A review of different configuration of hybrid energy systems with case study analysis

Uttara Das, Sarbani Mandal, Somudeep Bhattacharjee and Champa Nandi*

Department of Electrical Engineering,
Tripura University,
Suryamaninagar, Tripura, India
Email: uttarad1995@gmail.com
Email: sarbani9774@gmail.com
Email: somudeeptit812@gmail.com
Email: cnandi@tripurauniv.in
*Corresponding author

Abstract: Increasing energy demand worldwide is directly related to the power generation process. Carbon emissions cum greenhouse gas emissions have direct contact with global warming and climate change. Energy generation from conventional power plants is the cause of a huge amount of environmental pollution. Different renewable energy sources are a great option to fulfil all the criteria as these are cost-effective, environment-friendly and abundantly found in nature. But renewable energy sources are varied in nature and for overcoming this problem; renewable energy-based hybrid system is a better solution. This paper reviews various challenges and recent developments in the area of the hybrid renewable energy system and also reviewing a backup system like pumped hydro energy storage system (PHES). We also discuss some real-world case studies of renewable energy-based hybrid power plants adopted in various parts of the world. This paper concludes with suggestions for future research opportunities in this field.

Keywords: renewable energy; hybrid system; greenhouse gas reduction; cost-reduction; backup system; pumped hydro energy storage system; PHES.

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Biographical notes: Uttara Das received her Diploma degree in Electrical Engineering from Dhalai District Polytechnic, Ambassa, Tripura, India in 2015. She received her BE degree in Electrical Engineering from Techno India Agartala, Agartala, Tripura in 2018. Currently, she is pursuing her MTech in Electrical Engineering from Tripura University, Tripura, India. Her research interest includes renewable resources, conventional energy, hybrid system, control technologies, energy management system, power system protection, power flow control, power system optimisation, demand-side management, cost analysis, different communication technology, climate change due to global warming, smart grid and microgrid.

Sarbani Mandal received her BE degree in Electrical Engineering from Tripura Institute of Technology, Narsingarh, Tripura, India. Currently, she is pursuing her MTech in Electrical Engineering from Tripura University, Tripura, India. Her research interests include voltage stability improvement in power system, hydro power plant, wind power plant, solar power plant, different renewable energy sources, environmental pollution and global warming, power factor improvement, economic benefits of hybrid renewable energy sources, and environmental impacts of conventional energy sources.

Somudeep Bhattacharjee received his BE degree in Electrical Engineering from Tripura Institute of Technology, Narsingarh, Tripura, India. He received his MTech degree in Electrical Engineering from Tripura University, Tripura, India. Currently, he is pursuing his PhD in Electrical Engineering from Tripura University, Tripura, India. His research interests include hybrid power plant, micro-grid protection, climate change, chaos, communication, renewable energy resources, electric vehicle, solar energy, wind energy, bioenergy, hydro energy, energy management system, smart grid, cost analysis of hybrid energy system, feasibility analysis of hybrid energy system, and optimisation analysis of hybrid energy system.

Champa Nandi received her BE degree in Electrical Engineering from Tripura University, Tripura, India in 2004 and MTech in Electrical Engineering from Tripura University, Tripura, India in 2008. From 2008 to 2010, she served as a Lecturer at the Department of Electrical Engineering in N.I.T. Agartala. She received her PhD from N.I.T. Agartala on May 2016. She is serving from 2010 to till date as an Assistant Professor for the Department of Electrical Engineering Tripura University, Tripura, India. Her research interest includes renewable-based hybrid energy, microgrid protection, controller design, energy management controller and FACTs controller.

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1 Introduction

Globalisation is the cause of the rapid increase of industrialisation, use of more energy in urban areas due to new technology turns energy demand uncertain. Conventional power plants like thermal, nuclear power plants produce huge pollution. Combustion of coal releases nitrogen oxide, sulphur dioxide, particular matter (PM), mercury, and dozens of other substances. These substances are hazardous to human health. Moreover, the limited availability of fossil fuel makes energy generation unpredictable. Combustion of high price fossil fuel has made harmful carbon emission and has led to the high energy gap between demand and generation due to the rise of population. Now, it is necessary to equalise the gap and cut down the use of high price fuel to enhance the dealing of a clean environment. Thus, renewable energy resources are a better alternative solution for energy generation (Bajpai and Dash, 2012; Venkateshkumar et al., 2018; Air Pollution from Coal-Fired Power Plants, 2019).

Due to air pollution, 9 out of 10 people’s breath contains high level of pollutants. Air pollution kills thousands of people in every year (Air Pollution, 2020). Air pollution is

the cause of 9% deaths in the world. Rates of death due to air pollution are highest in the countries where income is at a low-to-middle level (Air Pollution in the World, 2020). It is found in some research that almost 32% of air pollution occurs due to electricity generation in the USA (Learn about Carbon Pollution from Power Plants, 2020). Another study has been said that Egypt is the most polluted country in the world. After Egypt, India is in the second position. China placed in the third as the most polluted country in the world (Tawfeek, 2018). A study says that 30% emission of CO_2 emits from the coal-fired power plant of China (Sonnenberg, 2014). In research, it is found that air pollution is a major problem in India. Various industries are the reason for 51% of pollution of India, where 27% is from vehicles, 8% is due to crop burning and 5% is due to Diwali fireworks. About 2 million premature deaths occurred every year because of air pollution in India (Air Pollution in India, 2020).

So, the world needs to focus on renewable energy resources for power production instead of non-renewable energy sources to control air pollution. Renewable energy resources such as wind, sun, water, sea, biomass, etc. have a consequential chance to use the inefficient energy in contrast to other energy resources. Efficient energy use stands for providing proper production as well as service with less amount of energy. To access cheap energy and comfort economy, it is required to the rapid disposition of renewable energies and their technological diversification. Renewable energy helps to improve public health by reducing pollution and saves several hundred billions money from the associate health cost. It is expected that renewable energy which is directly or indirectly related to the sun, hydro, wind, would supply power for more than one billion years even when the earth's surface becomes too hot for exist of liquid water (Renewable Energy, 2019).

