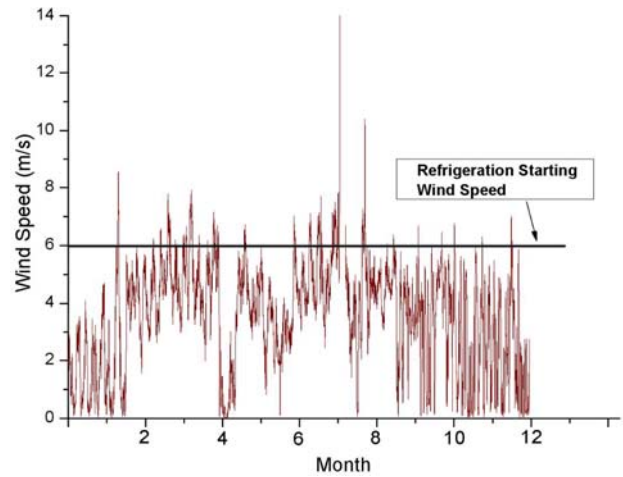


Figure 1

Statistic annual wind speed distribution.



Figure 2

The wind forced dual system.

Integrating wind forced chiller with wind generator can increase to use the total captured wind energy. This paper presents experimental studies of logical control action for the integrated system of wind forced chiller and generator using the programmable logic controller (PLC). Design and working principle of the logical control action will be detailed in the following sections.

ANALYSIS OF WORKING ABILITY

Addition of Wind Generator

Addition of the wind generator in the dual system aims to use the wind energy of smaller wind speed, which can not drive the refrigerating compressor. A truck mounted generator with full output power of 12V and 70A in 1800 rpm is applied in this work. It's well known, a traditional generator is in terms of the Faraday's induction law. The induced electromotive force (EMF, $\mathcal{E}$) in a circuit is equal to the rate at which the magnetic flux (ϕ_B) through the circuit is changing,

$$\mathcal{E} = -\frac{d\phi_B}{dt} \quad (1)$$

where the minus sign is an indication of the direction of the induced EMF. If the magnetic flux (ϕ_B) is enclosed by N rectangular loops with length (l) and width (x) individually, equation (1) can be further rewritten as

$$\mathcal{E} = -N \frac{d\phi_B}{dt} = -N \frac{d}{dt}(Blx) = -NBl \frac{dx}{dt} = NBlv \quad (2)$$

where B is magnetic field and is not zero. Equation (2) indicates that the induced electromotive force ($\mathcal{E}$) is influenced by magnitude of N , B , l , and v . For a commercial truck mounted generator, N , B , and l are fixed. The output voltage is mainly influenced by the moving speed (v) of the circuit [13].

Analysis of the Rotating Torque

Determination of rotational torque (τ) for compressor and generator indirectly uses the wind machine. Considering the wind vanes swept rotational area as a

disk, the yielded rotational inertia (I) is

$$I = \frac{1}{2}mr^2 \quad (3)$$

where m is total mass of disk and r is radius of disk. The rotational torque is time rate of change of angular momentum (L)

$$\tau = \frac{dL}{dt} = I \frac{d\omega}{dt} \quad (4)$$

Where ω is angular speed. To measure the rotational torque of the compressor or the generator can record the reduction of angular speed in a short duration for the wind machine. The measured rotational torque of the wind machine equal to the compressor or the generator [12].

EXPERIMENTAL DETAILS

Experimental details illustrate the home-made wind forced dual system and its logic control action, where the wind forced dual system uses the previous wind forced chiller integrated with the electric generator and applies the PLC controller for the logic control action.

The Wind Forced Dual System

The applied experimental facility is the wind machine, which is combined with a refrigerating compressor and a electric generator. The wind machine consists of five main parts, which are the wind vane system, the rotation axis, the transmissions system, the trestles, and the turnable trestle. The wind vane system is built in 8 vanes with 1.65m long and 30cm wide individually [6]. Figure 2 shows photo of the wind forced dual system, which is built on the tall building at the National Taipei University of Technology.

The wind forced dual system is integrated with a refrigerating compressor and a electric generator, where the compressor output power is with 0.22 refrigerating unit ton [6] and the generator is truck mounted generator with full output power of 12V and 70A in ca. 1800 rpm.

