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Detecting Refrigerant Leakage in Inverter-Based Air Conditioners – An Analytical Approach

Robin Goel
Research & Development, Voltas Ltd.
Delhi, India

Srinivasu Moturi
Research & Development, Voltas Ltd.
Delhi, India

Abstract— **Air conditioning systems play a pivotal role in maintaining comfort and quality of life in modern society. However, the problem of refrigerant leakage in air conditioners poses significant challenges, both environmentally and economically. This research paper provides a potential solution associated with refrigerant leakage in air conditioning systems based on the feedback of temperature sensors which give real time values of the certain critical parts associated with refrigerant cycle of the system.**

Keywords: **Refrigerant leakage Detection, Inverter Air Conditioner, Temperature Sensor, Refrigerant cycle, Controller, Algorithm, Evaporator Coil, Discharge, Room ambient, Gas leak**

I. INTRODUCTION

Air conditioning systems have become an indispensable aspect of modern life, providing respite from extreme temperatures and improving indoor comfort. Whether in homes, offices, or industrial facilities, air conditioners are ubiquitous, serving as a technological marvel that has revolutionized the way we live and work. However, hidden beneath the cool and comforting breeze they provide lies a pervasive problem that demands our immediate attention—refrigerant leakage.

The efficient operation of residential air conditioners relies heavily on the proper functioning of refrigeration cycles, wherein refrigerants play a central role. Refrigerants facilitate the transfer of heat from indoor spaces to the outdoors, creating the desired cooling effect. Yet, over time, these refrigerants can escape from the system, compromising both its performance and environmental sustainability.

Refrigerant leakage detection in residential air conditioners holds paramount importance for several compelling reasons. Firstly, it addresses environmental concerns. Many of the refrigerants used in these systems are potent greenhouse gases, contributing to global warming and climate change when released into the atmosphere. Detecting and preventing leakage is a pivotal step in minimizing these environmental impacts. Secondly, refrigerant leakage detection directly impacts the economic well-being of homeowners and occupants. Leakage often leads to increased energy consumption, reduced cooling efficiency, and frequent repair costs, all of which can strain household budgets. Thirdly, ensuring the safety and well-being of residents is of paramount importance. Some refrigerants pose health risks when released, potentially causing respiratory issues and other health complications among occupants and HVAC technicians who service these systems.

This research paper seeks to delve deeply into the critical matter of refrigerant leakage detection in residential air conditioning systems. The objective of this study is to develop a cost-effective algorithm using existing temperature sensors which are already installed in the air conditioning system. This algorithm employes certain conditions based on which we can easily deduce the absence of refrigerant in the system.

II. LITERATURE SURVEY

The history of residential air conditioning dates to the early 20th century when Willis Haviland Carrier introduced modern air conditioning systems. Over the years, residential air conditioners have evolved from luxury items to commonplace appliances, significantly enhancing the quality of life in homes around the world.

These systems have a complex and dynamic process at their core, known as the refrigeration cycle, which is fundamental to their ability to cool indoor spaces effectively. Understanding this cycle and the role of refrigerants within it is crucial for appreciating the functioning of modern air conditioning technology.

Basic Refrigeration Components: To understand the role of refrigerant, first we need to understand the basic components of refrigerant cycle. It consists of five essential components: compressor, condenser, evaporator, expansion valve and refrigerant [1].

A. The Compressor

The compressor is a crucial component that pressurizes and circulates the refrigerant gas. It raises the temperature and pressure of the refrigerant, turning it into a high-pressure, high-temperature gas.

B. The Condenser

The high-pressure, high-temperature refrigerant gas flows into the condenser. In the condenser, the refrigerant releases heat to the surroundings, causing it to condense and change from a gas to a high-pressure liquid.

C. The Expansion Valve

After leaving the condenser, the high-pressure liquid refrigerant passes through an expansion valve or throttle valve. This component reduces the pressure and temperature of the refrigerant, causing it to undergo a phase change from a liquid to a low-pressure, low-temperature mixture of liquid and vapor.

D. The Evaporator

The low-pressure, low-temperature refrigerant mixture enters the evaporator, which is usually located inside the area or space that needs to be cooled. In the evaporator, the refrigerant absorbs heat from the surrounding environment (air, water, or other substances), causing it to evaporate and turn back into a low-pressure gas.

