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Fuel Cell and Renewable Sources of Power Generation-A Review

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Abstract. The requirement of electricity is increases day by day due to the increased population and growing economy. Major portion of electricity is still produced from the fossil fuel-based power plants. These plants are emitting harmful gases into the environment like carbon monoxide, carbon dioxide, oxides of nitrogen, oxides of Sulphur, particulate matter, etc. There are two major sources responsible for green house effects viz. Transportation sector and power sector. It has been estimated that the electricity requirement would be increased from 25,883.46 trillion Watthour to 44,247.26 trillion Watthour during 2020 to 2050. For the fulfillment of electricity requirement without emitting harmful emissions and greenhouse gases, attention should be more focused on renewable power plants. The efficiency of various renewable sources like hydro, solar, wind, geothermal and fuel cell are 60%, 20%, 36.4%, 30% and 60% respectively. Solid oxide fuel cell has emerged as a decent option with 60-65% efficiency as standalone system while as hybrid/combined system the efficiency can reach as high as 90-95% without producing any major emissions.

1. INTRODUCTION

In the last few decades due to the speedy growth of industrialization, transportation sector and population, power requirement has increased to its highest level of all times. The utilization of fossil fuels cause rise in greenhouse gases (GHG) and creating problems to both human and environment like global heating, retreating ice, and record sea level rise. According to the World Meteorological Organization, 2019, the average temperature of earth between January to October, 2019 was risen by about 1.1°C since pre-industrial period [1]. In recent years, it has been a common concern and biggest challenge for all to find some safe, affordable, highly efficient, low maintenance, long-term high- power range renewable energy source in power generation to fulfil the current energy requirement. According to IEA report, 2019, the global energy consumption between 2018 and 2050 will increase by 50%. Currently due to the use of non-renewable power plants like coal, gas, IC engine and nuclear power plants, high emissions are increasing ever more greenhouse gases which ultimately provoke many hazardous changes in the atmosphere. So, there is an urgent need to move towards other sustainable and renewable power plants such as hydro, solar, wind, geothermal and fuel cell power plants [2]. The European commission have decided that by 2050 they will reduce GHG emissions to 80- 90% below 1990 level [3]. For this they are going to invest heavily in solar and wind power plants [4]. In this regard, government of Sweden targets 2040 for 100% electricity production from renewable sources. Similarly, Brazil is one of the countries that produces its more than 71% of electricity from renewable sources like hydroelectric, wind and solar power plants while only 29% by non-renewable thermal power plants [5]. Meanwhile, Sweden has been announced their official goal that by 2040 they would produce 100% renewable electricity [6].

Along with the progressive use of renewable power sources there are some other methods that can be used as hybrid systems. A few of them are combined heating power (CHP), combined cooling heating power (CCHP), organic Rankine cycle (ORC), Kalina cycle, energy storage, etc. These methods can possibly increase the efficiency and meet rising power demand along with renewable sources by recovering waste heat and energy. These types of combined systems are very useful in water heating, space heating, industrial heating, defrost applications, water desalination, etc. [7,8]. The electric power producing systems can be majorly classified into two categories viz. Non-renewable and renewable systems. Today countries like India with continuously growing economy and large population have a huge energy demand to fulfil. In the coming decades they need more clean, reliable and efficient renewable power sources. Currently, in India the power production heavily relying on non-renewable sources which are 64.85% of total power generated, these sources are the major cause of GHG and other hazardous emissions like

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NOx, SOx, PM10, CO, and heavy metals [9]. The Non-renewable power producing systems include coal, IC engine, gas turbine and nuclear power plants.

