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A comprehensive study of renewable energy sources: Classifications, challenges and suggestions

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ABSTRACT

Renewable energy (RE) is the key element of sustainable, environmentally friendly, and cost-effective electricity generation. An official report by International Energy Agency (IEA) states that the demand on fossil fuel usage to generate electricity has started to decrease since year 2019, along with the rise of RE usage to supply global energy demands. Researches on RE technologies are continuously growing in order to enhance the performance of RE generation, especially in term of energy conversion efficiency. The aim of this review paper is to understand and study further the current RE technologies such as solar energy, hydro energy, wind energy, bioenergy, geothermal energy, and hydrogen energy. Several hybrid RE technologies have been also studied and compared, to improve the overall performance of RE in generating electricity. Lastly, suggestions are provided for the purpose to solve and overcome the challenges and limitations of RE technologies in terms of economy, technical, and energy conversion efficiency.

1. Introduction

Nowadays, more sustainable energy technologies are required to replace conventional electricity generation resources such as fossil fuel, due to the worldwide demands especially in developed and developing countries [1]. Fossil fuel-based energy sources are causing detrimental environmental issues such as global warming and climate change [2]. The greenhouse gas emission into the atmosphere from power generation has increased exponentially in the past few decades [3]. Therefore, Renewable Energy (RE) technologies such as solar, wind, hydro, biomass, geothermal and hydrogen energies have been introduced to generate electricity to overcome current environmental crisis [4–6]. Due to their environmentally friendly characteristics and ability to generate power with zero or almost nil emission of air pollutants, RE is getting more and more attention, due to the increasing awareness of clean environment among the society [7,8]. RE not only helps in sustainability but also has economic importance. It benefits the economy by reducing the cost of electricity generation, as it generates energy using natural, renewable resources [9]. Also, it can be a secondary medium of income as consumers can sell their generated electricity back to the power grid. Although the adoption of RE sources for power generation is increasing, majority of power generation is still performed by utilizing fossil fuel due to the intermittency of RE and the high initial cost. For example, photovoltaic system can only operate during daytime, wind turbine can only operate when there is sufficient air flow, and hydro turbine only operates when there is potential energy caused by water flow. Hence, researchers around the world are performing researches rigorously to improve the efficiency of RE, as well as overcoming their limitations.

The objective of this article is to present different RE sources and their applications for power generation, and to promote/introduce the latest RE technologies proposed by researchers around the world, as well as discussing the limitations of current RE technologies. The rest of the article is organized in the following manner: Section 2 presents the current status of energy sector and the contribution of RE in it, Section 3 presents the various RE energy sources which are used/developed until now. Energy Storage System has been considered in Section 4, Section 5 presents different hybridization techniques for more efficient power generation using RE, Section 6 discusses the challenges of these

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technologies and provides suggestions to overcome them, and finally, Section 7 concludes this article.

2. Current status of energy resources

Even in this 21st century, most countries still depend on fossil fuel for electricity generation, to lack of technologies, resources, and conditions to fully utilize RE to generate electricity. Nonetheless, RE-generated electricity in electric power sector is increasing rapidly nowadays due to the awareness of society towards environmental concern. The figure below presents an example of the data and analysis of fossil fuel usage, comparison of fossil fuel generation to RE generation, and trend of different types of RE usage for electricity generation.

Fig. 1 shows the total fossil fuel usage and the distributed sectors in United States in year 2020. In 2020, the total usage of fossil fuel in United States was 21,365 TWh. Petroleum contributed the highest with 44% with a total of 9400.6 TWh. Natural gas contributed 9187 TWh, which was 43%. The lowest was coal, with 2777 TWh used for power generation. As shown in the figure, there are five sectors supplied with power from fossil fuel resources. Transportation sectors used the most fossil fuel, which was 6623.2 TWh, or 31% in 2020. Besides that, 90% of coal contributed 2392 TWh of electricity compared to 36% of natural gas to produce 3529.5 TWh electricity in the same year.

Fig. 2 shows the comparison of fossil fuel generation and renewables generation growth from 2010 to 2019 [11]. Due to the outbreak of the Corona virus pandemic, up-to-date data on global electricity generation in year 2021 is still unavailable from various platforms. The gap between fossil fuel generation and RE generation has decreased from year 2010–2020. The fossil fuel usage for electricity generation slightly increased from 121,531 TWh in 2010 to 136,131 TWh in 2019, but then decreased in 2020. On the other hand, renewable generation has significantly increased from 4098 TWh in 2010 to 7,140 TWh in 2019. Compared with fossil fuel generation, RE generation was much lesser, only contributing around only 3.26–5.60% of electricity generation from 2010 to 2020. In 2020, RE generation surpassed the fossil fuel generation, particularly during the pandemic. It is believed that electricity generation of residential area could be fully supplied by renewable energy in the future.

Fig. 3 shows the total renewable energy usage for electricity generation from 2010 to 2020 [12]. According to IEA's global energy review in 2021, total renewable energy usage has shown a significant increment, from 4,098 TWh in 2010 to 7,627 TWh in 2020. Hydropower contributes the largest portion of renewable energy capacity around the world for electricity generation, even though the growth rate of hydropower is the lowest compared with other renewable energies. On the other hand, solar energy generation shows an elevating trend, particularly because solar energy technologies are progressively developed and enhanced by researchers to obtain higher energy conversion efficiency. Wind energy generation also shows an significant increasing trend. Compared to the three major renewable resources, bioenergy and geothermal energy have insignificant contribution since year 2010. This is because only specific locations are suitable to implement geothermal power plant, in addition to the complicated process of producing bioenergy.

Fig. 4 shows the worldwide weighted-average levelized cost of energy (LCOE) between 2010 and 2020 [13]. Levelized cost of energy (LCOE) is generally known to assess the average cost of electricity per kWh for a generator with considering all the expected costs of the generator from different renewable energies which including fuel, capital, maintenance and electricity's market price [14] According to IRENA's renewable power generation costs in 2020, solar energy system (photovoltaic and concentrating solar power) and wind system (onshore and offshore) have shown a significant decrement in LCOE from year 2010–2020. Concentrating solar power system showed the largest drop amongst all renewable energies which fell by 85% from 0.381 USD/KWh to 0.057 USD/KWh throughout the year 2010–2020. This phenomenon happened due to enhancement of the current technologies in concentrating solar power system in term of economies of scales, competitive supply chains and developer's experiences [13]. On the other hand, hydropower, biomass and geothermal system have shown insignificant changes and maintaining in the low band of LCOE throughout the year 2010–2020. Furthermore, LCOE of hydrogen energy system was estimated below 0.05 USD/KWh [15]. It is considered one of the low LCOE compared to other renewable energy.

3. Renewable energy technologies

Renewable energy is gaining wider use for power generation around the world nowadays. This is particularly due to society's concern about environmental issues coming from the conventional method of

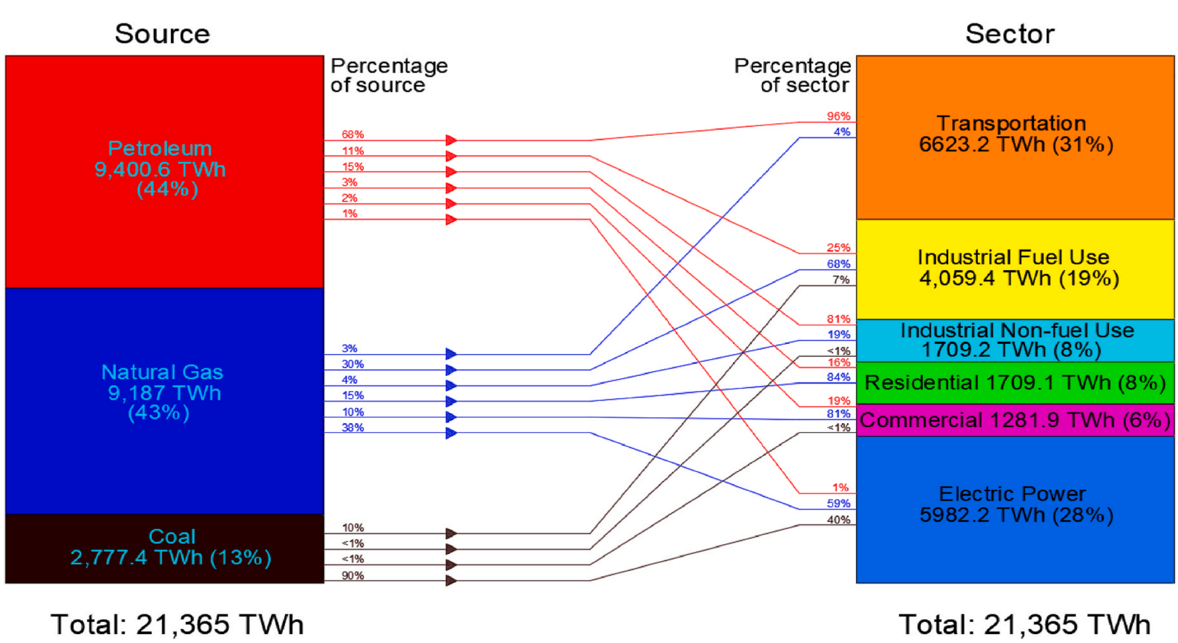
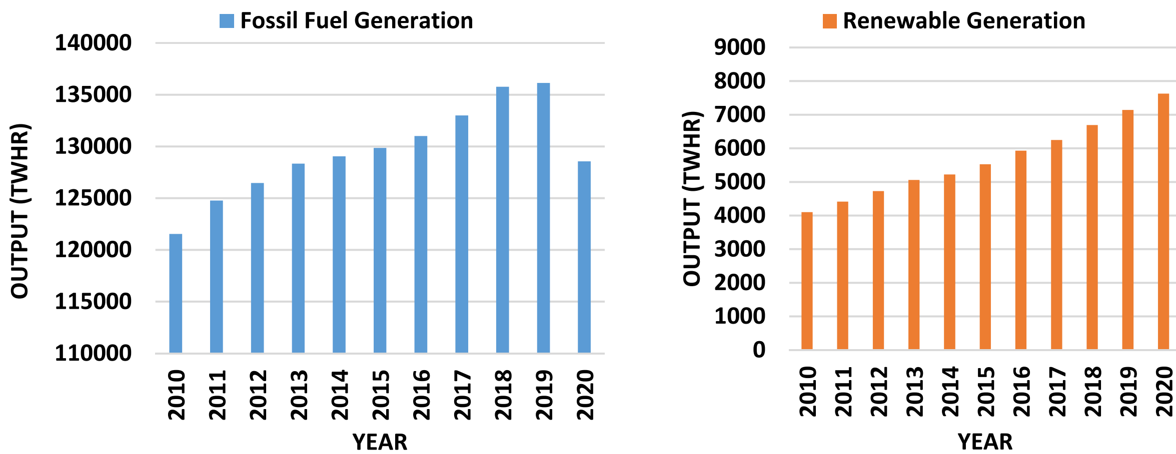


Fig. 1. Fossil fuel usage for different sectors in U.S. (2020) [10].



(a) (b)

Fig. 2. Comparison of (a) fossil fuel generation and (b) renewable generation growth (2010–2020) [11].

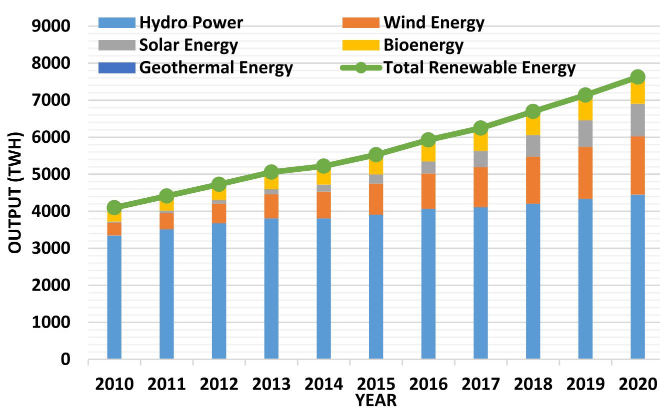


Fig. 3. Total renewable energy usage (2010–2020) [12].

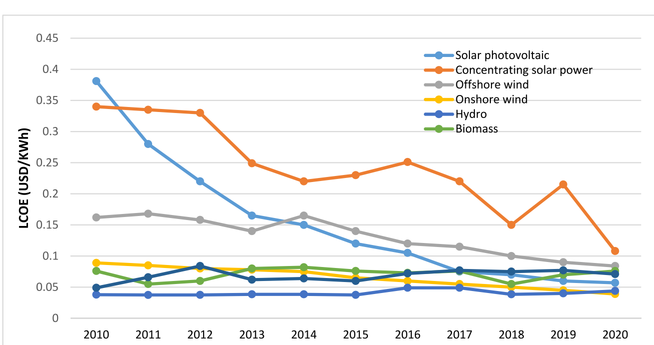


Fig. 4. Global weighted-average utility scale levelized cost of energy (LCOE) (2010–2020) [13].

electricity generation. The five major groups of renewable energy: solar energy, hydro energy, wind energy, bioenergy, and geothermal energy, have their own operation conditions and energy conversion efficiency, therefore, RE technologies depend on location and condition.

3.1. Solar energy

Solar energy (SE) is the radiant ionization energy emitted by the Sun, and one of the energies that highly utilized globally [16]. In order to improve and enhance SE conversion efficiency, most researchers explore various technologies to optimize the design of the SE system [17]. Researchers are also optimizing costs and energy conversion, while reducing environmental impacts [18]. There are two main types of SE system, which are solar thermal energy and photovoltaic energy, commonly implemented in developing and developed countries. These two SE systems are also progressively ameliorated by researchers to obtain better efficiency.

3.1.1. Photovoltaic technology

Photovoltaic (PV) energy is one of the favoured SE prominent technologies as a prospective source of energy in the future [19]. The current PV energy supplies approximately 2% of the global electricity demand [20]. Schockley and Queisser have shown that a conventional solar cell is only able to achieve 31% of conversion efficiency, which is known as Schockley-Queisser (SQ) limit [21]. In order to overcome SQ limit, some PV technologies have emerged, such as concentrator photovoltaic (CPV) system, hot carrier converters, multi-junction solar cells (MJSC), floating PV power generation, and down conversion of high energy photon.

