

CASE STUDY OF INVERTER AIR CONDITIONING LOGIC DURING OVERCHARGE REFRIGERANT

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Abstract

Preventative maintenance is a vital process for all mechanical machines. Known as routine or scheduled maintenance, it can be derived as a servicing and inspection activity aimed to prevent equipment from malfunction. It is a critical process because it prevents any machines from facing a breakdown which will cause an operation interruption and disturbance. For residential air conditioning systems, routine maintenance must be performed based on the usage frequency where a higher usage means an increase in maintenance activity. There are several air conditioner system parameters that need to be monitored during the maintenance activity which include refrigerant charge pressure (psi), operation current (amp), voltage (V), indoor unit supply and return temperature (°C). However, for an inverter air conditioner, there are two additional parameters need to be considered which are temperature of the compressor (°C) and expansion valve opening frequency which is measured in pulse units (pls). However, these additional two parameters often been neglected which cause an overcharge of refrigerant level during an inverter air conditioner system maintenance activity. An overcharged refrigerant in an air conditioning system will cause a drop-in cooling capacity, increase energy consumption, and shorten the lifespan of the equipment. Main objective for this study is to observe parameter changes that occur on inverter air conditioners during an overcharge refrigerant state. The observed parameter includes compressor discharge temperature, expansion valve opening and compressor frequency. Finding a suitable air conditioner capacity done prior to the experiment starts by calculating the cooling load requirements for the experiment area. Once the cooling load is determined, the installation of an R32 inverter air conditioner takes place and observation for overcharge refrigerant data is recorded. During the experiment, the refrigerant is being pump into the system starting from 100% capacity until 140% capacity with 10% increment for each charge level. The average recorded data and the differences between each refrigerant charge level is calculated to determine the percentage change for all three parameters considered in this study. Based on this study, a 10% increase of refrigerant level in the system will cause a compressor discharge temperature to be reduce by 12%, a 32% reduced in refrigerant flow due to the closure of the expansion valve and the compressor frequency drops by 17%.

Keywords: Overcharge Refrigerant, Inverter Air Conditioning, Maintenance

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1. INTRODUCTION

Nowadays, air conditioning system is widely used in residential, commercial, and industrial buildings as a means of treating air and to maintain and establish the required temperature (hot or cold), humidity (wet or dry), cleanliness and air motion in the building (Edward G. Pita-3rd ed., 1998). There are various types of air conditioner and the most popular among them is a split type air conditioner unit which is commonly used in residential buildings due to its simplicity and flexibility (M. A. S. S. A. Nada, 2017). However, due to its popularity, air conditioner has become one of the major electrical consumption appliances where it accounts for more than 50% of energy usage for a common household (Y. H. Jiangyan Liu Juanxin Chen, 2016). Since air conditioner has a high energy consumption among household equipment (Mohsen Farzad, 1990), inverter air conditioner system was invented and introduced to reduce the energy usage for up to 40% by regulating the compressor motor speed based on room load demand. Most inverter air conditioners in Malaysia have a 4 to 5-star rating, as mandated by Suruhanjaya Tenaga's guidelines. All air conditioners sold in Malaysia must meet a minimum 2-star rating for energy performance standards (MEPS), (Guide on Minimum Energy Performance Standard Requirements for Air Conditioner with Cooling Capacity $\leq 7.1\text{kW}$, 2018). Residential inverter and non-inverter air conditioners share the same main components, but inverter units have an extra feature to conserve the energy consumption. An inverter air conditioner is equipped with a special equipment which gradually adjusts the compressor speed when the system reaches the desired temperature. In contrast, a non-inverter unit forces the compressor to turn off abruptly. As a result, a non-inverter air conditioner consumes more power to restart the compressor. Purchasing cost of inverter air conditioner system is slightly higher compared to non-inverter unit due to several additional components such as intelligent sensor, outdoor printed circuit board (PCB), electronic expansion valve and multispeed compressor. However, the return on investment (ROI) can still be achieved by reduced electric consumption done by the inverter unit. Besides, inverter air conditioner type is preferred by mass consumer is due to its capability of maintaining the room temperature effectively and has a lower compressor sound level.

