Energetic Assessment of an Electronic and a Thermostatic Expansion Valve for a Variable Capacity Compressor

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Abstract: In this study, a chiller system with an electronic expansion valve (EEV) and a thermostatic expansion valve (TXV) were compared from an energy saving view under variable and fixed speed compressor. The experimental chiller system under study has a variable speed scroll compressor, EEV and TXV, air cooled condenser and auxiliary equipments. The R134a was used in the compressor as a refrigerant. Although in variable speed chiller systems usually EEVs are used, in this study a TXV was also used to compare its performance. The results of the experimental studies show that the chiller system with EEV has 30% lower superheat value and 6% lower power consumption than the chiller system with TXV under variable speed operation. From the fixed speed compressor view, the chiller system with TXV performs 1.7% lower superheat value than the chiller system with EEV and, the chiller system with EEV has 8.5% higher compressor power consumption than TXV.

Keywords: Electronic expansion valve, thermostatic expansion valve, variable speed compressor, superheat control, energy saving.

1. INTRODUCTION

Refrigeration is defined as a heat removal process. This process, also called the vapor-compression refrigeration cycle, has four main components such as compressor, condenser, evaporator, and expansion device [1, 2]. All vapor-compression refrigeration systems should have expansion devices to reduce the refrigerant pressure from condensation to evaporation pressure. It also regulates flow of the refrigerant into the evaporator. Various kinds of expansion devices are used in a vapor compression refrigeration system, such as capillary tube (CT), TXV and EEV. The most common expansion device in medium range refrigerators is the TXV. Mostly, capillary tube is used in small household refrigerators. Variable speed refrigeration systems may become more efficient when TXV or EEV are used.

It is hard to vary superheat, sub-cooling, evaporation and condensation temperature because the refrigerant flow is determined by CT size and pressure difference [3]. While TXV adjusts refrigerant flow via temperature, which is sensed by a bulb filled with a gas, EEV adjusts flow electrically by stepper type electric motor. Therefore, stabilizing a superheat value is easier with EEV than with TXV. The electrically driven control device needs a controller. Refrigerant flow through the evaporator is controlled by means of monitoring pressure and temperature at the outlet of the evaporator.

Recently, the energy optimization theme of a vapor compressed refrigeration system has had great interest. In this manner, expansion device type used in these systems has played a significant role. Lazzarin *et al*. [4] investigated comparison of the expansion devices in an air conditioner, which are equipped with both thermostatic and electronic type expansion valves. In order to evaluate the energetic and economic advantages of electronic valve, the annual analysis is supplemented by a transient simulation program to simulate the behavior of the system in two different operating modes, in different European climates.

Chen *et al*. [5] investigated the stability study for superheat at evaporator outlet. According to authors, superheat value exhibits an unstable behavior known as hunting. This phenomenon has adverse effects on the safety and efficiency of the system. There are two possible explanations for the hunting behavior of the evaporation system: some investigators think that it is caused by the evaporator characteristics and others believe that it is the reflection of stability of evaporator fluid supply control system. The authors find that, for the first time, although the opening of EEV was not changed in the experimental process, the superheat decreased suddenly when it descended below a certain value. It is because the evaporator superheat has a close relation with the heat transfer temperature gradient. Also, for an EEV-evaporator system, the minimum stable superheat exists and has the same importance as in the TXV system. This demands that the superheat setting point cannot be set too low, whatever TXV or EEV is used, otherwise it will lead to hunting.

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Aprea *et al*. [6] conducted an experimental study to investigate performance of the energy consumption of an EEV and a classical TXV for cold storage. Their main aim was to verify which type of expansion valve would be preferable.

