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Hybrid energy sources status of Pakistan: An optimal technical proposal to solve the power crises issues

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ABSTRACT

Power outage owing to shortage of power generation, transmission losses, lack of planning and inappropriate policies has led to escalate the energy crisis in Pakistan. The reason for selecting Pakistan is to facilitate its 220 million population and to attract the international investors to take benefit by integrating power generation units into National Grid of Pakistan (NGOP). Domestic, Industrial, health and education sectors are badly affected due to this power crisis. Instead of remedial measures and providing incentives to the investors in power sector, the government of Pakistan (GOP) has remained unable to overcome the dilemma in power sector due to improper check and balance. The failures in completion of hydropower dams and generating electricity by fossil fuels has resulted in increased power generation cost and environmental hazards. Therefore, some suitable solutions are compulsory for meeting the escalating power demands adequately. The incorporation of renewable energy units and stopping electricity theft can be the most explicit choice for meeting aforementioned problems. This paper explores the vast potential of Pakistan with respect to energy production by means of solar and wind power units. Moreover, most appropriate sites for incorporating power generation units are also critically reviewed. The paper also proposes the short-term, mid-term and long-term effective solutions along various practical proposals for overcoming the existing power crisis in Pakistan.

1. Introduction

In the epoch of globalization and huge advancements, research developments and most specifically its practical implementations are taken into consideration [1]. In order to keep these phenomenon's moving, energy is the basic need of the day. In this situation, the fact to be taken under consideration is diminishing of the conventional energy sources for the generation of electricity by the passage of time, or they may result in augmenting global warming which is precarious for the environment [2]. As the natural gas, petroleum products and the usage of coal are hazardous for the environment, so huge concerns are made to halt the production of electricity via these resources, for which their linkage with the world politics is increasing [3]. Therefore, nuclear energy is being observed as a suitable alternative to the above-mentioned resources in the developed as well as developing countries. But comparatively due to its large expenditures, being perilous for the environment, technical dominations, availability as well as restricted issues, it is unavailable in the most countries of the world. Antedating this deterioration, some other non-conventional alternatives like mini-hydropower, solar, wind, geothermal, biomass, ocean, tidal etc. projects are preferred as a suitable source for the production of energy in the long term [4,5]. Therefore, this coherent vision in order to stay safe from health hazards, its environmental friendly approach and keeping the pollution free surroundings is highly esteemed. In next 10 years, due to the increasing cognizance regarding the paybacks of solar energy as well as wind energy, both these production entities are termed as the

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most apposite energy sources in the largest markets of Asia [6]. The expectant approximations also estimate that almost more than one-fifth of the world energy production will be via wind energy generation sources till in the F.Y 2030. This directs both environmental as well as an economic benefit for planting wind energy as the unhazardous source of renewable energy [7]. To enhance the industrial production, a most popular form of energy these days is electricity. The electric power systems in modern era comprise of generation, transmission, distribution, and consumption. Frequently, most of the power generation units are installed in the distant areas, where power is generated and transmitted over a long distance to the urban areas via transmission network and electricity after its transmission is distributed by means of distribution lines [8]. As electricity plays a significant role in today's society so all the production possibilities for electricity are thoroughly taken into consideration. By the end of 2017, the world energy generation capacity was 25551.3 TWh [8]. Meanwhile, in 2017, fossil fuels i.e. coal; oil and gas were the largest contributors in electricity generation that has accumulated contribution of 73.5%, followed by hydropower projects that contribute about 16.4%, whereas solar and wind having contribution about 7.5% of the renewable energy production, followed by other renewable energy sources that give about 2.6% as shown in Fig. 1 [8].

This paper particularly highlights the influence, current need, and solutions regarding Pakistan's power sector. Pakistan is enriched with lots of natural reservoirs but due to the unemployment, unfocused attitude towards energy crisis solutions, lack of proper planning and policy making in the energy sector are the root causes for power crisis in Pakistan. Meanwhile, approximately 200 million of the world's population is suffering in the result of the electricity crisis [9–11]. Some of the ferocious crowd protests have also been observed in multiple cities of Pakistan to overcome energy shortfall problem [11]. For this purpose, furnace oil is used on the larger scale for electricity production [11]. Whereas owing to the fluctuation in prices of furnace oil, electricity per unit price is also becoming difficult to stabilize on one particular position and huge inflation deviations are explicitly shown in the prices of commodities that deeply affect the life of a common person [11]. For electricity production, the dependence on furnace oil costs a huge financial burden on Pakistan [11]. This enhancement in the ratio is due to increasing number of consumers from approximately 17.9 million to 21.7 million [12]. While the shipment of furnace oil costs Pakistan almost 786.3 billion US Dollars for to cope needs of electricity production. Electricity generation capacity of Pakistan was 60 MW after its independence in 1947 with a population of about 31.5 million [13], which has been improved to 7000 MW in the 1980s and afterward to 16000 MW in 2014 [13]. But Pakistan is still facing a severe shortfall of energy. The serious efforts are required to overcome this crucial concern. Being residents of Pakistan, the authors can confirm that in summer, the shortfall of electricity has increased from 8 to 10 h in urban cities while 12–14 h in the rural areas of Pakistan, while 4–6 h in cities and 6–8 h in villages during the winter season [10]. The existing energy crisis in Pakistan has prescribed the policy-makers to bring a mandatory exemplary shift in Pakistan's energy policies. However, an appropriate solution to diminish dependence on furnace oil is to participate in renewable energy generation technologies [14]. The various countries in the world have installed their RE generation plants successfully to meet their demand for daily electricity consumption [15,16]. Several ways of RE production has been invented, illustrated, demonstrated and published for a description of possibilities to deal this energy deficit [17–23]. Therefore, in this paper, the detailed analysis of whole data as well as the solution for overcoming the energy crisis is elaborated comprehensively.

2. Power sector organization mission in Pakistan

Basically, the generation of electric energy, its supply, and consumption by the consumers is a complex process. In Pakistan, this process is carried out by several companies and it includes multiple steps. The detailed analysis of such process is shown in Fig. 2.

The below mentioned Fig. 3 illustrates the complete power sector structure of Pakistan. There are several institutions in Pakistan which are responsible for regulation of tariff plans, estimation of generation and supply, maintaining the electric systems and to facilitate the people as well as keeping the government update for upcoming power consumption estimates. These institutes are also accountable for maintaining the generation, transmission, distribution and consumption setups.

- Ministry of Water and Power

The most fundamental body in power sector organizations is Ministry of water and power. This organization is the supreme association of government for maintaining the generation, transmission, and distribution with in the country. It executes various functions i.e., to maintain demand and supply balance, to facilitate the consumers, to implement new policies for power sector development, to provide suitable conveniences and provide amicable support for investors in power sector.

- National Electric Power Regulation Authority (NEPRA)

The NEPRA was developed in 1997 for regulating the power supply to the people of Pakistan [24]. It is responsible for permitting the investment, to issue the license for GTD (Generation, Transmission, and Distribution) and to balance the tariff in bulk as well as retail for demand and supply in order to maintain the profit/loss statement. It is also responsible to develop policies for tariff and to implement the

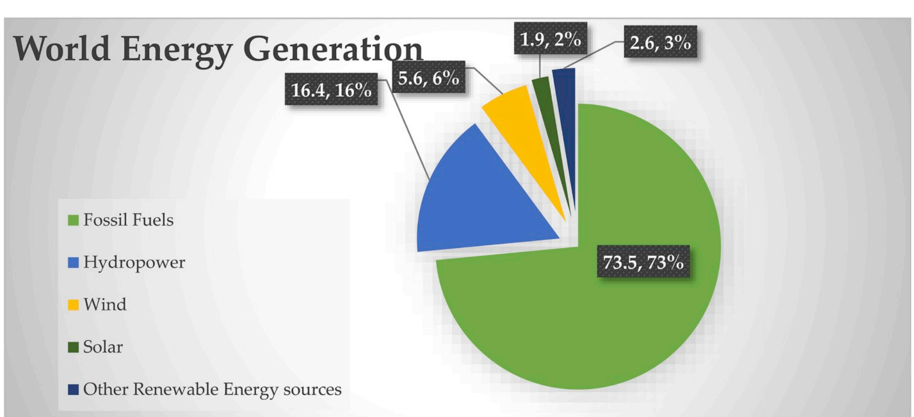


Fig. 1. Approximate share of renewable energy sources.

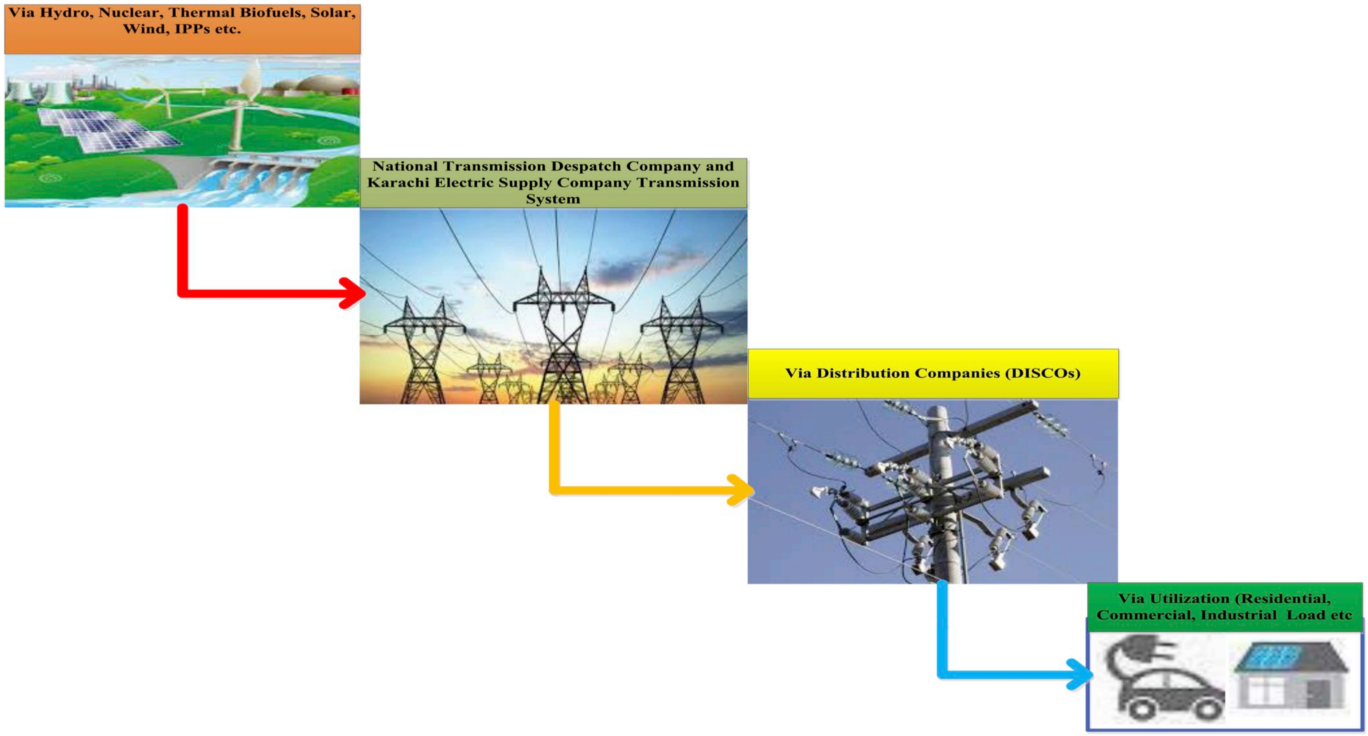


Fig. 2. Power sector organization basic model.

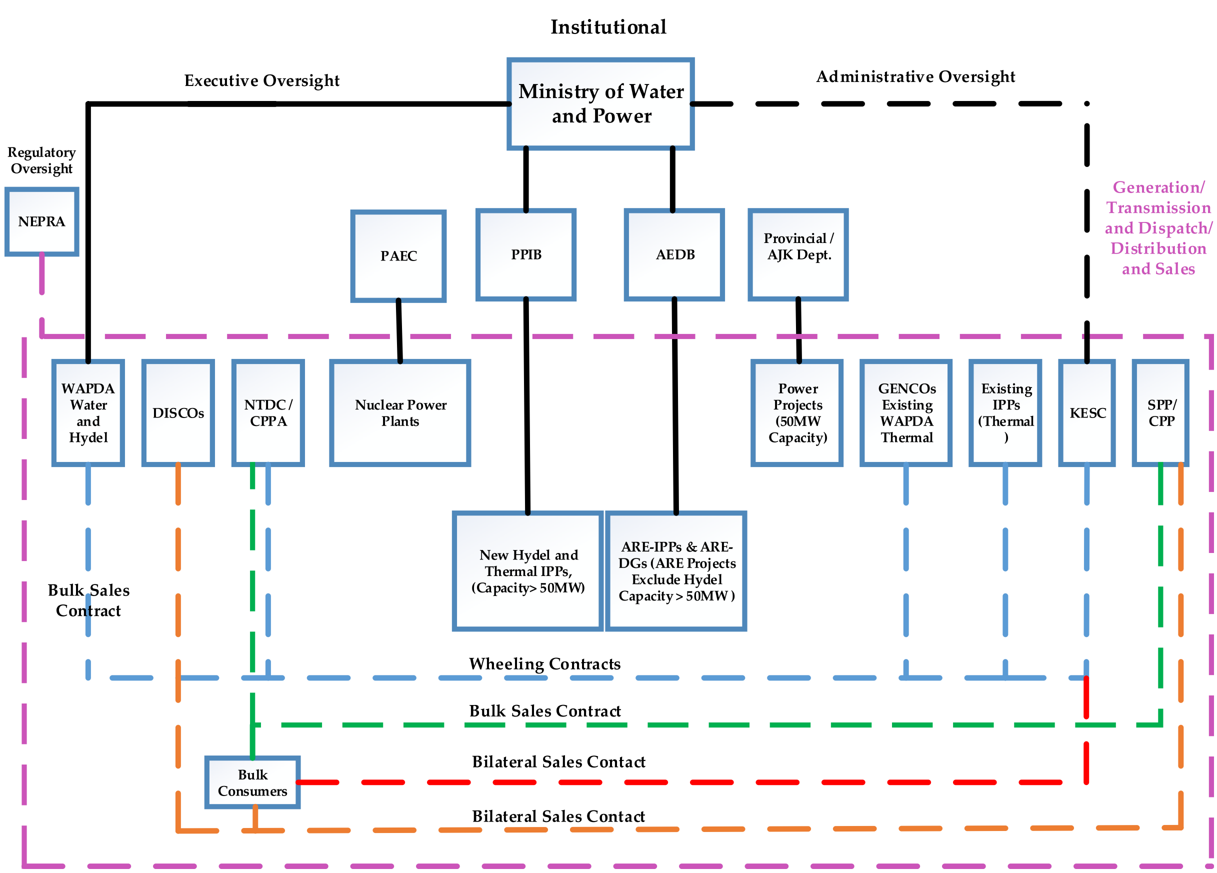


Fig. 3. Power sector organizations in Pakistan.

standards for power supply and to ensure the safety of the consumers [24].