(a) Concentrated Photovoltaic

Concentrated Photovoltaic (CPV) system is a method of focusing light on PV receivers, using concentrating optics on a small area of solar cells. The purpose of CPV is to collect beam radiation and scattered radiation, which are then concentrated on the solar cells [22]. There are three types of CPV, based on the factor of concentration, which are low concentration (1–40x), medium concentration (40–300x), and high concentration (HCPV) (300–2000x) [23]. HCPV is the most potential as it has the highest efficiency [24]. According to International Energy Agency (IEA), the efficiency of current CPV system can achieve at least 40% [25]. There are more emerging researches on CPV, by using different types of concentrator; and all have their advantages and disadvantages, as shown in Table 1. Nonetheless, CPV systems can indeed give practical positive impact to large scale planning of SE with promising features.

(b) Hot Carrier Converter

Hot carrier converter is a solar cell that exploits excessive photo energy to generate more electrical energy [37]. In common quantum-utilizing SE converters, the transitions of energy occur between two sets of electronic states, which are known as conduction and valence bands, with the aid of absorbed photon energy [38]. However, the excess of photo energy in between threshold energy gaps is usually dissipated as heat. Therefore, hot carrier converters are proposed to

Table 1
Advantages and disadvantages of solar concentrators.

Type of Concentrator	Advantages	Reference	Disadvantages	Reference
Fresnel lens	a. Light weight b. Less volume c. Mass production	[26]	a. Loss of light possibility caused by the incidence on draft facet b. Rays are improperly focused at receiver due to defects at the edges of facets c. Light intensity is reduced in order to overcome the above disadvantages.	[27,28]
Dielectric internally reflecting concentrator	a. Able to operate without any external cooling treatment b. High concentration ratio and efficiency	[29]	Unable to harness all radiation energy, and only offers media with low index	[29]
Parabolic trough	Effective on direct solar radiation energy	[30]	a. Expensive b. Only applicable on direct radiation c. Low efficiency of optic and quantum	[30]
Compound parabolic concentrator	Able to transmit most of the radiation within accepted boundary through the output aperture into receivers	[31]	Requires external tracking system in order to get optimum efficiency	[32]
Quantum dot concentrator	a. Inexpensive sheets b. Lesser problem of heat dissipation c. Non-tracking concentrator	[33,34]	Restricted by strict standard of luminescent dyes	[35]
Hyperboloid concentrator	Compact	[36]	Requires lens at entrance aperture in order to operate effectively	[36]

enhance the efficiency of SE by utilizing the excessive photon energy in the system. The basic concept of hot carrier converter is to reduce the rate of cooling for photo-excited carrier and to allow longer time for carriers of photon energy to be utilized and interacted under higher temperature, as shown in Fig. 5 [39]. As a result, the efficiency of conversion produced by hot carrier converters can reach around 65%, which is much higher than a conventional cell [40].

Multi-junction solar cells (MJSC), or commonly known as tandem cells, consist of multiple p-n junctions made of various stacked individual materials of semiconductor (subcells) connected in series, in order to obtain higher efficiency of SE [41]. In order to avoid blockage of current flow caused by reverse diodes between the subcells, an interconnector is needed to be installed between subcells, as shown in Fig. 6. An interconnector should have high optical transmissivity and low electrical resistance, therefore Esaki interband tunnel diodes, which consist of thin highly doped p-on-n diodes, are the most suitable diodes to become a standard component for an interconnector [42]. The highest efficiency of MJSC recorded for PV systems is currently at 40.7%, by the use of InGaP/InGaAs/Ge stacked materials [43]. Topcells materials selection plays an important role to achieve high efficiency of MJSE. In order to latticed-match with Ge or GaAs subcells, InGaP is the best option to be topcell as it has less oxygen issue, lower velocity of interface recombination, and better window layer material compared to AlGaAs [44]. Besides that, InGaAs was proposed for lattice-matching to Ge substrates, due to increment of short-circuit density (J_{sc}) and open-circuit voltage (V_{oc}) provided by lower middle cell's band gap energy and specific lattice adaptation's characteristics, respectively [45]. Lastly, Ge subcell is promising as bottom cell as it has the lowest value of band gap energy in order to absorb the longest wavelength of radiation energy [46]. The spectral responses of subcells InGaP, GaAs, Ge and MJSC of InGaP/InGaAs/Ge on optical wavelength are shown in Fig. 7 [46]. The plotted graph shows that InGaP, InGaAs and Ge subcells

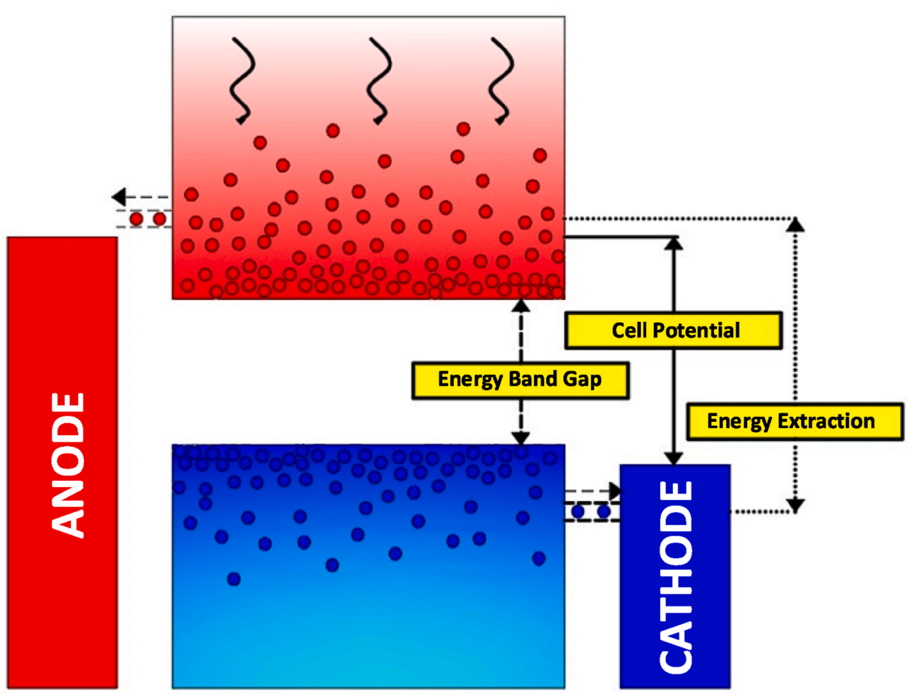


Fig. 5. Hot Carrier Converter Structure [40].

(c) Multi-junction Solar Cells

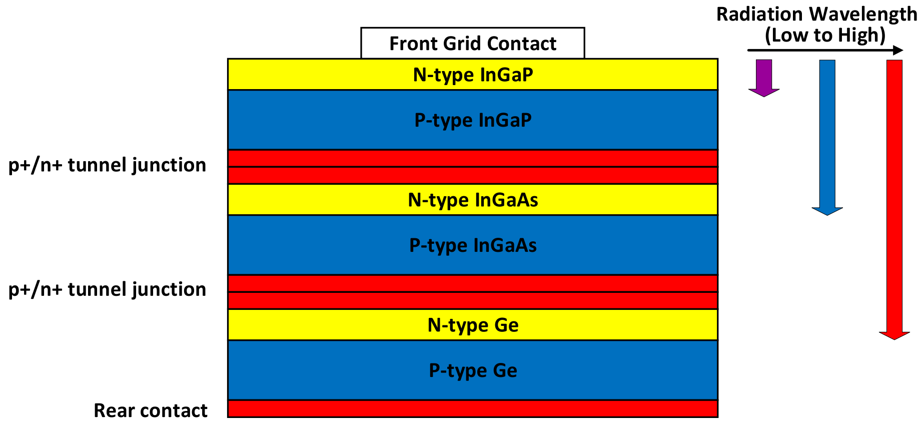


Fig. 6. Structure of InGaP/GaAs/Ge Triple Junction solar cell [40].

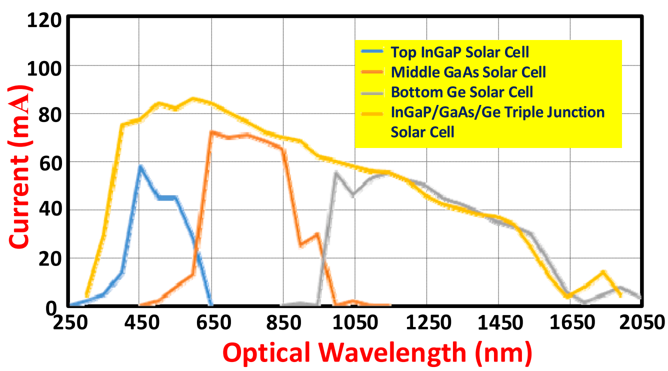


Fig. 7. Spectral Response Curve between individual InGaP, GaAs, Ge solar cells and InGaP/GaAs/Ge Triple Junction solar cell [46].

(d) Floating PV Power Generation

have their own specific optimum spectral responses across the 300 nm–1800 nm wavelength, while MJSC of InGaP/InGaAs/Ge show positive responses from 400 nm to 1600 nm with higher J_{SC}. However, the application of MJSC is mostly suitable for implemention on the photovoltaic power generator for satellites and space vehicles due to its high implementation cost [47].

Floating PV (FPV) power system is PV system installed on water surfaces like small lakes, ponds and reservoirs, supported by floating structures such as pontoon or rafts [48]. This technology is widely implemented in Japan, United State, Italy, Brazil, and China [49]. This PV system utilizes conventional PV arrays but with cooling effect from water body to prevent solar cells overheat [50]. The cooling benefit provided by the underlying surface of water has been reported to slightly increase the efficiency of PV energy harvesting. The FPV installation has two-way beneficial relationships between the solar cells and water body. Firstly, the FPV system is able to decrease the rate of algal growth [51], and secondly, it reduces water evaporation from the water storage system [52] while the water provides cooling effect on the system, thus increasing the efficiency of solar cells [53]. Lastly, as the system is installed on water storage structure such as reservoir and pond, it contributes to positive environmental solution in term of sustainable land management practice, as it does not occupy any land space to generate energy. Furthermore, there are no environmental issues specified nor mentioned by any authorities to date [54]. Fig. 8 shows the biggest floating PV system in Saemangeum, Korea, which has more than 5 million solar cells over 30 km^2, providing 2.1 GW of power [55].

Down conversion of high energy photon is essentially a method by the use of multiple electron-hole pairs per photon to breakdown high energy photons into at least two photons with lower energy [56]. In

Fig. 8. The biggest floating PV system in Saemangeum, Korea [55].

(e) Down Conversion of High Energy Photon conventional solar cells, the excess high energy photons are wasted [57]. Hence, down conversion is proposed to reduce the losses of energy from solar cells by introducing electron-hole pairs with double band-gap energy of solar cells [58]. With this method, a photoluminescent converter is installed at the front of the solar cells in order to breakdown one high photon into two photons with lower energy [59]. Fig. 9 shows the schematic energy diagram of the combination of solar cell with a down-converter. According to Vos [60], high energy photons with energy > 2 Eg can be more efficiently by the solar cells through the radiative transitions that happen in the converter, between the conduction band and valence band (solid arrow) or between one of the bands and the impurity level (I_L) (dotted arrow) by transmitting lower energy photons. As the result, the efficiency of solar cells can reach around 39.63% [58,61].

Photovoltaic thermal (PV/T) technology converts SE into thermal energy and electrical energy simultaneously, using a device which has both solar collector and solar cells [62]. This PV/T system is able to harness a wide range of solar radiation, which results in enhancement of both electrical and thermal efficiency of the system [63]. In conventional PV system, only about 20% of solar radiation is converted into electrical energy while the rest are wasted in the form of thermal energy [64]. It is worth to note that the electrical efficiency of PV system is inversely proportional to the cell temperature [65], which means the higher the temperature of solar cells, the lower the electrical efficiency of PV system. Solar collector can be combined with PV system to absorb and utilize the excess heat loss from PV system. Fig. 10 shows a typical PV/T module structure that comprises several layers [66]. First, solar radiation is emitted and concentrated onto solar cells by the glazing cover. After that, solar radiation with wavelength from 0.6 to 0.7 μm is absorbed and converted into electrical energy, while the remaining solar radiation passes through solar cells and transforms into heat energy [67]. The heat energy is collected by solar collector and is transmitted by the fluids in flow channels to the heating applications. This PV/T system manipulates both the light and heat energy of the sun, therefore has much higher percentage of SE than an individual solar collector or solar cells under the same condition [68]. Lastly, PV/T provides a significant positive solution for both electrical and heat generation with the same cost [69].

3.1.2. Solar thermal energy

Solar thermal energy (STE) is obtained thorough conversion of radiation energy into thermal energy [70], which is currently implemented in most industrial and domestic sectors by industrial process heat [71], power generation [72], and water and space heating [73] purposes. This heat conversion technology has attracted the interest of researchers to convert heat energy directly into electricity [74].

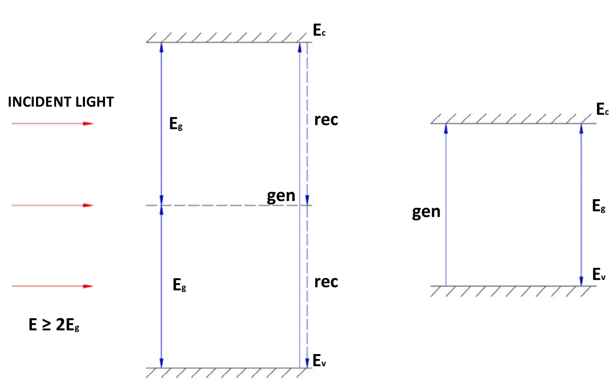


Fig. 9. Schematic energy diagram of a solar cell combined with a down-converter [60].

(f) Photovoltaic Thermal System

Theoretically, STE is a form of technology for capturing solar radiation and turning it into heat energy with the aid of a flowing fluid underneath the receiver [75]. There are three types of solar thermal collectors, which are low, medium and high temperature collectors [76]. Low and medium collectors are usually flat plates that are used for heating swimming pools and heating space and water for domestic uses. High temperature collectors has mirrors or lenses to harness the solar radiation from sunlight, and this type is msot preferred for electrical power generation. Unlike PV energy, STE is able to absorb more than 90% solar radiation, thus a higher efficiency of SE conversion [77]. Researchers are looking for ways to reduce STE implementation cost by proposing alternative materials to replace expensive components such as the high-maintenance vacuum tube and optical concentration system [78].