When Earth gave a new weather pattern by changing its climate system for at least few decades, then it's called climate change. The Sun is the predominant asset of energy for the change of climate system and this climate gets warm when the incoming energy is greater than earth released energy. It is found that billions of years ago the sun emitted only 75% power as it does now. Although, it is very much important to understand the benefit of reduction of greenhouse gas emission for climate change. The high amount of global greenhouse gas emission affects the energy sector by heavily changing temperature and precipitation. Hydropower generation faces numerous troubles under climate change conditions caused by an increase of variation in precipitation, river run-off, and the rise of evaporation. Under favourable circumstances, renewable energy can contribute to the mitigation of climate change, improvement of public health, secure energy generation and supply and overall social-economic developments (Boehlert et al., 2016; Climate Change, 2019; Renewable Energy Sources and Climate Change Mitigation, 2019).

Single source systems of renewable resources have to encounter different difficulties, which can be overcome by two or more integrated renewable energy systems called hybrid systems to provide higher quality and more reliable power to the customer. The hybrid system can use as grid-off or grid-connected. The grid-off or standalone system needs to generate power and sufficient storage system to handle the load. On the other side, the grid-connected system requires a comparatively small storage system because the demand is fulfilled by the grid. Thus the grid-connected hybrid system can give and get energy from the grid. However, voltage, frequency, load, harmonics of the grid-connected system are required to be controlled by the electronics controller for faster response. To minimise power production cost, minimise the purchasing of power from

the grid, reducing the emission, reduce the total life cost of a system and increase power continuity are the main goal of the hybrid system. However, power quality is an important aspect to deliver power to all customers (Bhandari et al., 2014; Saha et al., 2014).

A source of electric power which independently supports an important electric system during the break of the normal power supply is called a power backup system. To supply uninterrupted power and to reach peak electricity demand, it is necessary to maintain a backup system in every power generation plant. Moreover, the pumped hydro energy storage system (PHES) is a very traditional way to provide support to any stand-alone system. In the electricity grid, PHES systems are the perfect concentrated arrangement for the management of load. Oversupply of electricity from a shortage of electricity can be possible by the PHES system. During different season like the flooding period, PHES produce secondary power with no extra additional cost. Moreover, other backup systems like batteries that store DC power. Here, one rectifier is used to convert generated AC power to converted DC power and thus it is stored. Batteries are connected to provide steady electric power in the emergency period. Another storage system is a compressed air storage system. In this system, using electrolyser excess electricity is converted into hydrogen and then it is compressed and finally stored in a tank. When electricity needs for a constant supply, this compressed hydrogen is again used to generate electricity. Thus, it is a complex process (Bhattacharjee et al., 2018; Bhattacharjee and Nayak, 2019; Emergency Power System, 2019; Islam, 2012).

Various researches have been proposed under wind-hydro hybrid systems which are incorporated with the other renewable and non-renewable energy sources, to verify different results for maximising the efficiency of any hybrid power plant. Thus, some of the recent studies are shown in Table 1.

Table 1 Some overviews of hybridising wind-hydro hybrid plant with another energy system

Study	*Year*	*Description*
Xu et al.	2019	A unified model of hydro-turbine governing system and hydro-turbine generator unit is proposed for identifying the stability of the system by using hydraulic force. Here, voltage source converter control method is used to designing hybrid solar-wind-hydro system.
Yiwei et al.	2019	A day-ahead optimal dispatching method for hybrid wind-solar-hydro-thermal-pumped storage system is focused to maximise security level, economic benefit and consumption of renewable energy.
Wei et al.	2019	To gain any nonlinear result, a hybrid hydro-wind-solar system was proposed for a two-stage approach. Unit commitment optimisation and cascading hydraulic connections are taken to solve this two-stage approach.
Dawn et al.	2018	A two-stage competent and efficient approach for hybrid wind-pumped hydro storage-solar-thermal system is presented to maintain grid frequency and get maximum revenue with profit.
Hemmati	2018	A hydro-thermal-wind-solar hybrid optimisation system is proposed to minimise the cost of energy production. Energy storage systems are also incorporate to smoothing the fluctuation of renewable resources. A stochastic programming has been adopted to deal with the uncertainties of solar and wind.

Solar, wind-based hybrid systems are more popular than others because of their abandoned availability in nature. The sun, the wind is the primary source of energy in our society. But they are intermittent in the environment and site-based. Depending upon weather conditions it is necessary to calculate the number of PV modules, size of the fixed capacitor, battery bank, etc., because continuous sunny day gives abundant power whereas cloudy day needs battery contact of any solar project. The size of the hybrid system component for minimising the cost of the system is determined by the method of unit sizing and optimisation. There is a chance for the failure of the power supply under the over-sizing of different components and it leads to an increase in system cost. Thus, maintaining the minimised cost of any system, sufficient sized components should be used. Hence, the energy balance concept is helpful to find out the size of different components (Bajpai and Dash, 2012).

Furthermore, wind power is very fluctuating in nature; by wind-hydro-based micro-grid this problem can be overcome. The micro-grid has a control unit based on voltage source inverter (VSI). Using diode rectifier, generated wind power from permanent magnet brushless DC (PMBLDC) generator is converted into DC power which helps to cut down the overall system cost. Also, PMBLDCG does not require various sensors for controlling the MPPT, thus cost is reduced. Reweighted zero attractor least mean square (RZALMS) controlling technique is used for faster response at the time of dynamic and steady conditions. It also manages power of micro-grid during various conditions as load unbalancing, high wind power generation and peak load demand. Wind-hydro-based micro-grid plays a great rule in energy generation of rural areas and also helps to reduce the use of fossil fuel (Pathak et al., 2019).

A hybrid solar-wind power system is optimised by a mathematical model with a genetic algorithm (GA) for a remote island (Javed et al., 2019). Two various systems are analysed which have two distinct wind turbine sizes and according to the cost of the system and reliability, result shows a small difference. By using a slight (1–5%) loss of power supply probability (LPSP), initial and operating costs can be reduced.