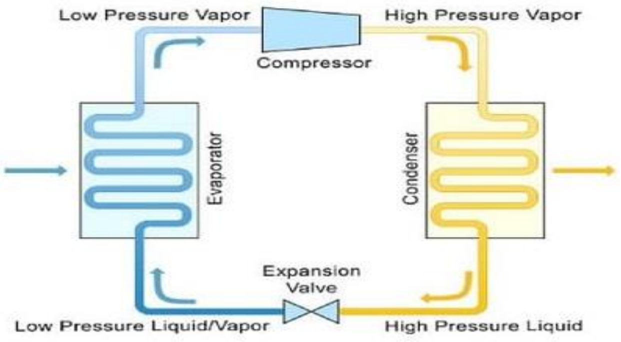

Figure1: Schematic representation of Refrigerant cycle [2]

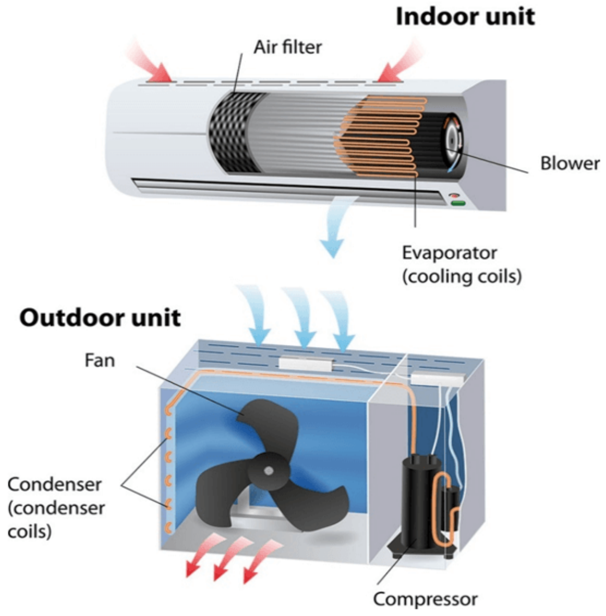

Figure 2: Representation of Residential Air conditioning system

E. The Refrigerant

A specialized fluid selected for its thermodynamic properties, is the working fluid that cycles through the system, absorbing and releasing heat as it changes from gas to a liquid and back to a gas. Refrigerants are carefully selected for their ability to facilitate this heat transfer efficiently. These substances possess unique thermodynamic properties that enable them to undergo phase changes at relatively low temperatures, making them ideal for the task.

Historically, refrigerants such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) were commonly used. However, environmental concerns, particularly regarding ozone depletion and global warming, prompted a shift toward more eco-friendly alternatives like R410, R32 & R290. There are various factors to consider when choosing a refrigerant [3][4].

Ozone Depletion Potential: These are chlorinated and brominated refrigerants, act as a catalyst to destroy ozone molecules and reduce the natural shielding effect from incoming ultraviolet B radiation.

Global Warming Potential: Gases that absorb infrared energy, with a high number of carbon-fluorine bonds and generally have a long atmospheric lifetime.

Combustibility: Some refrigerants are highly flammable & toxic. So, selection of these refrigerants should be done carefully.

After understanding working of the critical components of an air conditioner system it is imperative to understand that Refrigerant leakage is the most frequently found fault in a refrigeration system and efficient detection is highly important. Refrigerant leakage eventually leads to low cooling or no cooling by the system. Leakage of refrigerant from the unit may take a few hours to few days depending on the size of the and location of leakage point whether it is in the evaporator coil, condenser coil, valve or interconnecting copper tubing in which refrigerant is flowing [5]. There are several potential leak points all over the system so it is almost impossible to anticipate the leakage point before it happens but there can be certain methodologies which make it possible to detect it after it happened or while it is happening. Some methodologies use a special gas sensor, pressure sensor or flow rate, installed within the air conditioning system, which detects the refrigerant leakage and gives its electrical feedback to the air conditioning controller unit. This controller unit will have some kind of alert mechanism which enables the user to be aware of the fault.

Large scale refrigeration systems have abundant data to detect or diagnose leakage. However, in cases of small residential air conditioner, installed sensors are mostly temperature sensors, and the number of these sensors is also limited. In this study, a refrigerant leak detection method for an EEV (electronic expansion valve) installed residential air conditioners with limited sensor information.

III. DETECTION METHODOLOGY

A new technique to detect and diagnose leakage in a Air conditioning unit is proposed in this paper. The proposed technique is not only based on simple and inexpensive measurements of refrigerant thermodynamic states but also accounts for the complexity of the system.

Generally, in a residential Inverter Air Conditioner below mentioned sensors are employed.

1) Evaporator Coil Temperature sensor (Te)
2) Indoor Room Ambient sensor (Tr)
3) Condenser Coil Temperature Sensor (Tc)
4) Discharge Tube Temperature Sensor (Td)
5) Outdoor Ambient Temperature Sensor (Ta)

A separate sensor like a gas sensor or pressure sensor can also be used in the air conditioner but it requires other interfacing components as well which will further increase the raw material cost of the system. So, to keep the overall cost of the air conditioning system minimum, this refrigerant leakage detection methodology utilizes the measurements of only three existing sensors.