(a) Porous Structure Receiver

Porous structure receiver (PSR) has shown a high efficiency in reducing the heat loss issue from STE system, compared with the conventional vacuum enclosures in solar collector [79]. By using a porous receiver layer in solar thermal collectors, this simple method can reduce the issue of conductive heat loss in the receiver, with greater maximum acceptable flux [80]. With the capability of PSR to store conductive heat, PSR is promising as alternative method to improve the performance of STE system [81]. Different materials with high porosity and unique thermal insulation characteristic have been investigated to absorb a wide range of radiation wavelength [82]. Comparison of various porous insulating materials and their potentials in STE application are shown in Table 2. There are three layers in STE collector as shown in Fig. 11 [75]. Glass cover, as the top layer of the collector, harnesses the incoming solar radiation in the form of thermal energy, which is then transmitted to the porous transmitter layer. In order to reduce heat loss, the pore diameter of PSR layer plays an important role in the penetration, radiation and re-emission of heat to the bottom layer which is known as black absorber layer. Lastly, heat transfer fluid (HTF) which is contained perpendicularly in the absorber layer, receives the heat and delivers it to domestic and industrial heating application, or by conversion of heat into electrical power using steam turbine systems.

Nowadays, nanofluids are utilized as HTF in STE system in order to improve the heat transfer process of the system as they have better thermos-physical property compared to conventional fluids such as ethylene glycol, water, and oil [93]. Nanofluids are a mixture that consists of nano-sized particles with larger thermal conductivity, which are less than 100 nm in base fluid [94]. Nanoparticles in fluids are classified into three categories which are metal, carbon, and nanocomposite groups (see Fig. 12.) [95]. Nanocomposites have the highest heat carrying capacity and thermal conductivity among these three groups. A lot of experiments using nanofluids as HTF in STE system have been conducted by researchers by various applications such as solar water and space heater, and solar collector [96]. The advantages of Nanofluids are shown in Table 3.

3.2. Wind energy

Wind energy is the second major preference of renewable energy for electricity generation after hydro power [103] due to its relatively simple/easy infrastructure, cost-effectiveness, and maturity of technology [104]. Wind energy is converted into electricity by wind turbines-based power plants. There are two types: onshore wind farms, and offshore wind farms. A wind farm installed at sea or freshwater is an example of offshore wind farm, while a wind farm installed on land area is an onshore wind farm [105]. Majority of wind farms are situated onshore; nonetheless, the offshore wind farms are growing rapidly, especially in Europe [106]. Selection of the wind farms location depends on the yearly average speed of wind, which should be sufficient to generate the estimated power. For example, widespread land with high elevation, or seashore is ideal for onshore wind farms.

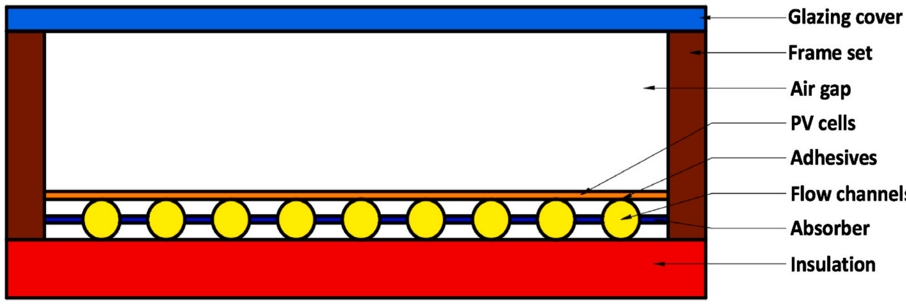


Fig. 10. Typical PV/T structure [66].

Table 2
Comparison of porous insulating materials.
(b) Nanofluids

Design structure	Features	References
Foam	- Reticulated porous ceramic-based materials (79%–87% porosity) with 71% steam conversion efficiency and 92% solar absorption across wavelength 200 nm to 2500 nm	[83] [84]
Sponge	- Polydimethylsiloxane altered graphite bilayer onto polyurethane (73.3% solar thermal efficiency) - Hybrid of Bi_2S_3/polyvinylidene fluoride onto polyurethane (1.66 kg/m^{2}h water evaporation rate & 92.9% solar thermal efficiency across 200 nm–2000 nm	[85] [86]
Honeycomb	- SiCw/Al_2O_3 honeycomb - $Co_2O_4^-$ $Mn_2O_3^-$ coated porous cordierite honeycomb - Polycarbonate honeycomb	[87] [88]
Fibers	- Made from polydopamine nanofibrils fabricated into a high absorbance material (86% solar thermal conversion efficiency)	[89] [90]
Aerogel	- Visually transparent insulating silica-based aerogels (88% solar absorption efficiency for wavelength <2700 nm and 99% solar absorption efficiency for wavelength >2700 nm) - Hybrid NFC-graphene aerogels (phase change materials with high melting enthalpy range) - Hybrid graphene-carbon doped with nitrogen (90% solar thermal conversion efficiency)	[91] [92]

3.2.1. *Classification*

Apart from location, wind power plants can be classified based on axis type and the generator type that used in the wind turbines.

(a) Axis Types of Wind Turbine

Wind turbines can be classified into two types based on their axis setting: horizontal axis, and vertical axis. Fig. 13 shows the inner structure of a horizontal axis type, which is the most popular type of wind turbine. It consists of a support made from a steel or concrete pole, a yaw system that guides the wind turbine toward wind direction, which is connected between the nacelle (hub section of wind turbine) and the tower, a rotor with blades, a convertor, and gearboxes [107].

Horizontal axis wind turbines (HAWTs) are the most general windmill design. Due to their more developed technology and likely capability, as well as long record of successful operation in history, HAWTs are preferred for both onshore and offshore utilization over the past 30 years [108]. There are several types of wind turbine towers to support HAWTs depending on different conditions. Table 4 shows the types of wind turbine and their characteristics. Recently, in order to achieve global energy demands, the size of HAWTs has been increased to produce higher power output of electricity. Fig. 14 shows the comparison of the largest wind turbine, MHI Vestas Offshore V236–15.0 MW™ which was launched in 2021 [109] and a conventional 2 MW wind turbine. However, the increment of the rotor size can exacerbate the scaling-up behavior of the wind turbine system, since larger rotor size will have more weight than the aerodynamic load [110]. The wind turbines' own weight may lead to fatigue issues on the wind blades, which induces cyclic gravitational load [111]. This factor needs to be considered for maintenance purpose in order to achieve cost effectiveness of large HAWTs.

Vertical axis wind turbine (VAWT) is characterized by its rotation axis that is perpendicular to the ground, and usually operates in urban application [113]. Compared to HAWT, VAWT has low operating speed, better starting characteristics, lesser structural support, no yawing requirement and noise concerns, and more capability to harness wind

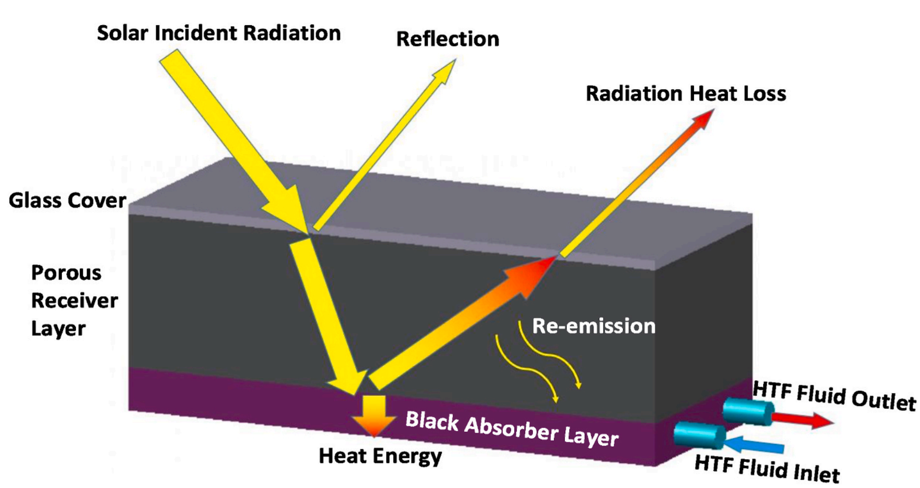


Fig. 11. STE collector structure with porous receiver layer [75].

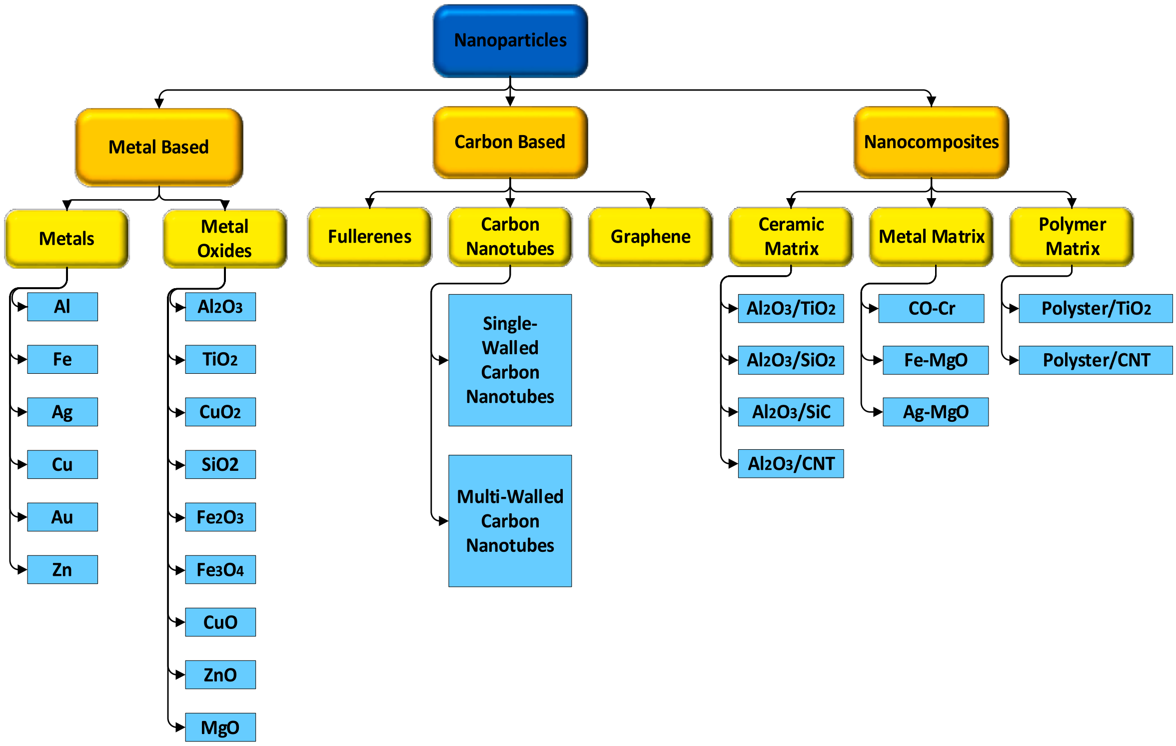


Fig. 12. Type of nanoparticles [95].

Table 3
Advantages of nanofluids.

Advantages	Reference
Small sizes particles (1–100 nm)	[97]
High heat capacity and absorptivity	[97]
High thermal conductivity	[97]
Better optical characteristics	[98]
Good stability property	[99]
No clogging, fouling and sedimentation issues	[100]
Cost effective	[101]
High energy conversion efficiency	[102]

from different direction compared to horizontal axis wind turbine (HAWT) [114]. However, it has lower aerodynamics efficiency than HAWT. VAWT is able to provide energy solutions for urban area and remote locations that are away from main distribution lines or the places where large scale of wind farm is not able to be implemented due to environmental concerns and only allow scattered generation units to operate [115]. Researchers are exploring various new VAWT designs in order to enhance and improve their performance [116] as presented in Table 5.

As energy demands are growing higher, larger generation units such as taller towers, high efficiency generator, and longer rotor blades are

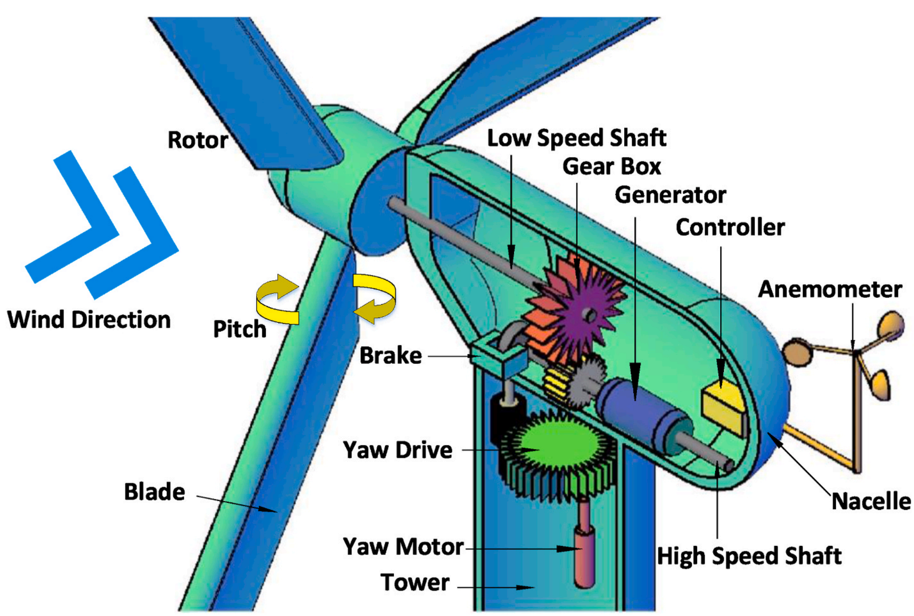


Fig. 13. Horizontal Wind Turbine System Configuration [103].

Table 4
Types of wind turbine tower [112].