Now, different price mechanisms of electricity will help to improve the economic benefits of any country. Two-part price which one-part peak and valley prices, one-part price, etc. are the different categories of the price mechanism. The two-part price will help to upgrade the economy by exchanging power as compared to other types. Two-part price consists of capacity and exchanged electricity price which makes the traditional cost system double. Thus, revenue increased in more amounts. Furthermore, iteration depletion of any hybrid system also helps to reduce the cost of electricity (Zhou et al., 2018; Li et al., 2019).

Some papers like Agarkar and Barve (2016) studied different renewable sources of energy for hybrid electricity generation. It can be said that the hybrid energy system is a less polluted and more economical system of energy generation. The hybrid power plant of India with combinations of wind-hydro, solar-wind, and solar-hydro are mentioned in this paper. Five years (2010–2015) energy production rate of hybrid power plants in India are studied here. According to their study, the generation of electric energy is rising year by year from 2010–2014. Studies said that the rate of energy generation from a hybrid system is more than the rate of energy generation from individual systems.

In Fathima and Palanisamy (2015), a literature survey has been made based on a hybrid renewable energy system (HRES). Different areas for optimisation of micro-grid and different tools and techniques of optimisation are discussed here. Major application areas for optimisation are operation control, generation control, cost control, power

dispatch control and decision making control for energy management. Some software tools used for optimisation are HOMER, GAMS, etc. They also discussed about different energy storage systems and it is found that redox batteries and sodium-sulphur batteries are very reliable for HRES to a continuous power supply.

Whereas, Jurasz et al. (2020), gives a comprehensive review of a hybrid energy system, by which they researched quantified, analysed and utilised the outcomes of spatiotemporal, temporal and spatial complementary inwards renewable sources of energy. Here spatial and sequential information has given based on the complementary concepts. A narrative method of writing has applied to write this paper and they focused to compare and summarised the theory/models and at a qualitative level conclusion is formulated. Here, a brief discussion of research papers, the definition of the main thought in detail, a summary of recent research and future research directions have been given here.

Thus, a brief concept about the configuration of the hybrid energy system, its modelling, renewable sources of energy, different control techniques, principles of hybrid energy system optimisation, and used software for sizing are given in this paper (Sawle et al., 2017). Also, a different combination of economic and technical analysis and the social effects of the hybrid energy systems are given here. In Barwani, India, a case study has been done where the different configurations of hybrid systems have applied. They conclude that the most optimal solution according to emission and cost is the combination of the PV-wind-battery-DG hybrid energy system.

Moreover, in this paper, we provided a detailed discussion about the concept of a hybrid energy system by focusing on solar, wind, and hydro-powered renewable energies. We also elaborate literature survey of different combinations between solar-wind-hydro-based systems with their contribution of works in different fields including their limitations.

In Section 1, a brief description of the necessity of a hybrid renewable energy system is described. In Section 2, the definition of a hybrid renewable energy system and description of some types of hybrid system are given. In Section 3, a study of some research papers has given according to different types of hybrid systems. Section 4 presents the discussion of this paper and Section 5 and section 6 have a conclusion and future research direction. We also described the future work of different hybrid systems. Thus, this paper will help to understand individual efforts to improve the future in terms of renewable energy by limiting carbon emission and cost reduction.

2 Hybrid renewable energy system

Hybrid renewable energy systems (HRES) are the combination of two or more renewable or non-renewable energy sources to bring balance in the supply of energy and to increase the efficiency of the system. In the world of development hybrid renewable energy systems are becoming a very important way to provide electricity in remote locations due to the advances in renewable energy technologies. Hybrid systems of energy have been aimed to produce electricity from different sources, like solar panels and wind turbines, hydro turbines, etc. Though, one of the main drawbacks of renewable energy is that the supply of energy is not constant. Different sources like solar and wind power intensity are not constant due to the change of climate and season and also water is not available in the dry season. Therefore, to overcome this problem, a feasible backup system is essential for

renewable energy generating stations so that they can generate or store energy during the off-peak period and use it during the on-peak period. For a continual supply of power, the rechargeable battery bank is to be connected with the output of renewable energy sources. The inverter is used to change the direct current (DC) from the battery to the alternating current (AC) load. Future advancement of Hybrid renewable energy systems depends on gradual research, improvement, and the accomplishment of these technologies and to improve operating function, reduction of cost and enhance the reliability of the system.

2.1 Wind hydro hybrid power plant

A hybrid Wind-hydro power plant produces electric energy with a combination of wind turbines and hydro turbines; this type of combination is a long term practice and exploration plant. On the island of El Hierro, world's first wind-hydro hybrid power plant was established. Some drawbacks like, wind power fluctuates in nature, when the speed of the wind is extremely high there is a risk of damage in wind blades. On the other hand during low wind speed, the output of wind turbines is not desirable. To overcome this problem, a joint energy source is used to produce electricity. In a hybrid wind hydropower plant when wind power is not available, hydropower is used to overcome the scheduling problem.

Although, the efficiency of a small hydropower plant is depend on the level of water flow in a hydropower plant. Here, the kinetic energy of water is converted into electrical energy. During the dry season, there is no proper water flow, so desirable output is not available. To overcome this problem hybrid sources of energy are used.

2.2 Hydro solar hybrid power plant

At present, hydro energy is the most broadly used form of renewable source of energy. Climate change is a great impact on the generation of in hydropower, if the water head is not properly available. Hybrid plant of hydro and solar energy is used to generate electricity, to overcome the effect of climate change on the hydropower plant. When the flow of the river is less than the desired rate then solar power is used for load management.

2.3 Solar wind hybrid power plant

Another type of hybrid system is a combination of solar photovoltaic plant with a wind turbine. This system will produce maximum power when wind speed is more, and during the summer season, solar panels will generate peak output. In wind-solar hybrid power plant, the wind turbine is used to produce electricity when the required wind speed is available and the solar panel is used to produce electricity when solar power is available at required quality. This type of hybrid power plants required less maintenance, but it is more reliable and long-time span.