- Private Power Infrastructure Board (PPIB)

The PPIB is responsible for upholding the power projects in private power generation sector. The most usual projects are IPPs and hydropower projects of Renewable energy having more than 50 MW capacity. Besides, this board has representation from all the 5 governing bodies of Pakistan as well as in AJK [25].

- Provincial and AJK Organizations

The various water and power organizations have been developed for assuring water and power supply to people of Pakistan. These organizations have also been developed by the provincial governments to ensure sufficient supply to the consumers. For this purpose, Irrigation and Power authorities in Sindh, Punjab, and Baluchistan are working while in Khyber Pakhtoon Khuwah (KPK) SHYDO (Sarhad Hydro Development Organization) is developed later its name was changed to Pakhtunkhwa Energy Development Organization (PEDO) in 2013. These small organizations are responsible for installation and maintenance of the units having less than 50 MW capacity [26–28].

- Power Pragmatisms

Under the WAPDA ACT in 1958, an organization titled as the “Water and Power Development Authority” (WAPDA) is developed for the unification of all the small agencies those were working for power generation and electric supply in Pakistan since 1947 [13]. The purpose of this organization was to look after all the power projects and to provide a counter check in maintenance of electricity standard in Pakistan. The structure of power sector organizations in Pakistan is shown in Fig. 3.

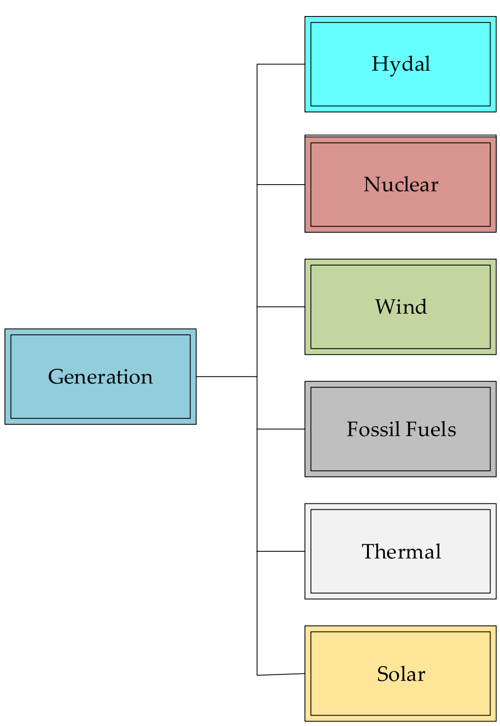


Fig. 4. Power generation sources in Pakistan.

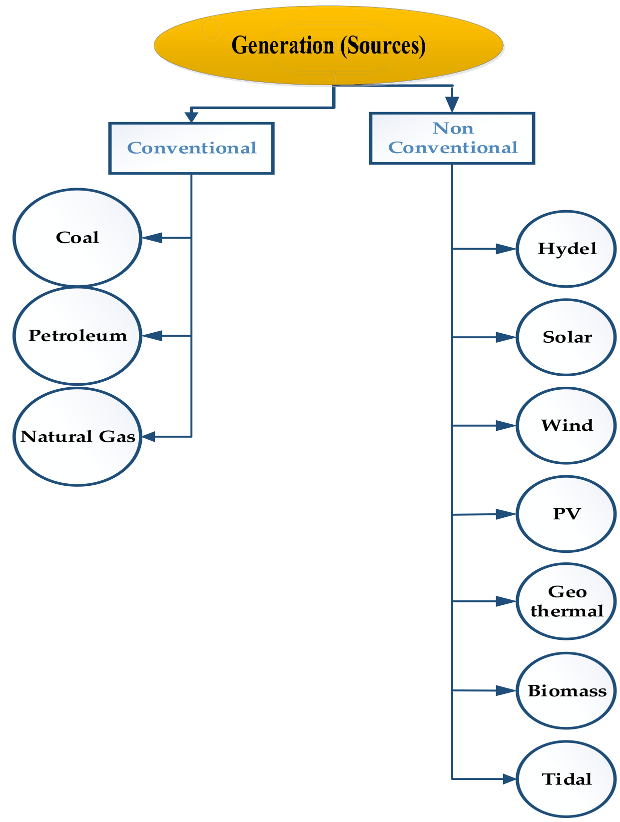


Fig. 5. GENCOs in Pakistan.

2.1. Generation systems

In Pakistan, numerous sources of electricity exist due to its geographical position and availability of natural resources. There is number of resources, Pakistan can produce energy through. Representation of these energy sources is shown in Fig. 4. GENCOs are of two major types; conventional and non-conventional as shown in Fig. 5. Most of the fundamental functions of electricity generation in Pakistan are controlled in appropriate manners by GENCOs. The three main GENCOs in Pakistan are as following [29]:

1. Southern Generation Power Company Limited (GENCO-I), Jamshoro district, Sindh
2. Central Generation Power Company Limited (GENCO-II), Guddu, District Jacobabad, Sindh
3. Northern Generation Power Company Limited (GENCO-III), WAPDA house, Lahore, Punjab

2.2. Transmission systems

In order to transmit electricity to the distant areas of Pakistan, several Grid stations were constructed, transmission lines were spread out, several systems should be installed. Therefore, to perform all these functions, NTDC is introduced in Pakistan [30]. The National Transmission and Distribution Company in Pakistan has installed thirteen grid systems of 500 KV each and thirty-seven grid systems of 220 KV each. Meanwhile, 7359 Km of 220 KV transmission lines as well as 5077 km of 500 KV transmission lines have been installed in Pakistan [30]. The locations of these grid stations in Pakistan are labeled in Fig. 6.

The core function of this organization is to act as system operator; for the purpose of secure and consistent transmission, control and operation of production facilities, transmission procedure, planning, designing and expandability of 500 KV and 220 kV transmission lines

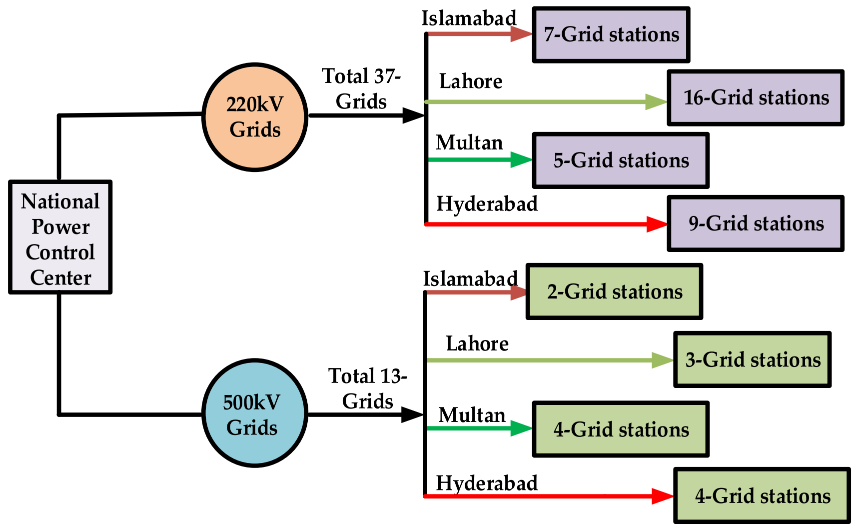


Fig. 6. Electricity transmission system in Pakistan.

along with their maintenance, and as Contract Registrar and Power Exchange Administrator (CRPEA); for recording and monitoring the indentures for bilateral trading systems [30]. While another company in Pakistan for transmission of Electricity is KESC, which transmits and manages the electricity in Karachi only. K-Electric's transmission system includes a total 1249 km of 66, 132 and 220 kV lines, 62 grid stations and 128 power transformers. The Company's contemporary transmission losses are less than 1.03% [30].

2.3. Distribution systems

After generation and transmission, the most significant role in the consumption of electricity is related to the appropriate and sufficient distribution throughout the country. In this regard, the proper structure of electricity distribution companies was designed and they were named as DISCOs [14b]. DISCOs have the sub-branches that are defined by the following tree except for KESC as shown in Fig. 7 [14b].

There is a huge difference to generate electricity in months of July/August than in December/January. This transparently discloses that there is less need of electricity in the winter as compared to the summer season. As a result, solar panels can be installed to increase the electricity production during months of June to September [31]. Moreover, owing to the increasing beam and diffusion during summer and due to longer (lower night losses) and clearer (lower atmospheric losses) days, the production of electricity can be increased by installing solar panels. The atmospheric losses are intensified with increasing clouds and day length, the combination of which results in large daily atmospheric losses in July. However, this can be compensated by using HVDC transmission systems along with suitable protection [32]. The alignment losses are truncated which resulted in constrained tracking options for PV systems as these could not enrich the resources significantly. However, losses during night time are unavoidable [33]. Electricity GTD is controlled by Water and Power Regulation Authority on the radical level. In WAPDA act 1981, eight Area Electricity Boards (AEB) were settled for providing more authority and representation to the provincial government [34]. Common people which include agriculturalists, elected representatives, industrialists, researchers and other persons having their affiliation with AEB are considered to be the part of this organization and were facilitated via this organization. For the accomplishment of this task, initially, 8 AEBs were founded by the

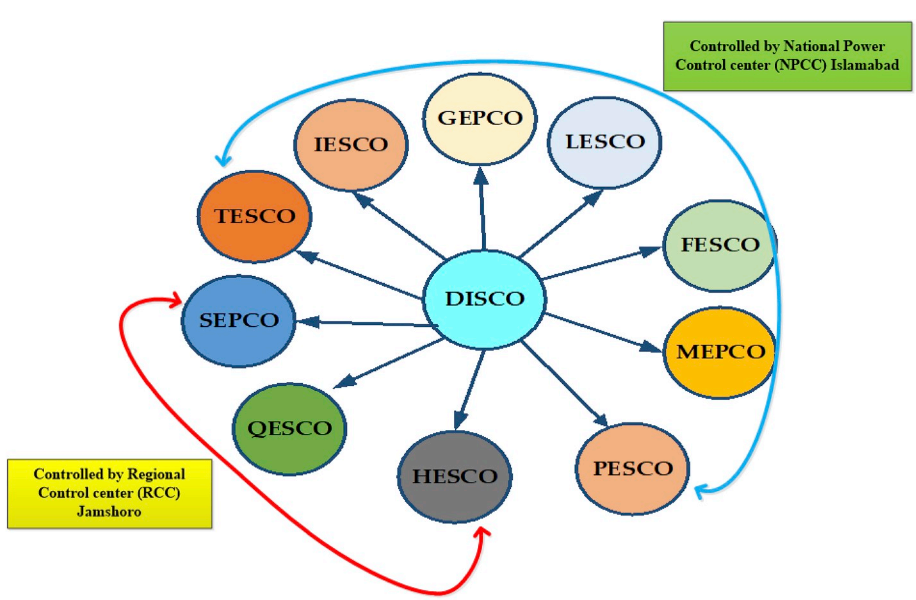
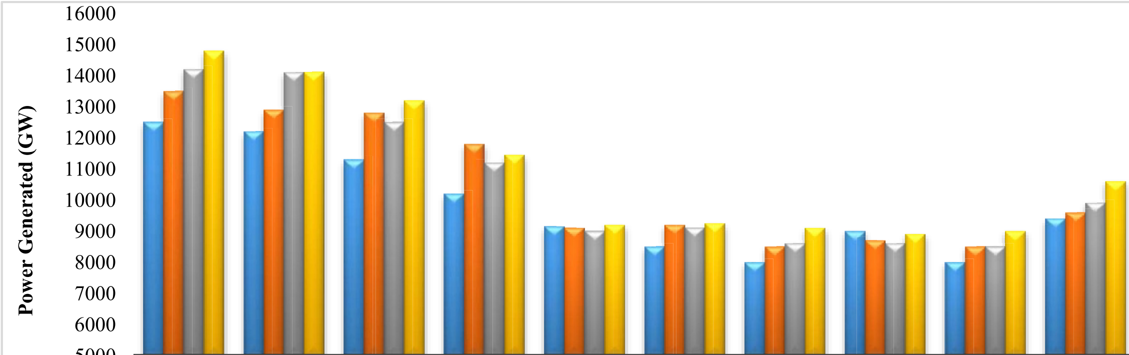


Fig. 7. Discos layout.



