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ENHANCING THE EFFICIENCY OF ENERGY STORAGE AND MANAGEMENT SYSTEMS FOR HYBRID RENEWABLE ENERGY APPLICATIONS IN TALL APARTMENT BUILDINGS

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***Abstract*—Given the current situation and projected future trends for population increase and the shortage of fossil fuels, distributed energy systems and renewable energy sources may offer a viable answer to the pressing problem of a steady and clean energy supply. Because hybrid renewable energy systems are unique, more thorough research is necessary. The purpose of this study is to evaluate the application of renewable energy sources (RES) for the provision of heat and electricity to a typical Indian household, as well as the system's cost-effectiveness. The impact of the feed-in tariff modification on the investment's value is analyzed. We look at a tiny, grid-connected hybrid system to meet the energy needs of a normal household. It consists of solar photovoltaic panels, a tiny wind turbine, and a geothermal heat pump for heating and cooling. Software called RET Screen was used to aid with system analysis. Techno-economic study results indicate that modest wind turbines are not as cost-effective to invest in as geothermal heat pumps and solar panels. In this article, we investigate the feasibility of producing a third of a high-rise building's overall energy usage. For the case study, we took into consideration a typical high-raised building that is 70 meters tall. We have suggested a hybrid system that combines the power of the sun, wind, and hydro to create electricity. Since high-rise building rooftops are typically empty, putting solar panels allows us to harness the building's solar energy. computation of potential energy production from various power sources, such as solar, wind, rain, R.O. waste water, and grey water. In our nation, numerous towering buildings have been built in various cities. Currently, coal-based power plants or other conventional power sources provide the majority of the energy needed for these buildings. These sources are more expensive and produce more greenhouse gas emissions within buildings than renewable energy sources.**

***Keywords*— Hybrid renewable energy system, photovoltaic, wind, ground- source heat pump, residential building**

I. INTRODUCTION

In the power industry, renewable energy is becoming more and more significant. By the end of 2019, it will account for around 27.3% of worldwide electricity generation, or 2588 GW. It has been accepted as a global decarbonization route toward a low-carbon energy supply and sustainable environment, particularly in vital industries like building and transportation that have large energy and carbon emissions. In Hong Kong, the transportation (16%) and power generation (70%) sectors are responsible for the majority of carbon emissions, with buildings consuming 90% of the energy produced [1]. In 2017, the residential sector accounted for 21% of Hong Kong's total energy consumption, while the transport sector accounted for 31%. Notably, the residential sector's energy and power consumption increased steadily between 2007 and 2017, rising by 15.7% and 9.6%, respectively. Therefore, the local administration has started working on aggressive objectives to reduce carbon emissions by 26–36% absolute by 2030, using 2005 as a benchmark. Accelerating the growth of renewable energy is crucial because, in 2017, it only made up 0.2% of the entire amount of power consumed locally, although 3–4% of the supply of renewable energy is planned [2]. High-rise residential buildings can now be powered by hybrid renewable energy and storage systems that combine lithium-ion battery storage, hydrogen-powered cars, and complementary solar and wind power.

Buildings are long-lasting—more than half of all commercial structures currently in use were constructed before 1970—so it's critical to choose technology that can be used to both new construction and old buildings for retrofitting. Retrofits pose specific issues, and due to the enormous amount of existing stock and its generally poorer efficiency, solutions aimed at retrofits deserve attention. These include low-cost fixes like simple, thin insulation that can be put quickly, leak detectors, tools for identifying issues with systems and equipment (such low refrigerant in air conditioners), and more effective techniques for gathering and sharing best practices. efficient maintenance and operations A building's ability to utilize less energy once occupied is influenced by well-designed energy systems and architecture. Buildings ought to be viewed as complex, linked, and interconnected systems. It should be acknowledged that different climates probably require different configurations and equipment, and that the effectiveness and utility of any individual piece of technology depend on the system into which it is integrated. Attractive lighting is influenced by a variety of factors, including window design, occupancy detectors, lighting controls, window coverings, and the efficiency of the apparatus that converts electricity into visible light. With major increases in light fixture efficiency, lighting controls will have less of an impact on net energy use. Thermal comfort and air quality One of the primary goals of building energy systems is to offer a comfortable and healthy interior environment, consuming about one-third of the energy consumed in buildings. Modern HVAC (heating, ventilation, and air conditioning) technologies increase indoor air quality, minimize unwanted temperature fluctuations, and provide more control over building systems, all of which contribute to significant efficiency gains and improved user satisfaction. There is room for improvement in the following core categories: Superb architecture, including landscaping and passive systems Improved building envelope that includes roofs, windows, and walls Improved equipment for heating, cooling, and removing humidity Enhanced sensors, control systems, and control algorithms to maximize system efficiency Enhanced thermal energy storage, which can be provided by independent equipment or integrated into the building structure The surrounding environment has an impact on both the architecture of the building and the equipment selection[3].

