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INDOOR TEMPERATURE CONTROL AND ENERGY SAVING POTENTIAL OF AN AIR CONDITIONING SYSTEM USING PD CONTROLLER

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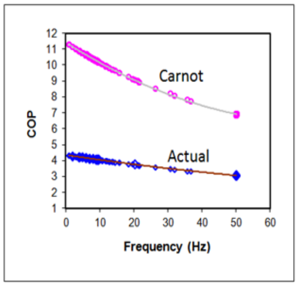
Graphical abstract



Abstract

This manuscript presents a PD controller implementation to control the compressor speed of an air conditioning system according to cooling load to fulfill thermal comfort requirements with higher energy efficiency. An interface has been designed to monitor the experiment including the controller algorithm. The temperature settings of the conditioned space are 20, 22 and 24oC with internal heat loads of 0 and 1000 W. The experiments conducted indicate that the proposed technique has better temperature control and energy efficiency compared to the on/off controller.

Keywords: Indoor temperature; energy saving; air conditioning; PD control

1.0 INTRODUCTION

Air conditioners are commonly found in home and in public enclosed space due to the natural demand for comfort in the thermal environment of living and working spaces in modern society. The conception of air conditioning has developed from a conventional single speed air conditioning system to that of a variable speed type. A variable speed air conditioning is the system that could distribute conditioned air at different temperatures. The system with variable speeds compressor can control the indoor temperature by changing the frequency of the motor that drives the compressor [1, 2].

The variable speed air conditioner maintains the required temperature of the air-conditioned space by means of an inverter, which varies the speed of the compressor through a controller. Actually, it is the cooling capacity matches the cooling load that varies at low load compressor runs at low speed hence saves energy [3, 4].

Krakow et al. [5] investigated the use of proportional-integral-differential (PID) controller on an AHU and a compressor of an air-conditioning unit. Such methods were shown to be suitable for attaining compressor and evaporator fan speeds such that sensible and the latent components of the refrigeration system capacity equals the sensible and latent component of the system loads. The investigation also indicated the space temperature and humidity were not successfully controlled simultaneously by the variation of evaporator fan speed and compressor speed, respectively. However, the study did not include the energy and the performance analysis of the air-conditioning unit.

With respect to these opportunities, current research is focused on indoor temperature control and energy saving potential of an air conditioning system using proportional-derivative (PD). The main idea of designing the controller is to maximize energy saving for an air conditioning system application through variable speed drive control.

1.1 Performance and Energy Analysis

The coefficient of performance (COP) of refrigeration machine is the ratio of the energy extracted by the evaporator (refrigerating effect) to energy supplied to the compressor. The equation is given as:

$$\mathrm{COP} = \frac{(h_1 - h_4)}{(h_2 - h_1)} = \frac{q_e}{w_{com}} \qquad \text{(Eq. 1)}$$

where h_1, h_2 (kJ/kg) are the enthalpy at the compressor inlet and outlet respectively, h4 (kJ/kg) is the enthalpy at the evaporator inlet, q_e (kJ/kg) is the refrigerating effect and w_{com} (kJ/kg) is the compression work.

The general equation for the output power from a three-phase induction motor is given as:

$$P = \frac{I \times V \times PF \times 1.73}{1000}\,(kW) \qquad \text{(Eq. 2)}$$

where I is current (Amperes), V is voltage (Volts), and PF is power factor.

In obtaining the energy consumed, the motor power from Eq. (2) is multiplied by the time of operation, t and is given as:

$$\mathrm{Energy} = P \times t \qquad \text{(Eq. 3)}$$

The energy saving calculated is expressed in terms of saving in percentage unit, based on the difference between energy consumed at the existing AC system using thermostat and energy consumed using PD controller. The equation is given as:

$$\text{Energy saving} = \frac{(\text{Thermostat energy}) - (\text{PD energy})}{(\text{Thermostat energy})} \times 100 \qquad \text{(Eq. 4)}$$

1.2 PD Controller

A proportional controller will have the effect of reducing the rise time and will reduce, but never eliminate the steady state error. A derivative control will have the effect of increasing the stability of the system, reducing overshoot, and improving transient response. The use of proportional control requires just one variable to be selected, the proportional gain Kp, for the control system to have the required dynamic behavior. The use of a proportional gain plus derivative gain (PD) controller requires the selection of two variables, Kp and KD.