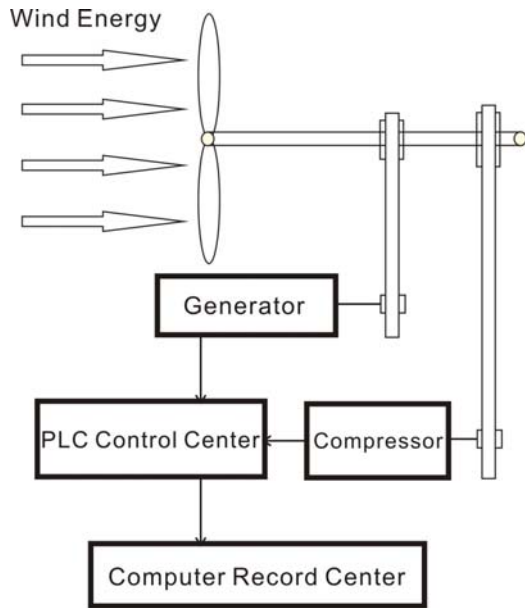


Figure 3

Schema of the wind forced dual system in connection with the PLC controller.

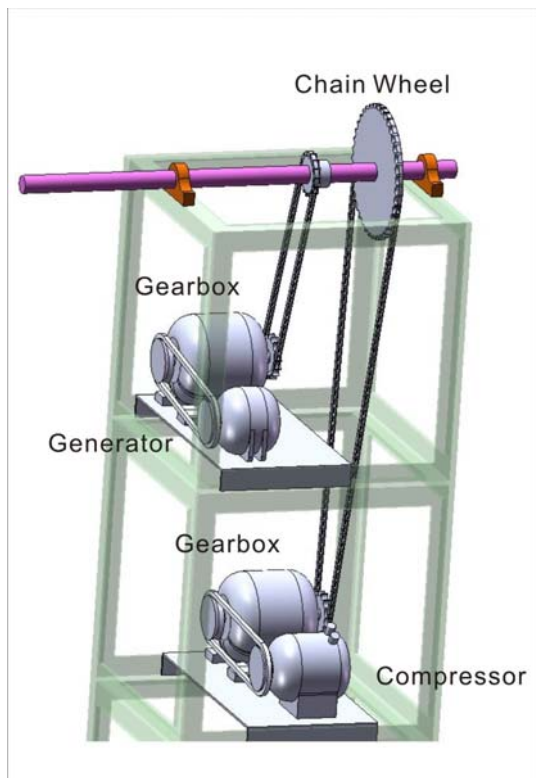


Figure 4

Schematic description of the transmission for the dual system.

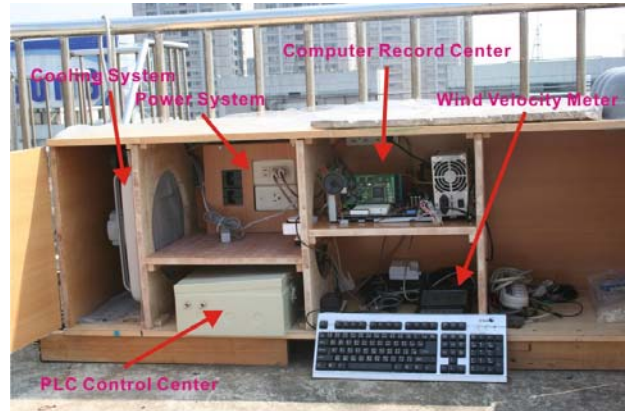


Figure 5

Photo of the control room.

Figure 3 exhibits schematic description of the wind forced dual system in connection with the PLC controller. The refrigerating compressor and the electric generator connect individually with the axis of the wind machine using the gear wheels. The transmission accelerated ratio in this dual system for compressor is 1:20 and for generator is 1:5. Determination of the dual system for starting the refrigerating compressor or the electric generator is operated by the PLC controller, which is in connection with computer. Figure 5 shows photo of the control room.

The Logic Control Action

The refrigerating compressor of the home-made wind forced dual system in this work has the starting torque ca. $0.68 \text{ N} \cdot \text{m}$ and its best rotating speed about 1500 rpm. Working wind speed of the wind forced chiller is actually very high and it therefore losses a lot of wind energies, which can not start the compressor effectively. To improve the working efficiency of the captured wind, the wind forced chiller is further integrated with electric generator. Figure 6 is schema of the applied logic control action with four pre-defined conditions of the rotating speeds. The generator is switched on and off while the rotating speed rises at 10 rpm and 70 rpm as well as the compressor is switched on while the rotating speed rises

at 80 rpm and off while the rotating speed goes down at 40 rpm. The compressor and the generator do not work at the same time.