	July	August	September	October	November	December	January	February	March	April
2012-13	12500	12200	11300	10200	9150	8500	8000	9000	8000	9400
2013-14	13500	12900	12800	11800	9100	9200	8500	8700	8500	9600
2014-15	14200	14100	12500	11200	9000	9100	8600	8600	8500	9900
2015-16	14800	14110	13200	11450	9200	9250	9100	8900	9000	10600

Fig. 8. Dimensional Graphical representation electricity generation in Pakistan.

government. Power plan reforms were introduced in 1994, through which WAPDA was divided into 14 companies; those were held responsible for generation, transmission, and distribution in Pakistan [35]. These companies include the Generation Companies, GENCOs, National Transmission Distribution Company Ltd. (NTDC) and distribution companies (DISCOs).

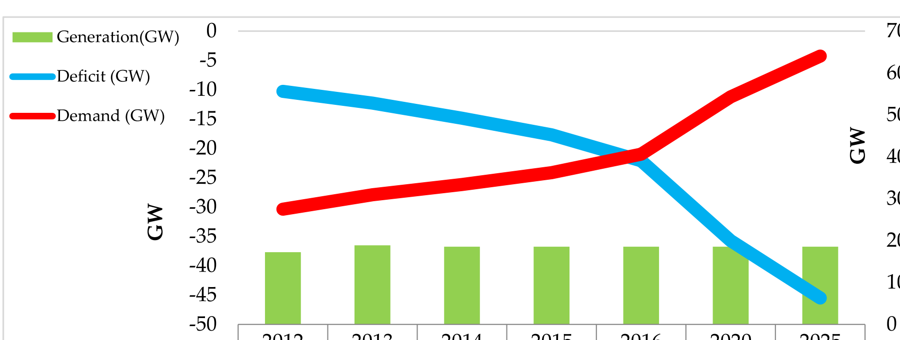
3. Power sectors installation and generation outlooks

The several sources such as hydroelectricity, wind, and solar exist for the production of electricity. Generation of electricity via thermal projects is also under production while a large amount of electricity in the world is also produced via fossil fuels like coal, gas, furnace oil, diesel, petrol or a number of other resources. While nuclear fission and fusion are the two other projects for production of electricity. The sources have predicted that the demand of Pakistan till 2030 will be more than 45 GW of electricity [35]. The maximum electricity generation capacity of Pakistan is 17 GW while the demand is increased to 23 GW, which results in 6 GW shortages [36]. A comparison of electricity generation since 2012-13 is shown in Fig. 8. As the graph demonstrates that from 2012, there is a noticeable variation in data in the months of July to April. There is a huge difference in the electricity generation for months of July/August than in December/January [37].

4. Power demand, generation, and deficit outlooks

Fig. 9 represents the relation between demand, generation, and gap. This graph is based on a general survey and literature review of electricity prices from reports related to the ministry of petroleum, the ministry of finance and ministry of water and power in Pakistan. It represents the data analysis and prediction from 2012 till 2025 in Pakistan [15]. The deficit is increasing by passing years due to increase in population. Therefore, the need of the hour is to install more and more electricity generation units for overcoming this gap between demand and supply [38]. In addition, the supply and demand chart are shown in Fig. 9 [38]. The prediction of demand and supply gap in Pakistan till 2030 is shown in Fig. 10.

Henceforth, a proper balance in energy production and energy consumption is required for a peaceful, prosperous and progressive Pakistan. Currently, the Government of Pakistan is emphasizing to maintain the balance in terms of demand and supply of electricity in Pakistan [38]. The beneficial policies to enhance the industrial sector in Pakistan and to support IPPs are also introduced for overcoming the energy deficit in Pakistan. In addition to it, Electricity demand in Pakistan is increasing at the rate of 10% while supply is 7% which results in the major shortfall of electricity in Pakistan. Along with the transmission and distribution losses, there is a huge amount of recoveries which are in pending [38]. But during the year 2015, the ministry of water and power has shown a significant improvement in recoveries



	2012	2013	2014	2015	2016	2020	2025
Generation(GW)	17.23	18.87	18.54	18.54	18.54	18.54	18.54
Deficit (GW)	-10.27	-12.27	-14.85	-17.67	-22.11	-35.74	-45.5
Demand (GW)	27.5	30.94	33.39	36.22	40.64	54.32	64.04

Fig. 9. Power gap, demand, and generation layout graph.

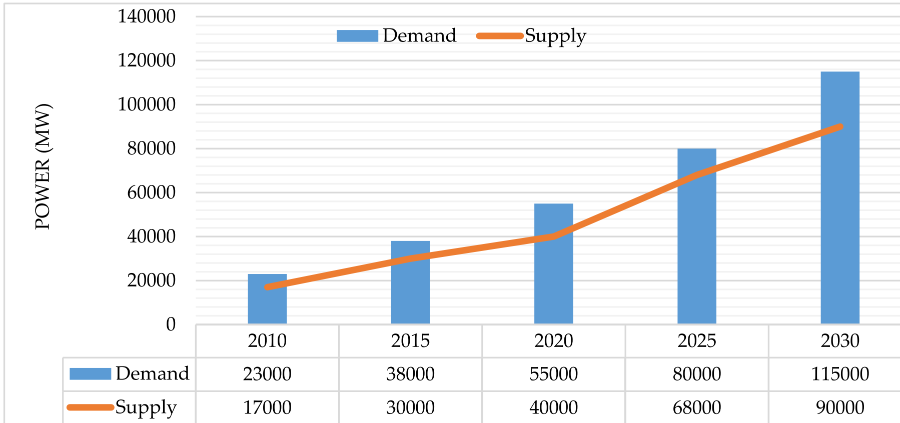


Fig. 10. Prediction of demand and supply gap in Pakistan till 2030 [16,17].

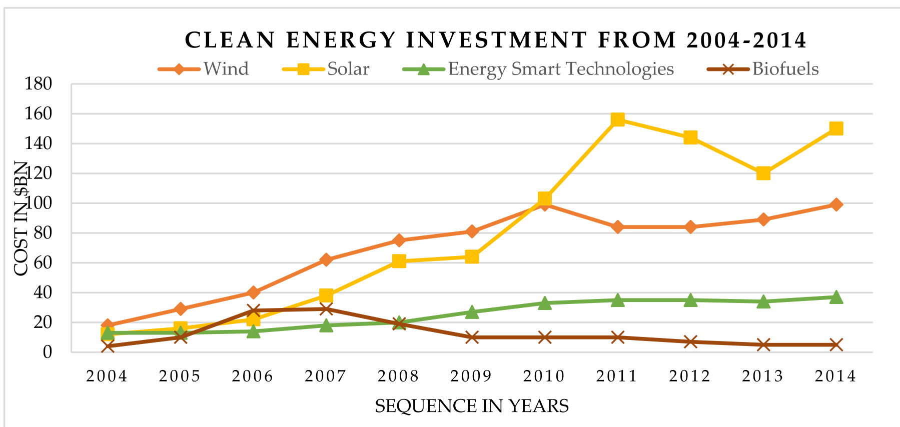


Fig. 11. Clean energy investment from 2004 to 2014.

and to overcome T&D losses. As revealed in the following graph, recoveries of almost 53 billion have been made by the government while T&D losses declined to 18%.

5. Global investment in clean energy

Renewable energy is becoming instant need to provide a better environment for the upcoming generations in the world. For this purpose, clean energy is highly emphasized by different organizations in the world. The Fig. 11 shows the graphical representation of new investment in harnessing energy up till 2014 [39,40]. In 2015, most of the countries invested a huge amount of their revenue for generation of clean energy and in this regard, renewable energy is taken into consideration [41]. The overall increase in the amount of investment was approximately 34% [40]. The entire investment included the investors from various sectors i.e. trading societies, Research and Development (R&D) forums from the government as well as from semi-government and private sectors, confined stakeholders and the distributed companies [18]. The world has invested a lot to make an environment better. Therefore, a handsome amount has been spent to date on various technologies for clean energy. Climatic conditions are the prime consideration across the globe owing to facilitate an ordinary person and upcoming generations of mankind to survive easily on the surface of planet. For this purpose, avoiding fossil fuels and adopting renewable energy for energy generation is the increasing trend nowadays [42]. Various health hazards are concerned with these climatic changes, for instance, the increased frequency and intensity of heat and cold waves results in death, floods and droughts are increased, malnutrition and risk of disaster. The heat radiations are trapped by increasing concentration of CO_2, CH4, CFCs, Halons, N_2O, Ozone and peroxyacetyl nitrate and are responsible for increased temperature on the planet [43,44].

The renewable energy sources usually employed for meeting the requirements of energy at domestic level have potential of providing electrical energy facilities without emission of greenhouse gases or air contaminants [45]. Recent development in renewable energy systems is making it possible to cope with most important issues of improving reliability in energy supplying system, economical rates of organic fuel, to solve problems of energy and water crisis, improving level of employment and living standards of local population, sustainable development of remote regions in distant areas, and commitments towards fulfilling the international agreements towards sustainable developments and environmental protection [46]. Advancement and deployment of renewable energy projects in rural and distant areas can produce employments and hence curtailing relocation near metropolitan zones [47]. Integrating the renewable energy in national grid system of a country is being achieved in decentralized way, as this is considered as most reliable options to meet the bucolic and domestic energy requirements in an inexpensive, reliable and ecologically sustainable mode [48,49]. A graphical representation of investment in the whole world regarding clean energy from 2004 to 2014 is depicted in Fig. 11 [48].

6. Global market share of wind turbine manufacturers

In the F.Y 2015, another record is broken when the wind energy entered into the electricity system of the world and crossed 63 GW [40]. It was an increase of approximately 22% as compared to 2014 when the

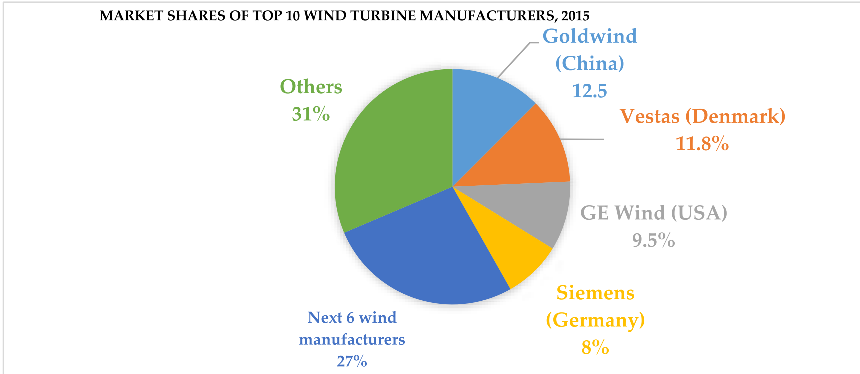


Fig. 12. Top 10 manufacturers of the F.Y. 2015.

global production of electricity via wind power generation was 433 GW. More than half of the global capacity of wind generation is introduced in last 5 years in the world. In the 4th quarter of 2015, it was noticed that more than 80 countries in the world have commercial wind activity and 26 countries from almost every region in the world has 1 GW of wind electricity generation in it [41]. In 2015, the wind remained the most popular source of electricity generation than any other source in the world, China at the top followed by the United States of America and then by Europe according to an estimate. China is leading the world in wind energy installation followed by United States, Germany, Brazil, and India. Whereas, the top ten countries include Canada, Poland, France, the United Kingdom and Turkey [50]. China has also developed its industry for wind energy installation and possess nearly half of the global increment in wind energy installation. On the other hand, new markets are opening in Asia, Africa, Latin America and the Middle East. Serbia, Jordan, and Guatemala have added their first large-scale wind plant while Samoa has added its first project. The market shares are contributed by various wind turbine manufacturers, where Goldwind, a china-based company is leading with 12.5%, followed by Vestas of Denmark which shares 11.8% of total wind turbine manufacturing industry. GE-Wind, a U.S. based company shares 9.5%, whereas a German based company Siemens shared 8% of the industry Likewise, Gamesa (Spain) 5.4%, Enercon (Germany) 5.0%, United Power (China) 4.9%, Mingyang (China) 4.1%, Envision (China) 4.0%, CSIC Haizhuang (China) 3.4% contributes into the wind manufacturing market. However, remaining 31.4% of the wind turbines manufacturing industry is shared by rest of the organization across the globe as depicted in Fig. 12 [50].