According to the report of IEA, 2019 [10], the electricity was generated majorly by petroleum, nuclear, coal, natural gas and renewable sources. It is expected to be in year 2020 electricity production by petroleum is 633.30 trillion-kilowatt hour (tkWh), by nuclear fuel is 2708.53 tkWh, by coal is 8498.92 tkWh, by natural gas is 5911.76 tkWh and by renewable sources is 8130.95 tkWh. It is expected to be in year 2050, electricity production by petroleum is reduced to 165.24 tkWh, whereas it is expected to be increased by nuclear fuel is 3575.67 tkWh, by coal is 9595.91 tkWh, by natural gas is 9254.54 tkWh and by renewable sources is 21655.90 tkWh. The share of net electricity generation in world by renewable sources like hydro. Wind, solar, geothermal and other sources are also presented. It is to be expected according to the available data that in year 2020 electricity production by hydro 4701.84 tkWh, by wind 1726.12 tkWh, by solar 1298.25 tkWh, by geothermal 81.41 tkWh and by others sources 323.31 tkWh. It is expected that in year 2050, electricity production would be increased by hydro 5989.30 tkWh, by wind 6707.87 tkWh, by solar 8331.10 tkWh, by geothermal 235.56 tkWh and by others sources 392.05 tkWh.

According to the report of the Ministry of Power, India (MOP) 2021, the net electricity generation in India by different sources in megawatts (MW) are as follows: Coal 209424.5 MW, Gas 24924.01 MW, Diesel 509.71 MW, Nuclear 6780 MW, Hydro 46367.22 MW, renewable sources 98882.72 MW. The share of these sources is coal 54.13%, gas 6.44%, diesel 0.13%, nuclear power 1.75%, hydro 11.98% and renewable sources 25.55% [11]. India has a great potential to generate more than 1000 GW from various renewable sources viz. minor hydro 20 GW, biomass power 25GW, wind energy 302GW and solar energy 748.99 GW, using around 3% wasteland [12]. The renewable power producing systems include hydro power plant, solar power plants, wind power plants, geothermal power plants and fuel cell power plants. These power plants are discussed in section 3 one by one on the basis of efficiency, emissions and their current situation.

2. NON-RENEWABLE POWER PLANTS

2.1. Coal power plant

India produces 209424.5 MW of electricity from the coal power plants which is its 54.13% of total electricity. There are different countries which for their electric power generation heavily rely on coal viz. Greece 43%, Germany 44%, Bulgaria 46%, Czech Republic 49%, China 75%, Estonia 77%, Poland 79% [13]. Typically, the conventional power plants have efficiency generally below 40% as large quantity of heat is rejected through different modes. These power plants also cause water pollution due to heavy metals like arsenic, lead, mercury, selenium etc. and air pollution majorly consisting of CO_2, SO_2, NO, PM, fly ash etc. If this waste heat could be utilized with CHP systems the total efficiency of the plants can may be enhanced to about 85% [14].

2.2. Nuclear power plant

India produces 6780 MW of electricity from the nuclear power plants which is 1.75% of the total electricity generated. Nuclear power plants do not produce carbon-based emissions so considered as clean source. Uranium-238 is mostly used as fuel and a small amount of fuel give a huge amount of energy. But any leakage of nuclear material from the nuclear power plant into the atmosphere results in radioactive pollution and causes damage to human and environment lasting for more than 30 years [15]. After the two major accidents happened at Chernobyl nuclear power plant on 26 April, 1986 and Fukushima nuclear power plant on 11 March, 2011 people all over the world start objecting and opposing nuclear power plants [16]. Various countries like the United States, Germany, Japan, Belgium, and Switzerland decided to decommission these power plants due the high investment cost, reactor accident, perception of radiation risk, concerns about the disposal of spent fuel, proliferation risk, political pressure, social acceptance etc. [17,18].

2.3. Gas turbine power plant

India produces 24924.01 MW of electricity from the gas turbine power plants which is its 6.44% of total electricity. Gas turbine plants standalone efficiency is 34.10 %, but the gas turbines are producing a fair amount of pollution majorly consisting of NOx, CO, CO_2 etc. [19]. Gas turbine hybrid system by utilizing some bottoming cycles such as Rankine cycle can reach to thermal efficiency as high as 60% [20]. Hence, it is treated as the most advanced technology as compared to other fossil fuel-based power plants. For power generation currently hybrid gas turbine power plants are being used which are least pollution emitting and most efficient systems [19].

