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Forecasting the Diffusion of Grid Connected Solar PV Systems in Pakistan

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Abstract: Pakistan is facing severe load shedding problem due to a demand-supply gap of about 5-8 GW. Fortunately, the country receives 5-7 kWh/m2/day of solar insolation. The potential of grid-connected PV plants in terms of installed capacity is about 1600 GW. This paper presents the forecasts foran installed capacity of solar PV systems for grid-connected electricity generation in Pakistan. The logistic model and analogous approach are used for forecasting the diffusion of PV systems. The paper concludes that about 920-3060 MW of grid-connected solar PV systems could be added to the power supply in Pakistan up to 2030. These projected installations of grid-connected solar PV systems are only 1.2-4% of the maximum assumed the technical potential of solar PV systems for grid-connected electricity generation in Pakistan. The use of grid-connected solar PV plants would help to overcome power shortage and reduce the overdependence on hydropower, the adverse environmental effects of fossil power plants and the dangers of nuclear power plants in Pakistan.

Keywords: *Electricity Generation; Grid Connected; PV systems; Solar Energy;*

I. INTRODUCTION

Pakistan is facing severe load shedding problem due to a demand-supply gap of about 5-8 GW. The power shortage problem is costing around 2.5 billion US $ per annum to the nation's economy. Also, about 0.4 million local people are losing their jobs per year due to this demand-supply gap of power. Oil, gas, hydropower and nuclear power are the main powergeneration sources in the country. The share of oil, gas, hydropower, coal, nuclear, LPG, renewables and imported electricity in the total power generation in Pakistan as shown in Figure 1. Recently, two wind farms and one solar PV power plant are connected to the central grid. Though there is a huge potential of coal (about 185 billion tonnes) in Pakistan this indigenous resource (black gold) has not been utilized due to technical and other reasons. Pakistan's energy sector heavily depends on imported oil as the indigenous production and reserves of oil are limited. More than half of Pakistan's annual foreign exchange is used for importing inexpensive fossil fuels [1,2]. Like in Pakistan, power generation worldwide is dominated by fossil fuels. Fossil fuels, renewables and nuclear power share 78.4%, 19.3% and 2.3% worldwide of the global final energy consumption [3].

Excessive use of fossil fuels by the developed countries have dumped a significant amount of harmful emissions in the atmosphere.Resultantly, global warming and its associated effects are now seriously affecting the living creatures on earth. Ironically, victim are the developing nations whose share of Greenhouse Gas (GHG) emissions is very less as compared to developed ones.

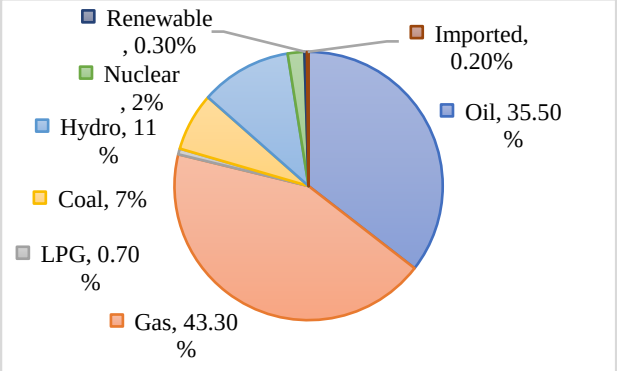

Fig. 1 Primary Energy Supplies by a source in Pakistan[2]

Like United Nations Framework Convention on Climate Change (UNFCCC) have been emerged to develop some incentive mechanisms at international levels to reduce the share of fossil fuels in energy mixes so that environment can be safeguarded for future generations. The world is now switching over to clean energies and solar PV is leading in terms of capacity additions in 2016 [3].

Pakistan is a solar rich country. The solar energy source is extensively scattered and abundantly available in Pakistan. The mean global solar insolation falling on a horizontalsurface in Pakistan is about 450-650 W/m^2 per day and this amounts to about 1500 to 3000 sunshine hours and 1.9 to 2.3 MWh/m^2 per year with an annual mean sunshine duration of 8 to 8.5 hours/day. These values of sunshine hours and sunshine duration per day are among the highest in the world. These conditions of solar energy availability in Pakistan are ideal for utilization of PV technology for electricity generation. This vast renewable energy potential can be exploited for generation of electric power using solar PV technology for improving the energy access and managing the energy crisis in the country [5,6,7]. The recent drop in prices of the silicon solar cells and even lower prices in case of Polycrystalline silicon solar cells, has tremendously increased the viability of PV technology. Work on research and development of a 2nd, 3rd and 4th generation of solar cells is also under process [4]. A prior knowledge of the likely diffusion of solar PV systems for grid-connected electricity generation is very important for policy interventions and planning in Pakistan. In this article, the diffusion of grid-connected solar PV plants in Pakistan are forecasted and presented. The logistic model and analogous approach are used for projecting the diffusion of PV plants in the country.