Ekren *et al*. [7] studied to decreasing the energy consumption by a convenient control algorithm in an unpublished paper work. This study dealt with the effects of different control methods on variable speed scroll compressor (VSSC) and EEV in a chiller system. It is crucial to define the relationship between variables such as water temperature (T_w), water flow rate m_w, electronic expansion valve opening amount (EEV_{OA}), compressor speed and impacts of these parameters on coefficient of performance (*COP*), superheat (*SH*), compressor power consumption (W_c), evaporation temperature (T_e) and condensing temperature (T_e). The objective of this study is to conduct an experimental comparison for the TXV and EEV under variable and fixed speed compressor operation in a chiller system. Also, with this study an EEV control algorithm for the system, which was retrofitted from on-off control to variable speed one, had been carried out. VSSC and EEV had controlled by a fuzzy logic algorithm.

2. DESCRIPTION OF EXPERIMENTAL CHILLER SYSTEM

The experimental chiller system had vapor compression refrigeration cycle, working with the refrigerant R134a. It consisted of a scroll compressor, a shell and tube liquid type evaporator along with an air-cooled condenser inside a thermally insulated air-channel. Besides, an electrical heater, a fan and a nozzle were mounted in the insulated air channel. Air flow rate and temperature can be changed by a fan and an electrical heater, respectively, to simulate external conditions. Both EEV and TXV were used to adjust refrigerant flow in the chiller system. A spherical, fully tight stop valve was used to open or close the desired expansion device's pipe line in the system. To obtain a constant cooling load in the evaporator, electrical heaters were used in the water tank. Temperatures were measured at different points by "*T*" type thermocouples and pressures were measured by ratiometric type pressure transducers, on the cooling cycle. The other measurement taken during the experiments was the power consumption via wattmeter. A control and a data acquisition unit were installed to send control signals to the VSSC and EEV. The experimental setup allowed us to vary the compressor speed by an inverter that was linked to the three-phase electric motor of the compressor. Variable speed refrigeration system (VSRS) consisted of EEV with stepper motor, controlled by a fuzzy logic algorithm through a computer parallel port. The control was realized according to degree of superheat by monitoring the pressure and the temperature at the evaporator outlet. Another control algorithm was also conducted to control VSSC via inverter and control card. Figure **1** shows schematic illustration of the experimental plant.

In the schematic illustration, components of the plant are given as follows: 1-compressor, 2-condenser, 3-dryer, 4-sightglass, 5-electronic expansion valve, 6-

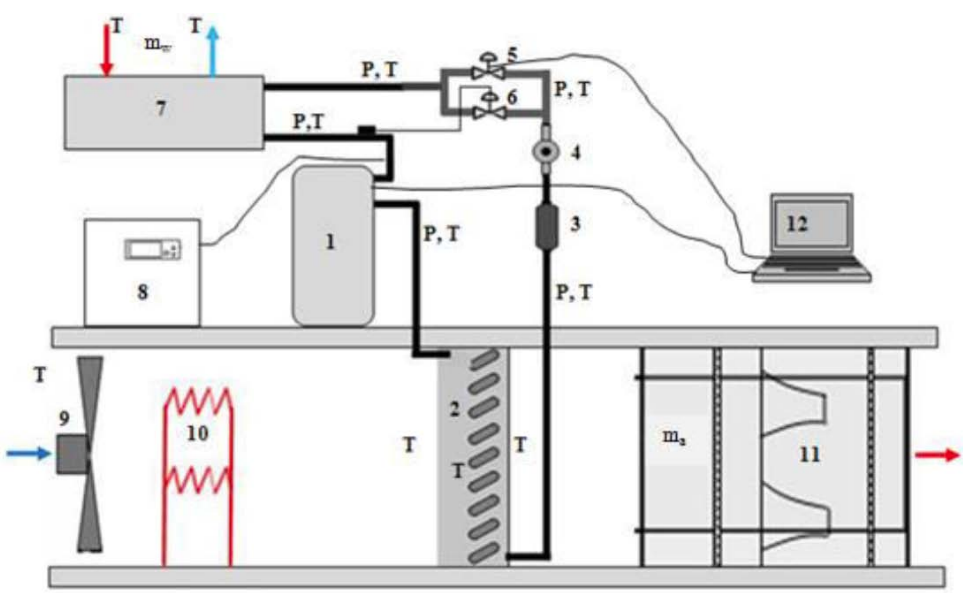

Figure 1: Schematic illustration of the experimental setup [7].