7. Wind energy outlooks

7.1. Global wind energy development

At the end of 2015, the utmost wind power producers across the globe as per inhabitant were Spain, Ireland, Sweden, Germany, and Denmark. In the large markets of the world, the growth of business associated with wind turbines undertake the uncertainty in future policy amendments, wind power's cost competitiveness, environmental conditions and some other factors prominently [51]. Wind is becoming the most appropriate and most economical option in the new markets for power generation [52]. Asia remained the largest market for wind production since last eight years, contributing 53% of the global production while European Union and North America are following with 20.1% and 16% [53]. While Africa has shown an inevitable increase in the power generation through the wind in 2015 as compared to 2014. Moreover, offshore wind farm projects are the most vigorous developments in the power generation through wind energy. In this regard, a lot of countries across the globe are deploying the offshore wind farms. The estimated 3.4 GW of wind power generation capacity is added globally till the end of 2015, which is approximately two times of the offshore wind power generation capacity added in 2014. Majority of the added capacity (89%) as well operating capacity (91%) was in Europe, where 3 GW capacity was installed for a total 11 GW of grid-connected capacity across the coasts of 11 countries [54]. Germany is involved in two-thirds of global offshore additions of about 2.2 GW, counting capacity connected but not grid-allied in 2014 [55]. It was followed by the United Kingdom (571 MW), China (361 MW), the Netherlands (180 MW) and Japan (3 MW) are the major countries for the addition of offshore capacity in 2015. Apart from that, if strategy deviations have deferred some progress, the United Kingdom sustained to lead in overall offshore capacity with 5.1 GW till the end of 2015; followed by Germany (3.3 GW), Denmark (1.3 GW) and China (1 GW). The offshore deployment in Asia and North America is relatively slower. China is about three years behind its 2015 target for deployment of 5 GW of energy. The delay factors include the high cost, unsuitable ecological conditions and technical and governing issues. India has approved the offshore wind policy opening the pathway for deployment of offshore wind farms. In the United States, construction is started on the first offshore wind project of 30 MW. Even diesel generators in Pakistan can be replaced by small-scale wind turbines. As small wind turbines can be used for several applications like battery charging, rural electrification, telecommunications, defense and water pumping. After a decline in 2013, the global market has risen up to 8.3% in 2014. The usual dimensions of small-scale turbines continue to increase, with significant differences among countries, because of growing awareness in larger grid-connected systems. Fig. 13 shows the total capacity of the world and annual addition in Gigawatts throughout the world. However, Fig. 14 indicates the total capacity of the world till 2014 and annual addition by the top 10 countries of the world in 2015.

7.2. International standards for wind power generation classification

The wind power classification is a specific rating system to determine the quality of the location for the purpose of wind turbine installation by considering the average wind speed of that site. The rating of wind is in numbers, the higher the class number, more suitable the location is for installation of the wind turbine. An anemometer is a device for measurement of wind speed and it is attached to the wind turbine. Wind speed is the fundamental factor affecting energy output capability of the wind turbine. Wind speed is directly related to the energy output, higher the wind speed, larger the energy output, keeping all the other factors constant [37]. Wind speed is directly related to the energy output considering the condition that wind speed must be less than 20 m/s and lie in class 3 to class 7 as shown in Table 1, which implies that higher the wind speed, larger the energy output, keeping all the other factors constant. Each wind turbine can have an allocation of a typical power class. However, a general rating of a wind turbine is difficult to know because there are numerous parameters involved in

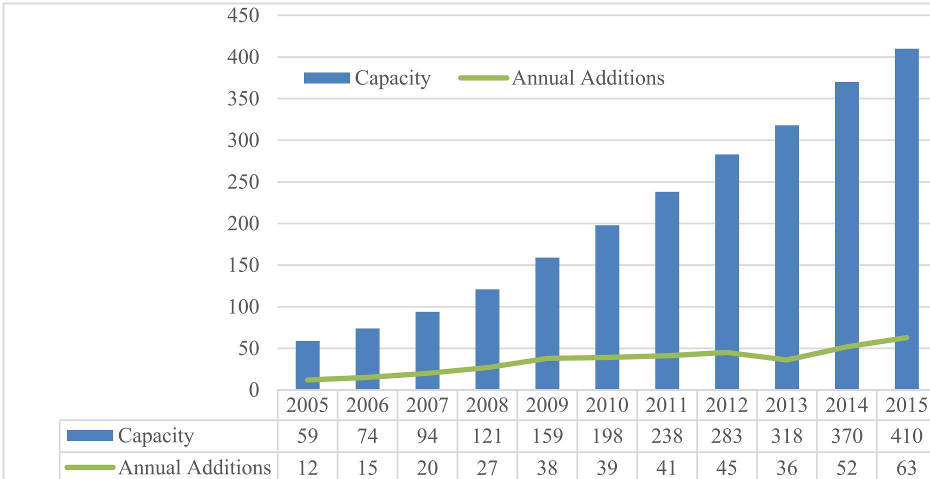


Fig. 13. Global increment in wind energy (GW).

determining the electrical output of a wind turbine. Wind speed and diameter of the blades of a wind turbine are the most vital parameters employed for determining the optimal kinetic energy from the wind [56]. A wind turbine; assembled and designed in most appropriate manners can never give output until or unless it is installed in a wind area of higher class [56]:

Wind speed varies on different altitude respectively, power density and speed of the wind at 10 m height would be lesser as compared to the wind power density and wind speed at 50 m height [57,58]. Table 2 represents the seven wind classes and their respective association with a range of wind speed and power density. Table 2 depicts each wind power class is linked with 2 power density classes, for example, class 2 represents the range of wind power density range between 100 and 150 W/m^2. In the table, offset cells mentioned in the first column exhibit this concept.

Normally, power wind class is described by average annual wind speed that is measured on the level of turbine's hub height and the extreme gusts that passed by over 50 years along with the turbulence at the wind site.

7.3. Wind power production outlooks in Pakistan

In Pakistan's energy market, the wind energy technology started at a slower pace. In Iran, the first windmill for production of energy to pump water and grinding grains was developed the in 500–900 A.D. Being very first neighbor of Iran, still, the history of Pakistan is mute about the existence of wind turbine or research on a wind turbine. It was not realized till the 1980s, research efforts were made and concluded that windy areas of mountains and of wind turbines were installed 10 kWh and 1 kWh in Sindh and Baluchistan respectively [59]. Water Pumping was a major issue and a lot of energy consumption occurred while performing this task. Therefore, Pakistan Council for Appropriate Technology, PCAT installed more than 12 windmills in both Sindh and Baluchistan provinces for water pumping. In March 2001, a report submitted to PCAT by Pakistan Meteorological Department, PMD was based on the data which is recorded at almost 50 stations for last 50 years at 2–10 m altitude from the ground. Estimated wind speed was

Table 1
Seven wind classes and their respective association with range of wind speed and power density.

Wind Speed m/s	Wind speed Miles/hour	Quality of site	Power Class
4	8.9	Not acceptable	1
5	11.2	Poor	1
6	13.4	Moderate	2
7	15.7	Good	3
7.5	16.8	Very Good	4
8	17.9	Excellent	5
8.5	19.0	Exceptional	6
9.0	20.1	Excellent-Hi	7

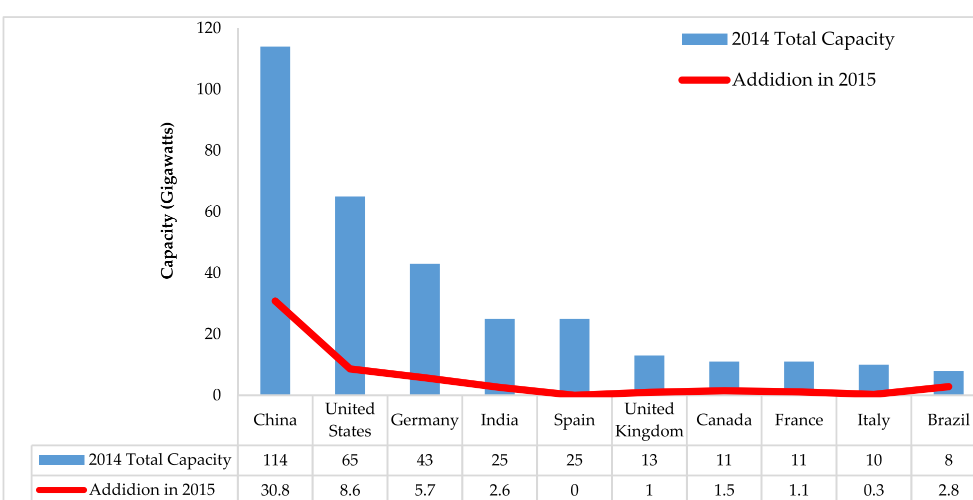


Fig. 14. Increment in wind energy generation by top 10 countries of the world.

Table 2
Wind Power class linkage.

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Wind Speed (m/s) mph	Wind Power Density (W/m^2)	Wind Speed (m/s) Mph
1	0	0	0	0
2	100	(4.4) 9.8	200	(5.6) 12.5
3	150	(5.1) 11.5	300	(6.4) 14.3
4	200	(5.6) 12.5	400	(7.0) 15.7
5	250	(6.0) 13.4	500	(7.5) 16.8
6	300	(6.4) 14.3	600	(8.0) 17.9
7	400	(7.) 15.7	800	(8.8) 19.7
8	1000	(9.4) 21.1	2000	(11.9) 26.6

obtained for 30 m height showing promising wind energy potential. Another report says that Hyderabad, Karachi, Chuhar, and Badin are the most appropriate places for installation of wind energy turbines. Moreover, in 2001, another project with the title of 'Commercialization of Wind Power Potential in Pakistan' was launched by Ministry of Environment and it was financed by Global Environment Facility, Nordic Trust Funds, and United Nations Development Program. The project was aimed to determine the feasibility report of the wind power project at Pasni, on the Makran coastal area of Baluchistan. Unluckily, there was no outcome of that project due to a shortage of wind data and incentives. Though, valued sanctions regarding tariff, strategic agenda, legitimacies were suggested which leveled the pathway for progress in wind energy generation for future perspective [60,61].

Later in 2002, 14 small sized WTGs were purchased from China to fulfill the necessity of power generation via wind energy. Six of these turbines were fixed in the coastal areas of Sindh, while the other eight were fixed in the coastal line of Baluchistan. It was observed that small wind turbine generators, WTGs are relatively more efficient as compared to larger one for the rural electrification in coastal zones [62]. In 2004, a foreign company completed the implementation of a hybrid wind-diesel project for rural electrification in Sibbi Baluchistan [59,63]. Various studies are done for assessment of wind speed at several sites of Sindh, the report in Ref. [64] states the data for almost 20 sites. Among these sites, Nooriabad, Talhar, Jamshoro and Kati Bandar were stated as the most excellent four sites for the production of electricity, while Thatta, Gharo, Hyderabad and Thana Bula khan were considered as good locations for electricity generation via wind energy [65]. Likewise wind potential in Karachi is evaluated and its corresponding solutions are proposed in Ref. [33].

During 2005-06, the knowledge and awareness in common people improved and the industrial sector in Pakistan started stabilizing in good manners, the ministry of water and power in Pakistan took some initiatives for the improvement of energy generation under Energy Security Action. Wind energy sources will contribute to 30% of the total energy production in Pakistan till 2030. Wind projects of 100 MW will be installed at two places in Sindh Province, i.e. at Kati Bandar and Gharo, which will be upgraded to 700 MW till 2010 [66]. PMD in financial collaboration with Ministry of Science and Technology has presented the accomplishment of the first phase with the title of 'Wind Power Potential Survey of coastal areas of Pakistan' in June 2005. Second Phase of the project for wind mapping in northern areas of Pakistan was initiated in July 2005. Sindh and Baluchistan areas were found as the most suitable areas for installation of wind turbines. In comparison, coastal areas of Sindh were found much better than coastal areas of Baluchistan. The windy areas in Sindh covered about 9700 Km^2. Approximately 43 GW can be produced through wind energy in Sindh. While technical feasibility report mentioned that 11 GW can be generated here. A feasibility study model was prepared for 18 MW Wind Turbine the payback years were 7–8 years [63,67]. In 2009 a report, by Asian and Pacific Center for Transfer of Technology in United Nations, described that only 2–3% of the area is covered by Wind Turbines and rest of the area can be used for low height cultivation and cattle farming. In this report, it was also mentioned that PMD has started measuring the parameters of Northern Areas of Pakistan for finding the wind potential. The wind farming areas of Pakistan having high potential exists in Hyderabad, Kati Bandar and Gharo in Sindh, while Mardan in KPK, Kalar Kahar in northern Punjab, Makran, Kolpur, Nokundi and Chaghi Areas in Baluchistan [68–72]. The major breakthrough occurred in development towards renewable energy generation in 2006, when the first energy policy was introduced and almost 56 letter of Intent (LOIs) were issued about the wind energy generation projects of different capacities, which were then increased to 97. Later on, some of the firms either embittered or didn't avail the opportunity [73].

The renewable energy policy presented in 2006 didn't have an immediate effect but this strategy played a role to some extent. As it was the first big policy given in Pakistan for green and clean energy [74]. There was not even a single grid-connected wind farm till 2008 in Pakistan but later on, a short plan was formulated for the generation of electricity via wind energy. The duration of the implementation of the formulated plan was from 2009 to 2014. In this plan, three clusters of windy regions in Sindh were taken under consideration for installation of wind farms i.e. Jhimpir, Kuttikun, and Bhambore, which allocated land to 23 wind farm developers with each having 50 MW power generation capacity. Moreover, transmission facilities were also analyzed for the generation of integration of these wind farms in National Grid System. It was also mentioned that there are no technical constraints in bringing the 500–700 MW wind power in the national grid system considering the parameters for dynamic performance, power quality, and load flow in Sindh [75]. In order to provide electricity to 1431 houses in Sindh, 135 micro wind turbine units were installed with a generation capacity in a surplus of 151 kW. Gul Muhammad village was the first village in Pakistan electrified via wind turbines. 26 units of 500W each were installed in the village for generation of electricity. Wind power guard posts and wind power battery charging facilities were installed in Lasbela for facilitating the people in villages. In 2009, AEDB (Alternate Energy Development Board) installed a 4 MW grid-connected wind turbine in Gharo, Sindh that was the largest wind turbine in the country at that time. AEDB also installed forty small-sized wind turbines in Karachi and then 500W in the University of Baluchistan for research on wind power generation technology. In 2009, US secretary of state announced to support Pakistan, for the project titled as "Pakistan Power Distribution Companies Performance improvement program (PDIP)".

