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Review Article

A Review on DC Inverter Operated Air Conditioner

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Abstract

Air conditioning system is essential for maintaining thermal comfort in indoor environments, particularly for hot and humid climates. Nowadays, air conditioning, comprising cooling and dehumidification, has become a necessity in commercial and residential buildings and industrial processes. It accounts for a major share of the energy consumption of a building or facility. Energy efficiency for air conditioners has received increasing attention in recent years with the intense emphasis on environmental concern and energy consumption. As the main energy consumption component of air conditioner, compressor needs further work to accomplish the transition of performance evaluation from one operation condition to its actual usage. Inverter, a device in the air conditioner, controls frequency of power supplied to compressor motor. Compressor motor controls the rotational speed of the compressor and the compressor ensures refrigerant flow is commensurate with the cooling requirement of the room. This paper discusses Inverter operated air conditioners which are being more popular due to better energy efficiency, excellent control over room temperature, and less noisy.

Keywords: *Air Conditioner , DC Inverter Compressor , Natural Refrigerant, COP ,Power Consumption , Energy Efficiency*

1. Introduction

Nowadays, a great deal in research has been made on energy-efficient and environment-friendly techniques in response to shortage of fossil fuel energy resources and environmental damages such as air pollution ,greenhouse effect and global warming. Air conditioner is essential part of modern life in producing comfortable environment, air conditioner has found many applications in residential, commercial or industrial buildings, as well as in transport vehicles and process applications, which leads to high consumption of electricity and CO2 emissions. Due to increment in energy prices, the need for less energy consumption has become a global concern. The Energy consumption for air-conditioning in buildings accounts almost 50 per cent of the total energy consumption. It has been acknowledged that 30 per cent of worldwide energy consumption is due to refrigeration and air conditioning installations, and therefore these systems has a large impact on energy demand. For this reason, it has been an aim of many researchers to improve on conventional air conditioning systems, as this would result in a significant energy economy. Improving the energy efficiency of air conditioner is one of the fruitful strategies implemented in tackling with energy shortage and environmental issues. The refrigerants used in air conditioning system is also an another concern due to ozone depletion potential(ODP) and global warming potential(GWP). More attention should be paid on compressor of air conditioner as it is a highest energy consumption when it comes to system component level. The energy efficiency guidelines has gone through a transition from rated condition to the actual usage of air conditioner.

The application of inverter technology in air-conditioning systems for commercial and residential purposes was first implemented in Japan in 1980s. Since then, these systems have become popular owing to their energy saving and better maintaining of thermal comfort when compared to the constant speed air conditioner. The inverter system is often used to control the compressor rotational speed with respect to variable load. Mostly, when the air conditioner is operated at part-load for much of their life, the energy consumption is reduced exactly than the on/off compressor cycle.

The refrigerant R-22 is the most widely used working fluid. Due to its ozone depleting effect and the Montreal Protocol that will ban the use hydro-chloro-fluoro-carbon (HCFC) in 2020. HCFC-22 is a widely used refrigerant for air conditioners in India. Due to its environmental concerns, ODP and high GWP, it is being phased out from air conditioners. The most promising alternatives to HCFC-22 considered by air conditioner manufacturer are R-407C, R-410A, HC-290, HFC-161, R-744, and HFC-32. A few HCFC-22 AC systems are

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already converted to R-410A. However GWP of R-410A is 2100 and is significantly higher. HC-290 and HFC-161are flammable and safety precautions are required when used in air conditioners. HC-290 is compatible with materials used in AC system and it has better oil miscibility. HFC-32 has moderate GWP and it is mildly flammable. The high operating pressure of R-744 requires sturdy system and its energy efficiency is lowered at high ambient. Currently, new refrigerants HFC-410A (R-410A) are considered to be the major substitutes for R-22. The vapor pressure of R-410A is about 60% higher than that of R-22. As a result, in order to achieve competitive performance relative to R-22, the modification in design is needed to the existing compressor.