1. Evaporator Coil Temperature sensor (Te)
2. Indoor Room Ambient sensor (Tr)
3. Discharge Tube Temperature Sensor (Td)

Apart from the measurement values of these sensors we will also use the running time of the compressor in minutes and the speed of the compressor in RPM or Hz. The speed of the compressor is directly proportional to cooling capacity delivered by the air conditioner.

In Inverter Air conditioner there are mainly two controllers installed which control the complete functioning of air conditioner including the cooling capacity. One of these controllers is in the indoor unit of the air conditioner and the other is located in the outdoor unit of the air conditioner. Temperature Sensors such as Evaporator Coil (Te) & Indoor room ambient (Tr) are connected with the Indoor unit controller and Discharge tube (Td) is connected with the outdoor unit controller. Complete controlling of the compressor operation including its speed control is done by the outdoor unit controller. Indoor unit controller and outdoor unit controller are connected by the communication wire to synchronize their actions.

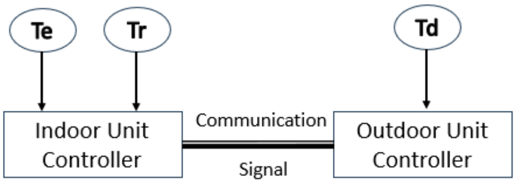

Figure 3: Representation of Controller Connection

When we turn on the Power of the Air conditioning unit, Indoor controller gives signal to outdoor controller to turn the compressor ON. As the compressor starts, it compresses a low-pressure, low-temperature gaseous refrigerant to a high-pressure, high-temperature gas. This gas is discharged from compressor via discharge tube towards the condenser coil. It then condensed in the outdoor condenser coil, releasing heat to the outside air and becoming a high-pressure liquid. It is then expanded through an expansion valve, causing it to cool and change into a low-pressure, low-temperature liquid-gas mixture. In the indoor evaporator coil, this liquid-gas mixture which is at a very lower temperature, absorbs heat from the indoor air causing it to evaporate and turn back into a low-pressure gas, and the cycle repeats, transferring heat from indoors to outdoors and cooling the indoor space [6]. So, considering this process we can deduce that when unit starts and there is sufficient gas in the system then Evaporator Coil temperature (Te) will start decreasing rapidly compared to indoor room ambient temperature after compressor start and Discharge tube temp. (Td) will start increasing.

When we turn on the main power supply to the unit, after some time the compressor of the unit will start. There are two conditions, Condition A & condition B, which need to be judged based on certain criteria. Condition A will be judged from start of the compressor till 10min. of its running time. Within these 10 minutes, if discharge tube temperature (Td) reaches more than 100°C at least for 30 sec, and at the same time if evaporator coil temperature (Te) ≥ Indoor room ambient temperature (Tr)-2°C. Then it is judged that condition A is true which means there is refrigerant leakage in the system, and it is present in very low amount in the unit. As soon as this controller gets to know that Condition A is satisfied then it will immediately turn off the compressor from a safety point of view.

In case condition A is not satisfied then Condition B will be judged. Suppose compressor has now completed the run till 10 minutes. If still evaporator coil temperature (Te) ≥ Indoor room ambient temperature (Tr)-2°C (for more than 5 seconds) and during these 10minutes compressor was running at more than 2700RPM at least for 3 minutes, then Condition B is true and compressor will be turned off forcefully by the controller. This complete cycle, from compressor start to forcefully compressor off, will be recorded as 1st time in the counter of the algorithm in controller. Now the algorithm will automatically repeat the same process two more times and count it as 2nd & 3rd cycle. If at end of the 3rd cycle either condition A or condition B is also true, then algorithm will conclude it as a refrigerant leakage detection.