The aim to support was to take measures for power sector self-sufficient, ensuring the financial and operational health of power sector and to improve electricity supply. In 2008–2009 poles for installation of wind turbines were installed at three locations in Sindh i.e. Babur bund, Hawks bay and Kati Bandar. The wind energy generation capability of all the three areas was analyzed and Babur bund was found as the most appropriate place for installation of wind turbines in an annual report by AEDB in 2010 [76]. Alternative energy board act of 2011 was passed by Government of Pakistan for authorizing AEDB for certifying and evaluating the renewable energy projects and for developing policies and strategies for utilization of renewable energy in the country. Moreover, AEDB was also instructed to act as a middleman for interaction and coordination with international and national innovation in technologies for renewable energy. This energy policy has replaced the energy policy of 2006 and the target for AEDB to five percent share in electricity through wind and solar projects was restrained [77].

7.4. Wind and solar power investment outlooks in Pakistan

Pakistan is naturally blessed with the most germane geographical location in the world, where there is the availability of generation of huge amount of energy. Unfortunately, this region is suffering from the power outage, low voltage transmission lines, major line losses, load

Table 3
Operational wind projects.
Source: Alternative Energy Development Board (AEDB)

Sr. #	Name of Project	Capacity	Location
1	FFC Energy Limited	49.5	Jhampir District Thatta, Sindh
2	Zorlu Enerji Pakistan Pvt. Ltd.	56.4	Jhampir District Thatta, Sindh
3	Three Gorges 1st wind farm Pakistan Pvt. Ltd.	49.5	Jhampir District Thatta, Sindh
4	Foundation Wind Energy-II Ltd.	50.0	Gharo District Thatta, Sindh
5	Foundation Wind Energy-I Ltd.	50.0	Gharo District Thatta, Sindh
6	Sapphire Wind Power Company Ltd.	52.8	Jhampir District Thatta, Sindh

shedding, environmental issues due to the usage of fossil fuels and negligence from the power consumption policymakers in the government institutions. The consumption of solar and wind energy would be highly beneficial for the environment as well as the generation is vastly suitable according to the available resources in Pakistan. Therefore, there should be a huge investment in the wind and solar energy. As a result, sufficient energy can be generated to overwhelm the worst deficit of it in Pakistan.

7.5. Wind energy projects in Pakistan

The government of Pakistan is taking some extraordinary measures for improvement in the wind power generation as discussed in generation systems as described in section 2. Yet the ongoing projects and installed projects in Pakistan are shown in Table 3.

7.6. Wind energy production in Pakistan

Table 3 indicates the operational wind projects in Pakistan along with their capacity and location while Table 4 [78] shows the wind projects which are under construction and their COD (Date of Completion) along with capacity and location. While, Table 5 [78] shows the projects, which are expected to be completed till 2017-18 along with their capacity, location and names.

8. Economic evaluation of solar panels

Economic evaluation is the fundamental need to take any decision for installation of solar panels in order to generate electricity. For this purpose, various studies have been explored. An electric power project in Quetta; a city in the Province of Baluchistan, Pakistan is evaluated in Ref. [79] and it is concluded that for this region electricity produced through PV is much higher as compared to conventional sources. Yet, it is helpful to provide the clean energy environment by reducing carbon dioxide. The issue of correspondence with grid electricity is much confusion and it is much expensive as compared to the grid produced electricity [80–82]. Such arguments for users are quite complicated which create confusion that whether their investment will be fruitful or not. Furthermore, another research is made by the authors in Ref. [83], in which they have compared the cost with financial payback for solar PV systems installed at various business locations in the USA. The case studies for four different locations in the USA were carried out included Honolulu, New York, Phoenix, and Minneapolis. The interesting fact was the results variation in cost and payback factors for solar PV locations at different installed locations. The recommendations made for consideration of several factors are mentioned as under:

1. The present cost of electricity and inflation rate for grid-produced electricity.
2. Amount of Solar insolation available.
3. Cost of PV based solar panels and the related components.
4. Government dogmas for financial sustenance i.e. tax reimbursements for attracting handsome investment in Solar Energy production sector.

8.1. Global solar energy production outlooks

Solar PV experienced a record growth in the year 2015, with annual market new capacity up to 25% till 2014 [4,73]. More than 50 GW of energy is added that was equivalent to 185 million solar panels increasing the world capacity to 227 GW via solar energy. A decade earlier the cumulative world capacity was ten times lesser than the annual growth of solar energy production in 2015 as shown in Fig. 15. Even though the top 3 markets of the world are responsible for such excessive addition in the whole world, still globalization continued with the new markets of all the continents [84]. However, the increment in solar energy by top 10 countries of the world is shown in Fig. 16 and the global percentage of share in increasing the solar energy are shown in Fig. 17.

Once again, Asia dominated all other continents with 60% of the global addition [85]. Yet China, Japan, United States used to maintain their top positions followed by the United Kingdom. Others included in top 10 were India, Germany, Korea, Australia, France and Canada [86]. By the end of the year 2015, each and every continent has increased almost 1 GW of energy except Antarctica. Presently, almost 22 countries have the ability to produce more than 1 GW electrical energy by means of solar panels [87]. Again, the cream of the crop of the solar market was Germany, Italy, Belgium, Japan, and Greece.

Electricity demand in the rich countries is at its peak to date. Whereas, currently the developing countries are also making a

Table 4
Wind Projects under construction [78].
Source: Alternative Energy Development Board (AEDB)

Sr.#	Name of Project	Capacity (MW)	COD	Location
1	Yunus Energy Ltd.	50	June 2016,	Jhampir District Thatta, Sindh
2	Metro Power Company Ltd.	50	Sep. 2016	Jhampir District Thatta, Sindh
3	Tapal Wind Energy Ltd.	30	Sep. 2016	Jhampir District Thatta, Sindh
4	Gul Wind Energy Ltd.	50	Sep. 2016	Jhampir District Thatta, Sindh
5	United Energy Pakistan Pvt. Ltd.	99	Sep. 2016	Jhampir District Thatta, Sindh
6	Hydro China Dawood Power Pvt. Ltd.	50	Sep. 2016	Gharo District Thatta, Sindh
7	Master Wind Energy Pvt. Ltd.	50	Sep. 2016	Jhampir District Thatta, Sindh
8	Tenaga Generasi Ltd.	50	Sep. 2016	Gharo District Thatta, Sindh
9	Sachal Energy Development Pvt. Ltd.	50	May 2017	Jhampir District Thatta, Sindh

Table 5
Wind Projects expected to be completed till 2017-18.
Source: Alternative Energy Development Board (AEDB)

Sr. #	Name	Capacity (MW)	Location
1	Jhampir Wind Power Ltd.	50	Jhampir District Thatta, Sindh
2	Hawa Energy Ltd.	50	Jhampir District Thatta, Sindh
3	China Sunec Energy Ltd.	50	Nooriabad
4	Three Gorges Second Wind Farms Pvt. Ltd.	50	Jhampir District Thatta, Sindh
5	Three Gorges Third Wind Farms Pvt. Ltd.	50	Jhampir District Thatta, Sindh
6	Tricon Boston Consulting Corporation Pvt. Ltd.	50	Jhampir District Thatta, Sindh
7	Tricon Boston Consulting Corporation Pvt. Ltd.	50	Jhampir District Thatta, Sindh
8	Tricon Boston Consulting Corporation Pvt. Ltd.	50	Jhampir District Thatta, Sindh
9	Western Energy Pvt. Ltd.	50	Jhampir District Thatta, Sindh
10	Burj Wind Energy Pvt. Ltd.	14	Gujju, District Thatta, Sindh
11	Hartford Alternative Energy Pvt. Ltd.	50	Jhampir District Thatta, Sindh
12	Zephyr Power Pvt. Ltd.	50	Gharo District Thatta, Sindh

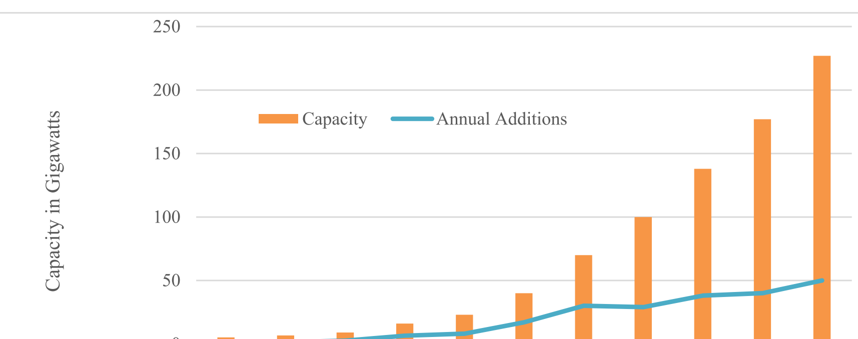
significant contribution in research progress for global growth; therefore, solar PV is taking off almost in all the continents wherever electricity is needed most, especially in developing countries [88]. However, a vigilant fact is little or no installation of solar panels in many Gigawatt sized markets of Europe. The primary factors for increasing demand and expansion in markets of Solar PV electricity include the competitiveness of solar PV, new government programs, increasing demand for electricity due to exaggeration in population & industry, and improvement in awareness of the people for a reduction in CO_2 and pollution.

8.2. Solar energy outlooks in Pakistan

The recent developments in CSP (Concentrated Solar Power) and PV (Photovoltaic Technology) immensely improved development of solar power in Pakistan. As Pakistan is one of the blessed countries, who have a significant amount of solar power production ability. The solar source is comprehensively disseminated, undoubtedly usable and abundantly accessible in Pakistan. The solar energy perspective in Pakistan is copious as the average 5.5–6 kW/h^2/day as well as about 1800–2200 kWh/m^2 per year radiations [89]. The estimated solar power generation capability in Pakistan is almost 50,000 MW. The north-eastern part of Sindh and south-western part of Baluchistan are a most suitable location with approximately 2500 h of sunlight for about 8–10 h per day and 2400–2800 per annum. Moreover, another report shows that there is the capacity of generation for solar power in Pakistan is more than 2,900,000 MW in Pakistan with the 7–9 h sunshine per day, more than 300 sunshine days, 26-28 °C temperature and 1900–2100 kWh/m^3 [90]. In order to implement a solar power plant, location feasibility should be taken into consideration; the planning procedure determines the solar energy potential in the target area. For assessment of the potential in the region, the digital assessment models, temperature, surface reluctance, cloud cover maps, surface pressure, humidity and wind data are taken into consideration [91]. Baluchistan is among the richest provinces in the world with 8–8.5h of sunshine per day; it has average global isolation of almost 5–7 kWh/m^2, southern Punjab and northern Sindh with 5-6.5 kWh/m^2 and 4.5–5 kWh/m^2 respectively [92,93]. Another survey depicts the solar power production capacity in Pakistan approximately 2900 GWh. This survey illustrates that implementation of solar energy projects in such areas can be beneficial for at least 40,000 villages [94].

8.3. Solar energy projects

At present, several major projects of production of electricity via solar systems are in progress. One of the major projects for generation of 1000 MW of electric power is through Quaid-E-Azam Technology Park in Bahawalpur for suppressing the deficit of electricity in the province of Punjab [95]. Likewise, in Quetta, a 300 MW plant to be made by a South Korean company as per the agreement signed on Dec 15, 2013 [96]. Moreover, in 49 villages of Tharparkar Sindh, 3000 domestic solar systems are installed under the rural electrification project in Sindh. Furthermore, almost 51 more villages in Sindh and 300 villages in Baluchistan are approved for solar electrification [97]. The chief benefit of such project is to decrease the transmission cost and meet electricity demands of small localities via solar panels. Almost 1500 units of solar water heaters have been imported and installed in various territories of Baluchistan, Khyber Pakhtun khuwah, Gilgit-Baltistan and northern Punjab. Correspondingly 22 more projects of 772.99 MW are ready for their commercialization at various locations until the end of 2016 [98]. Only 3000 Km^2 would be enough for meeting the current demand for electricity in Pakistan. However,



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Capacity	5.1	6.7	9	16	23	40	70	100	138	177	227
Annual Additions	1.4	1.4	2.5	6.5	8	17	30	29	38	40	50

Fig. 15. Global increment in solar energy (GW).

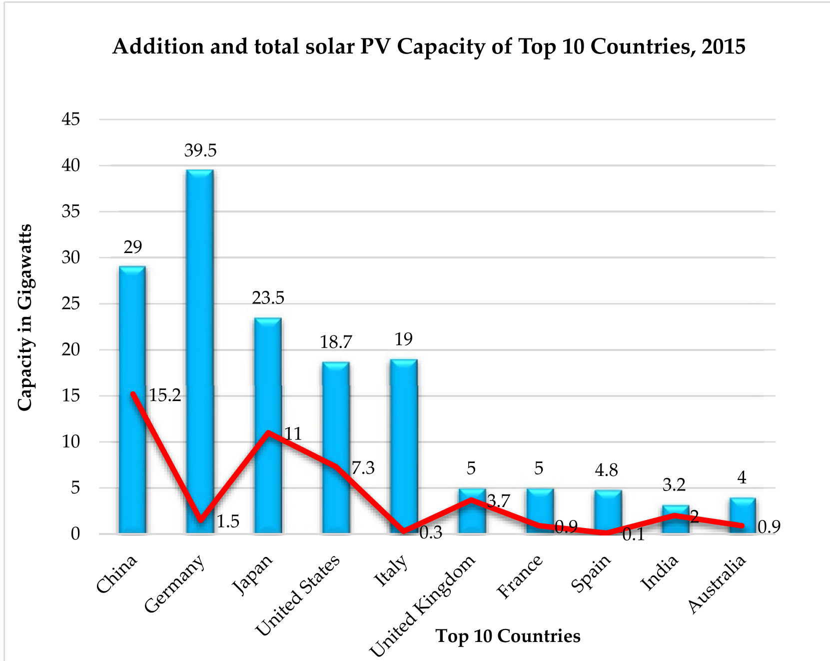


Fig. 16. Increment in solar energy generation by top 10 countries of the world.