A. Electronics and Other Building Energy Loads

Buildings utilize approximately 36% of their energy for a variety of systems, most of which are electric. These comprise a wide range of electronic gadgets, including phones, computers, TVs, network equipment, imaging devices (including printers and multifunction devices), audio/video equipment other than displays, and telephony devices. Applications-specific commercial building systems are also provided, along with kitchen and household appliances. This category also includes chargers for electric vehicles[4]. They may not be significant now, but in the years to come, they might become so.

B. Computers and Other Electronic Devices

According to U.S. Energy Information Administration projections, energy consumption in data center servers is expected to increase fivefold by 2040, while energy consumption in other IT equipment is expected to more than quadruple. Approximately 6% of the energy used in buildings is used by computers and other electronic equipment. The remarkable growth of computers and other electronic devices has been fueled by fundamental advances in hardware and software, which have been made possible by federal research investments. Nonetheless, corporate research investments have financed the majority of applied research projects. This has led to ongoing advancements in the functionalities and financial savings of computers, displays, imaging equipment (such as printers), communications devices (such as network equipment, telephony, and settop boxes), and other audio/video equipment. There are still a lot of chances to get better[5].

C. Major Energy Consuming Appliances

Refrigerators, clothes dryers, and hot water heaters Around 18% of the energy used in buildings is accounted for by large energy consumers such as clothes dryers, refrigerators, and water heaters. These appliances' efficiency can be raised by utilizing many of the same technologies that were previously addressed and intended to enhance the energy performance of the entire building. For example, water heating efficiency can be boosted utilizing current heat pumps, low-cost variable-speed motors, thin insulation, and other better designs. Long hot water distribution lines in homes and businesses can lose heat; this can be minimized with better insulation and other techniques. Water heaters with storage tanks are great options for load shifting and other services that are essential to maximizing the efficiency of electric utilities, thanks to improved controls and communications technologies. Verifying that these techniques are designed for the size ranges needed for appliances is often important. Significant improvements in refrigerator performance have been made over the last few decades, however the increasing number of refrigerators and freezers used per home has somewhat offset these improvements. Significant performance enhancements can emerge from advancements in heat exchangers, sophisticated thermal cycles, heat pumps, and thin, highly-insulating materials (such as vacuum insulation). Compressors made especially for freezer and refrigerator sections, variable speed drives, innovative sensors, and controls that can sense the outside temperature and react to utility signals can all help save even more money [6].

D. Buildings using solar systems

Passive solar design is the process of applying a building's form and shell to accept, store, and transfer energy from renewable sources that are suitable for buildings. Passive systems don't use mechanical or electrical equipment to heat, cool, or light buildings; instead, they use solar energy and fresh air.

1) Passive heating

The most typical application for passive heating systems is in passive solar architecture. It is feasible to optimize the use of solar energy for solar heat during the winter months by using design applications for passive solar systems. The primary idea behind using solar energy for heating is to maximize the use of solar radiation in the construction of the building's exterior (the floor, walls, and roof are all strongly insulated). Three essential aspects are used in the software.What they are are distributors, retailers, and collectors[7].