In order to achieve the ROI for inverter air conditioner system a proper routine maintenance needs to be conducted. There are various activities involved during an air conditioning system maintenance and one of them is to monitor the refrigerant charge level. This monitoring activity is important because having an over-charge or under-charge level of refrigerant in an air conditioning system will cause a reduction of 20% in efficiency compared to proper refrigerant level (Proctor, 1996). Besides that, the efficiency of an air conditioner system operating with improper charge will deteriorate from 10% to 20% (Downey and Proctor, 2002). Furthermore, according to research conducted by (Mohd Hazwan Yusof, 2018), overcharging of 20% refrigerant in an air conditioning system will drop the cooling capacity up to 11.4% and coefficient of performance 16.4% respectively. According to Zhao Yuqing (2018), excess refrigerant will lead to an excessive amount of liquid inside the condenser. As a result, it will reduce the effectiveness of heat transfer area which leads to condensing temperature and pressure ratio to rise. Thus, the compressor will consume more power and the cooling efficiency and Coefficient of Performance (COP) will decrease. Even though monitoring the refrigerant charge level is an essential process during air conditioning system maintenance, this step is still being neglected. During the maintenance process, most of the air conditioner technician will usually pump in the refrigerant into the air conditioning system without emptying the trapped air and moisture inside the air conditioning component and piping route. As a result, the air conditioning system will produce an incorrect refrigerant pressure reading (psi), incorrect operation current reading (amp) and ultimately will shorten the lifespan of the system. Furthermore, the operation of an air conditioning system without going through the vacuuming process will reduce the cooling capacity, contaminate the compressor oil, and leads to corrosion of air conditioning components.

As a counter measure, Department of Environment under Malaysian Ministry of Natural Resources, Environment and Climate Change has developed a training manual and Standard Operating Procedure (SOP) for air conditioning technician to cater this issue. According to the training manual, the air and moisture must be pumped out from the refrigerant line (500 microns for HCFC and 200 microns for HFC) by using a vacuum pump before inserting the refrigerant into the air conditioning system. In addition, air conditioner manufacturer also provides an installation guideline on refrigerant pre-charge level for newly installed air conditioner split unit type which caters a piping system with length up to 7.5 metres. For a piping system that exceeds the pre-charge length, an additional refrigerant is required and must be measured using a weighting scale to avoid over-filling. The air conditioning performance is linked directly with refrigerant charge level in the system (H. M.-

T. F. Poggi D. Leducq, 2008). Therefore, this study will observe the effect to the air conditioning system by observing the parameter of compressor discharge temperature, expansion valve opening and operation current for inverter air conditioning unit during over-charge refrigerant level from 100% to 140%. These parameters were selected because it is unique to inverter air conditioner where it is equipped with specialized equipment such as discharge temperature sensor and electronic expansion valve. A lack of these equipment in non-inverter air conditioner hinders it from be use for the study. Additionally, the aim of this study is to investigate the correlation between these three parameters with the energy consumption level. The result of air conditioning parameter observe will be tabulate in table and presented for references.

The objective for this study as below:

- a. To study the logic for compressor discharge temperature, expansion valve opening and compressor frequency for residential inverter air conditioner system while operated in overcharge refrigerant level.
- b. To tabulate new table of data that presented inverter data parameter during overcharge for troubleshooting guidance at site and also for teaching and learning references.