2.4. Internal combustion power plant

IC engine is very old and conventional prime movers that can be used with cogeneration systems providing various advantages like simple operation, simple settings and low maintenance cost. But due to some disadvantages like high fuel consumption, low thermal efficiency, high engine emission production including NOx, PM, CO, HC, etc., and high level of noise generation these power producing systems are now becoming outdated and are not being used in large quantity but still used as small power backup plants in various applications like residential and industrial areas [21]. The efficiency of standalone ICE was 30% but with the combined system its efficiency can reach to about 38% [22]. A 300 MW CI engine with ORC results in overall fuel to electrical energy efficiency from up to 46.2% of the plant [5]. India produces 509.71 MW of electricity from IC engine power plant which is its 0.13% of total electricity.

3. RENEWABLE POWER PLANTS

3.1. Hydro power plant

Hydropower has several advantages like high efficiency (about 60–80%), long-life equipment, low operating and maintenance costs, no pollution and greenhouse gas emissions [23]. Many countries like Japan, US, China and Russia are using Pumped Storage (PS) power plants widely. Total 140 GW capacity PS power plant are used in entire world by 2019 and are estimated to grow every year. Japan has already planned 40 PS power projects to increase the capacity up to 50 GW [24]. But it also has some disadvantages like higher initial investment, long construction period, impact on water availability due to climatic changes, water flow rates variation throughout the year and cannot be constructed near to the load centres in most cases. Thus, further development is limited by economic, social, political, environmental, historical and regulatory issues of Small Hydro power technology [2, 23]. India produces 46367.22 MW of electricity from hydro power plant which is its 11.98% of total electricity.

3.2. Solar power plant

India produces 43940.12 MW of electricity from the solar power plants which is its 11.35% of total electricity. Solar energy is available in large quantity that can be harnessed to full fill the electricity requirement. From last decade use of solar energy is increased rapidly worldwide as a clean source of power supply. But the commercially available solar cells productivity can be affected by various reasons like geographic location and meteorological circumstances, temperature, solar intensity, dust, wind speed, day light hours, latitude, elevation, precipitation, etc. [25]. Further different systems like battery, converters, charge controller etc., also are required to get proper amount of electricity in different situations which further reduces the efficiency of the PV System. The life of a PV system is between 20- 25 years. So, to increase the reliability of PV technology there is a need to improve the module and other parts efficiency. Currently the efficiency of solar cells available commercially lies between 12 and 25% [8, 26, 27]. All these factors are affecting the safe, stable operation and restrict the operation of a large-scale PV and solar power plants. Total 19 factors which acts as barrier in the development of large solar power plants as alone or in combination with other systems have been identified but with more focused policies by the government it can be easily available at reduced cost [28].

3.3. Wind power plant

Wind energy is broadly distributed, perpetual, replenished, clean and economical. India produces 39588.85 MW of electricity from wind power plant which is its 10.23% of total electricity. Several researches have been carried out to simulate and evaluate stand alone or hybrid wind farms from the environmental, economic and technological point

of views [29]. Efficiency of a wind power plant is around 36.4% as standalone [25]. One of the greatest disadvantages of replacing power plants like nuclear with renewable source like wind is that it requires 5 times more space and around 3 wind power plants. Even after the various problems and restrictions encountered with the solar and wind power plants various countries like the U.S., India, China and Europe has projects to develop more and more PV solar and wind energy power plants which probably accounts more than 70% by 2050 [9]**.** Wind power plants capacity has been increased by 10 times in last decade. Many countries like USA, China, Germany, India, Denmark, Spain etc., are using wind energy to produce electricity. Total installed capacity is around 432 GW for all wind power plants across the globe in year 2016 and by year 2035 China, U.S. and European union has been planning to build 645 GW and 500 GW wind power plant respectively [30].

3.4. Geothermal power plant

The advantage of geothermal energy over solar and wind energy is that it is available year-long without higher variability and intermittence and can be found around the globe. The first ever geothermal power plant with a capacity of 10 kW was built in 1904 at Larderello, Italy. Geothermal plant has a 13.6% net heat-to-electric conversion efficiency when the geothermal brine was cooled down to 70 °C [14]. The geological survey of India estimates about 10 GW of geothermal power potential and could be used in near future. Currently India does not have any geothermal power plant. The total installed capacity of geothermal power plants all around the world was 12283.90 MWe in 2015, it increased up to 15950.46 MWe in 2020 and are forecasted according to the available data to reached at 19331.01 MWe by 2025. So, there is a very limited growth in geothermal energy and also only limited countries have geothermal sites [31].