Pakistan has not generated any grid energy in the duration from 2010 to 2013. Solar power projects completed till 2016 are shown in Table 6, while Table 7 shows the data of solar projects those have obtained the letter of support and Table 8 shows the list of solar projects those have obtained a letter of support (LOS) till now [99].

9. Promising solutions to solve the power crisis

This is apparent from current ground realities that it is awfully problematic to eradicate the ongoing energy crises in Pakistan by taking the short-term measures. Though, there is a possibility of lessening in the intensity of the current condition by instigating and implementing these short-term measures. A two-dimensional implementation measure is required to counter the current crises [100].

9.1. Short-term solutions and why?

In order to lessen the severity of prevailing energy catastrophes, the following short-term measures are obligatory to be implemented instantly:

1. In order to achieve the power shortage rapidly, wind turbines are a prospective solution. This is as the wind turbines are comparatively fast to install as compared to dams and nuclear plants which need almost five to six years for accomplishment and thermal power plants would be finalized in about two to three years at least [38]. Wind power can be a sustainable substitute and play a vibrant role in compensation of the energy deficiencies in Pakistan. Presently, there is an ongoing research for the employment of inclusive wind

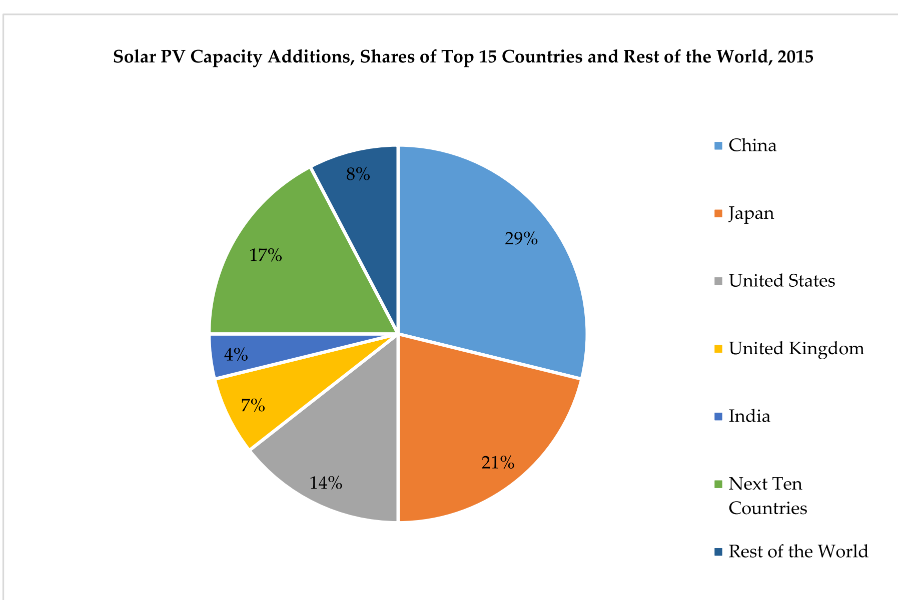


Fig. 17. Percentage of global share in solar energy generation.

Table 6
Solar power projects completed till 2016.
Source: Alternative Energy Development Board (AEDB)

Sr. #	Name of Project	Capacity (MW)	Location	COD	Status
1	M/s Appolo Solar Pakistan Ltd.`	100	Quaid-e-Azam Solar Park, Bahawalpur	Jun 2016	Completed
2	M/s Crest Energy Pakistan Ltd.	100	Quaid-e-Azam Solar Park, Bahawalpur	Jun 2016	Completed
3	M/s Best Green Energy Pakistan Ltd.	100	Quaid-e-Azam Solar Park, Bahawalpur	Jun 2016	Completed

Table 7
Solar projects those have obtained the LOS.
Source: Alternative Energy Development Board (AEDB)

S. No.	Name of Project	Capacity (MW)	Location
1	M/s Access Electric Pvt. Ltd.	10	PindDadan Khan
2	M/s Bukhsh Solar (Pvt.) Ltd.	10	Lodhran
3	M/s Safe Solar Power Pvt. Ltd	10	Bahawalnagar
4	M/s Access Solar Pvt. Ltd.	11.52	PindDadan Khan
5	M/s Blue Star Hydel Pvt. Ltd.	1	PindDadan Khan
6	Harappa Solar Pvt. Ltd.	18	Sahiwal
7	AJ Power Pvt. Ltd.	12	PindDadan Khan
Total = 72.52			

Table 8
Solar projects that have obtained LOI.
Source: Alternative Energy Development Board (AEDB)

Sr. No.	Name	Capacity (MW)	Location
1	M/s Integrated Power Solution	50	Nooriabad
2	M/s Jafri & Associates	50	Nooriabad
3	M/s Solar Blue Pvt. Ltd.	50	Nooriabad
4	M/s R.E. Solar I Pvt. Ltd.	20	Jamshoro
5	M/s R.E. Solar II Pvt. Ltd.	20	Jamshoro
6	For shine (Pakistan)	50	Gharo, Thatta
7	ET Solar (Pvt.) Ltd.	25	Thatta
8	ACT Solar (Pvt.) Ltd.	50	Thatta
9	Janpur Energy Limited	12	Sultanabad, Rahim Yar Khan
10	Janpur Energy Limited	12	Mehmood Kot, Muzafargarh
11	Blue Star Electric Pvt. Ltd.	1	Pind Dadan Khan
12	Siddiqsons Energy Karachi	50	KalarKahar, Chakwal
13	Adamjee Power Generation Pvt. Ltd.	10	Noorsar, Bahawalnager
14	ET Solar (Pvt.) Ltd.	50	Fateh Jang, Attock
15	Crystal Energy (Pvt.) Ltd.	2	Sambrayal, Sialkot
16	Asia Petroleum Limited	30	Punjab
17	First Solar (Pvt.) Ltd.	2	Jhelum

maps in the country.

2. It is compulsory that management authorities must ensure prompt completion of the under-construction power plants across the country. This is essential to eradicate the problem of overloading, which is a source of power outage, and to assure extreme generation.
3. It ought to be permissible that power plants should be established by the private investors. The private sector must pay their share in overcoming the energy crises by establishing different plants with their own equity and loans based on their schemes and feasibility.
4. In Pakistan, some power stations are currently not operational due to trivial faults that should be made operative. These power generation units can be refurbished by small amount of expenditures and technical advances. In a survey conducted in 2010, it was noted that 17.8 million consumers have consumed the 92, 480 GWh of electricity units, however, they were charged with 73,561 GWh of electricity units. Considering the 20.4 percent of electricity losses, 11% of the generated electricity was theft during 2010 [101]. Moreover, The need of the hour is to resuscitate such power production units for pulling out the economy out of energy crisis. The activation of these projects not only ensures the smooth stream of energy, but it also avoids any further broadening in the demand-supply gap.
5. Apart of the generation side, it is also obligatory that clients put their efforts in exterminating the crises. Due to this, the commercial sector should sternly impose the marketplaces as well as the shopping centers to be closed till 10 p.m. The power protected from this source can be directed to homes by an efficient directorial resident system. Thus, the domestic consumers can be facilitated from this saved power in various parts of the country.
6. Another key step needed is to control the outflow in the power supply. Power theft is becoming a big problem nowadays in Pakistan. Putting hooks on the electricity wires and meter tempering becomes the major problem. Almost $25 billion losses are reported across the globe due to electricity theft [102]. However, rough estimates have concluded that Pakistan is facing This is time to spread consciousness in the public and the electricity theft should be considered as atrocious crime. The administration and concerned establishment ought to frame the policies and stringent actions must be taken in case of any violations by industrial, domestic or commercial users. The customers who pledge such a misconduct must be accountable to legal consequences and complete power disconnection.
7. The billing irregularities should be overcome immediately. Some organizations do not measure the electricity exactly owing to their negligence or faulty equipment. Later on, charging approximated lower amount from the employees by adjusting it in computers lead to another problem that must be overcome. Likewise, corruption and bribery to move decimal one point left on the electricity bill leads to another irregularity in electricity bills. Moreover, unpaid bills from domestic, commercial, industrial and corporative units must be charged immediately [103]. Though pre-paid meters can also be a solution to avoid the electricity theft.
8. In industrial as well as agricultural sectors, the employees and stakeholders should be instructed on implementation of new and effective practices of energy and water consumptions. This step will tend to diminish the energy expenditures.

9.2. Mid-term solutions and why?

1. The governance of power sector should be upgraded. Renewal of power generation units is mandatory because they are functioning at relatively low efficacies. It will support in improving efficiency and reducing environmental impacts.
2. The losses owing to grid, transmission and distribution systems are approximately 20%, these losses should be lessened according to the global values.
3. The energy efficiency strategy would be planned and the employment of electrical appliances manufacturing standards should be assured in order to eliminate the substandard and ineffective devices from the souk.
4. A certain research and development (R&D) fund must be assigned from the yearly budget meant for renewable energy, so that the

universities as well as R&D organizations could classify confined solutions for familiarizing and allocating the use of renewable energy.

9.3. Long-term solutions and why?

By analyzing the expected intensification in power consumption for the future, the following long-term actions can be realized:

1. It is valued that Pakistan owns the third-largest and renowned coal reserves across the globe. In Thar, the south-eastern part of the country, a coal reserve of 33.0 trillion tons is being originated. The problem of power calamity in Pakistan can be undid by exploiting this coal for purpose of power generation. This can offer a long-term way-out for the problem. According to the international surveys, analysis and comparisons, it is found that cost of electricity generation by coal is comparatively cheaper than generated by fossil fuels [101], i.e. furnace oil, diesel etc. Moreover, the analysis shows that 2% usage of Thar coal could produce 20,000 MW of electricity.
2. To cater the boosted demand, the basic solution exists in the establishing of additional nuclear plants as well as small and large dams in Pakistan. For fabricating hydroelectricity, the Régime can refer numerous Chinese and Norwegian corporations in order to take advantage of their technical proficiency in the field of dam formation. In addition to power production, the formation of new water reservoirs as well as dams also has importance in incapacitating the growing problem of water deficiencies.
3. One more long-term measure is the restoration and replacement of the obsolete transmission and distribution systems. The perpetual setback of line losses and holdups by crooked clients in the country can be exterminated by implementing such measures.
4. It is found as a result of research and analysis that the power produced by natural gas for domestic purpose costs about Rs.6 kWh, whereas its cost is Rs.14.5 kWh by consuming furnace oil. Regrettably, the natural gas apportionment for power production is abridged to 27% from 53% in the last five years. Conversely, the consumption of furnace oil for power generation has amplified to 38% from 17% [38,104]. In 2010, this initiative has raised the generation cost by Rs. 130 bn., as a result, the rising circular debt leaded to higher power charges [105]. The response to a long-term solution for the power crisis in the country lies in reallocation of gas in power generation as power generation should take primacy over other sectors. By this technique, the crisis can be assuaged.
5. Vindicating the foreign dogma of the country conferring to its monetary and energy requirements is most important in the long-term forecasting and goals. It is compulsory for Pakistan's administration to improve relations and knot ties with future energy-rich countries. In order to take benefit from the economic and methodical aid for the power sector, this factor should not be ignored.
6. The integration of smart grids technology into the system and implementing the concept of smart meters and to detect the fault and isolation of faulty components from the system in case of severe fault can lead to an optimal solution for saving the electricity across the country.
7. The combined electricity generation projects like solar/wind, solar/biomass, wind/hydro has a significant importance regarding electricity generation. Such projects should be installed and the electricity produced through them should be integrated in the national grid system of Pakistan in order to cope with energy challenges.

9.4. Renewable energy potential and why?

In addition to short term, mid-term as well as long-term measures for overcoming the energy crisis in Pakistan, utilization and employment of the renewable energy resources are also a credible solution to exterminate the problem. The renewable energy potential and resources of Pakistan are comprehensive explained in aforementioned subsections [66]. However, the following lines give a brief overview of it:

1. *Biogas:* Pakistan is primarily an agricultural country as well as rich in livestock. Consequently, the country has huge potential for power generation by means of biogas. The assessed potential of generation by biogas is found to be 8.8 to 17.2 billion m^3 (Around 55 to 106 TWh. of energy, equal to Pakistan's overall power requirements recently). This expresses that approximately 5700 GWh (6.6% of Pakistan power production nowadays) of electricity can be generated by using biogas.
2. *Wind potential:* Pakistan's accumulated wind power potential is more than 300,000 MW. This much of wind energy can be effectually employed to rise the generation of electricity to meet the demand.
3. *Hydropower potential*: The predictable hydropower potential of Pakistan is about 51,700 MW. This includes large Hydro source PPIB, MoW&P.
4. *Solar Photo Voltaic potential:* Pakistan is fortunate to obtain a large amount of solar radiation and therefore rich in energy formation. The typical solar irradiation in Pakistanis 5–7 kWh/m^2/day which is one of the finest figures of solar irradiation levels acknowledged across the globe. By harnessing the solar energy, Pakistan can harvest more than a Million MW of Solar PV electricity to offer sufficient space for installation.