2) Natural lighting

17 percent of the energy used worldwide is used for lighting. With the right design, solar energy may provide 70% of the lighting needs. Typically, this ratio is 25% in constructions. By utilizing daylight as much as possible to illuminate spaces in buildings in accordance with criteria for visual comfort, it is feasible to reduce the requirement for artificial lighting. It enables buildings to operate with decreased energy consumption [8]. The easiest method to get natural lighting is to make use of the building's exterior apertures that are still sufficiently large. The traditional house plans below have window patterns that let in plenty of natural light.

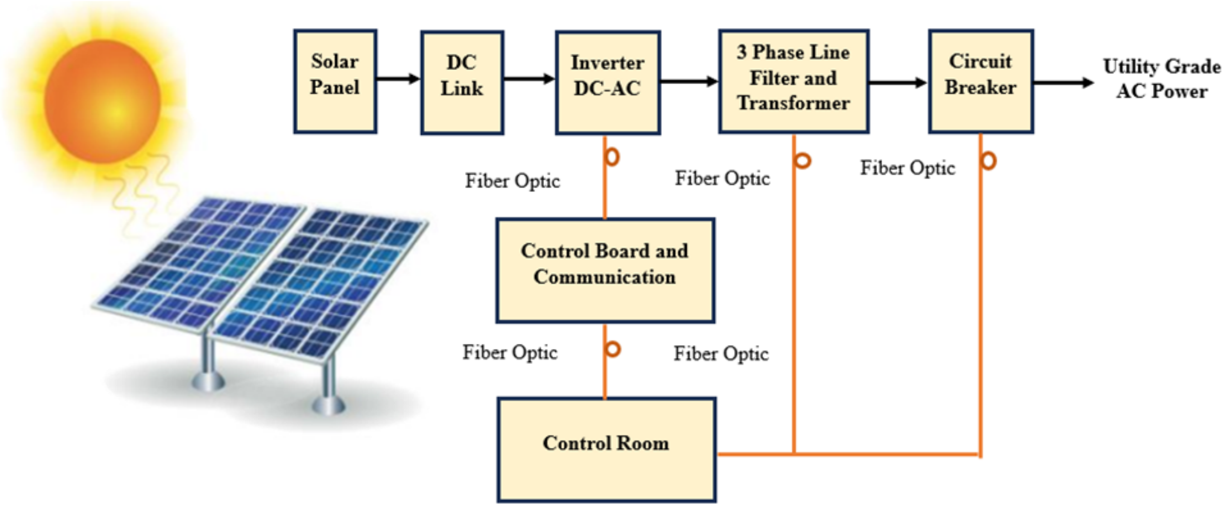

Fig. 1. Solar Power Generation System

II. LITERATURE REVIEW

By providing relevant surveys and reviews in this section, we hope to provide the reader with a comprehensive grasp of the subject of energy management systems in residential, commercial, and educational facilities. To learn about the fundamental technological, computational, and architectural elements of an energy management system as well as general approaches to energy efficiency, one could study the work of De Paola et al. (2014)[9]. Lin et al. (2017)[10] suggested a more abstract design for IoT-based systems, consisting of three layers: a Perception layer, a Network layer, and an Application layer. Leitao et al. (2020)[11] provided a similar architecture that also includes smart appliances. Boodi and colleagues (2018)[12] looked at models of building energy, which included gray, black, and white boxes. Additionally, they conducted a comparative analysis of the variables that most influence energy consumption. A survey was conducted by Himeur et al. (2020)[13] using information from several databases, including building power consumption. Numerous characteristics were compared and examined, such as sample rate, location, number of houses under observation, and others. This study team also introduced a fresh dataset for power usage anomaly identification. The training and testing of models that seek to identify abnormalities in order to minimize energy waste will benefit greatly from the availability of such a dataset. Lastly, they conducted a study of recent developments and fresh viewpoints in the field of energy consumption system anomaly detection.

IEMS deliver AmI at the environment when they are installed. Depending on the features that are included, there are many definitions of AmI, according to Cook et al. (2009). These settings have advantages for the environment, comfort, safety, and finances. The phrase "AI-augmented interface" (AmI) also refers to technologies that are integrated into a physical environment to produce an unseen user interface. They referred to the most recent AI techniques and implementation methodologies while providing a thorough overview of ambient intelligence (AmI) and ambient assistive living (AAL)[14].