3.5. Fuel cell

Fuel cells have been getting more and more attention of researchers and industries since last decade and have been considered as a clean, highly efficient renewable power producing sources with the life of around 40,000 hours [32]. The fuel cells can be used as standalone or as a hybrid system by combining it with other cycles such as CHP, CCHP, gas turbine and heat engines. Fuel cell have a wide range of application from automobile to stationary power plant and have been commercially used. Solid oxide fuel cells (SOFC) and Polymer electrolyte membrane fuel cells (PEMFC) are mostly used among the different types of fuel cell available. The PEMFC is generally used for automobiles due to its low operating temperature and SOFC are generally used for power production due to its high operating temperature. SOFC due to high temperature can be used as hybrid systems by coupling it with CHP, CCHP, Gas turbine etc. to utilize the waste gases and heat for additional power generation, heating purpose and for higher efficiencies above 90%. Fuel cell operation also does not affect by weather conditions like solar and wind systems.

Table 1: *Main characteristics of hydrogen fuel cells.*

Type	Electrolyte	Operating temperature (ºC)	Fuel/ Oxidant	Fuel cell efficiency (%)	Application
AFC	KOH solution, Alkaline polymer	50-200	Pure H_2/ O_2 in air	50-60	Transportation, portable and backup power, Space crafts
PEMFC	Nafion cation-exchange membranes, hydrogen ions	50-180	Pure H_2/ O_2 in air	40-50	Transportation, emergency services, residential and commercial
PAFC	Phosphoric acid, hydrogen ions	100-220	Pure H_2/ O_2 in air	40-55	Transportation, distributed power generation, Commercial cogeneration
MCFC	Molten Li_2CO_3/K_2CO_3, $LiAlO_2$ as matrix	550-800	H_2, CO, hydrocarbons / O_2 in air	45-55	Power plants, Transportation, industries
SOFC	Yttria stabilized zirconia (YSZ)	500-1200	H_2, CO, hydrocarbons / O_2 in air	55-65	Power plants, residential, industries, cogeneration

So, due to all these advantages fuel cell power plants being a good alternate in future for electric power generation. The fuel cell industries are growing very rapidly in the field of power generation and soon in coming decade a large amount of electric power will be generated by fuel cell power plants [33, 34]. Currently India is in the development stage in the field of fuel cell power plant, but developed and demonstrate some prototypes in the automobile sector. The classification of fuel cell and their efficiencies are listed in table 1 [32, 35].

The fuel required for the working of the fuel cells is either pure hydrogen or methane rich gas. Natural gas can be used as fuel in SOFC because of internal reforming it converts a methane rich gas into hydrogen at high operating temperature. In case pure hydrogen needed as fuel it can be produced from a number of sources like electrolysis converting water into hydrogen. One such method is suggested by modelling of a photovoltaic-wind hybrid power plant using Homer software producing 3,153,762 kWh of electricity and 31,680 kg of hydrogen annually [36]. So, it can estimate that the use of fuel cell power in both transportation and stationary power plant is going to increased heavily in coming decades [9]. Table 2 shows the comparison of different power producing systems.