Table 1: Specifications of the Experimental Plant [7]

Compressor	Type: Copeland ZR34K3-PFJ, vertical scroll (R134a refrigerant) Capacity: 2.8 Hp, 380 V, 50 Hz
Condenser	Type: Air cooled
Evaporator	Type: Shell-tube liquid
Expansion valve	Type: Electronic Port size: 1.8 mm Operating range: 0–480 pulse Rated voltage: DC 12 V Control method: Step motor controlled
Pressure Transducer	Type: Carel SPKT, Ratiometric Range: low pressure (between -1 and 9 bar), high pressure (between 0 and 45 bar) absolute Error: ±%1.2
Thermocouple	Type: "T" Range: -200 and 350 ^{o}C Error: ±%1.5
Wattmeter	Type: Bs157 Range: 220/600 V, 50/60 Hz Error: ±%1.5
Data Acquisition and Control System	Agilent-34970 data logger and 34907 control card Stepper control circuit and PC parallel port
Inverter	Type: PWM Capacity: 2.2 kW Frequency Range: 0-100 Hz

thermostatic expansion valve 7-evaporator, 8-control panel, 9-fan, 10-electrical heater, 11-nozzle 12-compressor and EEV control unit. Also, measurement point of the temperature, pressure and flow rate on the cooling cycle are shown as *T*, *P* and *m,* respectively. Air and water inlet and outlet are shown by arrows. Specifications of the equipment are shown in Table **1**.

3. EXPERIMENTAL RESULTS FOR EEV AND TXV

Compressor and EEV are the major components of the VSRS. These components are significant on the system's energy efficiency [6, 8, 9]. Therefore, a fuzzy logic control was integrated for the compressor and EEV in this study. The schematic illustration of the control system is shown in Figure **2**.

It is important to compare plant energy consumption and the system's performance while EEV and TXV are used under variable speed operation. Experiments on the chiller system can be devided into two parts. The first part was determination of the thermodynamic behavior of the compressor and EEV. During these experiments, the compressor speed was changed manually between 30-60 Hz with 5 Hz interval, and EEV opening percentage was changed manually between 10-45 % with 5% interval. The second part was the investigation of performance of EEV and TXV under variable and fixed speed operation. During the control experiments water mass flow rate was decreased from 0.5 to 0.1 kg/s in order to observe response of the EEV with partial load. Partial load condition was realized at 0.1 kg/s water mass flow rate. To observe convergence of superheat value to the set value, while fuzzy controlled EEV was used, cooling load and air temperature were constant.

Using EEV with variable speed capacity modulation is more important at partial load condition than at full load [4,6,8,10-12]. Therefore, during the fuzzy control experiments low outside temperature and low cooling load were used. In this study, the performance of the system is obtained in terms of electrical energy consumption and stabile refrigerant superheat value with EEV and TXV system. It is hard to find performance data for the EEV. However, these data are inadequate for all EEV systems, because they contain no information about the effect of particular conditions. Most of the variable speed refrigeration systems suffer from the agreeable control of the EEV in that the control algorithm is not widely known. Hence, some experiments were conducted to define the