2. Inverter AC VS Non Inverter AC

An Inverter is a device in the air conditioner, which controls the frequency of power supplied to compressor motor. The Compressor motor controls the rotational speed of the compressor and the compressor ensures refrigerant flow is commensurate with the cooling requirement of the room. In contrast non-inverter air conditioners which has fixed compressor that cannot increase or decrease their speed and refrigerant flow rate as per cooling requirement of the room and works only at one given capacity. The variable-speed capacity control works by means of a closed loop control system. An adjustment signal dependent on the outside and indoor temperatures as well as the set temperature is used to match the required heat load. This signal controls the frequency of the inverter, which changes the speed of the motor and thus of the compressor. As the compressor speed is reduced, the mass flow rate decreases as less refrigerant is discharged out of the compressor, adjusting the cooling capacity to match the load. But at very small loads, the variable-speed system cannot run constantly, since minimum speed constraints will restrict the operation of the machine. If the cooling capacity supplied by the system at minimum speed is still too large for the load, then the air conditioning system will cycle on/off, as in a conventional air conditioner. Thus the variable speed of the compressor ensures not only better temperature control but also reduces the power consumption.

The inverter air conditioners operate at maximum capacity on starting and consequently refrigerant flow rate is increased and the desired temperature is quickly achieved. In contrast non-inverter air conditioners has only one fixed capacity. Hence they cannot increase the refrigerant flow rate and the desired temperature takes more time to be reached compared to inverter air conditioners. In Inverter air conditioners on achieving the desired temperature the compressor speed slows and the refrigerant rate drops, hence inverter air conditioner works at lower capacity. As a result less average power is consumed. In Contrast the compressor in non-inverter air conditioners stops on reaching the desired stops and when the temperature rises again the compressor & refrigerant flow restart. This stop/start cycle continues whenever non-inverter air conditioner is in use resulting in higher power consumption.

In this manner the primary target of the review are to explore the advancement of DC inverter Air Conditioner.

3. Performance of DC Air Conditioner

The literature available on performance comparison of inverter and non inverter air conditioner is rare.

3.1 Using Variable speed Compressor

Compressor is the heart of Air Conditioner as it consumes the most power requirement. Compressor compresses the refrigerant from low pressure (low temperature) to high pressure (high temperature). This conversion raises the boiling point to higher temperature levels, facilitating elimination of the heat brought by the outdoor air. A few researchers have assessed the performance of air conditioner with constant speed and variable speed compressor.

Yurtseven *et al*. (2014) experimentally investigated inverter and non-inverter ACs in typical public offices for energy saving ratios. The study includes the comparison of constant speed air conditioners (non-inverter AC) and variable speed air conditioners (inverter AC) in two identical public office rooms. The period of test was conducted for 64 days. The author used Energy efficiency ratio (EER) for evaluating cooling efficiencies of ACs in which he got similar EER values, but energy consumption was different. The results shows that the energy saving of energy in case of inverter air conditioner was in the range 11% to 38% compared to non inverter air conditioner for a selected typical days of AC operation. The total and operational energy saving ratio for inverter to non inverter air conditioner was 21% and 25% respectively. The author also compared the total and operational energy saving ratios and the difference is due to higher stand-by energy consumption.

Zhang *et al* (2014) presented Annual performance evaluation and experimental study on variable speed compressors for room air conditioners. In this the author evaluated the co-efficient of annual performance and annual efficiency under 4 different condition namely rated cooling operation mode, half -capacity cooling operation mode, rated heating operation mode, and half-capacity heating operation mode. The author conducted a experiment on four different prototype made variable-speed compressors, in which the main difference between the prototype is the displacement volume and the four displacement volume are 7.2cm3, 8.4cm3, 9.2cm3 and 10.4cm3 respectively. the results show that the best one determined from annual efficiency is different from that of ASHRAE standard. The efficiency of compressor and dynamic pressure are different at rated and half-capacity test conditions. The Compressor running under half-capacity conditions is more energy efficient and peak phenomenon of dynamic pressure is less when compared with rated conditions. Air conditioner matching compressor is made on basis of highest annual efficiency. Therefore compressor with small displacement volume 7.2cm3 and 8.4cm3 are preferable in contrast with energy consumption and efficiency. The pressure varies almost in same manner for 4 condition. The compressor running under half capacity condition are more energy efficient than rated condition.