2.4 Pumped hydro energy storage

Pumped hydro energy storage (PHES) system stores energy as a potential form of energy of water. Through, pumping water is stored in the upper-level reservoir from the lower-level reservoir. During the off-peak period, low price electricity is used to conduct

the pumps and raise the water from the lower reservoir to the upper reservoir. At the time of high load demand, stored water from the upper reservoir is discharged by hydro turbines to generate electricity. To enhance the level of penetration in power systems, the most reliable technology is the pumped hydro energy system. Nowadays, the most important commercial means of large-scale type grid energy storage is PHES and to raise the routine capacity factor of the electricity generation system, PHES is used. Various advantages of pumped hydro energy storage systems are as:

1 its start/stop characteristics are flexible and its feedback speed is fast

2 it has the capability to identify the load changes and also to adjust intense load changes

3 it can set the frequency and sustain voltage stability.

2.5 Wind-pump storage hybrid power plant

Pumped storage is not engaged in the scheduling of power generation; it is used to fill up the gaps in wind energy. It is decent for improving the alternate wind power output. In several geographical areas, it is considered that the combination of wind power and pumped storage hybrid system are the most economical and technically competitive. By the implementation of hydro-turbine, the progress of the dynamic safety of non-interconnected systems can be done, which is a major advantage of these hybrid power plants. Pumped hydro storage required two reservoirs, one is upper reservoirs and another is the lower reservoir. Water is stored in the upper reservoir. The stored water is released through hydro turbines and generates electric energy at the time of maximum load condition.

2.6 Solar photovoltaic pumped hydro energy storage system

Solar energy is not constant and it is obtainable only in the day-time. Therefore, to make constant use of energy, an energy storage system is required. When solar energy is available it has to be store for the night when solar energy will not available. Thus, a PHES based on PV (photovoltaic) can be used for continuous generation of energy. The generated energy is dispatched by the grid and the additional energy at the low load condition is used to store water in the upper-level reservoir. During peak load conditions the stored water is discharged through hydro turbines and produces electricity (Rehman et al., 2015; Hybrid Renewable Energy Systems, 2019; Wind Hybrid Power Systems, 2019; Solar Hybrid Power Systems, 2019).

3 Case studies

Power generation through fossil fuel combustion is much risky for the human body as well as for the environment due to the huge amount of pollutant emission. These unwanted circumstances come from the effect of climate change. Such a situation can be controlled by using renewable resources instead of conventional resources. Renewable resources such as hydro, wind, etc. face different troubles due to climate change. To mitigate such a problem, the hybrid system is introduced to provide higher quality

reliable power to the customer. Wind, solar, hydro-based hybrid systems are more popular than other combinations due to less carbon emission. To get uninterrupted power from the hybrid system, it is very important to take a back-up power system relating to the main systems. PHES systems are the more traditional back-up system for any stand-alone system. Yet, hybrid systems are very useful to minimise the cost of power generation.

3.1 Hydro-wind hybrid power plant

In this section, we provide the overviews of case studies based on hydro-wind hybrid power plant. In addition, a short overview on the limitations and contributions of different research papers discussed in the section are provided in Table 2.

Table 2 Overviews of case studies based on hydro-wind hybrid power plant

Author	*Case study area*	*Contribution*	*Limitation*
Xia et al. (2019)	Southwest China	By unit commitment model for hybrid WTHS (wind power, thermal power, and cascaded hydroelectric system) short-term scheduling problem has reduced and economic condition has improved.	Economic operation is hampered due to uncertain budgets and various level of wind penetration.
Zhou et al. (2016)	China	A model is constructed for economic and secure wind power integration of hybrid coordinate hydro-thermal power generation systems.	Their modified constraints are more complex than practical transmission constraints.
Li et al. (2019)	Western China	Day-ahead coordinated scheduling methods of hydro and wind power generation system using two-part prices and power flow constraints have discussed.	Economic benefits decreases due to disconnection of wind farm or hydropower station from the external power grid.
Wang et al. (2019)	Northwest power grid of China	Hydro-wind compensating operation principle has used to reduce CO_2 emission.	Their simplification method is quite different from actual operating method.
Xu et al. (2018)	Bijie, Guizhou, China	Hydro-wind-thermal complementary optimisation system is to develop to generate clean energy.	This work is only done for short-term scheduling.

Xia et al. (2019) highlighted the short-term scheduling problem because of fluctuations of wind energy and complex confinement of hydropower. To overcome this problem, they proposed a unit commitment model for a hybrid wind power, thermal power, and cascaded hydroelectric system (WTHS) to establish a robust security-constrained for ensuring the utilisation of wind power and economic return from the day-ahead scheduling. In this hybrid system, pumped hydro energy storage (PHES) is incorporated with the wind power fluctuations to solve short-term scheduling problems. In this paper, a simplified policy was developed to decide the realisation of uncertainty about

adjustable variables. Lastly, this model was numerically tested by the modified bus of IEEE to verify the effectiveness of the model and also a case study was done in southwest China. A load curve is drawn from the daily load ratings of a local power grid of southwest China. The model was numerically tested in four types of situations; hydro power unit (HPU) with pumped hydro energy storage (PHES) and without automatic generation control (AGC), the economic achievement is improved from 15.00% to 26.00% and also the wind power accommodation is improving from 2.52% to 10.43%. When HPU has both PHES and AGC, economic achievement is improved from 5.28% to 9.66%. When HPU has no PHES and no AGC, it raises the management cost. HPU without PHES and with AGC ramp rate unit of the thermal unit is raised. Therefore, it can be said that by using PHES wind power utilisation and economic conditions can be improved (Xia et al., 2019).