Derivative control mode is normally not used alone. This is because the controller produces no corrective effort for any constant error and would therefore allow uncontrolled steady-state errors. A combination of proportional and derivative controls is a practical mode of control for industrial processes. The PD control equation is defined by:

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt} \qquad \text{(Eq. 5)}$$

For a digital PD controller, the controller gains KP and KD can be determine from the analog controller gains using the following relationships:

$$K_P = K_p$$
$$K_D = K_d / \Delta t$$

The output of the digital controller can be expressed by:

$$u_P(t) = (K_P \times e(t)) \qquad \text{(Eq. 6)}$$

$$u_{PD}(t) = [K_P \times e(t)] + \left[K_D \times \left(\frac{\Delta e(t)}{\Delta t}\right)\right] \qquad \text{(Eq. 7)}$$

where Δt is the sampling time (minute), $e\,(t)$ = *setpoint temperature (t) – measured temperature* (*t*) and .

$$\Delta e = e(t) - e(t-1)$$

2.0 EXPERIMENTAL

2.1 Experiment Apparatus and Method

The close-loop system is shown in Fig. 1 for the PD control application. A common signal conditioning and analog input channel is used to read all sensors/transducers signal. There is one analog input signal from the inverter, five signals from the ICs temperature sensors in the thermal environmental room and six signals from the thermocouples in the air conditioning unit. The sensors/transducers provide voltages to the analog channels of the multiplexer. The multiplexer selects one of these channels at a time and sends that signal to ADCs (TC-08 and PCI-1711), which feed binary number to the PC. The PC takes action based on the software program and the signal received. DACs is used to convert the software program output (including calculation and temperature setting) into analog form in order to control the process. A multiplexer transfers the voltage from the DACs to the analog output channel.

