A Review On Solar-Powered Refrigeration and Air Conditioning - A Renewable Alternative for The Future

Subramani Sundaram P[1], Nirutheeshwaran M[2], Nitish Narayanan[3], Surender Rangaraju[4], Amiya Bhaumik[5], Jayandaran Arumugam A[6], and Phu Le Vo[7]

[1,2,3]Department of Production Engineering, PSG College of Technology, Coimbatore, India

[4]Department of Business and Accountancy, Lincoln University College - Malaysia

[5,6]Lincoln University College, Malaysia

[7]Faculty of Environmental and Natural Resources, Ho Chi Minh City university of Technology, Vietnam

***Abstract*—** The sun is one of the largest sources of renewable energy, harnessed to fulfil our energy requirements. Being a clean form of energy the dependency on solar energy is increasing as we near the future where other forms of energy may become obsolete. Most developed countries in this era invest in renewable energy sources such as solar energy to meet their requirements. Refrigeration is one of the most widely used methods for storing temperature-sensitive products in industries and even in households, especially in hotter environmental conditions. It is most widely used to preserve food products for an extended period. As of 2018, the global refrigerator market was valued at $64.17 billion and is estimated to rise to $103.95 billion by 2026. Air conditioning is a type of refrigeration that removes the thermal energy from a physical space to reduce its temperature. An increase in the requirement for air conditioners with the rise in the need to stay comfortable in hotter conditions has been observed in recent years. Climate change is causing an unrelenting effect on India. In 2019, temperatures passed the 50 degrees' Celsius mark in the country's northern parts. Temperatures in India especially during summer over the last decade have repeatedly broken heat records, and there is no sign of respite from heat waves in the foreseeable future, making air conditioning an increasingly vital appliance in Indian homes. Increasing demand for home appliances, along with a relatively low penetration rate, has left the Indian air conditioner market with plenty of room to grow and is estimated to reach 9.7 million units in the financial year 2023. Powering air conditioners with renewable energy especially solar energy eliminates the harmful effects on the environment, making it a topic of interest. This has also led researchers to focus on renewable energy and extend its scope to the field of air conditioning and refrigeration.

***Keywords*—** Solar energy, Air conditioning, Refrigeration, Energy efficiency.

I. INTRODUCTION

With the rise in the global population level, the need for electricity has also increased exponentially. The electricity needs in India are met majorly by the non-renewable source of energy. Despite evolving technologies, infrastructure built to harness renewable energy fulfilled 40% of the energy demands of the Indian population by the year 2021(BusinessLine, 2021).

The name non-renewable energy means that the energy source will run out eventually and is not replenishable. Fossil fuels (coal and petroleum) are an example of such energy sources. The dependency on the non-renewable forms of energy leads to harmful effects on the environment and exhaustion of fossil fuels, making it a non-permanent solution for the energy requirement (Ashwani Kumara, 2010). Refrigerators and air conditioners are the electrical appliances in an average-income Indian household consuming considerable energy. Research claims that air conditioning in Indian households had consumed 42 Terawatt-hours in 2010 and 195 Terawatt-hours in 2020, and further projected at 552 Terawatt-hours in 2030.

Phenomena like the melting of glaciers and drastic climatic change have raised concerns on a global scale, making renewable and sustainable energy the most widely discussed topic in this era. In developing countries like India, facing a growing energy demand, Research is carried out in the field of clean and sustainable forms of energy and electrical appliances powered by renewable energies (Preeti H. Narnaware, 2015).

Systems integrating refrigerator and photovoltaic (PV) batteries used in the residential sector are critical, with their requirement increasing significantly. These systems face a rising potential for increased reliability, cheaper operating costs, and a longer lifespan. It is estimated that Refrigerators consume roughly 6% of worldwide electricity generation (Ahmad H.Sabry and Pin JernKer, 2021), making efficiency improvements critical to reducing greenhouse gas emissions.

The components of PV integrated refrigerator systems operated using AC and DC power sources with the direction of current flow are shown in Figures 1(a) and 1(b) respectively.