Wind Turbine Tower	Characteristics
Tubular Tower	- Built from rolled steel plates welded together from top to bottom with flanges. - Internal vertical ladders to access yaw mechanism and power cables.
Lattice Tower	- Built from specifically shaped steel rods that are put together to form lattice shape. - Strong structure - Inexpensive - Easy to erect and transport
Guyed Wind Tower	- Guy wires are used to support the wind tower - More space required to fix guy wire - Inexpensive - Suitable for small capacity HAWTS
Tilt Up Wind Tower	- Locking System for Wind Turbine is required to implement the tower - Wind Turbine is easily maintained by lowering it to the ground - Suitable for small capacity HAWTs
Free Standing Tower	- Common application of HAWTs - Diameter of tower is based on the size of HAWTs - Only requires small space

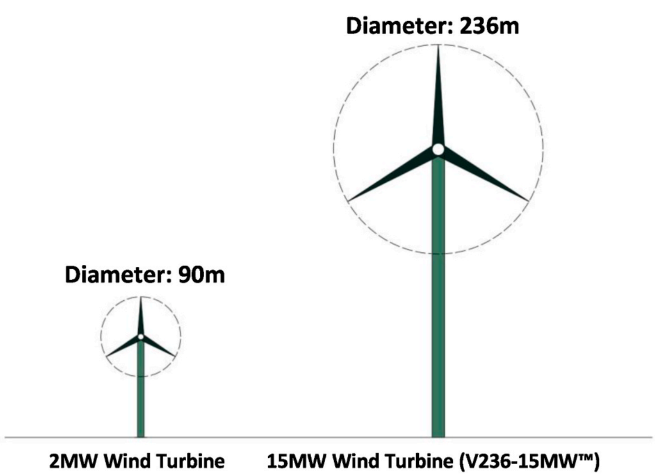


Fig. 14. Comparison of 2 MW conventional wind turbine and V236-15MW™ [109].

proposed to enhance the performance of wind energy generation [122]. Modern utility-scale wind turbine generators with pitch-regulated and fully-variable speed control systems are utilized to reduce the stress on mechanical components while optimizing the harvest of wind energy collected at low wind speeds [123]. Due to the augmented requirements of grid, partial or fully-rated power converter is commonly used between the generator and the grid [124]. Generators that are widely utilized for variable speed wind energy conversion are squirrel-cage induction generator (SCIG), doubly fed induction generator (DFIG), electrically excited synchronous generator (EESG), and permanent magnetic synchronous generator (PMSG) [125].

Squirrel cage induction generator (SCIG) has been implemented as a fixed speed generator for small scales generation since long time ago [126]. As a variable-speed generator, low to full rate power converter can be implemented between the generator and the grid [127]. Fig. 15 shows the general configuration of SCIG. SCIG is attached to the wind turbine through a gearbox, and its stator windings are connected directly to full power converter [128]. SCIG can be operated by various methods such as direct or indirect field orientation, scalar or vector control, and rotor or stator field orientation [129]. The benefits of a SCIG are cost-effectiveness, good reliability, non-complex application, and its robustness [130]. However, the speed of SCIG is uncontrollable and has limited variation [131]. Besides that, the multiple-stage gearbox in the SCIG systems always consumes the reactive power that is also uncontrollable [130]. As the result, it is difficult to build a multipolar SCIG system compared with PMSG.

In the late 1990s, double-fed induction generator (DFIG) was introduced due to the requirements of minimizing the mechanical pressure of the drivetrain and the noise level caused by the starting of variable speed operation, stable power quality required from the grid, and enhancement of the power level [133]. Fig. 16 shows a typical configuration of DFIG in a wind turbine system. Wind turbine is connected to a DFIG through a gearbox in order to convert the mechanical power from wind source into electrical power. Typically, the gearbox in wind turbine system has two helical and one planetary gear stages. High-speed generator rotor shaft is connected to the last helical stage, while the low speed shaft from the rotor of wind turbine is connected to the planetary stage [134]. DFIG operates by three-phase winding rotor, and it has enough range of variable speed. It is managed by controlling the reactive power and active power flow direction with the rotor current in the converter [135]. However, frequent regular maintenance of brushes and multiple-stage gearbox in DFIG system is required to reduce the possibility of machine failure. Not only that, the control strategies for DFIG according to the grid demands are very complex [136].

The first electrically excited synchronous generator (EESG) was invented having 500 kW variable speed direct drive wind turbine in 1992 by Enercon of Germany [138]. Typically, EESG is implemented by direct-drive application [139]. Fig. 17 shows the EESG system configuration. A diode rectifier is linked to the system in parallel to provide DC excitation current to the rotor [140]. The EESG stator is similar with an induction machine that carries a three-phase winding [141]. The rotor in EESG has salient poles that are normally operated in low speeds applications [141]. The generator side converter controls the frequency and amplitude of the voltage from the generator [135]. Due to its

Table 5
Characteristics of VAWT.
(b) Generator Types of Wind Turbine

VAWT type	Max capacity available	Features	Pros	Cons	Reference
Savonius rotor	4.5 kW	• Drag type wind turbine • Half cylinder attached to central of rotor	• Good starting torque	• Low aerodynamics efficiency	[117]
Darrius rotor (egg beater shaped)	4 MW	• Lift type wind turbine • Curved blades with varying cross-section	• High capacity	• High cost • Complicated shape	[118]
Darrius rotor (straight blade)	10 kW	• Lift type wind turbine • Aerofoil shaped blade with constant cross-section	• Low cost • Simple capital installation	• Low power coefficient • Low staring torque	[119]
Darrieus–Masgrowe	3 kW	• Lift type wind turbine • Two typical straight bladed Darrieus rotors combined and shifted by 90° with each other	• Self-starting capability	• Available for low power application	[120]
Sistan Wind Mill	1.8 kW	• Drag type wind turbine • Straight Bladed type	• Good Building Integration	• Low Efficiency	[121]

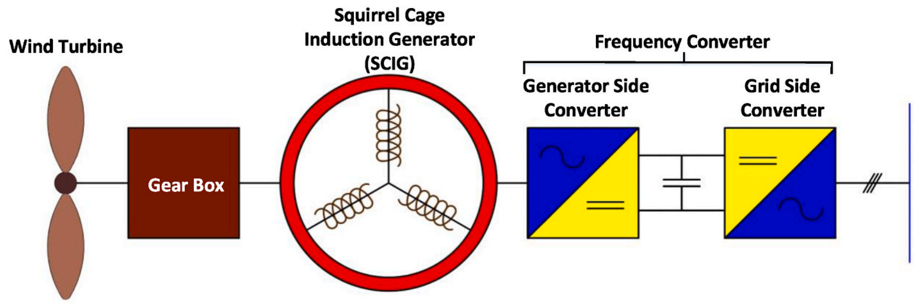


Fig. 15. Typical configuration of SCIG System [132].

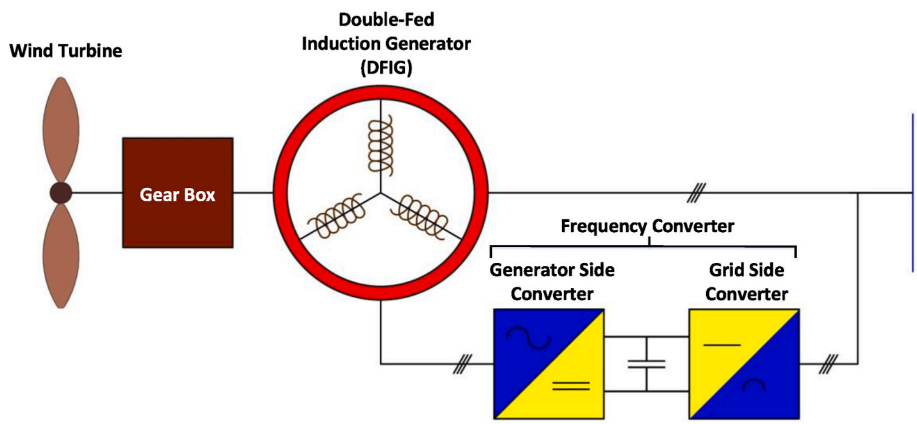


Fig. 16. Typical configuration of DFIG System [137].

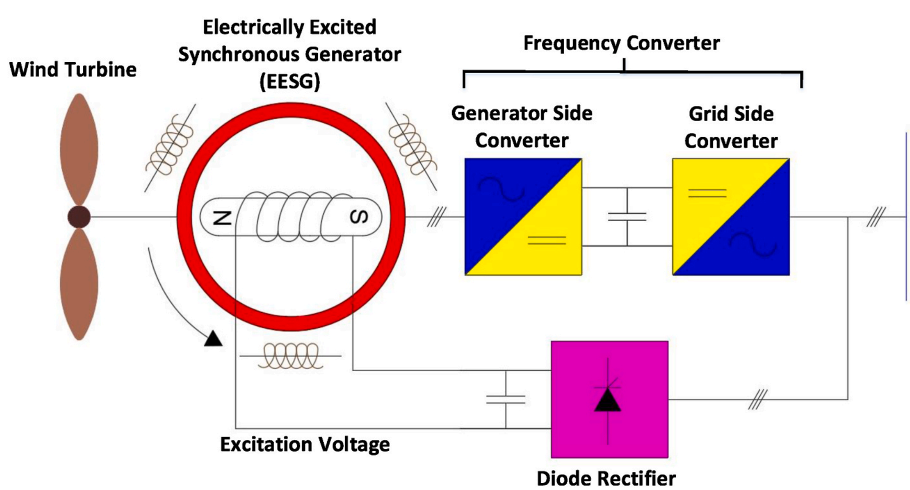


Fig. 17. Typical configuration of direct drive EESG System [142].

effective cost, EESG is widely used in large direct-drive wind turbines. However, the large diameter of EESG rotors causes inconvenience of transportation and installation, aside from the drawback of expensive electronic components [131].

A permanent magnet synchronous generator (PMSG) produces excitation field by permanent magnet instead of coils. PMSG is very efficient in operating at partial load of wind energy compared to EESG and traditional DFIG [143]. In addition, PMSG is more powerful and requires lesser maintenance, as it has fewer moving parts, compared to wound rotor induction and electrically excited generators [144]. Besides that, PMSG with fully rated power convertor is one of the best options for a variable-speed generation because of its higher energy conversion efficiency and longer lifespan [145], even though it has high capital costs [146]. Fig. 18 shows a typical configuration of direct-drive PMSG wind turbine [147]. Unlike traditional SG that is directly connected to the grid, PMSG requires the controllers to optimize the maximum amount of power from wind energy in order to achieve grid integration demands. A frequency converter, which consists of machine side converter and grid side converter, is connected with PMSG before transmitting power to the grid. A machine side converter which controls the operation of PMSG may be a diode-based rectifier, or pulse width modulation voltage source converter, while a grid side converter which controls the direct current link voltage by exporting active power to the grid network can only be a pulse width modulation voltage source converter [147]. These two converters are controlled with decoupled d-p frame control separately [148].

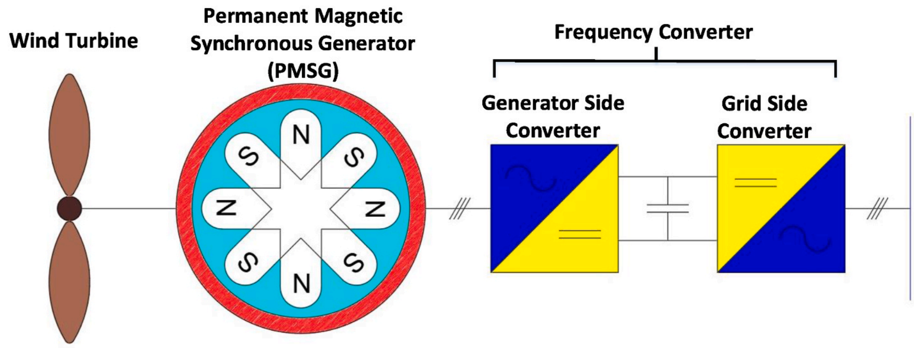


Fig. 18. Typical configuration of direct drive PMSG System [147].

3.2.2. Maximum power point tracking

Due to alternating characteristic of wind nature, maximum power point tracking (MPPT) is commonly used to find out the optimum speed of generator, to maximize energy yield from moderate-speed regions [149]. MPPT is a technique to achieve high efficiency of wind energy harvesting by adjusting the wind turbines rotation speed with the implementation of variable speed wind turbine [150]. MPPT has higher mechanical stress, higher power quality, more power output, and greater system efficiency, compared with wind energy conversion systems (WECS) by other applications [151]. There are four conventional types of MPPT controllers which are Power Signal Feedback control, Tip Speed Ratio, Optimal Torque Control method, and Perturb and Observe Method. Power Signal Feedback Method uses one sensor to measure rotational speed to adjust the output power into reference value, by delivering errors between measured turbine power and reference power to the controller [152]. Meanwhile, Tip Speed Ratio method requires two sensors on rotational speed and rotor radius to determine the wind and turbine speed, by the use of a tachometer and an anemometer that provides feedback signals to the control [153]. Optimal Torque Control uses mechanical torque equation to select the optimum torque by computing angular velocity [154]. The Perturb and Observe method only needs electrical measurement devices instead of sensors; it has high reliability but the lowest efficiency compared to the other three methods [155]. At least 5% error may happen in conventional MPPT control strategies, which means around 1%–3% energy losses [156]. This is because variable wind speed is very hard to determine due to its randomness of temporal and spatial distribution. Therefore, intelligence algorithm is introduced to combine with conventional MPPT to reduce the percentage of error and to improve system efficiency [157]. Combined methods still necessitate collective data for short-term wind speed prediction and wind turbine dynamics [158]. Basically, intelligent MPPT implements data forecasting techniques and artificial intelligence algorithms to estimate decent accuracy and computational cost [159]. Therefore, estimation error is smaller as the historical data is analyzed effectively while the prediction horizon is reduced [160].

3.3. Hydropower

Hydropower is a proven and cost-effective RE, in which electrical energy is generated from the harvested energy of moving water from higher to lower elevations. Compared to other RE sources, hydropower has the highest conversion efficiency, which is about 90%, to generate electricity [161]. Hydropower contributes 20% of electricity generations worldwide [162]. Hydropower system can be modified to meet the loading requirement with maximum capacity factor [163], thus there are various types of hydropower such as pumped storage systems, small hydropower plant, and cascaded reservoir hydropower plant.