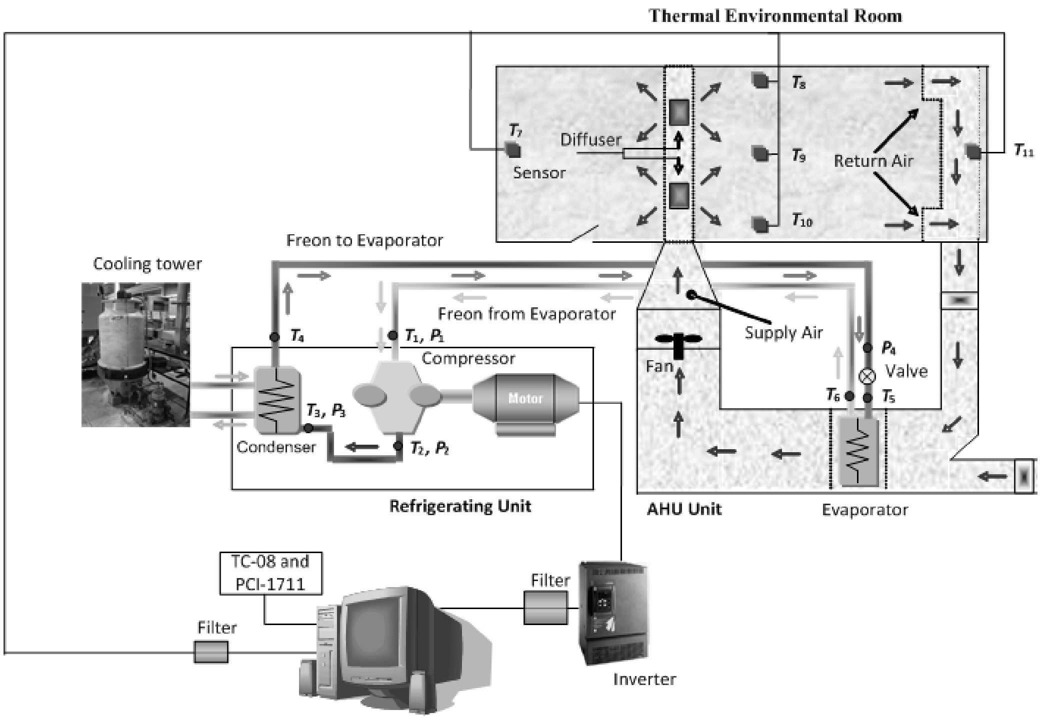


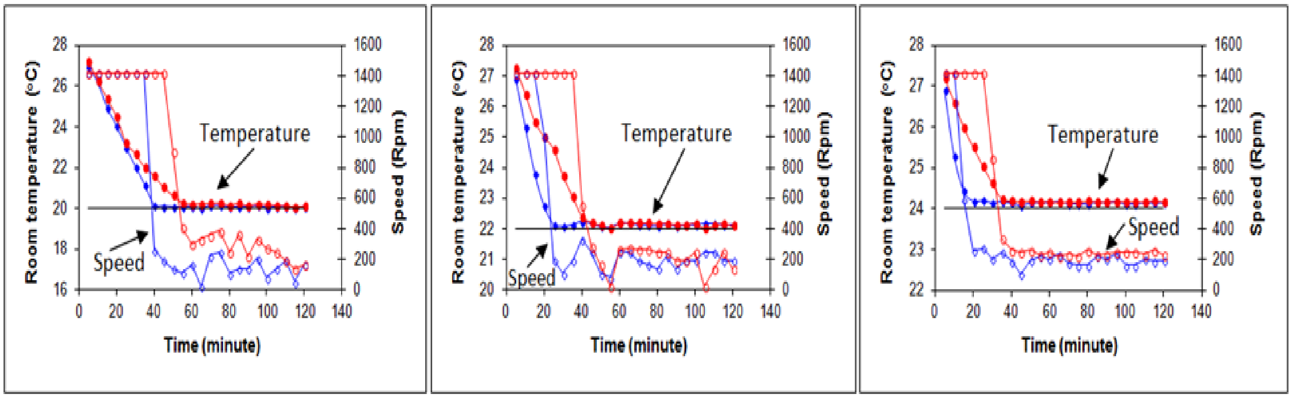
Figure 1 The experimental setup

The control system for the compressor speed consists of ICs temperature sensors of type LM35DZ, an on/off and PD subroutine installed to the computer, an inverter and an electrical motor coupled to the compressor. The ICs temperature sensors monitor the temperature of the room and emit electrical signals proportional to the state of the conditioned space. This signal is filtered (low-pass filters and optoisolator) before it reaches the controller and inverter, thus minimizing the noise, which may cause error in the control system. The output signal is supplied to the controller and computer, which output a control signal that is a function of the error. The on/off or PD control signal output is supplied to the inverter, which modulates the frequency of electrical supply to the motor such that it is linearly proportional to the control signal. Electricity of 50 Hz is supplied to the inverter, which supplies on/off electricity to the motor (on/off application) or variable-frequency electricity to the motor (PD application). Pressures were obtained using Bourdon type gauges. Those locations on the high-pressure side ranged from 0 to 30 bars by 1 bar scales. The low-pressure side ranged from 0 to 10 bars by 0.2 bar scales. The experiments were conducted for two different conditions: on/off and PD controller with 20, 22 and 24oC temperature setting and internal heat loads: 0 and 1000 W.

3.0 RESULTS AND DISCUSSION

3.1 Room Temperature Distribution

Fig. 2 shows the temperature distribution and motor speed at different temperature setting. Initially the motor is set to run at its maximum. As the compressor works at maximum speed, temperature inside room decreases. After it comes near to the temperature setting, the controller slows down the compressor to minimize error between the temperature setting and room temperature. This is to allow the room temperature to accelerate the heat recovery process until the temperature read is equal to the temperature setting. The controller controls the motor speed so that the temperature is always near to the temperature setting. It can also be observe that increasing internal heat load would affect the room temperature and motor speed. Longer time for compressor working is needed to reach the temperature setting as the internal heat loads increases.



a. $T_{setpoint}$ = 20°C b. $T_{setpoint}$ = 22°C c. $T_{setpoint}$ = 24°C

Figure 2 Motor speed and temperature responses

3.2 Coefficient of Performance

Fig. 3 shows the relationship between COP_{actual} and COP_{carnot} with motor frequency. Higher frequency has lower COP_{actual} and COP_{carnot} due to the high compressor power consumption. Average values of COP_{actual} and COP_{carnot} are 3.05 to 4.34 and 6.88 and 11.39 respectively. As the compressor power consumption increase, the COP decreases with an increase of compressor frequency.