Zhou et al. (2016) constructed a model to support secure and economic wind power integration of hybrid coordinate hydro-thermal power generation systems in China. By interval programming, the reserves of unit commitment (UC) of the model have been determined. Several reserves including online generation reserves, ramping reserves, transmission capacity reserves are identified in the UC model. In this paper, first of all, they used quantified reserves based on the uncertainty of wind. Then in next, they proposed an interval programming to a determined unit commitment for give these reverses, and finally, a hydro-thermal coordinate methodology has discussed for these reserves. Thus, they proposed a case study based on different seasonal effects, which are, the effects of the dry season and wet season in reservoirs and wind uncertainty. Dry season means a lack of natural water inflow, thus power storage is limited if the power production through wind is lower than the predicted value. Another-way, the wet season means the abundant natural flow of water, thus a slight possibility of power storage due to the huge amount of power production. The proposed model is 10.1% more secure than the stochastic unit commitment model while the cost is slightly higher. When the performance of the model is checked by applying in a practical power system, it has been found that the utilisation rate of power in the wet season is lower than the utilisation rate of power in the dry season. Although, the IEEE-118 bus system in China was tested to verify the effectiveness of the simplification method used in the model (Zhou et al., 2016).

Li et al. (2019) highlighted the problem of the non-availability of renewable energy and various pricing mechanisms and proposed a day-ahead coordinated scheduling method of hydro and wind power generation system (HWPGS) using two-part prices and power flow constraints. This will demonstrate the fixed and variable economic benefit with the secure operation of the hybrid system. Afterward, they use the interval analysis to find out the effect of water in-flow, uncertain wind power and load demand on the coordinate system. In this paper, the authors conduct a simulation study to identify the effectiveness of various interval price mechanisms on the coordinate method and observe the price mechanism effect on the hybrid system and the external grid. A case study is done in Western China and two tariff methods are applied there. Thus, the economic profit by interval analysis is $19,557.86, more than $18,692.40 which is obtained through robust optimisation. Moreover, the economic profit of HWPGS is more through coordinated scheduling compare with their differentiated operations (Y. Z. Li et al., 2019).

Wang et al. (2019) aiming to improve the power quality of wind power by integrating it into the grid with the use of hydro-wind compensating operation principle. Because of the fluctuating nature of wind power, large scale wind power generation is facing various problems. In this paper, they proposed a model of a hydro-wind-thermal hybrid power system, based on hydro-wind power compensating operation principle for reducing carbon dioxide emission and maintain optimal scheduling by using the peak regulation capacity of hydropower. To show the application of the principle of hydro-wind compensating operation in practical; different scenarios of operation modes are also proposed. A case study has been done in this paper in the Northwest Power Grid of China to verify the effectiveness of their proposed model compared to historical original data. In this area, hydropower is available at a high rate during the month of July and August and wind power is also available at a high rate. Here, thermal power is also available and due to the use of thermal power CO_2 emission is increased at a high rate. For overcoming the problem of CO_2 emission, hydro-wind compensating principle is applied in this area and CO_2 emission is decreased by nearly about $1{,}696 * 10^4$ t of every year in the Northwest Power Grid (Wang et al., 2019).

Xu et al. (2018) draw special attention to the carbon emission of Chinese coal combusted electricity generation and its effect on the environment. They proposed an optimised hybrid hydro-wind-thermal complementary system model to achieved carbon emission reduction and reliability in the generation of electricity under uncertain environments. The objective of the proposed daily hydro-wind-thermal complementary optimisation system is to develop a clean, reliable system that can satisfy local load demands, improve wind utilisation, reduce carbon dioxide emissions, and avoid water waste over a daily scheduling horizon. The paper also proposed a multi-objective programming method to give comprehensive consideration, cooperation between coal-fired power plants, hydropower stations, and wind-powered power plant. A wind turbine output price function is applied in this model to characterise the wind turbine power curve and the fuzzy theory is applied to describe coal to power production. A case study has been done under a different scenario of Bijie, Guizhou, China to demonstrate the effectiveness of the model to show the equilibrium strategy-based complementary generation in practically. Here, the amount of carbon emission is calculated in different scenarios, and it is observed that carbon emission is cut down about 17,389.25 kg when both the hydro and wind energy are at a high level, thus by using combine operation of hydro wind energy sources, carbon emission can be reduced (Xu et al., 2018).

3.2 Solar-wind hybrid power plant

In this section, we provide the overviews of case studies based on solar-wind hybrid power plant. In addition, a short overview on the limitations and contributions of different research papers discussed in the section are provided in Table 3.

Table 3 Overviews of case studies based on solar-wind hybrid power plant

Author	*Case study area*	*Contribution*	*Limitation*
Wang et al. (2018)	Qinghai and Gansu Grid, China	A complementary coordinated operation model is proposed to reduce the curtailment problem of hydro-thermal-wind-photovoltaic plants.	All input data are not given to solve overall curtailment problem.
Kong et al. (2019)	North-eastern China	An operative hierarchical distributed model predictive control (HDMPC) is proposed for solar/wind/battery hybrid system.	Robustness property is not yet increased as per requirement.
Ding et al. (2019)	Zhangbei, China	To reduce wind power curtailment problem hybrid the solar-wind power plant is introduced and also emission of CO_2 is reduced.	Their simulation model is not that much beneficial when electric heater is integrating.
Kirmani et al. (2018)	Ramapuram, Chennai, India	Hybrid system with the combination of solar wind coal energy is introduced to carbon emission.	Three different hybrid systems are used for various loads.
Srivastava and Giri (2016)	Gorakhpur, Utter Pradesh, India	The combination of a wind turbine, PV system, battery backup, diesel generator and a converter have been optimised and simulated to give a feasible, cheap and alternative source of energy.	Electricity cost is more in case of their proposed model.
Suhane et al. (2016)	Madhya Pradesh, India	A standalone hybrid energy system (HES) based on the wind-solar photovoltaic energy system is present.	Battery takes additional cost.
Zhou and Sun (2014)	Xuzhou, China	To reduce operation cost and one-time investment cost a HESS (hybrid energy storage station) with solar/wind has optimised.	Practical performance should be analysed.
Muralikrishna and Lakshminarayana (2008)	Poompuhar, Tamil Nadu, India	Optimisation cost of hybrid PV-wind power plant is lower than a standalone wind or solar PV system.	Any type of missing data can hamper the finding of the size of hybrid system.
Nandi et al. (2019)	Egypt	Optimised and simulate a model of the hybrid renewable power plant to reduce the problem of energy generation and cut down the carbon emission.	A proper control can help to utilise more accuracy.