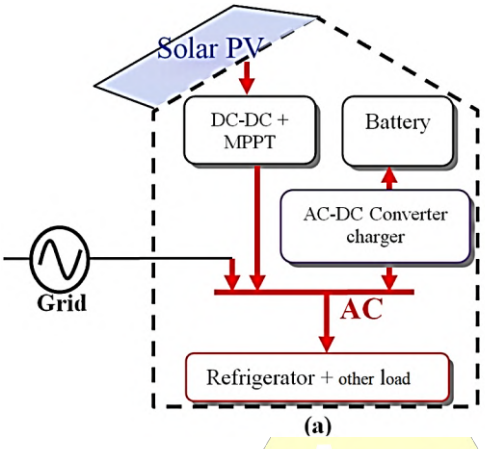

Figure 1: *The Addressed Application Of Refrigerators In The Residential Pv-Battery Storage with Ac Configuration (Ahmad H. Sabry And Pin Jernker, 2021)*

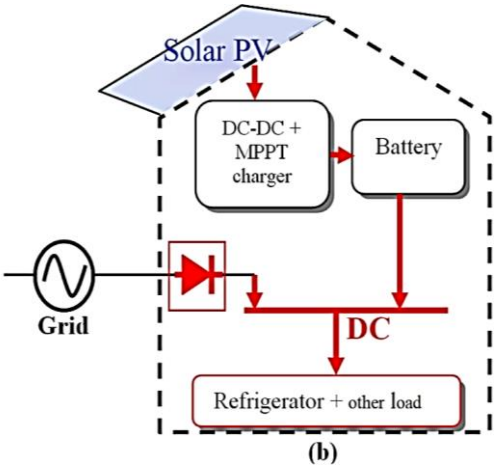

Figure 2: *Proposed Dc Configuration (Ahmad H. Sabry And Pin Jernker, 2021)*

In the PV integrated air conditioner systems shown in Figure 3, the PV array powers up the system during the daytime, while the system can also run on an AC source in the absence of sunlight. The system is connected with a DC source, acting as a backup energy source.

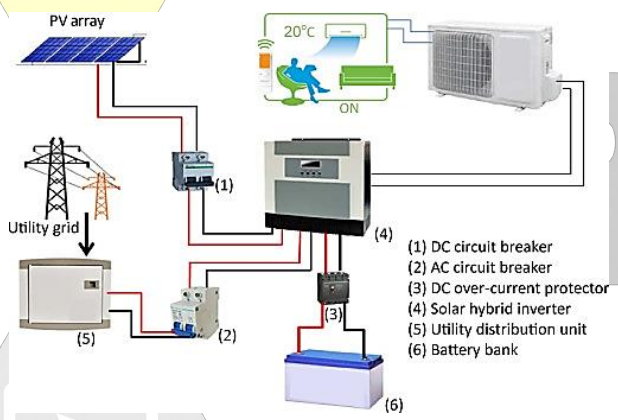

Figure 3: *Circuit of a PV-Powered Air-Conditioning System (Mohammadreza Aghaei et al., 2020)*

II. ASPECTS OF POWER CONSUMPTION IN AIR CONDITIONER AND REFRIGERATOR

The power consumption of an air conditioner or refrigerator depends on factors like size and energy efficiency and majorly depends on its usage. Size refers to the capacity of the air conditioner (often measured in tons) or refrigerator (measured in litres). Larger the capacity of the appliance, the more power it consumes. Compressor technology also heavily influences power consumption. Another major factor is the energy rating of the appliance. Presently all electrical appliances are tested and rated according to electricity usage. Refrigerators and air conditioners with more energy ratings use energy more efficiently (i.e.) consume less energy for cooling a given area than those with lower ratings. Finally, the usage comes into play, accounting for the capacity of the appliance utilized, the frequency of turning on/off the electrical appliances, and the place of utilization - commercial or residential (Jayesh Patel, 2020).

III. ENERGY SOURCES CURRENTLY USED AND THEIR DRAWBACKS

Refrigerators use electricity to remove heat from a given space and dissipate the heat to the surroundings. While an air conditioner works on the same principle but on a much larger scale. While the refrigerator cools down a limited enclosed area, an air conditioner cools down an entire room. Researchers indicate that the electricity demand for cooling appliances will continue to rise significantly since air conditioner sales are growing exponentially, especially in countries like India. A single air conditioner typically consumes about 10 - 20 times more energy compared to a ceiling fan. Fossil fuel-generated electricity fulfills most of the world's energy

needs, while only a marginal percentage of needs is fulfilled by renewable energy. Coal, petroleum, and nuclear energy are some of the non-renewable fuels used for energy generation. The risks involved in these types of energy generation include:

- The emission of CO2, CO, and other air pollutants from burning fossil fuels affects the atmosphere and is the reason for various respiratory diseases.
- Drilling is performed on the sea bed surface to pump crude oil from the underground and the extraction process disrupts wildlife habitats.
- During the transportation of the extracted oil, oil spills, urban runoffs, and natural seeps impact animals and need to be avoided.
- All these fuels exist in a finite amount on the earth's surface and cannot be replenished in a short period.