Table 2: *Comparison of different types of power plant.*

Type	Power plant	Efficiency (%)	Reference
Non-renewable	Coal power plant	40	[34]
	Nuclear power plant	21	[37]
	Internal combustion engines	30-35	[34]
	Gas turbines	34.10	[19]
Renewable	Hydro power	60-80	[24, 38]
	Solar cell	12-20	[8, 27, 28, 39]
	Wind	15.76	[39]
	Geothermal	13.6	[14]
	Fuel cell	40-60	[34]

3.5.1 Current trends, Challenges and Future of SOFC

The SOFC has many advantages, some of them are fuel flexibility, quiet operation, inexpensive material used, solid electrolyte, reliable, pollution free, low operating and maintenance cost etc. Due to these advantages a large number of SOFC power plants has been installed in the previous decade in various multinational companies like Apple, Samsung, Pfizer Inc, etc. Numerous countries like Canada, the U.S., Japan, South Korea, and Europe has already installed large number of fuel cell power plants. The growth of fuel cell have increased from 185.4 MW in 2014 to 658.6 MW in 2017 [33, 34]. There are many hybrid systems are proposed in a combination of SOFC with different cycles such as Bryton cycle, air reheating, Rankine cycle, absorption refrigeration cycle, PEMFC, biomass gasification, and many more. Most of these hybrid systems are proposed on theoretical basis and these hybrid power plants are still need to prove in actual practical mode [40]. Even after many advantages and promises posed by SOFC, the growth of SOFC power plants is very slow and still not used in very high number as expected. There are certain factor/challenges which encountered with the SOFC which need to address for the large-scale commercialization of fuel cells. The major challenges need more intense research are summarized below [40, 41, 42]:

1. High Cost: - The cost of fuel cell is still much higher as compared to the other conventional systems.
2. Diagnostic, safety and control system: - For practical operating conditions safety measures, controlling systems and diagnostic issues are need to ensured.
3. Hydrogen production: - The main fuel for fuel cell to operate is hydrogen but its production is still difficult and has major barriers that includes large scale production, storage, transportation and higher cost.
4. Advanced turbine system: - Turbine performance need to be enhanced to achieve a lower emissions and higher efficiency.
5. Operating temperature: - The operating temperature of SOFC is quite high between 750-1000 ºC. More deep and intense research is required to lower the operating temperature of SOFC below 600°C and to find suitable materials without affecting its efficiency and performance.

6. Fuel flexibility: - SOFC are fuel flexible in the sense that any kind of methane or carbon-based fuel can be used. But till now only natural gas is effectively used after reforming process to produce hydrogen. Other fuels like biogas, etc. creates problem for the effective working of SOFC, so it needs more research so that any kind of fuel available can be used cost effectively.
7. Nano-materials: - The application and integration of nanomaterial in the SOFC can be drastically change the performance to the next level. This is an emerging field which need more attention and it can be able to solve many problems related to the SOFC performance.

4. CONCLUSION

This paper discusses about the various types of power plant used for production of electricity including renewable and non-renewable sources. The growth of renewable power sources has been increasing day by day due to its clean energy production advantage, yet they have low efficiency but they do not harm human and environment. The fuel cell technology is speedily growing along with other renewable sources like solar and wind. Fuel cell is an excellent option for electricity generation. SOFC are mostly used for stationary power plants while PEMFC are used for transportation. Fuel cell working is independent of season, geographical and environmental condition like most of the renewable source does. Thus, fuel cell power plants are a reliable option all-time all-round year for power generation in all whether conditions. The total capacity of the fuel cells has been increased every year. This shows that in coming decades fuel cells and fuel cell-based power plants will became one of major clean, efficient and renewable electricity production systems. A lot of research and studies has been done in the field of fuel cell especially PEMFC and SOFC. Researchers have investigated the performance of different SOFC materials, performance of SOFC on different types of fuels and different types of hybrid systems have been proposed. Even after many efforts performed by researchers and scientists, more intense research would be required to eliminate different problems encountered in fuel cells. The important observations found in this study are summarized below:

- SOFC provides high efficiency more than 60% as standalone and 90-95% as hybrid system.
- Fuel cell do not produce any direct pollution but its pollution creating tendency depends upon the production of its fuel.
- Life of the SOFC is about 40,000 h, which is much less as compared to the other conventional and non-conventional systems. Thus, the life of SOFC need to further improved.
- Despite a number of advantages, SOFC possess many challenges like high cost, hydrogen production and storage, stack size, high operating temperature, long start-up time etc. need more focused research.
- Nano-material technology application in the SOFC would able to improve performance and life.
- Most of the hybrid systems proposed are on theoretical basis and they still need initial development.

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