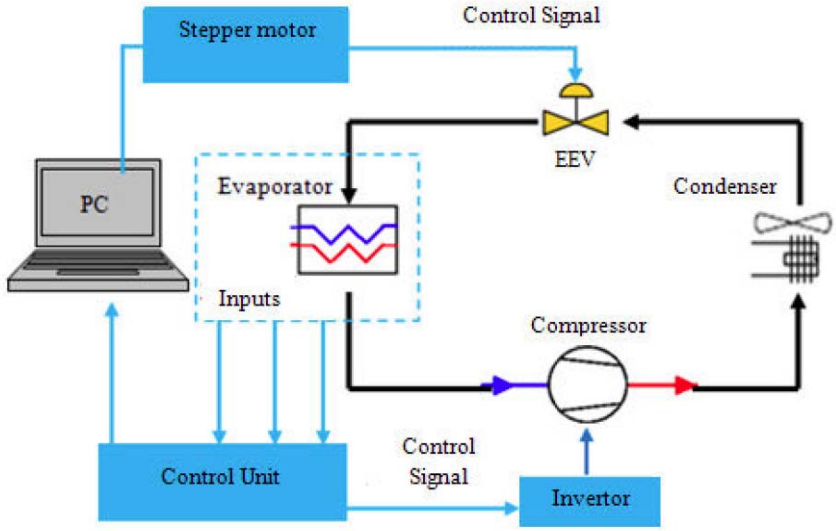

Figure 2: Refrigeration system components and control system [7].

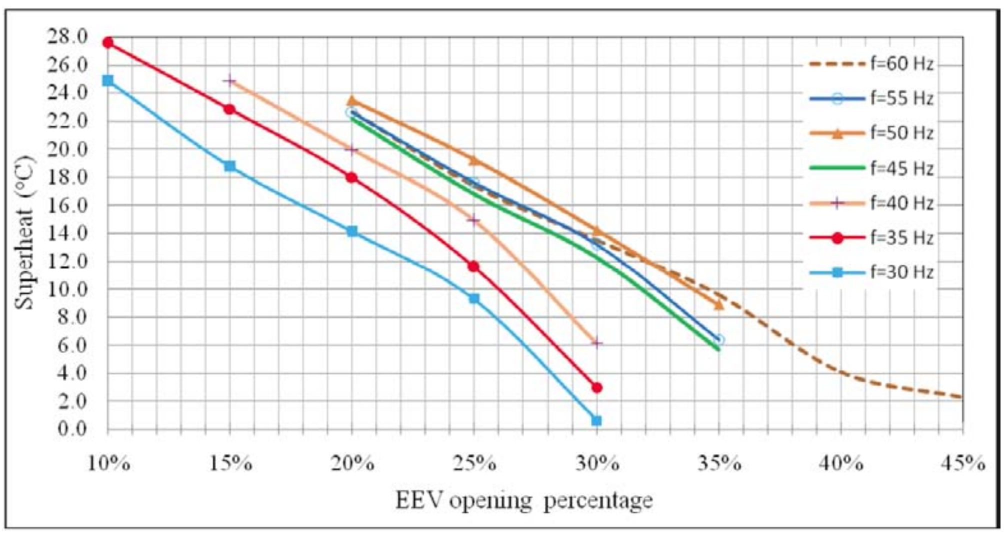

Figure 3: Variation of superheat degree with EEV opening percentage and compressor frequency.

characteristics of EEV. The graphical representation of these characteristics are given in Figures **3-5**. Variation of superheat value versus compressor frequency and EEV opening percentage are illustrated in Figure **3**. According to this figure, superheat decreases while the compressor speed also decreases. The highest superheat is 28°C while 10% of the EEV opening percentage and 35 Hz of the compressor speed. On the other hand, the smallest superheat is obtained at 30 Hz speed and 30% opening percentage of the EEV.

Under these conditions, COP values can be seen in Figure **4**. According to the figure, COP increases while the compressor speed decreases. The highest COP is obtained at 30 Hz compressor frequency while the smallest COP is obtained at 60 Hz speed which is the maximum possible compressor speed for this system. It is also evident from the figure that as the COP increases, the EEV percentage also increases.

In Figure **5**, relation between COP and superheat is given. Results show that the COP value decreases with the increasing value of superheat. This result plays a key role for the EEV and TXV performance comparison. Refrigerant superheat value is higher with TXV than with EEV. This causes higher cooling with same work because of lower specific volume at inlet of the compressor. Therefore, less electricity consumption is obtained with EEV than TXV. The reason is due to the lower superheat value at inlet of the compressor.