For the above reasons, it is essential to decrease the dependencies on the non-renewable forms and generated energy using renewable sources (Sheila Vieira, 2020).

IV. HARNESSING SOLAR ENERGY

One of the most popular renewable energy sources is solar energy where energy from the sun is trapped by a means and converted into electrical energy to power up electrical appliances. Solar energy is a renewable source that may be harvested directly for use in homes, offices, schools, and hospitals using a range of technologies. Photovoltaic cells and panels concentrated solar energy, and solar architecture is all examples of solar energy technologies.

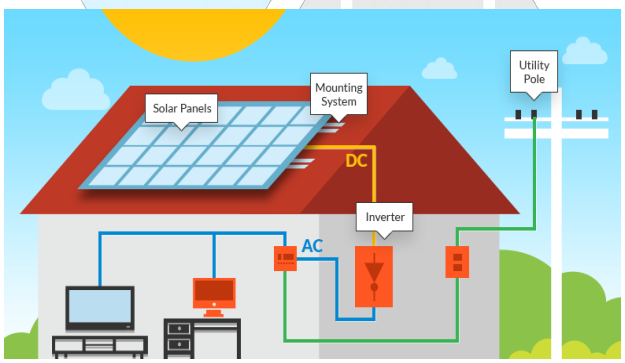

Figure 4: *Working of Photovoltaic Cells in a PV system (David Robinson, 2019)*

The most well-known method of harnessing solar energy is photovoltaics as shown in Figure 4. Solar panels, which are made up of dozens or even hundreds of solar cells, are commonly used in photovoltaic arrays. A semiconductor, usually silicon, is found in each solar cell. When a semiconductor absorbs sunlight, electrons are released. These free electrons are directed into an electric current that flows in one direction by an electrical field. The current is directed to an external energy storage device or a power station via metal contacts at the top and bottom of a solar cell. Photovoltaic cells generate Direct Current, which can be converted into Alternating current by directing current flow to an inverter. The converted AC electricity can be used to fulfill personal requirements (residential, office spaces) or can be fed into the National grid (commercial purposes) via utility poles (Andrew Turgeon and Elizabeth Morse, 2022).

V. MERITS AND DEMERITS OF SOLAR ENERGY

Merits:

- Limitless Supply, making it possible to fulfill energy demands at a larger scale.
- Generation of solar energy is possible even in difficult-to-access geographic regions.
- Pollution-free and no greenhouse gases are emitted after installation.
- Maintenance cost, in the long run, is cheaper making it preferable for residential purposes.

Demerits:

- The initial setup cost is higher due to the equipment cost.
- Solar energy generation is heavily influenced by weather patterns of the geographical area.
- For generating solar energy, a large area is required for the setup of photovoltaic cells and energy storage devices.
- There are some toxic materials and hazardous products used during the manufacturing process of the solar photovoltaic systems, which can affect the environment (Aris Vourvoulias, 2022).

VI. IMPLEMENTATION OF SOLAR-POWERED REFRIGERATION AND AIR CONDITIONING

In recent times, the decrease in the availability of conventional energy sources such as fuel-generated electricity and the substantial increase in the environmental pollution level posed by the use of such fuel has led to the widespread implementation of renewable energy sources in many countries, especially in heavily populated countries like India. Renewable energy sources, solar energy, in particular, are being utilized in many households with the government providing subsidy schemes to people for encouraging them. Solar energy is an inexhaustible source and much cleaner than conventional sources which affect the environment. The ever increasing demand for electricity

in many countries can be satisfied by utilizing this energy from the sun. Air conditioning and refrigeration are the two major energy-consuming appliances in many households in India. Solar energy can be utilized to power these appliances, reducing the dependence on conventional energy sources and preventing their harmful effects on the environment. Solar refrigeration and air conditioning can be classified into three major categories: Photovoltaic (PV) refrigeration system, Solar mechanical system and absorption refrigeration.

Out of these three systems, the Photovoltaic refrigeration system is the most widely used since it can be used for powering multiple appliances at the same time. In this system, the solar radiation from the sun is converted into consumable electricity using a PV array consisting of semiconductor cells. For example, in solar-powered refrigeration, the photovoltaic array produces DC electrical power that can be used to operate a DC motor. This DC motor is coupled to a compressor of a refrigeration system that circulates the refrigerant through a vapour compression loop which in turn reduces the temperature inside the intended space.