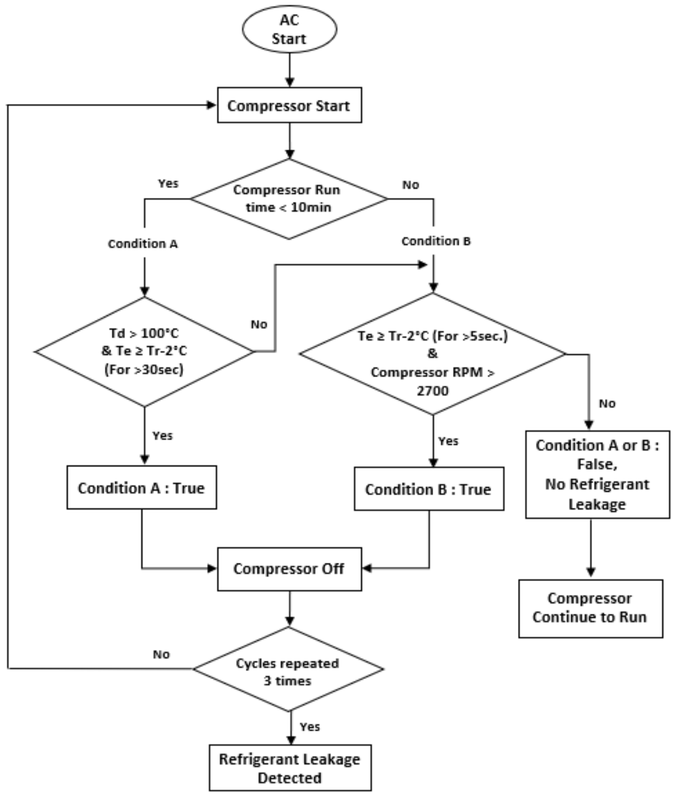

Figure 4: Flow Chart – Refrigerant Leakage Detection Algorithm

IV. OBSERVATIONS AND DISCUSSIONS

Once it is identified by the algorithm that there is either very low gas or no gas in the system then algorithm will turn off the compressor permanently from safety perspective & this fault can be displayed in the indoor display unit represented by some code display or some kind of LED blinking indicator. This indication will help the user to understand the kind of fault in the unit and he can take appropriate measures by calling the service engineer to the unit repair. This feature enables service person to pinpoint the issue and its rectification without doing any further delay in hit & trail to find the exact fault in the unit.

If both conditions A & B are not satisfied, then it implies that the air conditioning unit does have gas in the system required to deliver the cooling. These conditions will only be judged each time the unit is powered on and the compressor starts. In any case if the unit is powered on and compressor is not started then this refrigerant leakage algorithm will not get activated and there will not be any leakage related fault. As per the experimental data it is observed that when there is very low gas in the system, around <25%, then probability of condition A to be true is very high as Td will rise sharply after compressor turns on and starts reaching to higher RPM. But if all the gas exits from the system due to the unrepaired leakage point, the probability becomes higher for condition B to be true because in this case Td will not rise much. If there is > 40% of required gas quantity is in the system and user turned on the unit, then there are high chances that algorithm will not detect it as a leakage. Because air conditioning units would still be delivering some amount of cooling to user. As the leakage is a continuous process if unattended, eventually the gas quantity will drop to <20% to 0%. Now the cooling capacity of the air conditioner will be almost nil, and the algorithm will detect it as a fault in the unit.

This algorithm is only applicable to the air conditioning unit with inverter technology as it has separate outdoor unit controller and Td sensor. In the case of fixed speed air conditioners there is no controller and Td sensor in the outdoor unit so this algorithm will not be applicable. Usage of three sensors measurements and other parameters together makes this algorithm highly precise in judgement.

V. CONCLUSION

This research paper has explored the critical issue of refrigerant leakage detection in inverter air conditioner systems. The prevalence of refrigerant leaks in such systems poses environmental, economic, and operational challenges, making the development of effective detection methods paramount. In response to this pressing need, our research has introduced an innovative algorithm designed to detect refrigerant leakage in the residential inverter air conditioner. It offers a practical, efficient and cost-effective solution to enhance the sustainability and efficiency of such systems, benefiting both the environment and the end-users. The potential for wide-scale adoption and the ongoing research opportunities makes this work a valuable contribution to the field of HVAC technology.

VI. FUTURE SCOPE

The research on refrigerant leakage detection in inverter air conditioner systems presents several promising avenues for future exploration and development. It includes the upgradation of the algorithm system to a prediction level using the technologies below.

1) Integration with IOT - This would enable real-time monitoring and control of HVAC systems, allowing for more proactive responses to leaks and optimizing system efficiency.

2) Machine Learning: It can enhance the algorithm's ability to adapt and self-optimize, improving its accuracy in detecting leaks and reducing false alarms

3) Cloud based monitoring and analytics: It can be utilized to collect and analyze data from multiple HVAC systems, providing a comprehensive view of their performance.

4) Environmental and Regulatory Compliance: With increasing environmental regulations and standards, research can focus on developing solutions that not only detect leaks but also ensure compliance with refrigerant regulations and emissions standards.

5) Energy Efficiency Improvements**:** Research can continue to investigate ways to leverage refrigerant leakage detection to optimize energy consumption, not only by

identifying leaks but by suggesting system adjustments for maximum efficiency.

These future scopes represent opportunities to refine, expand, and apply refrigerant leakage detection technology in a broader context. Collaboration between researchers, industry stakeholders, and policymakers will be crucial in realizing these potential advancements and ensuring the widespread adoption of effective refrigerant leakage detection systems in inverter air conditioner systems.

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