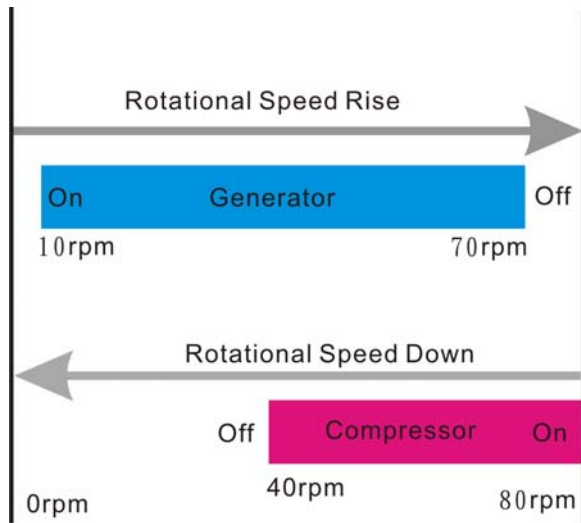


Figure 6

Schematic description of the logic control action used by the PLC controller.

To drive a wind forced chiller built-in a traditional compressor requires extremely large torque corresponding to the injected high speed wind. The refrigerating compressor can work effectively while the injected wind reaches a sufficient speed. An integrated programmable logic controller (PLC) is applied in the wind forced dual system, which drives the wind forced chiller and the wind generator in terms of the rotational speed.

RESULTS AND DISCUSSION

Development of a wind forced dual system in this work uses integration of truck mounted refrigeration and generator due to their embedded clutch function. The homemade wind machine for experiments is with large torque generation, which is especially designed to drive the refrigerating system. The wind machine should first reach a high rotational speed larger than 80 rpm, then it can start compressor of the refrigerating system using the

clutch function. Individual controlling the dual system uses the PLC system to receive the rotating information of the wind machine and give clutch decision of on or off. Addition of a generator in the dual system also selected a truck mounted generator due to its embedded clutch function. The applied truck mounted generator is an exciting generator. Figure 7 shows its open-circuit-voltage (V_{oc}) and short-circuit-current (I_{sc}) change vs. the rotational speed. Figure 7 indicates that V_{oc} and I_{sc} of the truck mounted generator are proportional to its rotational speed.

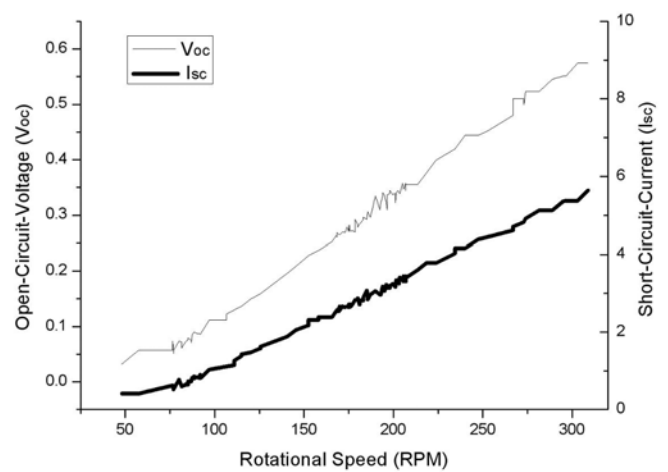


Figure 7

Relationship of V_{oc} and I_{sc} change vs. the rotational speed.

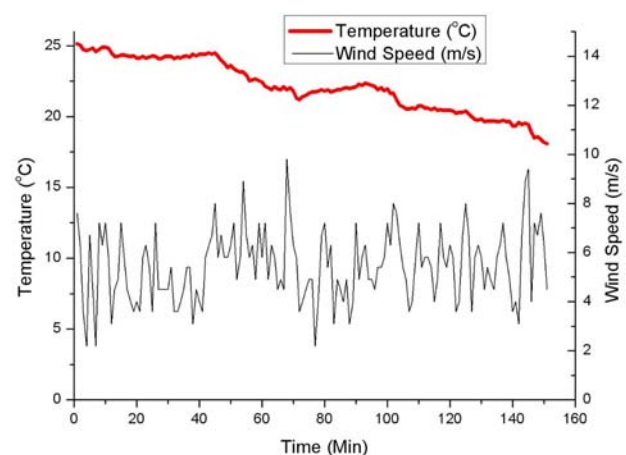


Figure 8

Time dependent water temperature variation and wind speed change.