VII. COMPARISON BETWEEN DIFFERENT COUNTRIES

Many developing nations, including Japan, India, New Zealand, Portugal, South Korea, etc., have implemented PV solar solutions in all kinds of fields such as commercial buildings, industries and also domestic homes. People can use solar energy to cater to their needs by utilizing this renewable energy from the sun.

This reduces their dependency on conventional sources. Thus solar energy can be used to light up homes in even remote parts of the country and it can also potentially reduce the electricity consumption costs in every household. Since solar electricity is now economically competitive with traditional energy sources in the majority of states, markets for solar energy are rapidly developing across the different nations (Surender Rangaraju et al., 2021).

India

We are aware that solar energy is cost-free, clean, and less dependent on other natural resources like coal and water. The government plans to put solar panels on every household so that each one can generate its energy. India had set a goal of installing 40GW worth of solar panels on residential structures, but as of 2021, it had only installed 5GW. By 2030, the Indian government intends to deploy 280GW worth of solar panels, and 10GW per year (Nishi Chandra, 2022).

United States of America

The capacity of solar energy in the United States has increased from 0.34 GW in 2008 to an estimated 97.2 GW currently. This is sufficient to supply electricity to 18 million typical American homes. Solar photovoltaics (PV) now account for over 3% of all electricity produced in the United States.

The average price of solar PV panels has decreased by around 70% since 2014. Moreover, rooftop solar PV systems can be constructed without having a significant influence on land use, and by 2030, it is anticipated that more than one in seven households in the United States will have one (Solar Energy Technologies Office).

Japan

The nation builds many household PV systems, the majority of which are grid-connected, and is a significant producer and exporter of photovoltaics (PV). The solar irradiation in Japan ranges from 4.3 to 4.8 kWh/(m2day).

Since the nation's policy switched toward renewable energy after the Fukushima Daiichi nuclear disaster in 2011, solar power has elevated to a significant national priority. Japan added a record 6.97 GW and 9.74 GW of nominal nameplate capacity in 2013 and 2014, making it the second-largest market in the world for solar PV growth. The cumulative capacity surpassed 50 GW by the end of 2017, making it the second-largest solar PV installed capacity in the world, after China. According to estimates, installed capacity worldwide in 2016 was adequate to supply over 5% of the nation's annual electricity demand.

VIII. PROBLEMS AND SOLUTIONS FOR SOLAR PANELS

Extraction of solar energy using solar panels requires minimal maintenance, making them preferable to fulfilling residential and small-scale industry power requirements (Solar Engineering Group). Similar to all other methods of energy generation, usage of solar panels involves setbacks that need to be considered during the setup process:

Delamination and internal corrosion

The internal circuits are vulnerable to corrosion and it is necessary to prevent the exposure of the circuit components to moisture. The components of the solar panel are laminated under vacuum pressure to prevent the initiation of the corrosion process. It is also to ensure that the moisture levels in the setup environment are within the acceptable range.

Micro cracks

It is one of the common issues in solar panels and heavily impacts their efficiency. They are tiny cracks, hard to notice by the naked eye, present on the panel's reflecting surface. The major cause of this problem is due to negligence during production and also can occur due to thermal and seasonal conditions. These cracks propagate for atmospheric changes, and it is necessary to prevent them through proper quality inspection and material handling techniques.

Electrical issues

Faulty or loose wiring in the circuit's connection deteriorates the overall performance of the solar panel, affecting the power generation. Hiring a licensed electrician to resolve any electrical problems is a solution to this problem.

Hot spots

Hot spots occur when the panels are subjected to an atmospheric temperature beyond the recommended or due to overloading. This issue can affect the working of the panel, even rendering them irreparable. The causes include accumulation of dirt on the reflecting surface, and low resistance in the circuit due to poorly soldered connections, thereby affecting the efficiency and lifespan of the panel.

PID effect

Potential Induced Degradation occurs due to the potential voltage difference between the earthing and the panel. This results in the protection of only partial voltage of the specified output by the primary circuit affecting the performance efficiency of the panel. Regular maintenance of the panel carried out by trained professionals minimizes the issue**.**

Snail trail

Caused due to defective silver paste (during manufacturing) or microscopic cracks, brown lines appear on the reflecting surface of the panel. It leads to penetration of moisture particles, rendering the circuits vulnerable to oxidation and eventually corrosion. This issue can even lead to premature failure of the panels.