3.3.1. Pumped hydro storage

Pumped hydro storage (PHS) is a type of hydroelectric storage system which consists of two reservoirs at different elevations. It not only generates electricity from the water movement through the turbine, but also pumps the water from the lower elevation to upper reservoir in order to recharge energy [164]. As shown in Fig. 19 [165], higher level water flows through the hydro turbine during turbine operation, while in pump operation, the water flows through both auxiliary flow machine and hydro turbine. A conversion block is utilized to switch between these two modes. There are two types of PHS: one is open-looped PHS that has ongoing connection to natural water body; another is closed-lopped PHS that is not connected to any water resource. Hydropower storage reservoir system is important in managing the water resources between periods of time. This is because a well energy balance between supply and demand is needed to maintain a sustainable supply to the grid [166]. However, most implemented PHSs are only able to store energy in daily cycle [167]. In addition, storage reservoirs require suitable geological formations for storing large amount of water, with the variation of reservoir level. Table 6 lists different types of PHS plants based on society's demand that are operating nowadays.

3.3.2. Small hydropower plant

Small hydropower plant (SHP) is one of the cost-effective RE technologies especially for electricity generation in rural area in developing countries [179]. In addition, it functions as outlook for future development of hydropower. Practically, small-scale hydropower operates by 'run-of-river' method where generally less or no water will be stored [180]. Thus, this type of installation does not have any negative impacts to the environment. However, the standard capacity of small hydropower plant differs between countries, depending on their own legislative and administrative reason [181]. Table 7 shows the maximum power capacity of small hydropower plants in certain countries [163]. Fig. 20 illustrates a conventional small hydropower plant scheme [182]. River water is diverted and collected by an intake in weir with the control a valve. Whenever SHP is not operating, the valve can be switched off, letting the river water pass through the system. In order to reduce conversion efficiency and to protect hydroturbine from damages, a settling tank is needed to install before the weir to filter and settle down any suspended solids present in the river. Therefore, small

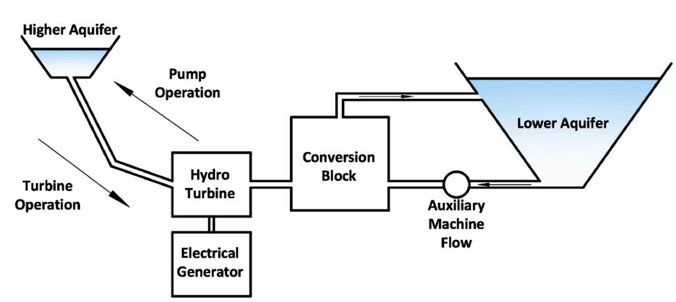


Fig. 19. Pump storage configuration with pump operations [165].

Table 6
Classification of PHS plants based on society's demand [168].

PHS Type	Typical reservoir volume size (km^2)	Operation Mode	Situation when the PHS operates	Ref
Seasonal Pumped Storage (SPHS)	30–1	Generation	- Low hydrogenation during dry period - Low solar power generation during winter - Low windy season	[169] [170] [171]
		Pump	- High hydro generation period during rainy seasons and ice melting season - High solar power generation - High wind power generation	[169] [170] [171]
Pluri-annual Pumped Storage (PAPHS)	100–5	Generation	- Annual shortage in power generation - Fuel price is expensive than usual - Higher average annual electricity demand	[172] [173]
		Pump	- Annual excess power in hydroelectric generation - Fuel price is cheaper than usual - Lower average annual electricity demand	[172] [173]
Weekly Pumped Storage (WPHS)	5–0.1	Generation	- Whenever power demand increases especially during weekdays - Low windy day - Low solar power generation	[174] [175] [176]
		Pump	- Whenever power demand decreases especially during weekend - High windy day - Sunny day	[174] [175] [176]
Daily Pumped Storage (DPHS)	1–0.001	Generation	- Whenever electricity demand increases normally during daytime - No solar power generation at night time	[177] [178]
		Pump	- Lower electricity demand - Whenever there is solar energy generation	[177] [178]
Hourly Pumped Storage (HPHS)	1–0001	Pump & Generation	- Provides backup power in case insufficient of power generation - Ancillary services with frequency control	[166]

hydropower plant can be implemented at any location that has low water output. SHP plays an important role as it provides an environmentally friendly and economical solution for domestic and commercial users [183].

3.3.3. Cascaded reservoir hydropower plant

Cascaded reservoir hydropower plant (CRHP) is a complex non-linear system which involves non-linear interacting input and output parameters, non-linear dynamical hydraulic heads, and non-linear flow rates [185]. Cascaded reservoirs can generate electrical energy multiple times as water passess through multiple reservoirs from higher elevations to lower elevations continuously. Fig. 21 illustrates the arrangement of cascade hydropower plant scheme [186]. However, a CRHP can be a complex network of reservoirs, or as simple as consisting of only two reservoirs, depending on the natural topography of landscape. By building a collecting reservoir in specific area, an integrated CRHP could operate with any sustained water, accumulated rain water, or recycled water at any elevation [187]. Furthermore, CRHP is able to contribute significant environmental solutions through flood-control, irrigation and water supply, other than just electricity generation [188].

Table 7
Maximum power capacity of small hydropower plants in different countries [184].

Country	Maximum power capacity
Brazil	30 MW
Canada	50 MW
China	50 MW
European Union	20 MW
India	25 MW
Norway	10 MW
Sweden	1.5 MW
United States	5–100 MW
Malaysia	30 MW

3.4. Tidal energy

Tidal energy (TE) is harnessed by converting kinetic energy from tidal stream into electrical energy [189]. Theoretically, tidal energy is produced by different heads between two water bodies [190]. Tidal currents and tides are intermittent; occurring by semi-diurnal and spring-neap variability, although they are foreseeable like other RE resources such as wind and solar [191]. TE is widely utilized throughout North America's Atlantic coast and in Europe as tide mills centuries ago [192]. There are two current TE technologies, which are hydrokinetic system and oscillating water column. It is believed that tidal power will be enhanced and more cost-effective with greater technology by 2020 [193].

3.4.1. Hydrokinetic system

A hydrokinetic system consists of an electromechanical device which converts the kinetic energy of flowing water into electrical energy, along with a power converter and generator, as shown in Fig. 22 [194]. According to W. I. Ibrahim et al. [195], hydrokinetic system consists of a hydrokinetic turbine which is rotated by flowing water bodies at certain velocity, and a permanent magnet synchronous generator (PMSG) coupled to the turbine which rotates and shafts directly without any gearing system. A power electronic conversion system will convert kinetic energy into electrical energy, which will be stored in batteries or distributed to the grid. No impoundment or reservoir is needed because hydrokinetic system only requires free-flowing water to operate. Due to this small dimension, this system is easy to relocate, and can be installed at riverside, either on floating pontoon or moored to a firm structure [196]. Currently, this technology usually is only installed at fast-flowing water bodies and implemented in textile, paper, and food production [197].

3.4.2. Oscillating water column

Oscillating Water Column (OWC) plant is the most highly developed first-generation typical wave power plant. Each OWC site has its own unique design, as OWC plant is very dependent on the on-site conditions. Several considerations [198] such as local wave climate, geo-morphological constraints and hydrodynamics of wave energy absorption are required to be studied by utilizing wave basin model testing and various modelings, with attention to variables such as rotational speed, electrical power output and time domain analysis, for dealing

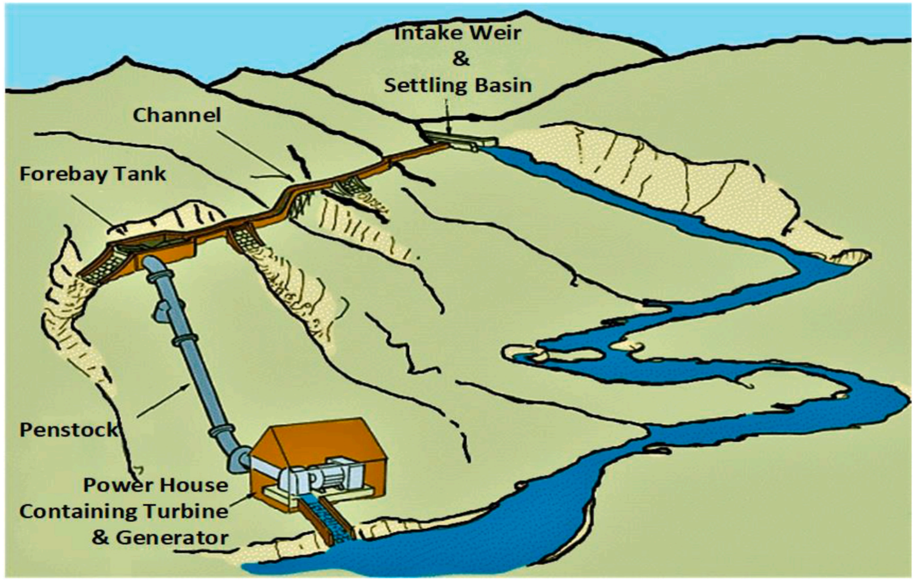


Fig. 20. Small Hydropower System [182].

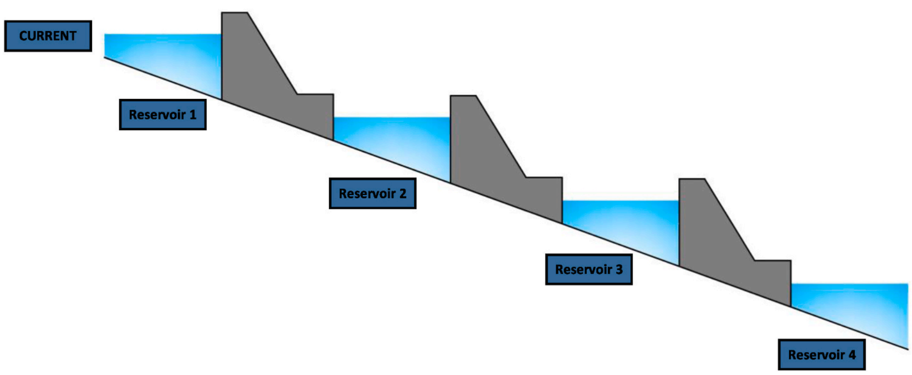


Fig. 21. Cascaded Reservoir Hydropower Plant System [186].

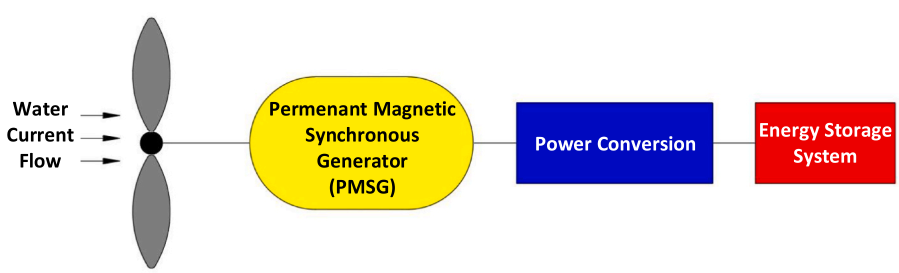


Fig. 22. Hydrokinetic System Structure [194].

with irregular wave's pattern and non-linear power take-off equipment like air turbine [199]. In typical OWC as shown in Fig. 23 [200], the concrete structure of a square chamber is built in-situ on rocky bottom, about 8 m depth of water. The structure of OWC needs to be able to handling various possible loads such as air pressure, hydrostatic loads, and kinetic loads from breaking of wave in front of the OWC. A horizontal-axis turbine connected to a generator is placed above water level to harness the velocity of air molecule transferred along with the wave energy of ocean, which is then converted into electrical energy. A relief valve is installed to prevent excessive pressure across the turbine. According to Sarmanto et al. [201], the significant wave height of sea, H_s cannot be larger than 4.5 m in order to operate OWC plant. Furthermore, a variable-speed turbine controlled by PLC can be installed in OWC plant to receive different velocities of wave energy, as to obtain maximum energy conversion [202]. There are a number of OWC plants in Europe, such as the LIMPET plant at Islay, Scotland [203] and a power plant on the Pico Island, Azores [204].

3.5. Bioenergy

Bioenergy has become an attractive RE that contributes to the heating and transport sector, as well as generation of environmentally friendly electricity [205]. Bioenergy originates from biological raw materials known as biomass, sourced either by traditional or modern

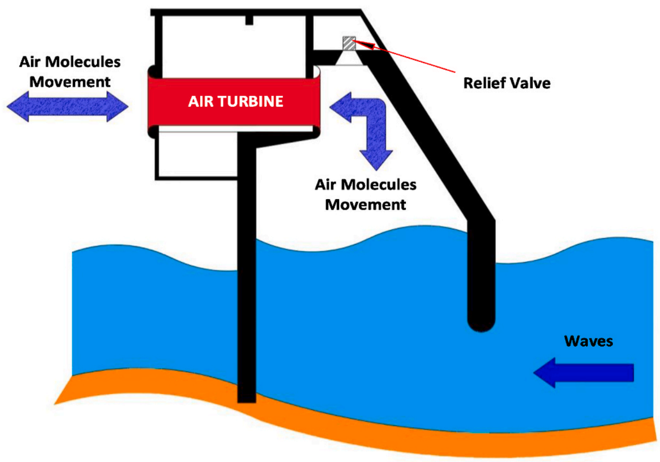


Fig. 23. Section view of OWC power plant [200].

methods [206]. In traditional method, bioenergy comes from agricultural materials such as fuelwood, charcoal, crop residues, and animal secretion, which are then processed for use in urban area. On the other hand, modern bioenergy is applied to generate heat and electricity on several industries with the product of biogas, biodiesel and biochar through various thermal conversion technologies of biomass such as carbonization, torrefaction, gasification, combustion and pyrolysis [207,208]. Fig. 24 shows various thermal treatments of biomass for bioenergy production. Different thermal treatment with different type of biomass will affect the properties of the products obtained [209]. Using biomass for the production of biochar, biofuel and biogas aids in enhancement of sanitation, landfill area reduction, good waste management practice, and various sustainable development achievements [210]. Bioenergy is acknowledged considerably in international, national and regional plans especially for rural growth as it can significantly devote to rustic development [211].