Variation of the refrigerant superheat value based on EEV and TXV is given Figures **6** and **7**, respectively. In Figure **6**, effect of the full and partial load on the EEV

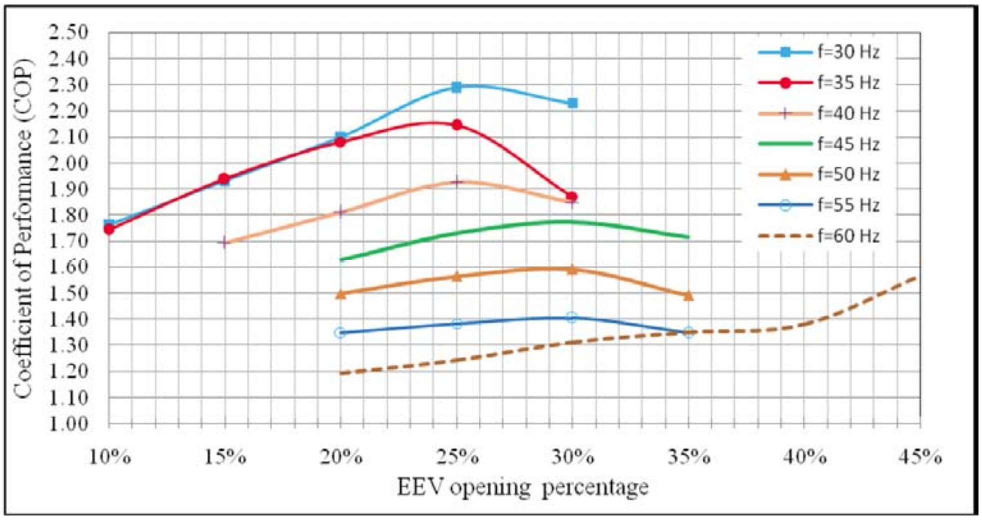

Figure 4: Variation of COP with EEV opening percentage and compressor frequency.

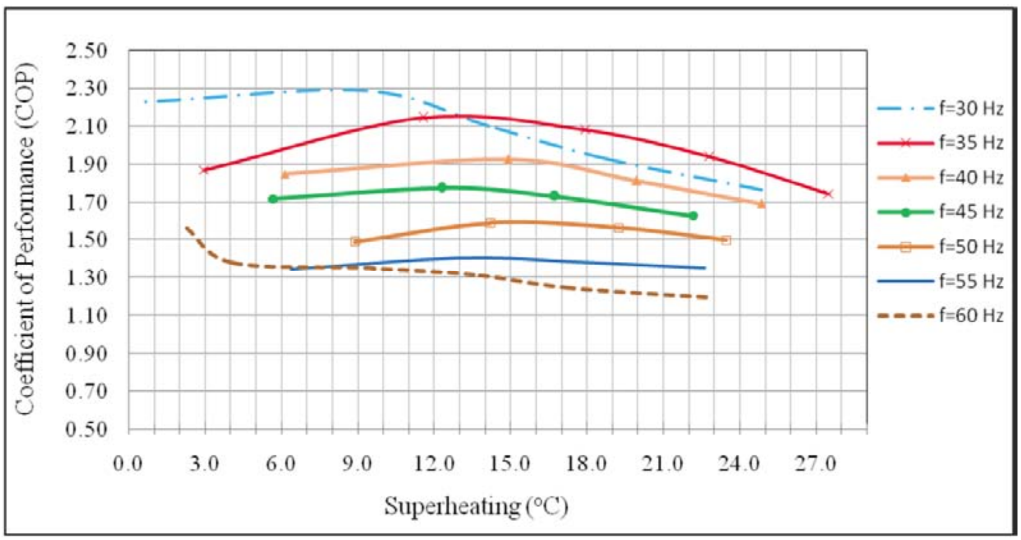

Figure 5: Variation of COP with superheat value and compressor frequency.

control is illustrated. In order to observe partial load response of the EEV, water flow rate is decreased from 0.5 to 0.1 kg/s in this figure. During the experiments, superheat set value is 8°C for the EEV and TXV operation. It can be observed that EEV is able to modulate superheat better than TXV despite the partial load. Superheat is 1.7% lower with TXV operation than with EEV operation under fixed speed compressor (50 Hz). Also, with TXV, 1.7% higher COP value is obtained than with EEV operation. Energy consumption is 8.5% lower with TXV operation.