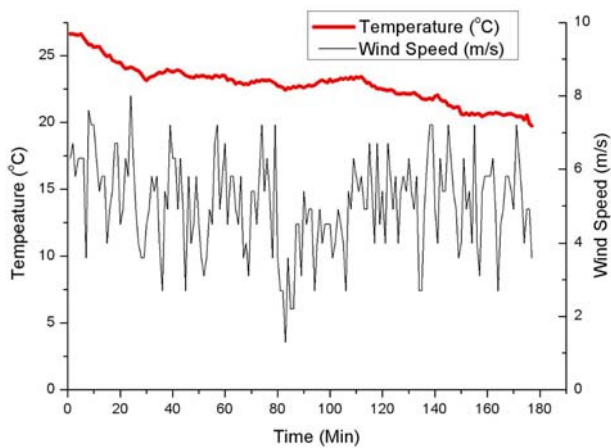


Figure 9

Time dependent water temperature variation and wind speed change.

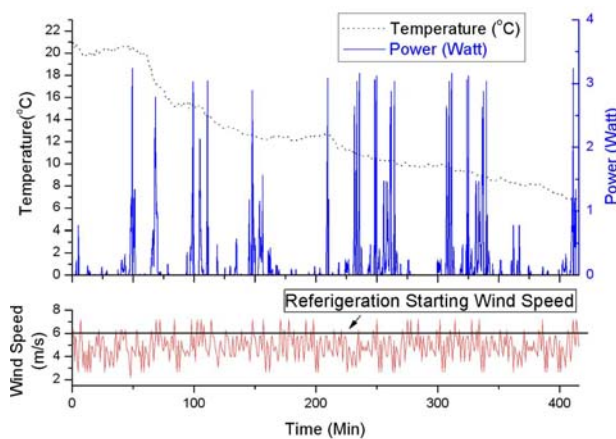


Figure 10

Time dependent water temperature variation and output electric power including wind speed change.

CONCLUSION

Building of the wind forced dual system combined with a wind forced chiller and a electric generator as well as a logic control action using PLC technique are carried out. The logic control action with four different rotational speeds 10, 40, 70, 80 rpm of the wind machine is pre-defined to switch on and off the refrigerating compressor at increasing rotational speed 80 rpm and decreasing rotational speed 40 rpm. The integrated wind

forced generator is switched on at increasing rotational speed 10 and 70 rpm. The generator is also switched on while the compressor is switched off. The starting wind speed for the applied refrigerating compressor in this work is ca. 6 m/s. The wind, which can not drive the compressor, can be used by the generator of the dual system. The wind forced dual system can expand the available wind speed range.

Figure 8 and 9 show two measurements of time dependent water temperature variation in ice-pail including the injected wind speed change. Figure 8 indicates that the 10 liter water temperature in ice-pail was cooled from 25.15 °C to 18.1 °C in the duration of 151 minutes. The total removed thermal energy (H) is

$$H = ms\Delta T = 294.69 \text{ Kjoule}$$

The effective works in figure 8 are ca. 42 times and every time is about 5 sec. Figure 9 exhibits another experiment with longer measuring time of 177 minutes. The water temperature in ice-pail was cooled from 26.65 °C to 19.75 °C and its total removed thermal energy is 288.42 Kjoule . The starting wind speed of refrigeration is about 6 m/s. The wind speed larger than 6 m/s can successfully drive the refrigerating compressor. The wind energy with wind speed smaller than 6 m/s was given up in these two experiments. Figure 10 shows the time dependent water temperature variation in ice-pail and the output electric power including the injected wind speed change. Figure 10 exhibits that the wind generator was switched on while the wind speeds lower than 6 m/s. The added wind generator did not disturb the wind forced chiller. It applied the wind energy field, where forced chiller can not use.

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