III. METHODOLOGY AND PROCEDURE OF WORK

A. Solar PV Cell

For the case study, two major cities—Delhi and Mumbai—have been taken into consideration. The monthly solar incident radiation for Delhi and Mumbai has been taken into consideration using data from NASA Surface and Solar Energy.Solar panels can be tilted to face the sun's rays during the day, which increases their net power output. It turns out that Delhi has a 28º tilt and Mumbai has an 18º tilt. Additionally, space should be left between two matching arrays of panels to accommodate shadows that might otherwise fall on the following array, reducing the panels' efficacy.

B. Specification of Solar Panel

Solar cell data and specification are taken from SRM Manufacturer China.

Efficiency Ƞ = 19-20% [30]

We take 19% (minimum)

Capacity of 1 panel = 250 Watt
Total pieces to be used = 320

Capacity of Solar panel PV System = 250 Watt
320 = 80 kW
Size of one piece = 1.650* 0.992 * 0.045
Aeff = 320 * 1.650 * 0.922 = 523.776 m

Performance Ratio = Usually 0.75 for mono-crystalline cell
Solar Panel tilt = 18° (Fixed for cost optimization)
Total Roof Top Area covered by Solar Panel = $A_{roof} = 1.90 \times A_{eff}$
Due to panel arrangement , shades and tilt more area is required.
So A_{roof} = 1000 m2 (66.67 % of roof area)

C. RO & Grey water power generation

Water is essential to the human body's mechanics. In actuality, water is essential to the operation of every cell and organ that makes up our complete anatomy and physiology. Humans would perish in a matter of days without water, which makes up more than two thirds of the body weight. Human blood comprises 82%, brain 95% water, and lungs 90% water. Merely a 2% reduction in our body's water content can cause symptoms of dehydration, such as foggy short-term memory, difficulties with simple calculations, and issues focusing on smaller type, such that on a computer screen. According to the Institute of Medicine, a man's appropriate intake (AI) of liquids should be approximately 13 cups (3 liters). By eliminating all of the salts from the water, the RO water filter fulfills its purpose of cleaning drinking water. This covers all hazardous substances that have the potential to seriously harm human health, such as arsenic, mercury, heavy metals, nitrates, etc. Important minerals are also eliminated from the water during the process of eliminating the toxic compounds. When you weigh the advantages of knowing that your water is free of all harmful chemicals, the loss of these vital minerals seems small. As a result, some RO water purifiers feature a cartridge known as a re-mineralizer cartridge that the clean RO water travels through and is filled with important mineral salts of calcium and magnesium that have been refined.

D. Calculations for RO water

Pump efficiency of 7.5kW pump,

$\eta_p = wQH/P = 9.81*1000*0.014*50/7500 = 0.9156$

Taking into account every loss, let the η_p be around 70%. In his work, H. Nautiyal compiled a number of PAT techniques. It is possible to establish the turbine parameters, such as effective head or discharge, under which the pump will operate in turbine mode by using Sharma's performance prediction approach for PAT, which uses BEP as the criterion.

Head ratio $H_t/H_p = 1/\eta_p$
1.2 $H_t = H_p/\eta_p$
1.2=50/0.701.2 = 76.7 m

Discharge ratio $Q_t/Q_p = 1/\eta_p$
0.8 $Q_t = Q_p/\eta_p$ 0.8 =0.014/0.70.8 = 0.0186 m3 /s
It is to be noticed that working head and discharge will always be lower than these. Therefore discharge (Q) is taken to be .015 m3 /s
Volume of collected water/day, V= 18 m3
Time taken to empty the tank = V/Q = 18/0.015=1200 s
Available head for RO power generation = 35 m (since RO collection tank is on th 11th floor)
Generated Power, $P_t = wQH = 9.81*1000*0.015*35 = 5.1503$ kW
Assuming spur gear efficiency in gearbox, ($\eta_{g.b.}$) = .94, generator efficiency(η_g.) =.97
Thus $P_o = \eta_{g.b.} * \eta_g = .97*.94*P_t = 5.03$kVA
Total Energy generated = 5.03*1200/3600 = 1.68 kWh/day