II. POTENTIAL AND GROWTH OF SOLAR PV POWER IN PAKISTAN

Pakistan receives about 1,550 PWh solar energy per annum. Total area suitable for installation of PV power plants for grid-connected electricity generation is about 16865 km^2 which is more than 2% of the total area of the country. The annual technical potential of PV to generate electricity for grid

supply is about 3.5 PWh, more than 40 times the total commercial electricity generation in Pakistan. The total potential for installation of PV power plants for grid-connected power supply is about 1600 GW. This estimated installation potential of PV for grid-connected electricity generation is about 78 times the current total installed capacity of electricity generation in Pakistan. These results of PV potential clearly demonstrate that PV has the potential to solve the energy problems of Pakistan [7,8].

Solar PV is the fastest progressing renewable energy technology in the world. In 2016, the world's leading source of additional power generating capacity was solar PV. Global investment in Solar PV has increased exponential over the last 10 years, the global capacity of Solar PV has been increased to 303. From 6 GW in 2006, global power generation capacity of Solar PV has been increased to 303 GW in 2016, with record annual addition of 75 GW in 2016 [3].Out of the total global PV systems installed capacity, the vast majority is grid-connected [9,10]. Solar map of Pakistan is shown in Figure 2, in Pakistan about 3,000 Solar PV units have been installed for rural electrification in villages of Tharparkardistrict of Sindh province. A solar park, the Quaid-e- Azam Solar Park Company (QASPC), to attract local and foreign investments has been established. The provincial government of Balochistan committed to a 300MW solar power project [11]. The Alternative Energy Development Board (AEDB) has issued 33LOIs for a total capacity of about 888 MW solar PV systems for grid-connected power supply in the country. One feasibility study of grid-connected PV plant has been approved by the AEDB. Also, for solar power projects,the upfront tariff for a total of 50 MW capacity has been announced by National Electric Power Regulatory Authority (NEPRA) [7,12,13].

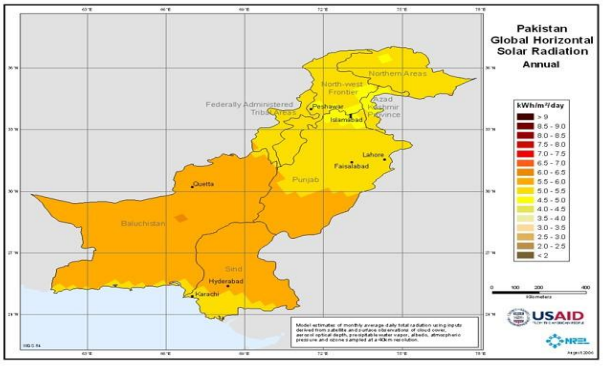

Fig. 2 Solar map of Pakistan [14]

III. DIFFUSION MODEL FOR SOLAR PV POWER IN PAKISTAN

The development of a technology over time may confirm to an S-curve in a variety of situations and a combination of slow initial growth and rapid growth after a certain take-off point and then again, a slow growth towards a finite upper limit to the dissemination as shown in Figure 3 [15,16]. Rao and Kishore have studied the models for diffusion of renewable energy technologies and concluded that the logistic diffusion model can be used for forecasting the diffusion of renewable energy technologies including solar PV systems in developing countries [17]. Lund has developed and applied the logistic diffusion models for estimating the market penetration rates of solar PV systems and other new energy technologies [18]. These and many other forecasts of solar PV system's diffusion suggest that the additions of solar PV systems to an installed capacity of power generation will continue to grow exponentially for decades. However, the high growth rate of diffusion of solar PV systems will eventually be replaced by slow growth rates due to market saturation of PV systems. The growth rates of the solar PV systems capacity addition will decrease after saturation point and finally reach a constant rate of replacement growth [19].