In Figure **7**, degree of superheat is compared for the EEV and TXV under variable speed compressor operation. Partial load condition - 0.1 kg/s water flow rates – was considered during this experiment. Superheat set value is 8°C for the EEV and TXV operation. It canbe observed that fluctuation of the superheat value with EEV is lower than with TXV. Also, with EEV the superheat value is 30% lower than with TXV. The EEV operation condition has 6% and 14.8% lower power consumption and higher COP values, respectively.

The power consumption of the compressor for both expansion devices and various compressor speeds is given Figure **8**.

4. CONCLUSION

In this study, energy saving potential and the ability of controlling superheat of different expansion devices - EEV and TXV -weare investigated under fixed and variable speed compressor in a chiller system. A scroll compressor was operated as variable speed with aid of

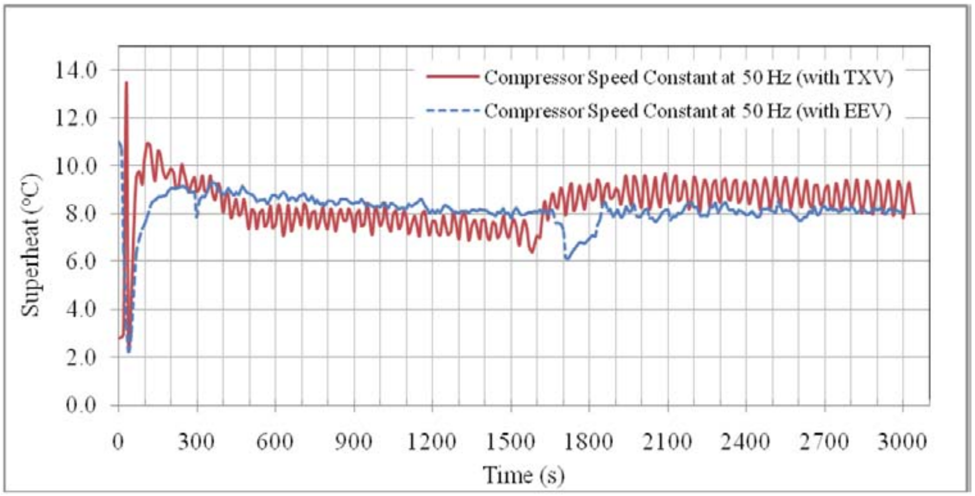

Figure 6: Variation of superheat value with EEV and TXV at constant speed [7].

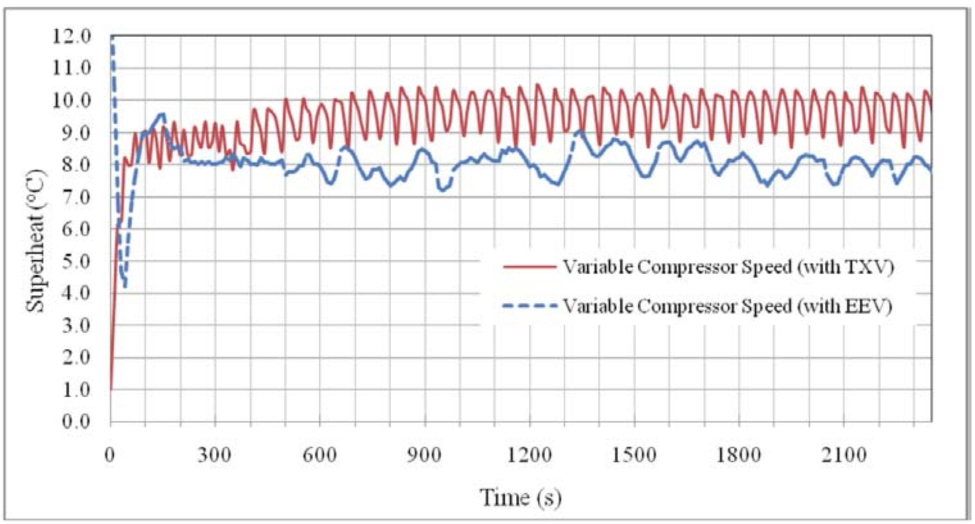

Figure 7: Variation of superheat value with EEV and TXV at variable speed.