3.5.1. Biomass

The energy in biomass is extracted by combustion and turning chemical energy into heat energy, which in turn used to generate electricity. The energy conversion efficiency of combustion and the energy utilization ability of biomass depends on several variables such as combustion method, type of biomass, and scale application. Table 8 shows three different methods of combustion for electricity generation, which are similar for coal, which are grate firing (GF), pulverized fuel (PF), and fluidized bed (FB) [212]. There are four groups of biomass, which are wood residues, agricultural residues, dedicated energy crops, and municipal solid waste (MSW), as presented in Table 9 [213]. Unlike coal, biomass has low nitrogen content and no sulphur content, thus it has less environmental impacts such as urban ozone pollution and acid rain, as it releases low emissions of NOx and SOx into the atmosphere. In addition, the use of biomass to replace fossil fuels in generating electricity helps in reducing greenhouse gases emission which leads to global warming [214].

3.5.2. Biodiesel

Biodiesel is ester-based oxygenated fuels produced from various biological sources such as processed organic oils and fats [215]. Biodiesel is potential to replace petrol and diesel in our daily activities, especially in the transportation and electricity generation sectors, because biodiesel does not need any modifications for use in engines, besides capability to enhance lubricity of the system [216]. Biodiesel also emits low amount of greenhouse gas [217]. Biodiesel is continuously modified to be more adaptable and attractive to modern energy system in order to ensure energy and environmental sustainability, and

Table 8
Different types of biomass combustion methods [212].

Combustion methods	Description
Grate Firing	Biomass is put on a grate and moved slowly through the boiler to combust with oxygen supplied through holes present in the grate. It is particularly suited for uneven coarse particles sizes.
Pulverized Fuel	Biomass is triturated into powder form, and then combusted. High efficiency of combustion can be achieved and can be applied in large scale power plant. Feedstock needs more energy to grind.
Fluidized bed	Biomass is kept suspended in a mix with incoming air in a medium such as sand. The sand bed's temperature allows a part of gasification to happen. This method can be used for coarse and wet biomass. The benefits of this method is to it releases low amount of NOx and SOx emission by combustion.

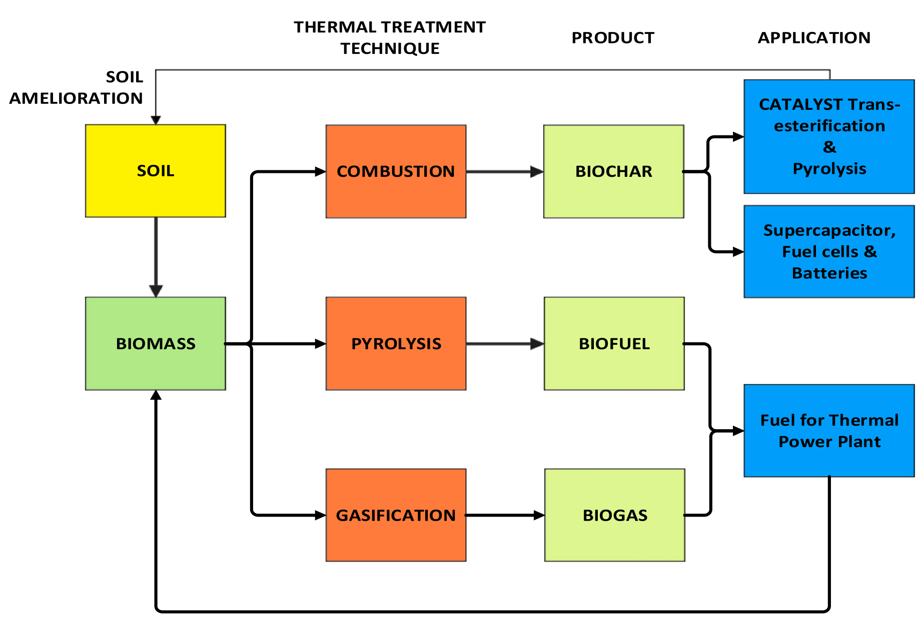


Fig. 24. Thermal treatment of biomass for bioenergy production [210].

Table 9
Resources of biomass by different groups [213].

Group	Resources
Wood residues	- Wood residues from wood product industries - Urban wood wastes - Construction wood residue - Wood packaging waste - Forestry residues
Agricultural residues	- Crop residues - Pruning waste - Food processing waste
Dedicated energy crops	- Short-rotation woody crops - Herbaceous crops
Municipal solid wastes (MSW)	- Paper - Organic food waste

green rural development by replacing petrol in agricultural industry. However, raw vegetable oils may cause problems to engine system due to carbon deposits and coking of injectors on engine head and piston [218]. Therefore, vegetable oils need to be transesterified first to achieve lower viscosity, to qualify as biodiesel for use [219].

3.5.3. Biogas

Biogas is a gaseous end product produced from waste-derived biomass, which is potential as alternative to conventional resources such as natural gas. Biogas consists of CH_4 (~65%), CO_2 (~35%), and trace gases such as N_2, H_2 and H_2S, produced through anaerobic digestion process [220]. The primary substrates to produce biogas in anaerobic digestion process are agricultural residues, crop residues and livestock waste, which are obtainable from nature [221]. Biogas can be processed as fuel to generate electricity, while having 50%–90% less organic pollutants [222]. Application of methane-enriched biogas at thermal power plant releases much lesser amount of greenhouse gases to the atmosphere and environment [223]. One of the benefits of biogas for electricity generation is the use of organic wastes into a useful and environmental friendly product [224]. This can also reduce the pathogens and odor presented in the organic waste by turning organic waste into biogas [225]. Biogas is a promising renewable energy as it can be used both for electricity and heat generation for public grid [226].

3.6. Geothermal energy

Geothermal energy is thermal energy from the radioactive decay of mineral resources and from primitive structure of the planet Earth [227]. Generally, geothermal gradient increases by 0.03 C m-1 according to depth of the earth, thus 99% percent of the temperature of Earth is higher than 1000 °C [228]. Compared to other intermittent RE resources such as solar energy, wind energy and hydro energy, geothermal energy inside the Earth is rich and inexhaustible [229]. Besides that, geothermal energy is naturally stable and has no emission of CO2 [230]. Geothermal energy has great economic potential in areas along with hydrothermal energy especially in countries with active volcanoes [231]. Nowadays, there are approximately 26 countries that utilize geothermal energy for generation of electricity [232], such as United States of America, Indonesia, Philippines, Mexico, Italy, Iceland, New Zealand, and Japan [233]. There are two main groups of geothermal power plants, which are steam and binary power cycles based plants [234]. In order to reduce heat loss of geothermal energy in thermally insulated pipelines, most geothermal plants are built and operated nearby their resources, usually not more than 10 km [235]. Development performance and implementation of geothermal energy have significantly enhanced through modernization of traditional idea and concepts in last few years.

3.6.1. Organic rankine cycle

A binary cycle is also known as organic rankine cycle (ORC), implemented where geothermal energy resources have chemical or mineral impurities that allow flashing or when the geothermal energy resources do not have adequately high temperature to generate steam [236]. One of the significant benefits of ORC is that it runs at lower temperature and puts low mechanical stress on turbine. Besides that, no erosion has been reported in the current ORC application because of the absence of moisture related to vapour expansion of the turbine. There has also been no leakage issue as it operates in vacuum condition [237]. As comparison, ORC power plants releases null CO_2 emissions, while a flash steam power plants releases about 27 kg/MWh CO_2 emissions into the atmosphere [238]. Fig. 25 shows the flow chart for binary cycle [239]. Firstly, geothermal fluid enters station s1 at the inlet temperature. None of the non-condensable gases will be removed from liquid, and no gas extraction system is needed if the pressure of the source is sufficiently high. A vaporizer vaporises the fluid. The vapour will be transferred to station 3, and then sent to the turbine. The exiting vapour from the turbine enters the regenerator at station 4 in order to pre-heat the condenser fluid, before going to station 2 and the vaporizer. Excess fluid will be cooled down at the vaporizer, and then transferred for re-injection at station s2. At station 5, vapour is cooled down, and then transferred to station 6 to condense into saturated liquid, with the aid of cooling air entering the condenser from station c1 and released at station c2. After that, the saturated liquid enters the circulation pump, thus the pressure increases to high pressure level at station 1.

3.6.2. Steam power cycle

Steam power cycle consists of two groups, which are single flash-system and double-flash system. A single-flash system flashes and separates steam and water of geothermal fluid from production well before transferring the steam to the steam turbine, while double-flash system flashes again the separated water as the water still consists of sufficient thermal energy, now into low-pressure steam, and which is then transferred to low-pressure steam turbine to generate more electricity.

(a) Single Flash Cycle

Fig. 26 shows the flow chart of single-flash cycle [239]. Geothermal fluid is collected from the production well at station 1, and then boiled when it is transferred to the separator at station 2. After that, the brine from the separator is transferred to station 3 to re-inject into the well, while the produced steam is transferred to steam turbine at station 5. After the steam is expanded through steam turbine, the condenser cools down the steam at station 6 with the aid of cooling air entering the condenser from station c1 and released at station c2. The steam is then

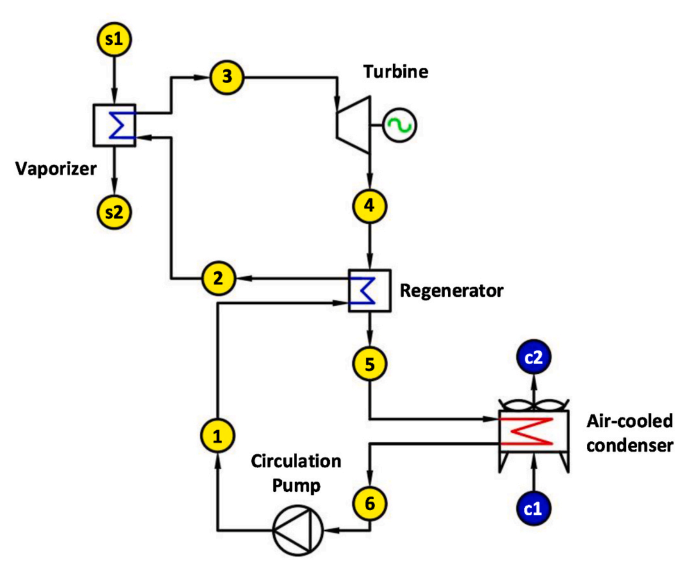


Fig. 25. ORC cycle flow diagram [239].

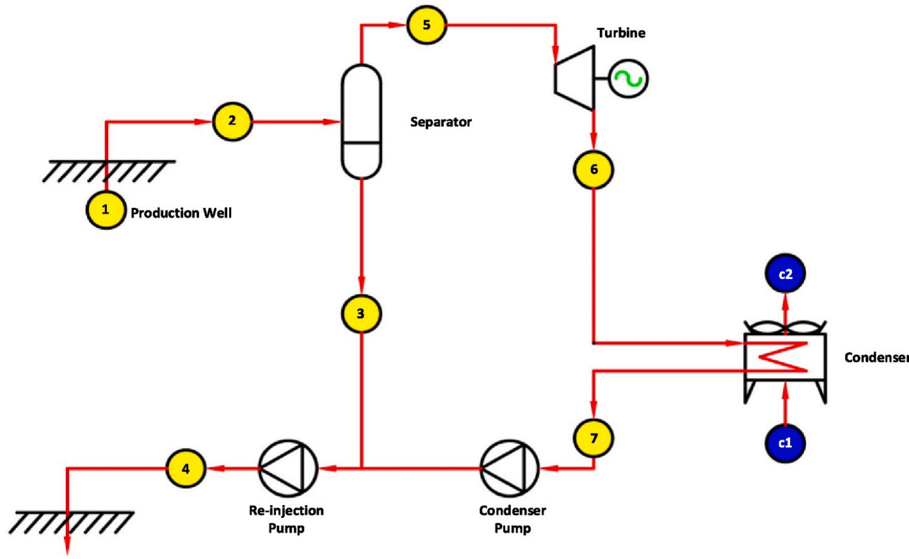


Fig. 26. Single Flash Cycle Flow Chart [239].

(a) Double Flash Cycle

transferred into condenser pump at station 7. Lastly, the condensed fluid is re-injected into a well at station 4.

Fig. 27 shows the flow chart of double-flash cycle [239]. First, geothermal fluid is collected from the production well at station 1, and then boiled when it is transferred to high pressure separator at station 2. The brine from the separator is sent to station 3, for consequent transfer into low pressure separator at station 8 through throttling valve, while the steam is directly transferred to the steam turbine at station 5. The steam produced from the low pressure separator is then sent to turbine at station 8. At the same time, the brine is collected at station 10, and then re-injected at station 4. After the steam is expanded through steam turbine, the condenser cools down the steam at station 6, with the aid of cooling air entering the condenser from station c1 and released at station c2. The steam is then transferred into condenser pump at station 7. Lastly, the condensed fluid is re-injected into a well at station 4.

3.7. Hydrogen energy

Hydrogen energy is known as a non-toxic and clean energy carrier that contains high specific energy on mass basis. For instance, the energy content of 9.5 g hydrogen equals to 25 g of gasoline [240]. Hydrogen energy can stored for electricity generation. Through direct or electrolytic methods, hydrogen is stored for a period of time before release, to obtain chemical reaction to generate electricity [241]. Fig. 28 shows the various process of H_2 generation [242]. There are many ways to produce hydrogen energy, such as water electrolysis, gasification of coal and other heavy hydrocarbons, direct and indirect thermochemical decomposition, and processes driven directly by sunlight [243,244]. Hydrogen energy sustainable since it can be generated from renewable and non-renewable energy sources [245], thus can be utilized in various sectors such as transportation, commercial, institutional, and residential [246]. The role of hydrogen energy will become more significant and may lead energy systems into generation where the primary energy carriers are electricity and hydrogen [247]. Moreover, the by-product, water vapour produced from hydrogen energy in fuel cell is harmless. Due to its high energy content compared with other types of fuel cells, hydrogen energy is utilized widely in power generation system as alternative fuel cell, as well as to power gas turbine and hydrogen plant [248].