Wang et al. (2018) development of wind-solar power plants is hampered because of the curtailment problem of wind-solar energy; they proposed a complementary coordinated operational model to mitigate the curtailment problem of hybrid hydro-thermal-wind-photovoltaic (HTWP) plants. This can be achieved by maximising new energy power generation and minimising the fluctuation of thermal output. Thus, new energy power is proposed to reduce the decision space and increase system efficiency. To identify the reasonability and feasibility of the hydropower generation plan, a peak regulation strategy has been proposed in this paper. Therefore, to verify the effectiveness of the proposed model, the actual operation data and a comparison model has presented without the use of regulation strategy. By the use of this model output fluctuation of the thermal plants can be controlled. A case study has done in Qinghai and Gansu Grid, China (X. Wang et al., 2018).

Kong et al. (2019) introduced an operative hierarchical distributed model predictive control (HDMPC) in this paper, for solar/wind/battery hybrid energy system. For the realisation of the adjustment of the power dispatch, the higher layer set an iterative distributed model predictive control (DMPC) and lower layer derive both the economic and tracking characteristics through a supervisory model predictive control (SMPC). To keep the firmness of confinement the back-calculation from the lower control layer to the upper layer is proposed in this study to eliminate execution degradation. The introduced HDMPC visualises the plug and play of dispense energy by organised optimisation within the subsystems. They also introduced a simulation model for the betterment of economic accomplishment and a case study was done in North-eastern China. In this paper, it is shown that the HDMPC is a good solution for the control of a complex micro grid (Kong et al., 2019).

Ding et al. (2019) introduced a hybrid solar-wind power plant due to reducing wind power curtailment. A wind turbine is combined with a solar thermal power plant. Here a capacity formations optimisation pattern based on particle swarm optimisation algorithm (PSO) is introduced for maximising the economic achievement. A case study was done in an 80 MW hybrid system in Zhangbei, China. Three operative modes are introduced here based on the inconsistency between load power and power output of the system also four implementation criteria are proposed to assess the economic, thermal and environmental operation of the hybrid power plant. And a simulation model is introduced to simulate and study the operation of the hybrid power plants, simulation study includes wind farm sub-models, concentrated solar power plant sub-model, mean power change rate (MPCR), performance evaluation criteria, the net present value (NPV), the lost wind rate, and CO_2 emission reduction are discussed here. The rate of CO_2 emission is minimised by about 15,470 tons per year as compared with coal-fired power plants (Ding et al., 2019).

Kirmani et al. (2018) proposed a hybrid system with the solar wind and coal energy to minimise carbon emission due to energy generation from fossil fuel. A grid-connected hybrid system is presented which is developed in Ramapuram, Chennai, India. It has wind energy system, PV system, load of three types (industrial, residential, and commercial), and boost converter inverter of level-two. Wind systems and solar PV systems are coupled with three-phase inverters through a two-level boost converter. In the ENNORE thermal power station, Chennai, Indian the grid is integrated with solar PV and wind system. Due to the combination with the wind systems and solar photovoltaic systems, unit generation from this plant is reduced. Hence the reduction of carbon

emission is almost 110,329.56 kg from the ENNORE thermal power generating unit (Kirmani et al., 2018).

Srivastava and Giri (2016) optimises and selects a combination of a hybrid system to give a feasible, cheap and an alternative source of energy. A combination of a wind turbine, PV system, battery backup, diesel generator, and a converter have been optimised and simulated. By used HOMER software, the simulations of the off-grid system have been done and also checked the system's economic criteria. Also, analysed each components' performance and sensitivity analysis was performed, at last for optimisation of the hybrid system at various conditions was done. On the basis of the simulation result, the optimal solution is found that a 4 kW generator, 5 kW PV panel, 10 batteries, and 4.5 kW inverter is suitable for this system. It is shown that about 25,472 kg/year of CO_2 emission would be reduced per year by the proposed hybrid system (Srivastava and Giri, 2016).

Suhane et al. (2016) represents a standalone hybrid energy system (HES) based on wind-solar photovoltaic energy system. This hybrid energy system is, for an un-electrified village of India in Madhya Pradesh. By ant colony optimisation technique performance analysis and sizing of this hybrid system have been done. Performance analysis has various parameters such as the generation of power through different sources, system total cost, load demand supply continuity, and unmet load. Rs. 10.177 is the levellised energy cost for the configuration of optimised sizing, which is lower than the cost of energy per unit for diesel generator (DG) which is mainly used for electricity generation in isolated areas. Total diesel fare per year is 4,805.l. Hence the optimised model of presented HES gives a low cost of energy and also gives a non-stop power supply with a 2% unmet load (Suhane et al., 2016).

Zhou and Sun (2014) optimised a hybrid energy storage station (HESS) with solar/wind. The aim of this optimisation is to reduce the operation cost and one-time investment cost of energy system, for the overall lifecycle, power supply reliability and, confines utilisation rate. They designed a mathematical model of solar/wind generating systems, super capacitor, and battery. Here, the simulated annealing particle swarm optimisation algorithm (SAPSO) is improved due to raise the efficiency of utilising renewable energy. Optimisation cost through standard PSO is 6,592.46 cost/USD and using SAPSO is 6,105.30 cost/USD, which is less than the previous one. Hence it is shown that using the SAPSO algorithm cost of energy generation can be reduced (Zhou and Sun, 2014).

Muralikrishna and Lakshminarayana (2008) highlighted that by using a hybrid system requirement of energy storage equipment can be reduced by which cost can be reduced. They analysed the impacts of relative excess power generated (REPG), deficiency of power supply probability (DPSP), energy to load ratio (ELR), coverage of PV and wind energy against the system size, a fraction of PV-wind energy and performance. They also assess technical feasibility in a given load demand range of a PV-wind hybrid system. Using the life cycle cost (LCC) method economic analysis of stand-alone wind system, PV-wind hybrid systems have been developed and the stand-alone photovoltaic system was developed and simulated by using this model. This optimised hybrid system assures for a given DPSP that REPG is minimum in a specific location. As of all types of load demand for hybrid PV-wind hybrid system levellised cost is always lower compared with the standalone wind or solar PV system. A case study has done in Poompuhar, Tamil Nadu, India and the model output is compared with real-time data of a hybrid power plant in Chunnambar, Pondicherry, India (Muralikrishna and Lakshminarayana, 2008).