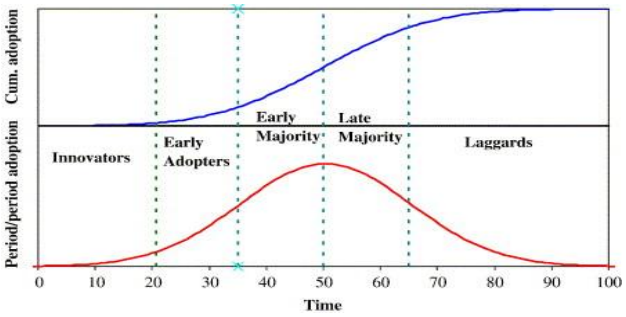

Fig. 3Stylized diffusion curves [15]

The diffusion of grid-connected solar PV units in Pakistan can be projected using the PV system's diffusion model [8]

$$N(t) = \frac{M}{1+e^{-qt+p}} \quad (1)$$

Where, N(t) is the cumulative installed capacity of grid-connected solar PV systems at time t, M is the maximum technical potential of solar PV systems for grid-connected electricity production, q is the adoption rate of solar PV plants for grid-connected electricity production, and p is the integration constant. The solar PV diffusion model (Eq. 1) can also be expressed in terms of peak time at the point of inflection (t') as

$$N(t) = \left[\frac{M}{1+e^{-q(t-t')}}\right] \quad (2)$$

The parameters of the solar PV diffusion model are estimated and used to forecast the installation solar PV plants in Pakistan for grid-connected power supply based on the assumptions (1) the contribution of grid-connected solar PV plants to Pakistan's power generation will reach a maximum of 20% by 2080; (2) the growth in Pakistan's power generation will stabilize by 2080; and the installations of solar PV systems after 2080 will represent only the replacement of PV systems. The assumption of 20% limit of contribution if solar PV system to future power generation in Pakistan is conservative. The maximum technical limit of renewable energy source like solar energy supply is grid is about 30%. The electricity generated from solar PV could also be used for hydrogen production for different uses mainly as a transport fuel. Thus, 20% maximum limit of grid-connected solar PV electricity to Pakistan's grid power supply is in the lower range of maximum technical limit forecasts. The assumption of the year 2080 as the peak for grid-connected solar PV electricity generation share and after 2080, the solar PV manufacturing for the Pakistani power market is limited to replacement of solar PV systems are likewise conservative [8].

Three scenarios are developed based on the above-presented assumptions. In an Optimistic Scenario (OS), the initial growth rate of grid-connected solar PV units is set at 30% and then decreases to zero in the year2080 when grid-connected solar PV units would have 20% share in the total grid power supply in Pakistan. In a Moderate Scenario (MS), the initial growth rate of grid-connected solar PV units is set at 25% and declines until 2080 when grid-connected solar PV units would provide 20% of the total grid power supply in

Pakistan. In a Business As Usual or Standard Scenario (SS), the initial growth rate for of grid-connected solar PV units capacity additions in Pakistan is set at 20%, and then decreases to zero in 2080, when grid-connected solar PV units would provide 20% of total grid power supply in the country. Electricity demand in Pakistan is projected to increase at an average growth rate of 8.8% per year upto 2030 under the BAU scenario. After 2030, it is assumed that the demand for electricity would gradually decrease to zero by 2080. For meeting 20% of the electricity demand under the BAU scenario in 2080, the required installed capacity of grid-connected solar PV power plants would be about 75 GW [8].

For this study, the initial annual growth rates of grid-connected solar PV power plants installation in Pakistan are assumed to be 20, 25 and 30% under the three different considered scenarios. It might be argued that these growth rates of grid-connected PV systems diffusion in Pakistan are too optimistic and cannot reasonably be expected to continue for about two decades assumed for forecasting the diffusion of grid-connected Systems in Pakistan. In order to check whether the assumed growth rates for grid-connected PV systems diffusion in Pakistan are realistic, historical trends of the growth rate of two silicon-based products i.e. PC and mobile phones and the consumption of CNG in the transport sector of Pakistan are examined. Sales of PC in Pakistan exhibited an annual average growth rate of about 25%. Among all the products considered, mobile phones have experienced the highest growth rates. Between 1995 and 2015, the mobile phones penetrated in the Pakistani market at an average growth rate of 90% per year. The consumption of CNG in the transport sector of Pakistan has grown at an average growth rate of 70% per year during 1995-2015. These comparisons of growth rates of considered products suggest that the growth rates assumed in this study for forecasting the diffusion of grid-connected solar PV systems in Pakistan are reasonable.

In this study, it is assumed that the cost of electricity generation from solar PV power plants is equal to that of electricity generation from fossil fuel-based power plants in Pakistan. It is also assumed that the solar PV has started penetration in the market of power generation in Pakistan by 2015 with 60 MW installed capacity in the first year. Based on assumed solar PV installation growth rates and maximum utilization potential, the diffusion model parameters have been estimated and are presented in Table 1.