The question rises that why renewable energy potential is very much significant to resolve the apprehension of energy crises; it is defined as follows:

1. The analysis and researches unveiled the fact that renewable energy resources are sustainable and enduring. The optimistic aspect of consuming such a source is their satisfactory performance for providing the required power supply without imposing any damaging effects on the atmosphere.
2. These energy resources are the artefact of nature and therefore environment friendly. These sources are consequential either from the natural source of energy or by adapting any of the natural material into energy. As an outcome, there is nominal or no maltreatment to the environment from garnering them as a source of energy.
3. The renewable energy sources are frequently gained from nature. Such resources are profusely and immediately available. Additionally, they have the advantage of reprocessing, therefore guaranteeing its endless supply.
4. One more key benefit of consuming renewable energy resources is their ready, local, and easy availability. Thus, there is no requirement to bear the burden of extensive networking in order to exploit renewable energy resources on separate or combined levels. Moreover, renewable energy resources turn out to be extensively dispersed all over the world and so, it can offer the following benefits:
   a. To better the socio-economic conditions
   b. To enrich health concerns
   c. Scarcity mitigation of people living in remote areas.

9.5. China Pakistan economic corridor (CPEC) solutions and why?

In Han Dynasty, China was considered as a richest and strongest nation across the globe. The ancient civilization was blooming on the trade route of "Silk Road" stretching from Capital Xi'an to ancient Roman Empire. Approximately, two thousand years later, history is repeating itself. Phenomenal growth for about two decades has prepared China to spread its economic advancement to the whole world. For this purpose, a new "Silk Road" or "One Belt, One Road" is in progress for linkage of the Chinese province of Xinjiang with the Arabian Sea. This route is provided by Pakistan's Gwadar port. This project is known in its entity as the China Pakistan Economic Corridor also abbreviated as CPEC and also as “China's Maritime Silk Road”. Expenditures of $ 46 billion will be spent on its infrastructure, this is considered as “big break” of Pakistan on the global front. 80% of investment is to strengthening the power infrastructure in Pakistan. In addition to power infrastructure, a network of railways, roads and business hubs is planned with the development of Gwadar as a port. This project is differentiated from all other proposed projects from the west because of reasonable expenditures and suitable outcomes for both the countries [106]. Board of Investment stated the major components of economic corridor as Gwadar (Port, City and Gwadar's socio-economic zone development), Energy (Coal, hydel, wind, solar, LNG transmission), Transport infrastructure (Railways, Roads and aviation), investment and industrial cooperation for Gwadar free zone and other industrial parks to be finalized. In order to fulfill the energy needs of the CPEC, 21 projects are identified along with up-gradation of existed power sector in Pakistan. Among the $37 billion assigned for energy projects, around $33 billion will be utilized for these 21 projects. Sindh gets the biggest lump of $ 11.3 billion in power development structure. Electricity production will be self-sufficient for Pakistan as a result of 10,000 MW addition in its generation capacity till 2018 while 15000 MW will be added by 2023–2025. Pakistan has enough coal reserves to contribute till next 40 years for a generation of 5000 MW of electricity, which is expected to be exploited till 2019 in the projects for Jamshoro, Qasim, Sahiwal and Hubco power plants with half of their generation capacity available by 2017 and full by 2018 [107]. Diameter, Bhasha, and Dassu Dam, each having capacity of 4500 MW are also planned with Rs. 100 Billion already spent for Bhasha Dam's land acquisition. Sukhi Kinaro Hydro project of 870 MW and Krote Hydro project of 720 MW are also in pipeline for 2018 in KPK. Moreover, 3600 MW is expected to integrate into National Grid system by Liquefied Natural Gas (LNG) till 2017. To elevate Nuclear power plants for production of 2200 MW is also in progress. Renewable energy projects are also in working with 500 MW to be generated via wind and 1000 MW through solar power via Quaid E Azam Solar Park in Bahawalpur. $3 billion approximately are allocated for augmenting power distribution sector of Pakistan. IT sector is also developing for being in the path of CPEC; initial plans are to lay an optical fiber cable of 820 km length from Khunjerab to Rawalpindi with a budget allocation of $ 44 million. It is already started in May 2016 and it will last for two years, as a result of this, an alternate communication route between Pakistan and China will be developed as well as 3G, 4G and even the next generation capability would be increased. Table 9 and Table 10 demonstrate the progress of the projects and their contract companies as well as power production capability [108–111].

9.6. Proposed smart grid

At present, centralized electrical energy transfer system flows from production units to customers in one-way hierarchical flow [112]. This unidirectional uncontrolled power flow creates huge challenges for grid operators, therefore, questioning the reliability, efficiency, security, and quality of supplied power [112,113].

A smart grid (SG) is also called an Intelligent Grid (IG). An SG is referred to next-generation power grid system, which uses communication and information mechanisms for power transfer from central power generation station in two-way manners and to other consumers from Distributed Energy Resources (DERs) in a pervasive and intelligent manner [114]. Consequently, the network architecture is used in spite of hierarchical approach for information exchange between producers and consumers and to control multidirectional power flow. Communication and intelligent controlling ability an infrastructure in SG will lead to coping it to meet the demands of bulk consumers and to sustain in the market with environmental and economic benefits [115,116]. Table 11 depicts the comparison of the conventional grid to that of smart grid system:

Currently, the load is increasing power grids are subjected to structural weakness and environmental shortcomings as the load are increasing. Undoubtedly, power quality, economic development of a nation and reliability of the system gets affected due to such limitations [117]. The smart grid consists of modern information technologies for the safe and consistent dispatch of electricity in both directions, i.e. from distributed producers to consumers and vice versa, in suitable manners with information exchanging capability in real time [118].

The fundamental perception of SG initiated with idea of improving demand-side management and energy feeding efficiency by using Advanced metering infrastructure (AMI) and constructing a physically reliable, resilient grid system having self-healing capability and repulsive ability against cyber-attacks, therefore term Smart Grid is used for making an intelligent Grid system and taken into consideration in the 1990s [119,120].

However, the concept further developed and was primarily supposed as an SG, when U.S Government asked National Institute of

Table 9
Power production capacity and their progress.

Project Name	Company Name	Status	Progress
Prioritized/Early Harvest Projects, 10400 MW			
2 × 660 MW Port Qasim Coal-fired Power Plant	Power China Resources Ltd.	Under construction	60%
2 × 660 MW Sahiwal Coal-Fired Power Plant	Huaneng Shandong Ruyi (Pakistan) Energy (Pvt.) Ltd	Under construction	60%
4 × 330 MW Engro Thar Coal-fired Power Plant and Surface Mine in Block II of Thar Coal Field	China-Machinery Engineering Corporation(CMEC)	Under construction	60%
50 MW Dawood Wind Farm	Hydrochina International Engineering Co. Ltd.	Under construction/Almost Completed	90%
900 MW Quaid-e-Azam Solar Park in Bahawalpur	Zonergy Company Ltd.	Under construction/First 300 MW completed	60%
100 MW Jhimpir Wind Farm	UEP Wind Power (PVT) Ltd.	Under construction	60%
50 MW Sachal Wind Farm	Hydrochina International Engineering Co. Ltd.	Under construction	60%
720 MW Karot Hydro-Power Project	China Three Gorges South Asia Investment Ltd.	Under construction	60%
873 MW Suki Kinari Hydropower Project	China Gezhouba Group Corporation International Ltd. (CGGC)	To be inaugurated	15%
50 MW China-Sunec Wind Farm	China Sunec Company	Feasibility stage	15%
2 × 660 MW Rahimyar Khan Coal Power Plant	TBD	Feasibility stage	15%
Thar Coal Block I and 2 × 660 MW Mine Mouth Power Plant	TBD	Feasibility stage	15%
660 MW Hubco Coal Power Plant	China Power International Holding Ltd.	Negotiation in Process	15%
300 MW Gwadar Power Plant	TBD	Feasibility stage	15%
Matiari-Lahore Transmission Line	China State Grid	Negotiation in Process	15%
Matiari-Faisalabad Transmission Line	China State Grid	Negotiation in Process	15%

Table 10
Actively promoted projects.

Actively Promoted Projects, 17045 MW			
Project Name	Company Name	Status	Progress
2 × 660 MW Gaddani Power plant at District Lasbela, Balochistan	TBD	Feasibility stage	15%
1100 MW Kohala Hydro-Power Station	China Three Gorges South Asia Investment Ltd.	Negotiation in Process	15%
2 × 50 MW Wind Farm Phase II of Pakistan	China Three Gorges South Asia Investment Ltd.	Under construction	15%
660 MW HUBCO Coal Power Plant	China Power International Holding Ltd.	Negotiation in Process	15%
300 MW Salt Range Mine Mouth Power Plant including Mining	China Machinery Engineering Corporation (CMEC)	Feasibility stage	15%
2 × 660 MW Thar Mine Mouth Coal Fired Power Plant by Oracle	TBD	Feasibility stage	15%
2 × 660 MW Muzaffargarh Coal-fire Power Plant	China Machinery Engineering Corporation (CMEC)	Feasibility stage	15%
525 MW Gas-Fired Power Plant	TBD	Feasibility stage	15%

Table 11
Conventional Grid vs. Smart Grid System.

Conventional Grid System	Smart Grid System
Electromechanical/Analogue system	Digital/Binary System
Unidirectional Communication	Bidirectional Communication
Unified production	Distributed production
Rare utilization of Sensors	Overall Sensors network present
Manually monitored	Self-monitored
Manual Restoration	Self-restoration via self-healing ability
Power failures and shutdowns	Islanding and Adaptive
Limited control	Prevalent control
Limited consumer choices	Many consumer choices

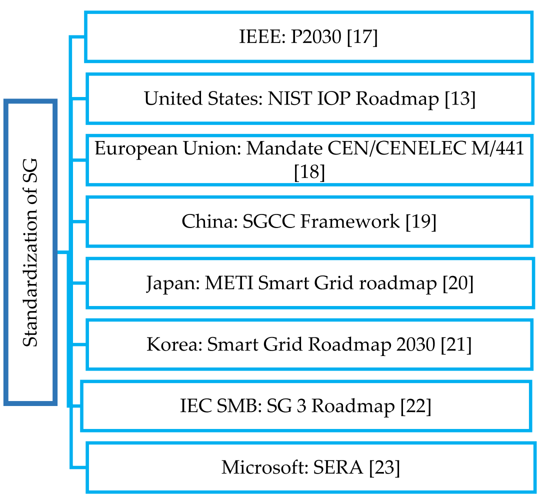


Fig. 18. Major adoptable standardizations of SG.

Standards & Technology (NIST) to focus their research perspective on assembly and demonstration of SG projects [121–123].

Several standards in various regions of the world are developed for SG. Some foremost standardizations adopted until date are depicted in Fig. 18 as:

The relative studies along with other calibration roadmaps would be found in Ref. [124]. As SG, is said to be a "System of Systems", it is an amalgamation of mechanisms and technologies implemented in the systems. The Integration of various technologies and their use to develop an SG can be found out in Ref. [125].

9.7. Smart grid conceptual model

SG is a concept containing unzipped integration of corresponding components, networks, services and subsystems under the prevalent control of radical-smart administration and control systems for providing support to both utilities and customers [126]. A huge landscape

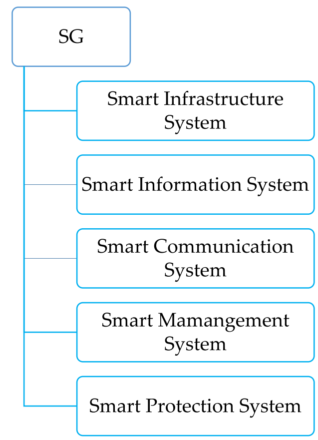


Fig. 19. Major adoptable standardizations of SG.

of the SG classified into three subsystems as shown in Fig. 19 is mentioned.

A SG system is capable of self-healing and has ability of immediate power transfer through both wired and wireless technologies by means of Optical Fibers (OFs) and power line communication (PLCs) in wired technology and by Wireless Mesh Network (WMN), Cellular Communication Technology (CCT), Cognitive Radio (CR), Satellite Communications, Point to Point Communication Technologies (PPCT) [127–131]. Moreover, Smart Generation, Smart transmission, and smart distribution systems are major factors involved for reliable power transfer. Smart Generation includes the concept of Virtual Power Plant (VPP), which is able to accommodate power generated by DERs equivalent to a huge Grid System. It controls fluctuations in renewable energy generation systems, therefore, making them convenient to integrate with centralized power grid system. However, Smart Transmission system consists of Smart Control Centers, Smart Transmission of Power and Smart Substations [132]. It is constructed on novel technologies i.e. newfangled constituents, innovative sensors, power electronics, control, computation and communication for improving the performance of the system for power consumption, power quality, safety, and consistency. The smart substations are proposed on the elementary structure of typical substation; however, it has enhanced assembly for scrutiny, control, automation and analysis [133].

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The distribution network is the prime part of power grid system that plays a vibrant role in the quality of power supplied to customers with the boosted economy. For discussing the delivered power to the consumers in a better way, [141] describes two domestic level power distribution systems: first one is through Direct Current (DC) power dispatching system via energy packet distribution consuming silicon Carbide Junction Field Effect Transistors (JFET) whereas other one uses circuit switching system for AC power distribution [142]. A smart energy system in an SG uses two Grid Patterns to enhance consistency and safety of power system i.e. Microgrid and Grid to *Vehicle/Vehicle to Grid (G2V/V2G)* technology. A Microgrid is a minor cluster of DGs with local customers that can achieve local demand in case of isolation (islanded) from macro-grid [143]. If a severe fault occurs at macro-grid, the microgrid can be functioned in the islanded mode for uninterrupted supply to local customers. Therefore, ensuring enhanced reliability and hybridization of Renewable Energy Resources (RERs), self-healing and better efficacies [144].