CONCLUSION

The use of fuels in conventional energy sources is one of the major causes of pollution such as the atmospheric release of carbon monoxide which is one of the most harmful gases in the atmosphere. India solely released 2,299 million tonnes of carbon monoxide in 2018, as per the International Energy Agency. According to this assessment, India's per-capita emissions were around 40% of the worldwide average and made about 7% of the world's total carbon dioxide load. After the 2011 Fukushima Daiichi nuclear tragedy. The Japanese government has decided to discharge radioactively tainted water into the ocean. However, many environmentalists claim that it might be detrimental to marine life. As a result, the changeover to renewable solar energy has become more prominent these days. The supply of conventional energy sources is finite and could eventually run out. To provide energy for our future generations and prevent further environmental damage, it is our top priority to look for alternate sustainable sources (Prosenjitbabaipaul, 2022). Renewable sources like solar, require no burning of fuel and therefore generally have no impact on global warming or local air pollution. Therefore, using solar energy for refrigeration and air conditioning can prove to be very beneficial for both the consumer and the environment.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to Mr Surender Rangaraju for giving us the opportunity, we would also like to extend our sincere gratitude to family members and friends for supporting us.

REFERENCES

[1] Ahmad H.Sabry, and Pin JernKer. "Energy Reports." *Improvement in energy consumption of a refrigerator within a PV system including battery storage*, vol. Volume 7, 2021. *ScienceDirect*, https://www.sciencedirect.com/science/article/pii/S2352484721000123#b31.

[2] Andrew Turgeon, and Elizabeth Morse. "Solar Energy." *National Geographic*, 2022, https://education.nationalgeographic.org/resource/solar-energy.

[3] Aris Vourvoulias. "Pros and Cons of Solar Energy." *GreenMatch*, 2022, https://www.greenmatch.co.uk/blog/2014/08/5-advantages-and-5-disadvantages-of-solar-energy.

[4] Ashwani Kumara. "Renewable energy in India: Current status and future potentials." 2010. *ResearchGate*, https://www.researchgate.net/publication/221991068_Renewable_energy_in_India_Current_status_and_future_potentials.

[5] BusinessLine. "India meets non-fossil fuel target much ahead of 2030 deadline." *The Hindu - BusinessLine*, 2021, https://www.thehindubusinessline.com/news/india-meets-target-of-producing-over-40-of-installed-

power-through-non-fossil-fuels-in-2021-against-deadline-of-2030/article38058235.ece.

[6] David Robinson. "Solar for Worthington homes: Residential PACE." *David Robinson Blog*, 2019, https://davidrobinsonblog.com/2019/09/solar-for-worthington-homes-residential-pace/.

[7] Jayesh Patel. "What Is The Power Consumption Of A Refrigerator?" *Lets Save Electricity*, 2020, https://letsavelectricity.com/power-consumption-of-a-refrigerator/.

[8] Mohammadreza Aghaei, et al. *New concepts and applications of solar PV systems*. Photovoltaic Solar Energy Conversion, 2020, https://www.sciencedirect.com/science/article/pii/B9780128196106000119.

[9] Nishi Chandra. "Solar Panel Subsidy in India, 2022." *LOOM SOLAR*, 2022, https://www.loomsolar.com/blogs/collections/solar-panel-subsidy-in-india.

[10] Preeti H. Narnaware. *Current Status And The Future Potentials Of Renewable Energy In India - A Review*. *All About Renewables*, http://www.iraj.in/journal/journal_file/journal_pdf/6-151-143471472733-38.pdf.

[11] Prosenjit Babai Paul. "Conventional Energy: Advantages and Disadvantages." *Geeks For Geeks*, 2022, https://www.geeksforgeeks.org/conventional-sources-of-energy/.

[12] Sheila Vieira. "Pros and Cons of 10 Types of Energy." *AJE Scholar*, 2020, https://www.aje.com/arc/energy-types-pros-cons.

[13] Solar Energy Technologies Office. "Solar Energy in the United States." *Office of Energy Efficiency and Renewable Energy*, https://www.energy.gov/eere/solar/solar-energy-united-states.

[14] Solar Engineering Group. "Nine Common Problems With Solar Panels." *Solar Engineering Group*, https://www.sunengis.com/nine-common-problems-with-solar-panels/

[15] Surender Rangaraju, et al. "Harvest the Sun on Water: A Review on Floating Photovoltaic Solution For Vietnam." 2021, https://www.researchgate.net/publication/349947866_Harvest_the_Sun_on_Water_A_Review_on_Floating_Photovoltaic_Solution_For_Vietnam.