Chen *et al*. (2009) presented the comparative performance study of 2.8 kW capacity constant speed and variable speed air conditioner. The author found that power consumption of constant speed air conditioner was twice compared to variable speed compressor. The energy consumption of constant speed to variable speed AC, for typical period of AC operation were varies from 0.81 to 1.03 for set temperature range 20 oC to 26 oC respectively. For different set temperature, this ratio varied in the range 0.67 to 0.84 at high heat loads.

Qureshi *et al* (1998) performed a experiments to investigate the performance of positive displacement refrigeration compressors. He investigated three types of compressor namely an open-type reciprocating, a semi-hermetic reciprocating and an open-type rotary vane. The majority of air conditioning and refrigeration systems operated using reciprocating compressors. The variation of the volumetric efficiency of three compressor types with speed are also tested. The volumetric efficiency of all three compressors decreased with decreasing speed. This indicated that all three compressors had designs for maximum volumetric efficiency at the design speed, which was the maximum speed. Since an air conditioner operates at part-load for most of its lifetime, an increase in the COP for low speeds would be at desirable characteristic. The open-type reciprocating compressor showed the most gain in COP at low speeds, increasing to about 118 per cent of the nominal value. The semi-hermetic compressor showed only a 3% rise in the COP over the same speed range, whereas the rotary vane compressor cooling COP decreased slightly from the nominal value. Thus, the open-type reciprocating compressor configuration is the most suitable for variable-speed operation.

3.2 Using Evaporative Cooling Condenser

The condenser receives gas at high pressure and high temperature from the compressor. In air-cooled condensers, the metallic surfaces cool the gas which changes phase and turns to liquid. In the case of water-cooled condensers, it is the circulation of the water that produces the same cooling effect.

Sarntichartsak *et al*. (2013) conducted an experimental study on the performance of an inverter air conditioner using R-410A with evaporatively cooled condenser. The author operated the whole system with the air cooling system of evaporative condenser which is used to decrease the condenser temperature. he tested by varying the frequency range of 30 to 90 hz. The results showed that the COP is increased by 18.32% at lowest frequency and spraying rate of 200 l/h. this system tends to improve performance at lower frequency when decreasing spraying water temperature. Also higher spraying rate decreases the dry bulb temperature at cooling pad outlet because of high heat and mass transfer co-efficient and the wet bulb temperature slightly increases. Lower spraying decreases the outlet dry bulb and wet bulb temperature.

3.3 By Varying the Length of Capillary Tube

The majority of air conditioning system use capillary tube as an expansion device. Capillary tube is a long and narrow tube which connects condenser directly to the evaporator. It is a simple copper tube with inner diameter of millimeter which has a complex flow and pressure drop has great impact on performance. Pongsakorn *et al* (2007) focuses on an investigation of the proper capillary tube length for an inverter air conditioner. the author first determined the optimum refrigerant charge for four capillary tubes at full load condition by varying the mass charge from 1.1 kg to 1.9 kg. The length of capillary tube were 1.016 m, 0.914 m, 0.813 m and 0.711 m are investigated with compressor frequencies with range 30-50 Hz. The R-22 capillary tube obtains the best performance with the addition length of 1.016 m at the lowest frequency. Especially, the length of 0.813 m with R-407C is the appropriate size at the operation frequency of 30–35 Hz. The base capillary tube of 0.914 m is optimum at other frequencies.