Smart Information Subsystem sets standards through IEEE: P2030 for data exchange, information management, optimization, modeling, and analysis. Data acquisition is attained by Smart Meters (SMs), Sensors and Phasor Measurement Units (PMUs).

Smart Management Subsystem is categorized into management objectives and management methods. Smart Management Objectives includes improved efficiency, demand side management, lower cost & higher profit optimization techniques using convex programming [145], and dynamic programming [146], emission control and price control. Whereas smart management methods include several techniques using optimization, auction & machine learning and game theory are employed thus far to solve the current management problems. Smart protection system includes system security against power outages and system faults; they are also helpful in case of cyber-attacks on the system. It also assesses the system's reliability and protects metering and measurement system by preventing AMI from hacking by sending obtained information back to the customer for confirmation as adopted in case of parity check technique.

An ideological model of SG is thoroughly advised and various technologies for modifying the conventional grid into the smart grid are explored. The jeopardies presented owing to advanced technologies are comprehensively assessed and resolutions anticipated by several researchers are presented. Certainly, the advent of the smart grid will lead Pakistan to a better place, better energy services and eventually transform our living style. Though, there is still a lot more to accomplish before this vision comes true. The several countries and organizations need to synergies to strive for this joint venture that eventually leads to an auspicious future for the whole mankind.

9.8. Proposed sites selections to solve the power crisis

Various locations are also proposed in this manuscript to harvest the energy potential found in Pakistan for renewable energy extracted from wind and solar projects. Wind and Solar energy production feasibility report are summarized in Table 12 for various suitable locations in Pakistan.

9.9. Proposed power converters for system stability

The adaptation of variable-frequency and variable-magnitude voltage to constant-frequency and constant-magnitude voltage involves three-phase AC-to-AC converters, i.e. cycloconverters. These converters can convert voltages directly or indirectly, contingent to the presence of DC link capacitor. Four quadrant switches are mandatory to perform direct conversion of variable-frequency, variable-magnitude voltages. Direct AC-to-AC converters, i.e., cyclo-converters and matrix converters are normally deployed, which eradicate the need for a high DC-link capacitor. Matrix converters are gaining large consideration due to their substantial advantages, i.e. renaissance ability, robust control over input power-factor, wide and dynamic range of frequency conversion, and smooth input-output waveforms. Furthermore, modular configuration of matrix converter empowers the converter to be employed at high power ratings. Additionally, applying the Insulated-gate Bipolar Transistors (IGBT) into the circuit further increases the power rating [147].

A matrix converter characteristically comprises of nine bidirectional switches connected in a matrix configuration. Each switch cell consists of IGBTs associated in H-bridge configuration to confirm four-quadrant operation of the converter. By linking an equal number of switch cells in series at each converter arm, a multilevel modular configuration can be realized. Moreover, the H-bridge switch cell can be substituted by some other bidirectional power flow formations as discussed in Ref. [147], whereas various modifications of modular approach are presented in Ref. [147] and any of them can be chosen to fit the application. The modular matrix converter is sharply different from conventional matrix converter and other DC link counterparts because of the fact that it is able to both increase and decreases voltage magnitude and voltage frequency [147]. This converter has the ability to control input and output side waveforms and power factor independently. Henceforth, this modular matrix converter plays a significant role in conversion and control of variable-frequency, variable magnitude voltages, produced by converting wind energy to electrical energy, into constant-frequency, constant-magnitude voltages.

Space Vector Modulation (SVM) based control algorithm [147] is usually applied to govern power converters, which enhances the harmonic profile of the converter, eradicates the need for power source required by each individual cell, and treats the capacitor of each H-bridge switch cell as a local voltage source. As the number of switches increases in each converter arm, the impediment of control also increases. Without doing complex calculation associated with a high number of series-connected switch cells, [147] discusses a variant of space vector algorithm and offers a transformation in d-q coordinates along with the technique to balance the capacitor voltages. The fundamental advantage of employing modular matrix converter is highlighted in Ref. [147], which explicated that if the conversion frequency is high then the transformer size, for stepping up the voltages, would be reduced to a substantial level. Nowadays, the high frequency transformers require less space and hence, reduces the financial problems in the wind energy plants.

9.10. Proposed HVDC transmission

In Jiwani, it is noticed that the site is relatively distant from the prime transmission network, and therefore, it requires the integration of new transmission lines into the system. The actual adjoining 220 kV grid station is located in Surjani Town, Karachi. However, it is governed by Karachi Electric (KE), a semi-private organization; having the route distance of 700 km. The need of the hour is to connect Jiwani to the GoP national grid So, the contiguous apposite site is accessible in Jamshoro city, Sindh, around 850 km distant from the wind plant, having an operational voltage equals to 220 kV. The momentous distance recommends the installation of High Voltage DC (HVDC) transmission lines as it is cost-effective to install HVDC line as a substitute of

Table 12
Wind and Solar Energy production feasibility of Different Wind/Solar Energy Setups.

Wind			Solar		
Locations	Avg: WS (m/s)	Month of the Year	Locations	Avg: Temp (^{0}C)	Month of the Year
Jamshoro/Sindh	8.5	July	Jacobabad/Sindh	35.3	June
Hyderabad/Sindh	6.4	June	Dadu/Sindh	26.1	July
Thatta/Sindh	6.7	July	Mohenjo-Daro/Sindh	35.0	June
Jhampir/Sindh	7.3	June	Larkana/Sindh	26.9	June
Badin/Sindh	5.5	June	Jacobabad/Sindh	27.3	July
T.B Khan/Sindh	5.1	June	Sibi/Baluchistan	27.2	June
Kotri/Sindh	4.8	May	Nawabshah/Sindh	26.6	July
Karachi/Sindh	4.2	June	Turbat/Baluchistan	27.9	July
Pasni/Baluchistan	5.9	April	Mianwali/Punjab	24.2	June
Jiwani/Baluchistan	7.2	April	Rohri/Sindh	27.0	June
K. Bandar/Sindh	7.0	July	Sukkur/Sindh	27.0	July
Gharo/Sindh	6.6	May	Rahimyaar Khan/Punjab	26.2	July
			Sargodha	23.8	June

High Voltage AC (HVAC), for distances more than 70 km, and provides rapid and robust control of active and reactive power. Additionally, as the wind energy conversion system as well as the main grid system are not coupled synchronously, therefore, the power generators in the plant don't promote short-circuit fluxes in the focal grid [147]. The foremost advantage of HVDC connection is the transmission of high power over long distances by consuming comparatively a reduced number of conductors. Generally, bipolar configuration having two independent poles is chosen for HVDC transmission which is comparable to double circuit structure of AC transmission lines. As, prior consumes only two conductors, therefore, it is considered as an economical, technical and more feasible way out.

9.11. Proposed model for wind turbines integration with national power grid

The model presented for wind turbines integrated with the national grid is shown in Fig. 20. The proposed draught connects the wind energy station located at Jiwani to the main grid located in Jamshoro. A modular matrix converter is connected with individual wind turbine output in order to convert the variable-frequency and variable-magnitude voltages to the fixed-frequency and fixed-magnitude voltages. In order to enhance the voltage level of the plant at relatively high frequency, a high-frequency transformer is connected. Afterward, a voltage source converter (VSC) is connected on plant side, based on HVDC link to convert AC voltages at high frequency to HVDC having a voltage level of approximately ± 300 kV. As revealed in Fig. 15, a bipolar configuration can be applied to tie wind energy conversion station and the focal grid station. If tapping along the route is circumvented, then HVDC link can provide huge financial benefit. On the focal grid station, DC to AC converter should be installed for converting HVDC to 220 kV, 50 Hz AC voltages. The inversion of HVDC to resident level AC voltages would settle a smooth interconnection between wind plant and the focal grid station. VSC–HVDC link lessens the harmonic content of the output waveforms, as a result of which the overall power factor is improved and the filter size is reduced. Filters can be coupled with the utility grid station for enhancement in smoothness of the output waveforms and to reducing the harmonic content of the output AC waveforms [147].

10. Energy storage system

The produced energy in form of electricity can become more useful if there exists an adequate system for energy stowage. Energy storage systems create a resilient energy infrastructure and provide economical techniques to utilities and customers. The perceptible approaches deployed around the world are mainly categorized into six categories. They include the solid-state batteries; a variety of electrochemical storage systems includes the advanced chemical batteries and capacitors

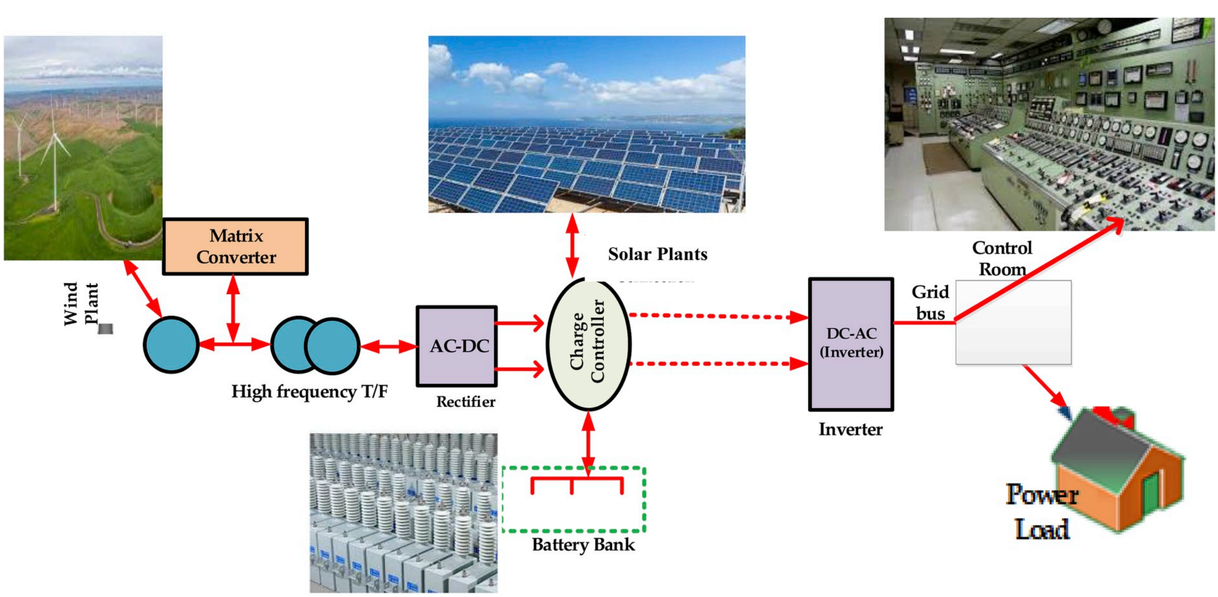

Fig. 20. Wind Turbine setup and its integration in National Grid.

[148]. The batteries in which the storage of energy is directly in the electrolyte having longer cycle life and rapid response time are known as the flow batteries. There are mechanical devices also available for harnessing rotational energy to deliver instantaneous electricity, which are called as flywheels. The compressed air can also be utilized to form a potent energy reserve. Moreover, capturing heat and cold to produce the demanded energy is classified as thermal mean. However, creating reservoirs of energy with water on large scale are known as pumped hydro power storage and categorized in the geological storage category of energy storage systems.

Several models are proposed for storage of electrical energy by various researchers across the globe. However, the model proposed in Ref. [148] is found relatively adequate and the technique proposed can be utilized on the larger scale for harnessing the solar energy without wasting it. Likewise, the renewable energy microgrids are one of the optimum options to be integrated in both grid-connected as well as islanded modes for energy harnessing, a detailed discussion is conducted in Ref. [149] for various models of PV and wind energy systems. However, the communities present in distant areas are mostly isolated and the residents of those communities mostly suffer owing to inadequate supply of electricity or shortage of available resources for electricity storage. This matter is critically analyzed and discussed in optimum manners by the author in Ref. [150]. Energy storage and then its utilization according to the requirement is supported by power electronics DC to AC converters, various control schemes, converter topologies and queries are addressed in Ref. [151,152]. Likewise, energy storage models can also be implemented with a wind hydro project model in Ref. [153] as well as wind turbine models and their respective control schemes described in [154–158].

11. Conclusions and future directions

It is concluded that, from the last two decades, the Islamic Republic of Pakistan is facing an increasingly serious power outage problem which is around 10–14 h and 14–20 h in urban and rural areas respectively. Furthermore, the Government of Pakistan (GOP) had undertaken variety of remedial measures and the provision of incentives for private investment in power sector at cheap rates. The new hydroelectric dams were proposed in the past, for example, Kalabagh dam, but yet couldn't be delegated. Fossil fuel consumption and oil requires to be consumed in oil-fired power generation plants which gets very expensive and considered as heavy burden on GOP trade and industry. This situation has caused a serious concern in citizens. However, in this frustrating situation along the countryside, there is an urgent need to explore and install the renewable energy resources, especially wind and solar energy sources should supplement existing power generation and power distribution unit. Besides, it has also been investigated that Pakistan has a vast potential for wind and solar energy, especially in its two provinces i.e., Sindh and Baluchistan. However, this paper describes a critical review of the utmost appropriate sites meant for future study purpose. At the end, various practical schemes are proposed for future implementation purpose.

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