Nandi et al. (2019) highlighted the problem of excessive heat, drought due to a change in the climate. Middle East countries face the problem of the generation of electricity and power because of climate change. To overcome this problem, they optimised and simulated a model of the hybrid renewable power plant. By using renewable sources emission of carbon is also reduced. They optimised a hybrid power plant by using real-time data of Egypt, solar-wind hybrid power is optimised there and the case study is based on the different situations of 24 hours' duration. In January from 6 AM to 5 PM, wind and solar power is available, during 5 PM to 11 PM wind power is good but solar is not available, during 12 AM to 4 AM both wind and solar power is not available, at 4 AM to 6 AM solar power is available but wind power is zero. When both is the power is available grid sale is high and when both the power is zero grid sale is zero and when one of the two power is good then grid power is medium good. By using HOMER software cost analysis is done here. The total generation of solar energy is 410,448,455 kWh/yr which is 20.5% of the total energy generation per year. Total wind energy generation is 1,590,322,890 kWh/yr which is 79.4% of total energy generation per year. The overall generation of renewable energy is 2,000,771,345 kWh/year and the levellised energy worth is \$0.00417/kWh and overall net present worth is \$106,890,700 (Nandi et al., 2019).

3.3 Pumped hydro storage-based hybrid power plant

In this section, we provide the overviews of case studies on PHS-based hybrid power plant. In addition, a short overview on the limitations and contributions of different research papers discussed in the section are provided in Table 4.

Table 4 Overviews of case studies based on pumped hydro storage (PHS) hybrid power plant

Author	*Case study area*	*Contribution*	*Limitation*
Bhattacharjee and Nayak (2019)	Tripura, India	PV solar power pumped storage energy system has implemented in a hydropower plant, to reduce the problem of energy generation during the dry season.	No other backup system is there to fulfil the energy demand at the time when both water and solar will not available.
Kocaman and Modi (2017)	Himalaya Mountains area	A two-stage stochastic mixed-integer programming model has been proposed due to sizing a hybrid energy system that is integrated, where alternate solar generation is supported with (PHES) pumped hydro energy storage system and diesel energy as a back-up source in the demand point	If both hydro and solar energy is not available then required of diesel will be high, at that situation the generation cost will increase.

Bhattacharjee and Nayak (2019) highlighted the impact of climate change for which freshwater is not available in many of the river basins in India. In dry seasons hydropower plants of north-east India are unable to fulfil the required energy demand due to lack of water in hydropower plants' reservoirs. The problem of water shortage occurs due to insufficient rainfall for which many hydropower units have to shut down, which is the cause of energy shortage at a large amount. By integrating PV solar powered pumped

storage energy system, the problem of energy generation in a hydropower plant can be reduced. This study aims a power supply option which will be continuous, cost-competitive and reliable in nature. A hydropower plant of Tripura, India has been considered in this study, where water is not available as required during the end of the year. At the time of water shortage, water is stored in the upper reservoir by using a pump, which is run by using energy from solar power and water from the upper reservoir is flow through a hydro turbine which produces energy. By using PV solar system in this hydropower plant, water storage in the upper reservoir has increased. Thus, power supply loss has decreased by about 4.4% and unmet load also reduced to 11%. It also shows that hydro energy generates 76% while the PV power unit generates 24%. This indicates that net power generation is improved by about 78%, where the overall efficiency is 59.8%. Thus, it can be said that by using PV-pumped hydro storage energy generation, overall efficiency of a power plant can be increased and the cost of energy generation can be reduced (Bhattacharjee and Nayak, 2019).

Kocaman and Modi (2017) mentioned that it is necessary to exchange the fossil energy sources into renewable sources. But renewable sources are variable in nature; to compact this problem of fluctuating nature of renewable sources; hybrid systems can be used which conduct as a combination of different sources, storage of energy and transmission line. A two-stage stochastic mixed-integer programming model has been proposed due to sizing a hybrid energy system that is integrated, where alternate solar generation is supported with pumped hydro energy storage system (PHES) and diesel energy as a back-up source. A case study has done in the Himalaya Mountains to examine the role of hydropower as a pumped-hydro or conventional hydro system for supporting the generation of energy from the solar panels in different load demands. For analysing the advantages of the geographic diversity of stream-flow potential; the part of a pumped hydro energy storage system in the integrated and isolated systems has compared and it is showed that the PHES system is more beneficial in isolated systems. By using the PHES system need for diesel is 10% for fulfil the demand. On the other hand, in conventional systems according to demand if stream-flow is limited the need for diesel can reach more than 50%. Moreover, using the PHES system unit cost of energy generation can be reduced (Kocaman and Modi, 2017).

3.4 Other configuration of the hybrid power plant

In this section, we provide the overviews of case studies based on different configuration of hybrid power plant. In addition, a short overview on the limitations and contributions of different research papers discussed in the section are provided in Table 5.

Beerbaum and Weinrebe (2000) highlighted the problem of power generation due to limited fossil fuels and the problem of environmental pollution. To reduce this problem solar thermal electricity (STE) generation system can be used for cost-effective amenities. They resolve the efficiency and cost-effectiveness of decentralised and centralised STE-generation of India and compare the present levellised electricity cost (LEC) for options of electricity generation with LEC for STE. Generation of power from STE generation system reduces CO_2 emissions and save the climate and help the development of developing countries like India which demand for electricity is increasing day by day (Beerbaum and Weinrebe, 2000).