3.4 Amount of refrigerant charge

The performance of the system is highly dependent on the refrigerant charge. The charge in the system should be adjusted to produce optimum performance for refrigerant type and capillary tube Pongsakorn *et al* (2013) also investigated the optimal refrigerant charge required with the variation in capillary length. the result concluded that the conventional system reached to maximum value of COP of 2.94, 3.12 and 3.01 with the refrigerant mass charge of 1.3,1.2 and 1.1 kg for the capillary tube length of 687mm, 787mm and 887 mm, respectively. The conventional system obtains a rate of increase in COP. For the capillary tube of longer length of 887 mm, the optimal charges are 1.1, 1.2 and 1.2 kg with the higher maximum COP of 3.86, 3.95 and 3.99 at the water temperature of 25°C, 22°C and 19 °C. the result showed that for higher capillary length, lower optimum charge can be obtained.

3.5 Natural Refrigerant as a working fluid

R-22 is the most widely used refrigerants in air conditioning system in India. Due to ODP and high GWP, it is being phased out from air conditioners. As per the Montreal Protocol it will be ban in 2020. The most promising alternatives to R-22 considered by Indian AC manufacturer are R-410A, HFC-161, HC-290, R-744 and HFC-32. Some of the system are already converted to R-410A. But GWP of R-410A is higher. HC-290 and HFC-161 is highly flammable and safety precautions are required when used in air conditioner. HC-290 is compatible with materials and it has better oil miscibility. As per ASHRAE Standard 34, HC-290 is classified as Class 3 (high flammability fluid) whereas ISO 817 and EN 378 classify HC-290 as A3 class fluid (low toxicity and high flammability). LFL of HC-290 is 0.038 kg/m3 by mass and 2.1% by volume. The flammability risk can be avoided if the HC-290 charge in the system is less that 20% of the lower flammability limit (LFL). HFC-32 has moderate GWP and mildly flammable. HC-290 has similar characteristics to R-22 so it can be used as a alternative for air conditioner.
Padalkar *et al*. (2014) experimentally investigated the performance of split air conditioner using HC-290. The author simulated the performance for cooling capacity, energy efficiency ratio (EER) and refrigerant charge. As HC-290 is highly flammable and refrigerant charge need to be reduced. In order to reduce the charge the author used two different type of condenser to reduce the charge. The author considered the performance test condition as per the Indian standard IS 1391 part 1. The author first conducted a baseline test with HCFC-22 and then the drop in test with HC-290 with optimum charge. The author again conducted HC-290 test with modified capillary length and mini channel parallel flow condenser. The result obtained is by using parallel flow condenser the cooling capacity is increased by lowering condenser saturation pressure and charge reduction also reduces. Also the EER is higher in HC-290 test than the baseline HCFC-22 test. The power consumption is also lowered using PFC than baseline test. To minimize the charge and to achieve better cooling capacity the HC-290 operated system requires small channel condenser and variable speed compressor are required.

Conclusions

Based on the various theoretical studies and experimental research works done by the researcher, it can be concluded that

1. Air conditioner operated with variable speed compressor are more energy efficient than constant speed compressor.
2. By using modified capillary tube better performance can be achieved.
3. Inverter Air conditioner using natural refrigerant (hydrocarbon) are more efficient than HCFC's and CFC's .
4. The cooling coefficient of performance increased as the operating frequency was reduced and thus an improved performance can be achieved at lower operating frequencies.
5. When AC's are operating at full-load, the conventional air conditioner is more efficient. This occurred since the inverter start-up did not result in significant energy savings when compared to the additional power required by the inverter.
6. A conventional air conditioning system always undergoes many on/off cycles, with each cycle requires high energy start-up whereas due to the softer start of the inverter, the power requirement to start up such a system is less.
7. An inverter driven AC system can offer energy savings over a conventional air conditioner when operating at part-load conditions.
8. The inverter system operates at reduced speeds during most of the on-time. At these reduced speeds, the overall power required is less than the system that were operated at fixed maximum speed under part-load conditions.
9. The annual efficiency of inverter air conditioner is much more higher than the non inverter air conditioner.
10. Inverter air conditioners are cheaper to operate and are less prone to breakdowns and the outdoor unit is normally quieter than that of conventional air conditioners.

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