2.METHODOLOGY

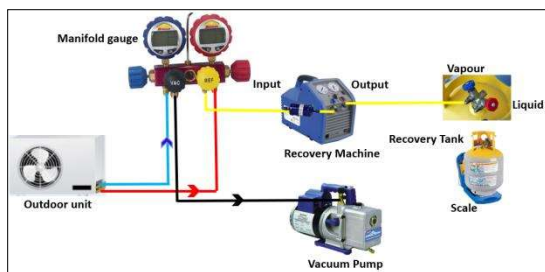


Figure 1. Recovery refrigerant setup

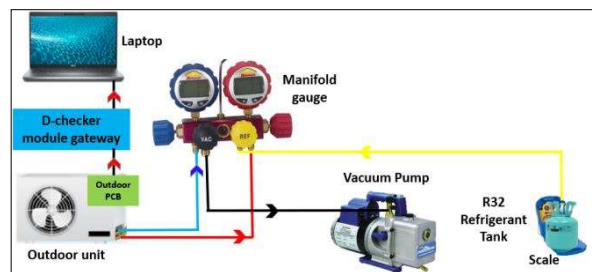


Figure 2. Refrigerant charging setup

The experiment was setup by using R32 inverter split unit air conditioner type, together with others relevant accessories and equipment as shown in figure 1 and figure 2. The study was performed by regulating the refrigerant charge level from 100% until 140% within 15 minutes. Air Conditioning & Refrigeration Institute (ARI) 210/240 standard is being applied during conducting this experiment (A.-C. & R. I. (ARI), Stand. 210/240, 2006). Prior to the experiment start, the cooling capacity requirement for the experiment's location (Metallurgy Laboratories, Politeknik Kuching Sarawak, Malaysia) was determined by using the following calculation:

$$\begin{aligned} \text{Rule of thumb} &= \text{Width (W)} \times \text{Length (L)} \times \text{Coefficient for laboratories} \\ &= 10\text{ft} \times 12\text{ft} \times 75\text{btu/hr/ft}^2 \\ &= 9000\text{Btu/hr @ } 2.63\text{kW} \end{aligned}$$

As a cooling load required for the laboratory is 9,000Btu/hr (2.63kW), the 9,100Btu/hr (2.67kW) inverter split unit air conditioner (model 2019) is selected and installed for this study. The air conditioner is using R32 refrigerant as the working refrigerant. D-checker module input wire is connected to outdoor printed circuit board (PCB) at outdoor unit of air conditioner and input wire was connected to the laptop for data collection. As shown in Figure 1, in order to get an accurate data, all the refrigerants, air and moisture inside the air conditioner system components and pipelines were pumped out using recovery machine and vacuum pump until it reaches 200 microns as R32 is an HFC refrigerant type. As shown in Figure 2, by referring to manufacturer standard, 0.55kg of new R32 refrigerant will be charged into the air conditioner system while being monitored by using weighting scale and manifold gauge. In this study, five different refrigerant charges level will be tested, and three fixed parameter setting is being used as shown in Table 1:

Table 1. Experiment setup parameter

Refrigerant charge (%)	100, 110, 120, 130, 140
Observe parameter	1. Compressor discharge temperature (°C) 2. Expansion valve opening (pls) 3. Compressor frequency (rps)
Temperature setting (°C)	24
Fan mode	High
Outdoor air temperature (°C)	30