E. Rainwater power generation

Between 1990 and 2011, India's primary energy consumption more than doubled to approximately 25,000 PJ. India faces difficulties meeting growing demand because of its reliance on imported energy supplies and the patchy reform of the energy industry. India is expected to increase its energy production by 117% and its consumption by 128% by 2035, according to the 2015 edition of BP's Energy Outlook. The process of collecting and depositing rainwater for on-site reuse as opposed to letting it run off is known as rainwater harvesting. Water for gardens, cattle, irrigation, domestic usage after appropriate treatment, indoor heating for homes, and other applications are among its uses. In many locations, the collected water is simply directed into a deep pit where it percolates. In addition to being utilized for storage and other purposes like irrigation, the harvested water can be drunk. When gathered on the top of a tall building, this water can be efficiently used to generate energy through the use of a ground floor turbine or, if necessary, an underground setup. This Micro Hydro Electric plant's efficiency can then be computed using the net effective head and discharge, or total available water. Figure 2 displays a schematic design of the suggested system. Utilizing PAT for generating also becomes cost-effective because the same PAT is employed. Additionally, there are two scenarios that could occur: either power is generated simultaneously with rainfall, or rainwater is stored in an overhead tank and power is generated later. Based on our observations, the first one appears to be more effective. This water can be used for more beneficial uses besides producing power, such as replenishing the groundwater table, preventing flooding, supplying water for emergencies like firefighting, or for less important tasks like car washing or cleaning.

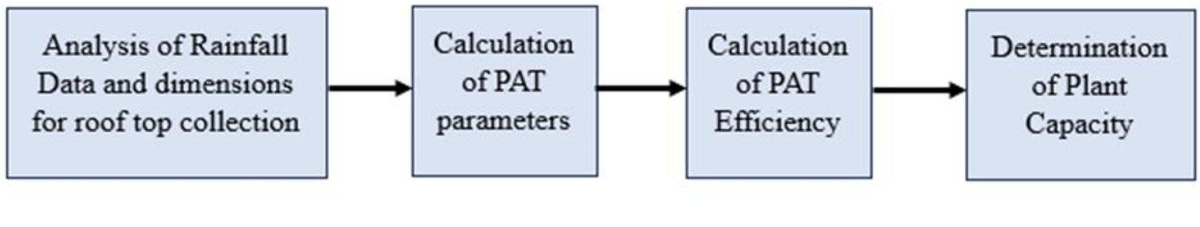

Fig. 2. Proposed process of harnessing energy from rainwater

IV. RESULTS AND DISCUSSION

The hybrid system's intended use is to maximize a building's renewable energy potential. Typically, these systems use two or more energy sources. By examining a variety of data from Delhi and Mumbai, two of India's largest cities, the study validates the usefulness and economic viability of solar, wind, and hydro energy systems. Figure 3 compares the power generation available from different renewable sources. It should be noted that as a single PAT is being used to generate electricity from greywater, rainwater, and RO waste water together, they have all been grouped together under one hydropower unit.