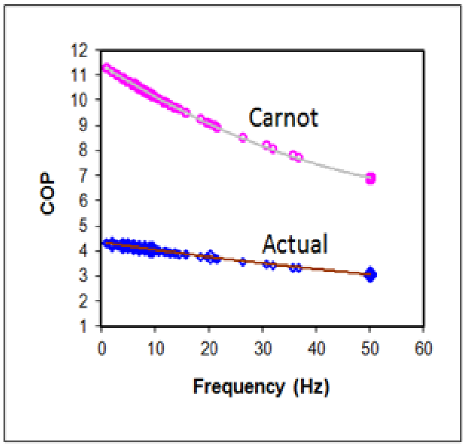


Figure 3 The actual and Carnot COP

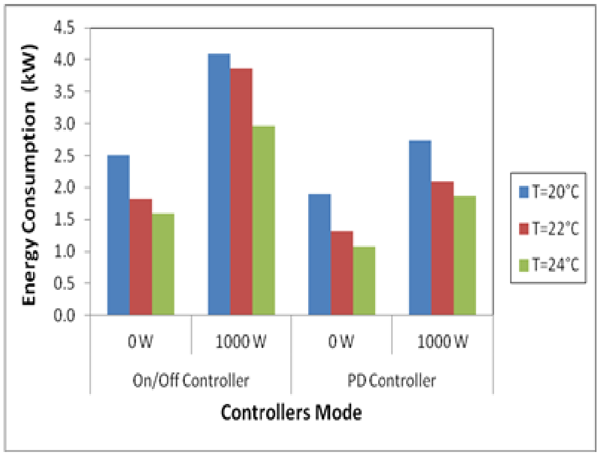


Figure 4 The energy consumption distribution

3.3 Energy Consumption and Energy Saving

Fig. 4 shows the energy consumption at various internal heat loads using PD controller. Equation (4) is used to calculate the energy consumption once the motor starts working. The power consumption is multiplied with the motor operating hours to get the energy consumption. The results show that higher internal heat load consumes higher energy consumption. PD controller results at lowest energy consumption.

Fig. 5 shows the energy saving of PD over on/off controller. Energy saving of 24.39 to 45.72% for internal heat load of 0 and 1000 W is achieved using the PD controller to control the motor speed depending on the cooling load inside the room. Energy consumption of the room is increased when the internal heat loads increase.

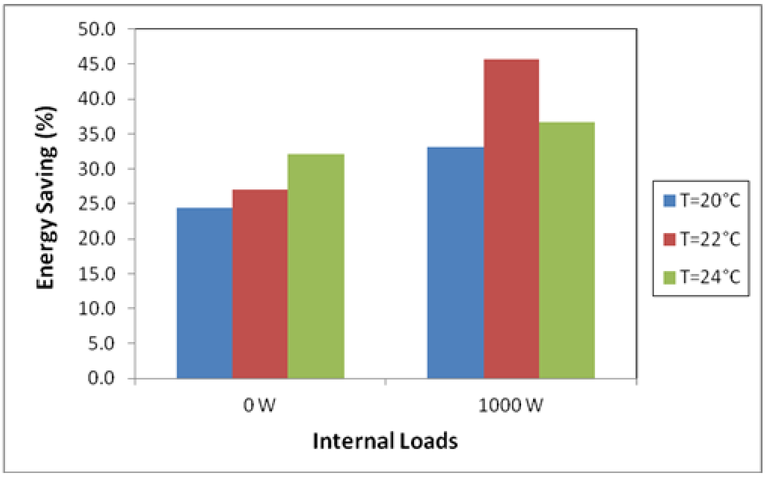


Figure 5 Energy saving

4.0 CONCLUSION

The developed on/off controller and PD controller to distinguish the energy consumption of a different controller is made. The PD controller controls the room temperature by varying the compressor speed to meet the temperature setting inside the room. Energy analysis shows that PD controller offers higher-energy efficiency compared to on/off controller. This manuscript managed to prove that by using variable-speed compressor method and suitable control strategy, the control of closed-room temperature could be achieved with significant energy saving.

Acknowledgement

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References

[1] Abidin, N. Z. 1995. Retrofitting of Compressor Motor in Air Conditioning System for Energy Saving, Universiti Teknologi Malaysia, Malaysia.

[2] Park, Y. C., Kim, Y. C. and Min, M. K. 2001. Performance analysis on a multi-type inverter air conditioner. *Energy Convers Manage*. 42: 1607-1621.

[3] Nasution, H. and Hassan, M. N. W. 2006. Potential electricity savings by variable speed control of compressor for air conditioning systems. *Clean Techn Environ Policy*. 8: 105-111.

[4] Nasution, H., Sumeru, K., Aziz, A. A. and Senawi, M. Y. 2014. Experimental study of air conditioning control system for building energy saving. *Energy Procedia*. 61: 63-66.

[5] Krakow, K. I., Lin, S. and Zeng, Z. S. 1995. Temperature and humidity control during cooling and dehumidifying by compressor and evaporator fan speed variation. *ASHRAE Trans*.101: 292-304.