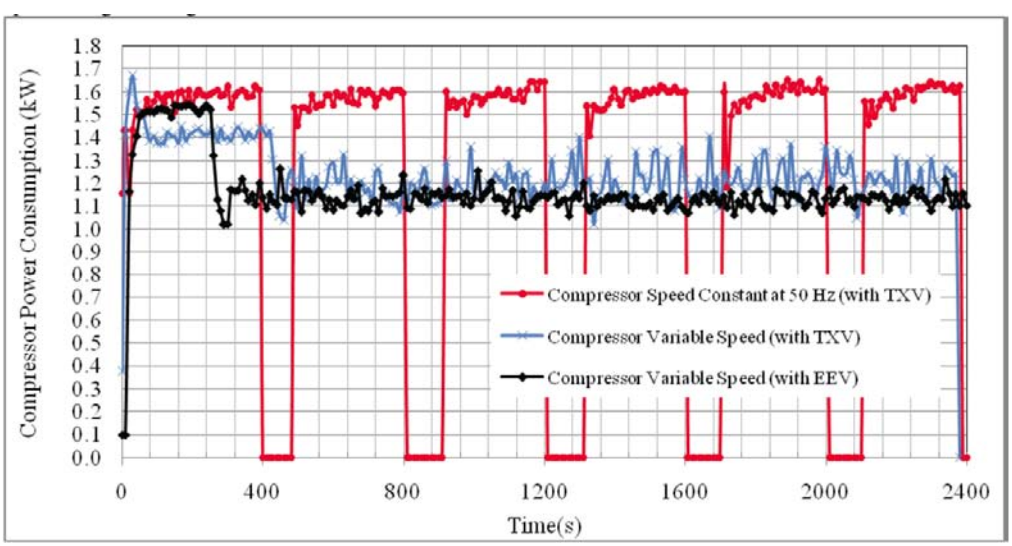

Figure 8: Power consumption of the compressor [7].

PWM inverter. A fuzzy logic control was integrated for the compressor and EEV in this study.

The highest superheat was obtained as 28^{o}C at 10% of the EEV opening percentage and 35 Hz of the compressor speed. The smallest superheat was obtained at 30 Hz speed and 30% opening percentage of the EEV. COP increased while the compressor speed decreased and the superheat decreased while the compressor speed also decreased. The highest COP is obtained at 30 Hz compressor frequency and the smallest COP was obtained at 60 Hz speed, which is the maximum possible compressor speed for this system. Also, the COP value decreased with the increasing value of the refrigerant superheat. This result plays a key role for the EEV and TXV performance comparison. Superheat was 1.7% lower with TXV operation than with EEV operation under fixed speed compressor (50 Hz). This caused lower cooling with the same work because of higher specific volume at inlet of the compressor. Also, with TXV, 1.7% higher COP value was obtained than with EEV operation. Energy consumption was 8.5% lower with TXV operation. The reason for the less power consumptions with EEV than TXV was lower superheat value at the inlet of the compressor. This result means that there is no significance of the EEV operation under fixed speed compressor (50 Hz). Consequently, TXV can adjust refrigerant flow at constant speed better than EEV.

From the experiments, it was observed that with EEV, the superheat value was 30% lower than with TXV. Also, the EEV operation condition has 6% lower power consumption value. As a result, a reasonable performance improvement - 14.8% - was obtained based on the fuzzy controlled EEV in comparison with TXV under variable speed compressor. Besides, the fuzzy controlled EEV performed more stabile superheat value than with TXV in a chiller system.

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