3.RESULT AND DISCUSSION

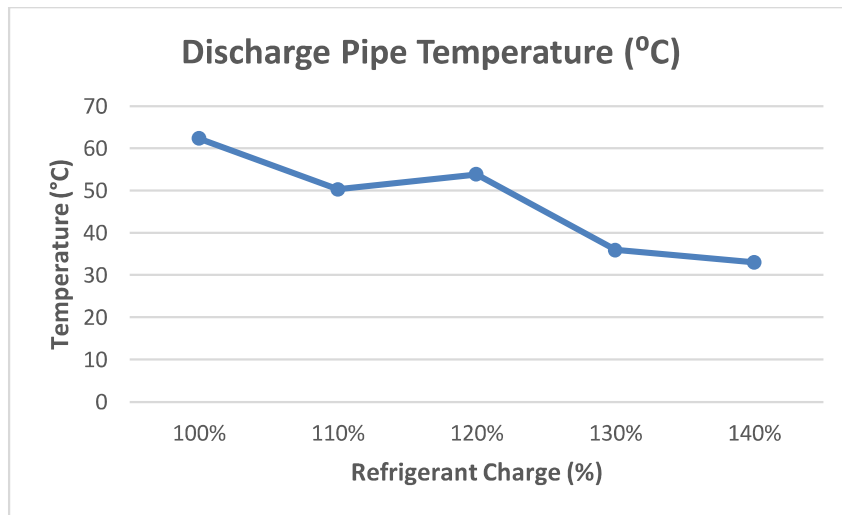


Figure 3. Compressor discharge temperature (°C) data

Figure 3 shows the average data of compressor discharge temperature (°C) in a duration of 15 minutes. The compressor discharge thermistor was located at the compressor outlet line approximately 5 cm from the compressor housing. Based on the observation, the initial temperature recorded is 62°C where it is on the optimum refrigerant charge level. The temperature keeps decreasing when the refrigerant charge level is increase by 10% until it reaches a value of 140%. At this level, the temperature is reduced by 46.77% with a temperature value of 33°C. Normal operating temperature for the compressor is between 60°C to 70°C. This descending temperature reading occur due to increase in refrigerant flow through the compressor. During the air conditioner system operation, the increase in refrigerant flow will result in excessive refrigerant. This excessive refrigerant will not be transformed into vapor phase during evaporation stage, thus it remains in liquid form. This liquid form will enter the compressor and consequently will affect the compressor suction valve function.

This negative affect from this experiment is expected as according to (Woohyun Kim, 2010), the overcharge refrigerant will reduce air conditioner lifespan, capacity for cooling or heating and overall efficiency. The increase in refrigerant volume will also reduce the superheating process in the evaporator (John Houcek, 1984). Next, based on study conducted by (John Houcek, 1984), the overcharge refrigerant will cause a slugging, motor overheating and liquid flood back which reduce oil dilution and lubrication of the components in compressor. In addition, the situation will become worse if the outdoor temperature is low and no routine maintenance is performed. Plus, liquid compression may also transpire if the capacity of air conditioner is larger than a required capacity

To counter this issue, modern residential air conditioner is equipped with accumulator at the compressor inlet that act as a temporary storage for refrigerant and to separate the liquid and vapour refrigerant. However, in

this experiment, it still unable to cater the excessive volume of refrigerant which indicate inserting excessive amount of refrigerant into the air conditioner is not recommended.

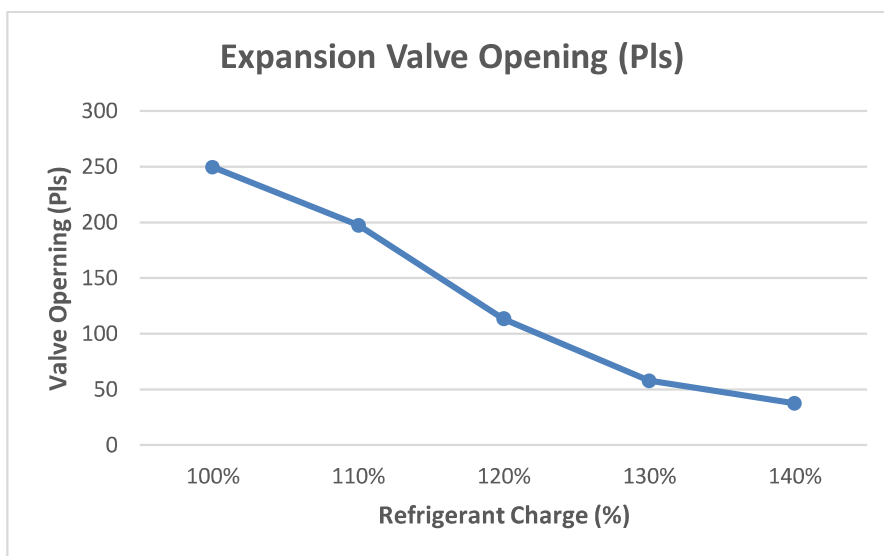


Figure 4. Expansion valve opening (Pls) data

Figure 4 shows the effect of overcharge refrigerant on the expansion valve opening pulse value (pls). As illustrated in figure above, the expansion valve pulse value (pls) shows a declining trend as the quantity of refrigerant increase. At the optimum refrigerant level (100%) setting, the expansion valve opening pulse value (pls) is at the peak with a value of 250 pls while during the highest refrigerant level (140%) setting, the pulse value drops significantly by 84.8% with just 38 pls. An increase of 10% of the refrigerant volume into a system will reduce the valve opening approximately by 50-60 pls. There are also a correlation between compressor discharge temperature with the expansion valve opening pulse value, where the value of compressor temperature is directly proportional with expansion valve value. At 100% charge setting, the compressor temperature was at 62°C with a greater valve opening value (250 pls) and at 33°C compressor discharge, the opening of the expansion valve is 38 pls. This phenomenon occurs because expansion valve is adjusting its opening to match the target temperature and the actual discharge temperature.