Table 1: Parameters of Solar PV diffusion model for Pakistan

Scenario Parameter	SS	MS	OS
q	0.18282	0.22376	0.26311
t’	40	33	28

IV. FORECASTS OF SOLAR PV SYSTEM DIFFUSION IN PAKISTAN

The installed capacity of grid-connected solar PV power plants in Pakistan has been projected using the logistic growth model, solar PV diffusion model Eq. (2), for various scenarios up to 2085. The projected results of installed capacity of solar PV systems for grid-connected electricity generation are depicted in Figure 4. The S-shape characteristic of the curves indicates that during early years, the growth of diffusion of solar PV power plants for grid power supply is very slow and after this slow growth region, the growth for grid power supply increases exponentially. Finally, the growth in cumulative capacity for grid power supply again slows down and approaches the upper technical potential limit. The projected annual installations of solar PV plants for grid-connected electricity generation in Pakistan are depicted in Figure 5. It infers that the annual installations of solar PV plants for grid-connected electricity generation in Pakistan are increasing up to the peak or inflection point and then decreasing gradually as the installed capacity of solar PV plants approaches the upper limit. Table 2 gives the forecasted values of the cumulative capacity of grid-connected solar PV plants in Pakistan for all the three considered scenarios from 2015-2030 [8].

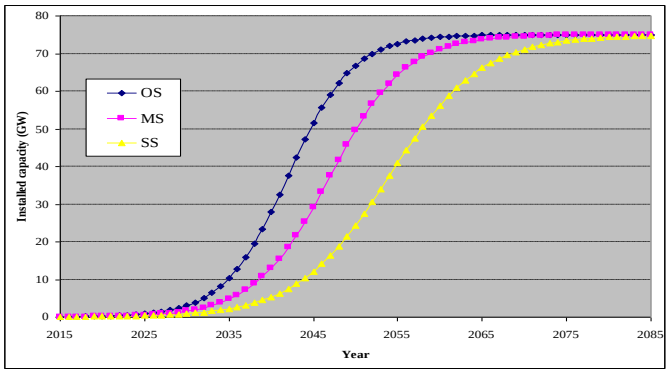

Fig. 4 Projected cumulative installed capacity of grid-connected solar PV systems in Pakistan

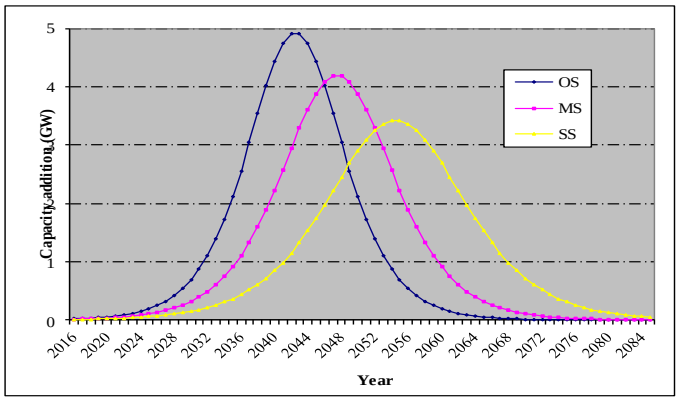

Fig. 5 Projected capacity addition of grid-connected solar PV systems in Pakistan

It is projected that about 921, 1636 and 3060 MW of grid-connected solar PV systems could be added to the national grid in Pakistan up to 2030, under SS, MS and OS scenarios respectively. These projected results of solar PV systems installation in Pakistan indicate that only 1.23, 2.2 and 4.1% of the maximum assumed the potential of solar PV plants for grid power supply could be harnessed by the year 2030. These projected values of grid-connected solar PV systems installations in Pakistan also indicate that even using highly solar PV favorable assumptions, the diffusion of grid-connected solar PV units in Pakistan is not possible to reach its maximum assumed technical potential after 5 more decades [8].

Table 2 Projected cumulative capacity of grid-connected solar PV systems in Pakistan

Year	Cumulative capacity [3]		
Scenario	SS	MS	OS
2015	0.060	0.060	0.060
2020	0.150	0.178	0.230
2025	0.372	0.542	0.846
2030	0.921	1.635	3.060

CONCLUSION

The diffusion of solar PV systems for grid-connected

electricity generation is forecasted for Pakistan. The logistic model and analogous approach are used for forecasting the diffusion of PV systems. The study concludes that about 920 to 3060 MW grid-connected solar PV systems could be installed in Pakistan up to 2030. These projected installations of grid-connected solar PV systems are only 1.2-4% of the maximum assumed the technical potential of solar PV power plants for grid power supply in Pakistan. The use of solar PV systems for grid-connected electricity generation would help to overcome power shortage and reduce the overdependence on hydropower, the adverse environmental effects of fossil power plants and the dangers of nuclear power plants in Pakistan.

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