Maqbool et al. (2020) highlighted that most of the rural areas of India need to fulfil the demand for electricity and to decrease the burden on the national power grid due to

urban lifestyle and industrial development. To get rid of this problem distributed energy generation is needed. Hybrid renewable energy sources based on locally obtainable energy sources is the best way of energy generation. An optimal micro-grid based on PV-biomass-grid is proposed in this paper which depends on local energy sources. A case study has been made in WanigamPattan village, Baramulla District, Jammu, and Kashmir. Here improved harmony search (IHS) algorithm has used for optimised the micro-grid and also genetic algorithm has been used for verifying. This proposed micro-grid helps to decrease the grid dependency for energy by almost 90% and decreases the CO2 emission from 454.24 tons to 250.19 tons which is around 55% (Maqbool et al., 2020).

Sawle et al. (2017) represent various ideas about different combinations of technical and economic analysis, the strategy of control and the social effect of the hybrid systems. In this paper, a case study has made in remote area Barwani, India, the result of the case study using HOMER and PSO has compared with each other. The total emission rate of PV-wind-battery-DG biomass by using HOMER is 13,489.22 kg/yr and 12,436.68 kg/yr is by using PSO algorithm. That is the emission rate is lesser using PSO with respect to HOMER. Total net present cost (TNPC) is $179,326.20 by using HOMER and $170,657.59 by using PSO which shows that TNPC and levellised cost, operating costs are also less by using PSO. Efficiency by using HOMER is 21.88% while 22.97% is by using PSO, which shows that the electrical efficiency is better with PSO than HOMER (Sawle et al., 2017).

Table 5 Overviews of case studies based on other configuration of hybrid power plant

Author	*Case study area*	*Contribution*	*Limitation*
Beerbaum and Weinrebe (2000)	India	Solar thermal electricity (STE) generation the system can be used for cost-effective amenities.	No storage option is given case of solar energy.
Maqbool et al. (2020)	WanigamPattan Village, Baramulla District, Jammu, and Kashmir	An optimal micro-grid based on PV-biomass-grid is proposed which depends on local energy sources to reduce the dependency on the national power grid.	This proposed model is location-based. Thus, replace of plant may cause economic downfall.
Sawle et al. (2017)	Barwani, India	Various ideas about different combination, technical and economic analysis, the strategy of control and social effect of hybrid systems are discussed.	Losses due to energy conversion decrease of battery's life due to faster charging-discharging affects economic scenario of hybrid system.

4 Discussion

Electricity plays an important role in the development of any country. The demand for electricity is increasing day by day due to the rapid growth of industrialisation. The generations of electric energy from conventional sources are one of the causes of environmental pollution. Renewable sources-based hybrid systems are the better option of energy generation to reduce environmental pollution and to fulfil the increasing

demand for electricity. The generation of electricity using a combination of different renewable and non-renewable sources is called a hybrid electricity generation system. Wind-hydro hybrid power plant, hydro-solar hybrid power plant, solar-wind hybrid power plant, wind-pump storage hybrid power plant, solar photovoltaic pumped hydro energy storage power plants are some of the types of hybrid power plant. A combination of wind-hydro energy sources can be reduced the fluctuating nature of wind power and the problem of short-term scheduling using the unit commitment model. The economic condition can be improved by the pumped hydro energy storage system. By hydro-wind compensating principle and hydro-wind-thermal complementary model, CO_2 emission is reduced in a hydro-wind-thermal power plant. The curtailment problem of wind-solar energy hampers the development of wind-solar power plant. By using a complementary coordinated operational model, curtailment problems of hybrid hydro-thermal-wind-photovoltaic (HTWP) plants can be reduced. Although, by particle swarm optimisation algorithm (PSO), economic achievement can be maximised. On the other hand, using optimal combined operation scheme (COS), loss of revenue can be cut down. The cost of optimisation by simulated annealing particle swarm optimisation (SAPSO) algorithm is less than that of standard particle swarm optimisation (PSO) algorithm. But, by using the PSO algorithm different costs of a system become less. Distributed energy generation can reduce the dependency on the national grid and also helps to reduce the emission of CO_2.

5 Conclusions

Renewable energies are energies that are collected from naturally replenished renewable resources on the human timeline. They are freely found in nature which makes it's reliable, cheaper and environment-friendly. Power generation through renewable energy is a key aspect of today's life. But the energy resources capacity varies throughout the day based on time and also varies with season along a year. This drawback can be overcome by aggregating two or more renewable energies based on the condition of availability of renewable resources at a particular location.

Thus, an extensive review of renewable energies is conducted, focusing on its existing technology of aggregation, advantages, use, economy, and pollution scenario. This review illustrates some particular points; they are:

- renewable energies are pollution-free, thus less impact on global warming through the power generation
- aggregation of renewable energies used to fulfil a certain peak demand and minimise the use of the grid as much as possible
- due to abundantly found in the environment, renewable energies are cheaper as compared to fossil fuel for energy generation
- the renewable energy-based hybrid system incorporated with PHES is a great option for an autonomous island to fulfil its maximum demand.

These points simply indicate that renewable energies are a better option in energy generation. If renewable resources are works stand-together, they can avoid all the drawbacks based on conventional energies. In the Northwest power grid of China, using

hydro-wind hybrid system compensating principle, emission of CO_2 is reduced $1{,}696 * 10^4$ t per year. Although, by hybrid hydro-wind-thermal complementary system CO2 emission is reduced about 17,389.25 kg in the area of Bijie, Guizhou, China. Therefore, in hybrid power plant cost of energy generation is less. Thus, the overall review concludes that renewable energy-based hybrid system is profitable, economical, environment-friendly and effective in maintaining continuity of power supply for a particular location. Hence, renewable energy-based hybrid plants can set-up in any area over the world according to their presence.

6 Future research direction

This paper gives a brief study of various research papers for reducing environmental pollution and the cost of energy generation. Here, mainly renewable energy-based hybrid systems are discussed. The role of the back-up system and storage system in a renewable energy-based hybrid power plant is very essential as it helps to maintain the energy fluctuation of renewable energy sources. In future research work, a detailed literature review on various back-up systems and storage systems of hybrid power systems can be carried out. To expand this review, an idea for reducing climate change is an excellent field. Moreover, in order to gain the maximum efficiency from a hybrid power plant, the appropriate location is required and therefore, we can also carry out a survey to find out best possible location for a hybrid power plant on the basis of its renewable energy generation capability.

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