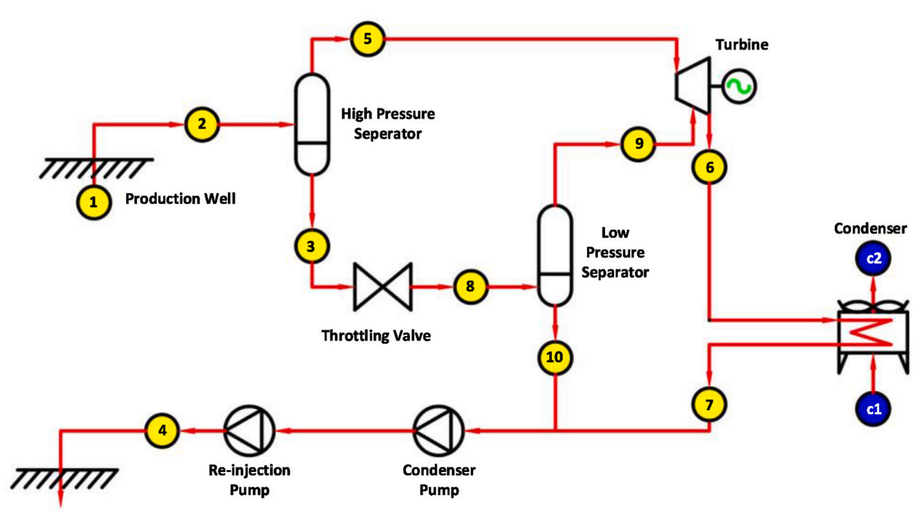


Fig. 27. Double Flash Cycle Flow Chart [239].

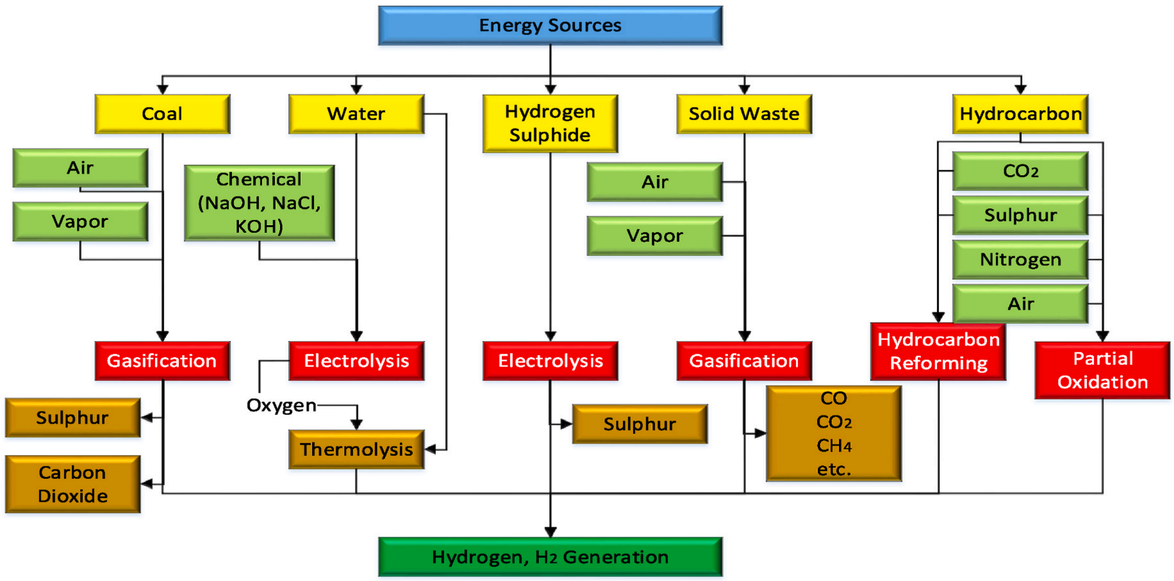


Fig. 28. The process of hydrogen, H_2 Generation [242].

3.7.1. Hydrogen fuel cell

A fuel cell (FC) normally serves as storage system with electrochemical reaction to generate electricity. Fuel cells have been utilized in non-linear load applications such as motor drives, power electronics devices, electric arc furnaces, and switch-mode power supplies [249, 250]. Different from common batteries, a hydrogen fuel cell requires constant supply of oxygen and fuel sources such as H_2, methane and alcohols to operate and produce electricity continuously. Fig. 29 shows a typical configuration of polymer electrolyte membrane fuel cell (PEMFC) [251]. There are three fundamental elements of PEMFC, which are anode, cathode, and catalytic electrolyte to aid in the process of changing chemical energy into electricity. Anode, which is a negatively charged component in fuel cell functions as a conductor of the free electron associated with hydrogen fuel, while cathode which is a positively charged component in fuel cell, allows the charge to flow through some load. The anode is connected to the cathode through a catalytic component in order to allow hydrogen to combine with oxygen at the end of the process to form harmless by-product, which is water. The electrolyte is made from a material that has positively charge ions to force electrons to flow through the external circuit to the load to produce electricity [252]. However, the operating conditions such as temperature and suitable fuel type rely on the materials utilized, like electrolyte and electrode catalysts. Additionally, FC is categorized according to the type of electrolyte employed. There are five main groups of FC currently in much interest of development by researchers. Table 10 shows the general characteristics of major fuel cell technologies [253]. The efficiency of FC can reach 60% in term of energy conversion into electricity, and 80% by co-generation with thermal and electrical energies, besides 90% lesser environmental pollutant emission, compared to conventional method of electricity generation [253]. Lastly, the advantages and disadvantages of major FCs have been demonstrated in Table 11.

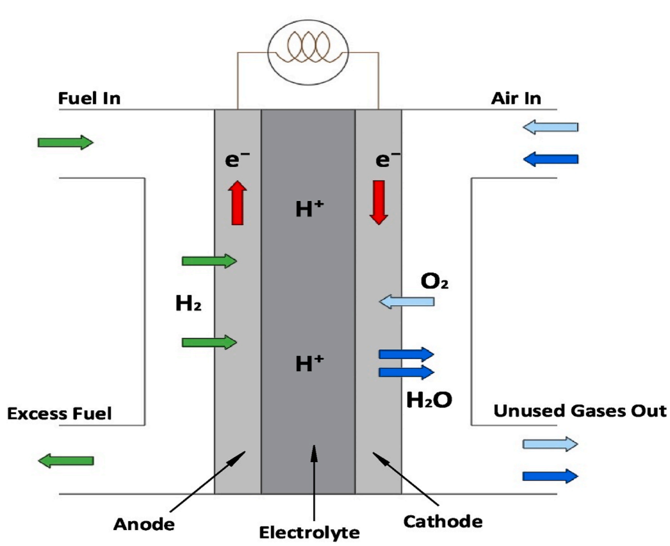


Fig. 29. Typical Configuration of PEMFC [251].

3.7.2. Hydrogen gas turbine

One of the efficient ways to generate electricity at large scale from gaseous fuel is by implementing gas turbine engines. Based on the accumulative knowledge on traditional gas turbine technologies, a hydrogen gas turbine with high efficiency of energy conversion has been introduced, which requires minimal researching and producting cost [271]. In addition, electricity generation by hydrogen gas turbine does not produce the emission of CO_2 and NO_x [272]. Three types of hydrogen gas turbine applications are currently implemented [273], which are integrated gasification combined cycle (IGCC) power plants, power plants using pre-combustion CO_2 captured by Carbon Capture and Sequestration (CCS) context, and power plants in a fully developed RE based society in which hydrogen energy is utilized as secondary energy or energy storage for integrated power system of wind, solar, or other intermittent RE sources. Recently, a new concept of thermal cycle has been proposed, also based on hydrogen gas turbine, which is combination of hydrogen turbine and steam turbine in series with aid of water photolysis pool (WPP) [274], as shown in Fig. 30. By this method, firstly, water is decomposed into hydrogen and oxygen through WPP with the aid of solar energy. The generated hydrogen is then sent into a hydrogen heat exchanger (HHE) to heat up into expanded hydrogen before entering the gas turbine. After that, the expanded hydrogen is sent into a hydrogen-oxygen combustor (HOC), to combust with pure oxygen generated from WPP to produce steam with high temperature. Partial heat energy produced in the HOC is used to heat up hydrogen in HHE. Meanwhile, the steam produced is then sent to the steam turbine to generate additional power. After that, the used steam is condensed into water and transferred to WPP.

Table 10
Typical charactericstic of major FC technologies [253].

Type of Hydrogen Fuel Cells	Solid Oxide FC (SOFC)	Polymer Electrolyte Membrane FC (PEMFC)	Phosphoric Acid FC (PAFC)	Molten Carbonate FC (MCFC)	Alkaline FC (AFC)
Electrolyte Type (ion/media)	O^{2-} or ceramic matrix with free oxide ions	H^+ or ions conducting polymer membrane	H^+/H_3PO_4	CO_3^{2-} or mixture of molten alkaline carbonates	OH^- or KOH aqueous solution
Typical materials used	Ceramic, High temperature metals	Metal, Carbon, Plastic	Ceramic, Carbon	Ceramic, High temperature metals	Metal, Plastic
Fuel	H_2 or reformate gas	H_2 or Methanol	H_2 or reformate gas	H_2 or reformate gas	H_2
Internal Reforming Oxidant	Yes	No	No	Yes	No
Working Temperature (°C)	750–1000 °C	25–85 °C	190–210 °C	650–700 °C	90–260 °C
System Electric Efficiency, % of HHV$^+$	45–55%	25–45%	35–45%	40–50%	30–40%
Total System Efficiency, % (Electrical + Thermal) of HHV$^+$	68–77%	60–75%	69–80%	60–65%	65–68%
Main Sensitivities to Contaminants	Sulphur	Sulphur, CO, NH_3	Sulphur, CO if over 1%	Sulphur	Sulphur, CO, CO_2

Table 11
Advantages and disadvantages of major FC.

Type of Hydrogen Fuel Cells	Advantages	Disadvantages
Solid Oxide FC (SOFC)	Able to reduce the electrolye management problems [254] - High efficiency - Able to operate with a variety of catalysts [254] - Fuel Flexibility [255]	- High operating Temperature [256] - Several requirements on ceramics material such as chemical compatibility, thermal expansion compatibility, and stability in oxidating and reducing conditions [257]
Polymer Electrolyte Membrane FC (PEMFC)	- Able to reduce electrolyte management problems & corrosion [254] - Quick start-up with low temperature [258]	- High cost [259] - Complex bipolar plate design [259]
Phosphoric Acid FC (PAFC)	- High tolerance to the impurities in hydrogen [260] - High efficiency [261]	- Lesser power produced compared to other FC [262] - Short lifetimes [262] - High manufacturing cost [263]
Molten Carbonate FC (MCFC)	- Able to reduce the electrolyte management problems - High efficiency [264] - Able to operate with a variety of catalysts [265]	- High manufacturing cost [266] - Short lifetime [264]
Alkaline FC (AFC)	- Able to operate with a variety of catalysts [267] - Faster cathode reaction in alkaline electrolyte, thus high performance [268]	- Short lifetime [269] - Pure oxygen and pure Hydrogen is required to supply continuously [270]

4. Energy Storage System

Energy storage system (ESS) plays an important role in sustaining RE, especially for wind and PV energy, for the purpose to control and manage power supply due to the intermittency nature of RE [275]. ESS has the potential to become the leading RE technology in microgrid development [276], since it is a feasible alternative to reduce uncertainty of energy generation [277]. ESS has been used in ancillary services [278], reliability advancement [279], and transmission overcrowding remission [280]. In ESS, excessive electrical energy can be converted into various forms for storage, as shown in Table 12 [281]. In addition, ESS for shifting of energy time can contribute to profit increment [282]. At night, wind power output is normally high, thus the electricity cost is low. In contrast, wind power output is low during daytime, and the electricity cost is high. For solar energy, the radiation energy output is generally high at daytime, but low at night. Therefore, the electricity cost is low during day but high at night. If the renewable energy is stored using ESS during high power output which has lower cost and then released back to the grid during peak time, this brings in profit, and transmission congestions can be alleviated. In order to achieve this, ESS implementation should be continuously and properly managed hour-to-hour to suit renewable energy's market price. Therefore, a stochastic dynamic programming (SDP) framework, which is a mathematical tool that is able to estimate hourly policy, has been proposed to solve this problem, along with increasing the storage's efficiency [283]. Overall ESS should achieve a good balance between revenue and cost [284].

5. Hybridization of renewable energy sources

Each RE resource has its own limitations and conditions, which include reliability, intermittency and discontinuity in energy supply. Thus, hybrid renewable energy system (HRES) is introduced to overcome the drawbacks of RE [285]. Plus, it allows the opportunity to use multiple RE resources available at a certain location. HRES combines two or more energy sources with at least one RE, which can be operated by grid connection or standalone mode [286]. For standalone mode HRES, it is commonly implemented for distant energy production and electrical distribution system in rural areas such as villages, small islands, telecommunication and meteorological stations, and research laboratories [287]. Grid connected HRES is widely operated in connection with distributed generation at developing and developed places such as city, residential and commercial area. Fig. 31 shows typical configuration of HRES, which consists of energy sources, power converters and loads. Specific configurations of HRES such as DC coupled, AC coupled, and hybrid coupled system are chosen based on different applications [288]. DC coupled system that contains DC sources and DC loads is operated by DC micro-grid as it does not need to synchronize the system, while AC coupled system that comprises AC sources and AC loads is usually used in defense applications and by AC micro-grid. Comparatively, hybrid coupled system, which consists of either AC or DC source, has even higher efficiency and is more flexible compared with the two aformentioned configurations [289]. Besides that, control operation performed by different requirements of HRES is constantly assessed through simulation and experimental outcomes in order to achieve steady state and transient conditions [290]. Table 13 shows the type of converters and controllers utilized in HRES [288]. One of the significant benefits of HRES is higher efficiency and optimum operating conditions by combining two or more RE technologies. In addition, the power converter utilized by HRES is able to convert uncontrolled power generated from RE sources into suitable useful application at the end load [291]. One of the major aspects of creating HRES is to optimize the system cost per kW capacity and LCOE. The LCOE of different type of HRES which was studied recently by the researchers worldwide is shown in Table 14. The summary in the table shows that the LCOE of a HRES can be as low as 0.05 $/kWh whereas, the lowest LCOE of a single RE source is 0.057 $/kWh. Lastly, HRES can overcome

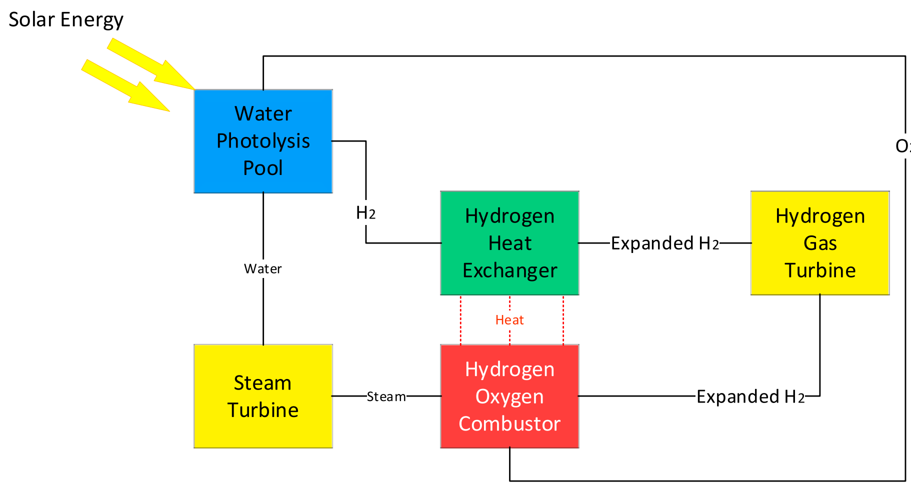


Fig. 30. Structure of combined hydrogen gas turbine and steam turbine system [274].