Beside over charging the refrigerant level, there are other factor that contribute in a reduce value of expansion valve opening. Improper maintenance on the interior air filter and evaporator, over-sizing capacity of the air conditioner and faulty procedure during the air conditioner installation also contribute to the decrease value of expansion valve opening. Furthermore, if this condition is still continuing to exist, it will reduce the superheat value in which will reduce the lifespan of the compressor due to liquid compression phenomenon.

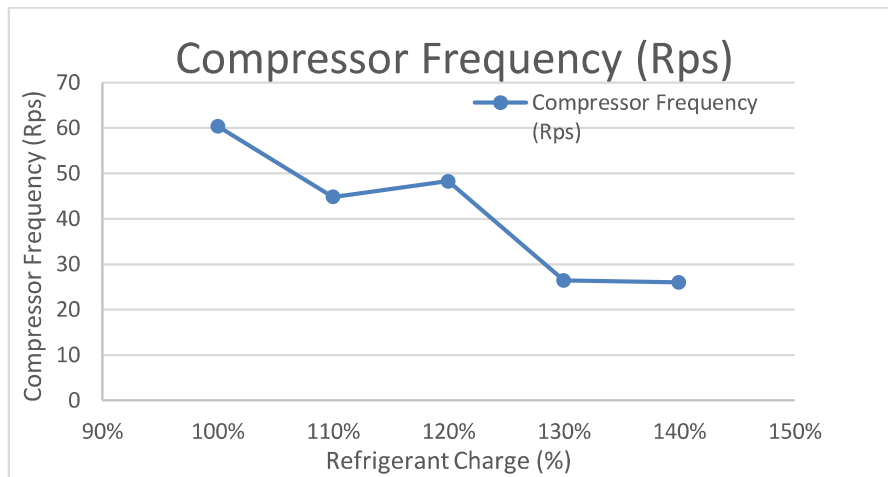


Figure 5. Compressor frequency (Rps) and temperature difference data

Figure 5 illustrate the value of compressor frequency (rps) recorded within 15 minutes for multiple refrigerant charge level. The lowest frequency recorded is at 26rps where refrigerant charge level was at 140%. The compressor frequency value will drop due to increase in pressure in the air conditioning system. During refrigerant overcharge condition, the liquid refrigerant is not vaporized completely by the evaporator. Therefore, the air conditioner system is forced to operate in wet mode, where the liquid refrigerant flows through the compressor suction and damages the compressor valve.

During the experiment observation, the frequency of the compressor was automatically adjusted according to the temperature differences between ambient temperature and the temperature set by the user. In other word, bigger temperature gap between ambient temperature and the set temperature will result in higher compressor frequency value and it is applicable vice versa. In addition, the same phenomena as overload refrigerant conditions also occur when there is insufficient condensation occur in the condenser, a malfunction expansion valve and a reduction of the heat load inside a room.

4.CONCLUSION

The current research focuses on determining the value of three different parameters of the split unit inverter system. These data can provide some information to the air conditioner technician on air conditioner characteristic during overcharge refrigerant and could be act as a guidance for troubleshooting work on the inverter system. Increasing and decreasing of refrigerant charge will give impact on the reading for each component. The summary for this case study is tabulated in Table 2. As per the data in Table 2, an elevation in the refrigerant charge level results in a roughly 17% reduction in compressor frequency, primarily due to heightened workload. Additionally, the expansion valve exhibits a tendency to close by as much as 32% owing to the decrease in discharge pipe temperature. Furthermore, a 12% drop in compressor temperature leads to the closure of the expansion valve. Consequently, the air conditioner may not be able to deliver its intended cooling capacity and may struggle to reach the desired temperature setting. According to Farzad. M (1991), the air conditioner performance will decrease due to increase of compressor work.

Table 2. Case study summary

Refrigerant Charge (%)	Compressor discharge temperature (°C)	Expansion Valve Opening (pls)	Compressor (rps)
100	62	250	60
110	50	198	45

120	54	113	48
130	36	58	26
140	33	38	26

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