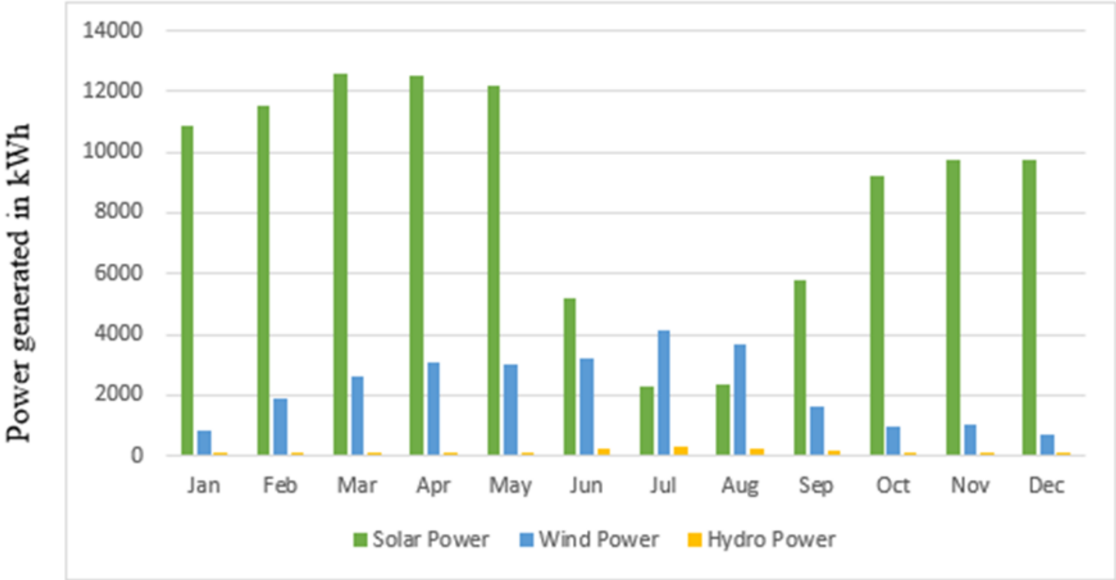

Fig. 3. Comparison of estimated power generation by various sources (Mumbai)

The hybrid solar-wind-hydro (HSWH) system is beneficial since it produces electricity all year round. Climate change causes variations in solar energy, but at the same time, wind energy makes up for the loss of solar energy because we receive more wind power on overcast or windy days than on typical ones. Rainy-season electricity generation can make up for the significant drop in solar and wind power by using collected rainwater collected in a rooftop collection tank. Figure 4 illustrates how 79% of the power in a 20-story high-rise building in Mumbai is generated by solar energy. As a result, the current research employs a novel approach that is supported by a theoretical formulation that effectively takes into account a range of geographic variables. We propose to use the refuse generated by RO water in addition to grey water. Urban areas require the usage of water purifiers, and drinking and cooking water must be purified. Therefore, by using the R.O. waste water, additional little power is continuously produced by R.O. waste throughout the year. It should be noted that, depending on the availability of the input water source, a single PAT is used with varying input water sources. Additionally, when a pump in turbine mode is employed, mass production won't be problematic because such a pump is already on the market. Moreover, the suggested hybrid system seeks to improve cost effectiveness.

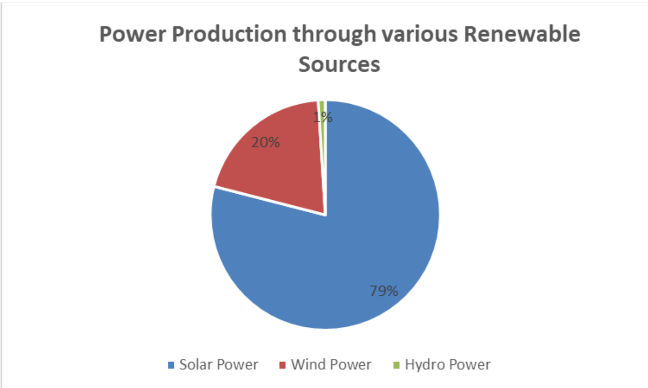

Fig. 4. Power production through various renewable sources

V. CONCLUSION

A significant amount of the energy used in the region and worldwide is produced by buildings. Maintaining a comfortable facility requires a lot of energy, particularly when the building is being used. Fossil fuel usage rises as a result of the increasing proportion of energy-consuming buildings. Consequently, the environmental issues associated with energy use are also growing. On the other hand, structures that are designed to use renewable energy sources can be made in either an active or passive manner. It goes without saying that installing renewable energy sources in buildings will benefit the economy and the environment. We concluded from the case study of Delhi and Mumbai, two major Indian cities, that Mumbai had significantly more wind energy potential than Delhi. Hydro (R.O. waste and grey water) and solar-PV are suitable for both locations; however, since rainfall occurs only for two or three months and Mumbai receives more rain than Delhi, Mumbai is a more favorable location for installing hybrid energy systems due to the abundance of solar, hydro, and wind potential, while solar PV is most appropriate in Delhi.

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