Table 12
Different form of energy for energy storage system [281].

Energy Storage System (ESS)	Description	Form of energy
Pumped hydro storage (PHS)	Generates electricity by principal of hydro turbine flow, with an auxiliary flow machine, a conversion block that stores or discharges energy by controlling the water flow process, lower and higher aquifers.	Potential energy
Battery energy storage system (BESS)	Battery is recharged by internal chemical reaction and discharged when this internal reaction is reversed	Electrochemical energy
Flow battery energy storage system (FBESS)	Rechargeable energy is stored as electrolyte by dissolving two different chemical components in liquids.	Chemical energy
Hydrogen-based energy storage system (HESS)	Chemical reaction between exogenously supplied reactants, such as hydrogen and oxygen, produces electricity.	Chemical energy
Flywheels energy storage system (FESS)	Kinetic energy of rotational mass is stored by the use of flywheels. Discharge process begins when a generator is connected to the flywheel, and the system is recharged when a torque is applied to flywheel.	Kinetic energy
Superconducting magnetic energy storage (SMES)	DC flowing through a superconductive coil is cooled down lower than the critical superconducting temperature, using liquid nitrogen or helium in order to generate magnetic field to store energy	Magnetic energy
Supercapacitor energy storage system (SESS)	Double-layer capacitors that contain two carbon electrodes are isolated from each other by a porous membrane. The entire components are immersed in an electrolyte to allow ions to flow between the electrodes.	Electrical energy
Compressed Air Energy Storage (CAES)	Grid surplus is utilized to compress the air aboveground or underground reservoir, and then the compressed air is discharged by heating. The expanding air is sent to a turbogenerator to produce electricity	Thermal energy

the limitations of individual RE sources in terms of energy efficiency, reliability, fuel flexibility and emissions [291].

6. Challenges and suggestions

Renewable energy is gradually becoming the major source of electricity generation in low-carbon energy economies. Appropriate alternatives should be integrated to current conventional energy system to allow corresponding RE sources to involve. It is undeniably challenging to implement the transition of energy from non-sustainable to RE [316], as there are major technology challenges to overcome, although there is growing trend of RE applications [317]. Essentially, most of the limitations of REs are due to their natural characteristics. Table 15 shows the limitations of each RE type which are yet to be solved.

6.1. Challenges

Currently, subsidies and support for the implementations of RE are constantly developing among industry, governmental and non-governmental organizations. Authorities are seeking for the agendas of environment, energy and development at different, local, regional and global scales in order to expand the policy, economy and production of RE across developed and developing countries [327]. Most developing countries rely majorly on hydropower, which is cost-effective and highly efficient, while countries with rich RE resources are progressively moving towards sustainability measures [328]. There are also complex challenges in different aspects faced by developing RE markets, industries, and policies. One of the significant impediments of RE implementation is the reservation of fossil fuel, which disperses the attention of the relevant authorities and society to concern about the importance of RE. Most authorities are more willing to provide subsidy for fossil fuel development instead of RE [329], due to advanced technologies of fossil fuel and nuclear energy, compared to REs which are mostly still under developing phase in terms of market, policy, and technical perspectives. Lack of financial supports and funds from government is also a barrier in introducing, exploiting, and promoting RE utilization. Besides that, developing countries are in short of approaches to adjust the price discrepancy between fossil fuel and RE, in addition to lack of RE policy implementation. Developing countries are also inexperienced in handling serious adverse environmental issues that might come from RE power plants which collapse from external financial or environmental shocks [330]. Therefore, fossil fuel is still preferred as the main resource to generate electricity in developing countries although they are rich in RE resources.

On the other hand, countries with high gross domestic product per capita and high concern of energy sustainability usually have the

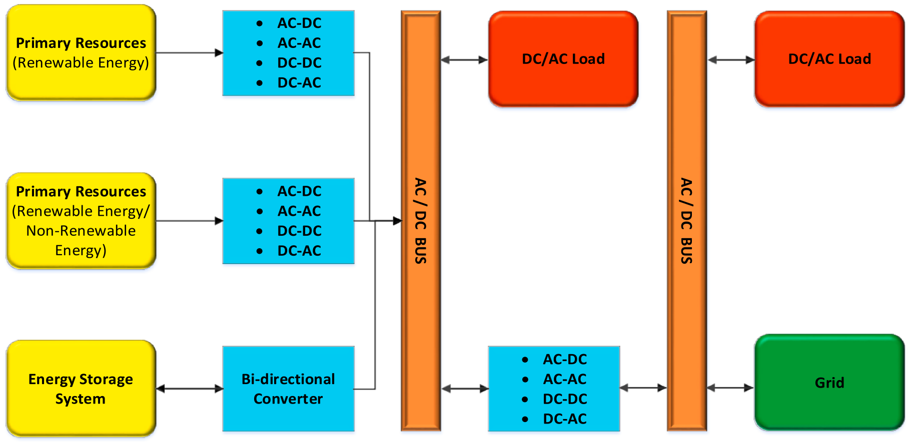


Fig. 31. Typical configuration of HRES [288].

Table 13
Type of converters and controllers utilized in HRES.

Sources	Power Converter	Controllers	Grid-connected (GC)/Stand-alone (SA)	Features	Ref
Wind/PV	Boost	Hysteresis	GC	Connected to the grid with single DC-DC converter, followed by an inverter	[290]
Wind/PV	Cuk	Proportional Integral (PI)	GC	Cost-efficient on reducing power converter size, by reducing of non-essential components.	[292]
Wind/PV	Boost	Proportional Integral (PI)	GC	Optimum power obtained by considering variation of solar radiation and wind speed	[293]
Wind/PV	Buck/Boost	Proportional Integral (PI)	GC	Able to deliver generated power individually or simultaneously from wind and PV sources with multi-input inverter to the grid	[294]
Wind/PV/Diesel-engine	Boost	Proportional Integral (PI)	GC	Fast and stable response for real power control	[295]
Wind/PV/flywheel	Boost	Proportional Integral (PI)	GC	Designed for residential implementation and able to satisfy energy demand with an efficient energy storage system	[296]
Wind/PV/battery	Boost/Buck	Proportional Integral (PI)	GC	Grid service provider	[297]
Wind/PV/battery	Boost	Proportional Integral (PI)/Hysteresis	GC	Consists of supervisory control strategies for versatile power transfer	[298]
Wind/PV/fuel cell	Boost	Proportional Integral (PI)	GC	Able to produce 35 kW power at peak capacity, and at least 10 kW power under bad environmental condition	[299]
Wind/PV/fuel cell	Boost	Proportional Integral (PI)	GC	Able to deliver power with improved reliability, compared to single source	[300]
Wind/PV/fuel cell	Boost	General Regression Neural (GRNN)/Radial Basis Function Network-sliding Mode/ Proportional Integral (PI)	SA	Able to supply reactive power with static var compensator and adjustable output voltage of HRES	[301]
Wind/PV/fuel cell/battery	Buck/Boost	Neuro-fuzzy Inference System (ANFIS)/ Proportional Integral (PI)	GC	Able to provide more power to the grid with ANFIS based EMS	[302]
Wind/battery/supercapacitor	Boost	Proportional Integral (PI)	SA	Entire remote area is simulated in order to operate under different condition	[303]
Wind/PV/superconducting magnetic energy storage (SMES)	Boost	Proportional Integral (PI)	GC	Able to overcome the fault ride with SMES system through capacity of HRES	[304]
PV/fuel cell/battery/ supercapacitor	Buck	Microcontroller	GC	Adjustable output voltage of each component by buck converter with type III compensator	[305]
Wind/PV/fuel cell/flywheel/ micro-turbine	Buck/Boost	Fuzzy/Proportional Integral (PI)	SA	Fuzzy logic pitch controllers are used to smoothen wind power output	[306]

capability and supportive funds to research and implement RE; concurrently enhancing the overall economic growth and energy security [331]. The cost of innovating and researching RE resources is tentatively high during initial development stages, and only front-runner countries are willing to engage and absorb it. Moreover, developed countries often serve as pioneer in setting up new policies, while developing countries adapt support policies, with enhancement by addition of various specific regulations [330]. Selection of RE to be implemented in a country can be determined through the introduction and promotion of specified support policies to a large degree of community [332]. Nonetheless, the purpose of RE application is to ameliorate the quality of life of distant and rural populations, and to eliminate adverse environmental impacts caused by fossil fuel usage.

6.2. Suggestions

Innovation and research are continuously going on to improve and develop the current state of RE in terms of economic, technical, and energy conversion efficiency. Technological learning plays an important role to a country in order to achieve higher implementation rate of RE. Progress needs to be continuous since the RE technology is also advancing globally. The global market knowledge and trends of RE

Table 14
LCOE of different type of HRES.

Sources	Capacity	LCOE	Reference
PV/Biogas/Battery	3 kW	USD 0.17 kWh	[307]
PV/FC/Battery	5 kW	USD 0.57/kWh	[308]
PV/Biomass/FC	1.2 MW	USD 0.061/kWh	[309]
PV/Wind	2.3 MW	USD 0.123/kWh	[310]
PV/Wind/Diesel	4 MW	USD 0.23/kWh	[311]
PV/Wind/Hydro	5 MW	USD 0.091/kWh	[312]
PV/Fuel Cell	47.3 MW	USD 0.49/kWh	[313]
PV/Wind/Biomass	50 MW	USD 0.05744/kWh	[314]
Wind/STE/Electric Heater	395 MW	USD 0.176/kWh	[315]

Table 15
Limitations of renewable energy.

Renewable Energy	Negative Impact	Limitation	References
Solar Energy	Release of toxic chemicals used in heat transfer system into the river system.	Water scarcity in arid regions	[318]
	Use of toxic chemicals (CdS& GaAs) in PV system	Disposal and recycling of highly toxic materials can bring negative impacts to the environment for centuries.	[319]
Wind Energy	Birds colliding with the supporting towers and rotating blades	Adverse ecosystem	[320]
	Noise pollution	Social health issues and adverse ecosystem	[321]
Hydro Energy	Changing hydrologic characteristics	Affects river body's ecology by disturbing the ecological continuity of sediment transport and fish migration.	[181]
		Artificially created structure leading to flooding of the former natural environment.	[322]
Bioenergy	Release of chemical pollutants	Air Pollution	[323]
	Overexploitation of forest	Soil erosion, Vegetation Degradation	[324]
	Diversion Of crops or land	Increase of Food commodity prices and risks of food security	[325]
Geothermal Energy	Hydrogen Sulfide production	Air Pollution	[326]
	Release of toxic metal (arsenic, boron, lead, mercury, radon, and vanadium)	Disposal and recycling of highly toxic materials can bring negative impacts to the environment for centuries	[326]

essentially helps in the development of technological capacity in various industries beyond domestic tendency [333]. Technological knowledge and experience are essential for poverty reduction, socio-economic enhancement, and local production capacity increment [333]. Developing technological skills through learning process is very much encouraged in ensuring performance improvement, cost-effectiveness, and mitigating climate change [334].

Proper and suitable policy is needed to overcome the barriers of RE implementation. The selection of policy instruments and sectors need to meet the objectives of each country based on its specified priorities toward socio-economic development, environmental protection, and financial resources allowances [335]. Policy tools to estimate costs and risks are required to involve multiple complex considerations of renewable resources availability, local market organization and objectives in order to avoid disproportionation of policy approach [336]. In addition, RE production in developing countries has a strong relationship with the regulatory policies and economic instruments [337]. Therefore, an effective RE policy should be enforced by the government and be considered with the interconnection of elements affecting RE sustainability and supplies [338].

Lastly, the achievement of deploying new and advanced technologies relies on the capability to build, control, and sustain energy infrastructure, while involving decision makers, researchers, and manufacturers at both national and international levels [339]. There is also a need of constant trade-off between economic growth and environmental protection in order to achieve beneficial status [340].

7. Conclusion

Environmental issues such as climate change, global warming, and ozone layer depletion have become more severe/catastrophic/devastating. To solve the problem, more developing and developed countries are collaborating to increase the usage of renewable energy technologies. In doing so, various researches and innovations need to be carried out, and introduction of newer methods and components is very much welcomed for more efficient and affordable renewable energy-based power generation. This article reviews the current situation of renewable energy sources development and their limitations, as well as suggestions to overcome those limitations. It is believed that most of the limitations of each renewable energy can be overcome in the near future if the suggestions are accepted for consideration. Apart from technological advancement, to avail the benefits of renewable energy, affordable costing, incentives, friendly regulations, and social awareness and acceptance are required. Governments and non-governmental organizations need to play important role in these aspects. Further researches are also necessary to include these factors to ensure suitable selection and proper implementation of renewable energy resource based on location.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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