Analysis of Optimization Model of Solar and Wind energy for meeting electricity demand of Sindh Province

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Abstract - The world has limited resources of fossil fuels with increasing energy requirements, these resources are depleting rapidly. On the other hand, Renewable energy sources have a huge potential all over the globe. Sindh Province is one of the few places in the world which has high potential of more than one renewable energy sources. But high system cost and low reliability is associated to single source renewable energy systems. To deal with such limitations of RES, concept of hybrid renewable energy systems is introduced. And in case of 100% conversion to renewable energy, it is very important to find the optimal combination of energy sources for these hybrid renewable energy systems. The results of this study show that although solar energy can alone easily fulfill electricity demand of Sindh Province but monthly solar energy production does not match with monthly electricity demand which results in energy storage system. This study shows that the magnitude of this energy storage system can significantly be reduced if wind energy is also included in electricity system of Sindh Province. The research work demonstrates that an electricity system containing 82.65% of solar energy and 17.35% of wind energy is the optimal combination for which storage requirements are minimum.

Keyword: PV and Wind Power Generation, Optimization Model, Storage Requirements, Sindh Province

I. Introduction

Pakistan is trying to overcome one of the worst energy crisis of its history. Power sector of Pakistan has failed to drive an energy policy which can keep up with Pakistan's rapidly growing population and economy. Pakistan has potential of 42000MW wind energy, 535000GWh of solar energy and 41700MW of hydro power [1]. Instead of using the high potential of locally available energy resources, Pakistan mostly rely on imported oil. Such policies resulted in power crisis [2]. The shortfall is nearly 6000MW annual [3]. Pakistan has started to establish new power plants to decrease this shortfall. But most of the power plants are thermal power plants which are using coal as their power source. CPEC is establishing 10 coal based power plants [4]. These power plants has estimated capacity of nearly 8880MW [5]. The situation of air pollution is already is very critical in Pakistan. And these power plants can make it worse.

Sindh is one of the few places in the world which has very high potential for both sustainable and unsustainable energy resources. But Sindh mostly rely on sustainable energy sources for its electricity demand as shown in Fig. 1. According to an estimate, Sindh has 184,623 million tons of coal reserves in the areas of Thar, Lakhara, Sonda-Jherruck, Meting- Jhimpir, Indus East and Badin. And the new government of Pakistan is using these reserves to overcome its energy crisis by installing new coal power plants of thousands of megawatts power. Installation of this scope of coal based thermal power plants are expected to create serious climate issues for Sindh in upcoming years [6].

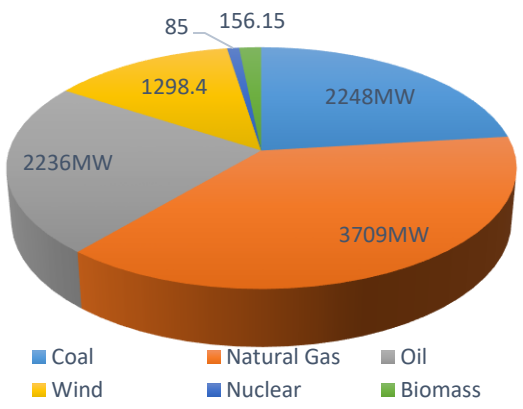

Fig. 1 Electricity installed capacity in Sindh Province

Sindh can easily meet its energy demand by renewable energy sources. Sindh also has very high potential of wind and solar energy. The average annual Horizontal Solar Radiation in Sindh is 5.34 kWh/m^2. Sindh is mostly an agricultural province which is a very important part of its economy so most of its area is fertile which can't be used for PV. But Sindh also has a very large area of barren land which is very suitable for solar energy use. It has a very long summer season and the sunlight is available almost the whole year. During the period of February to October in Sindh province the solar radiation intensity is more than 200W/m^2. And for the 10 hours a

day the average solar radiation is between the range of 1500W/m^2/day to 2750W/m^2/day[7]. Similarly Sindh has a very high potential of wind energy. According to a study conducted by Pakistan Meteorological Department at the coastal area of Sindh, wind energy potential of Sindh is nearly 43000MW annual. But if some constrains like land use etc. are taken into consideration it still can produce nearly 11000MW annually. Despite such a high potential in solar and wind energy the current installed capacity of renewable energy is very low in the province.

Government is aiming to increase renewable energy share in near future. But high share of renewable energy also generate some concerns. Due to the high dependence of Renewable energy sources on meteorological conditions, power generation can't be controlled. Renewable energy shows very high variations. And with the increasing share of renewable energy sources, these variation also increase causing a large uncertainty in the power system. And for a 100% renewable scenario, to make sure the power availability at any time, these renewable energy sources are needed to be maximally exploit but at the same time make sure the storage needs are at minimum [8]. To reduce the storage costs, it is very essential to determine the optimal combination of wind and solar energy for which the variations in power generation are minimum.

II. Related Literature

There had been extensive studies performed to design the best hybrid Renewable energy systems. In these studies various techniques were used to determine the optimal combination between different renewable energy sources. This study is dedicated to design a hybrid renewable energy system for Sindh Province only having optimal combination of solar and wind energies. This type of research had also been undertaken for different areas.

In Ref. **[9]**, Rout, K. and J.K. Sahu discussed different optimization techniques established to optimize the hybrid renewable energy systems. Two parameters were used to discover the optimal combination for hybrid system: reliability and system life cycle cost. The optimization techniques were categorized as graphical construction, probabilistic technique, iterative approach, artificial intelligence, dynamic programming, linear programming and multi-objective technique.

A. Graphical construction

Two types of graphical constructions used in optimization were discussed in [9]. One was presented by Salameh and Borowy [10] and the second was presented by Markvart [11]. In Salameh and Borowy method, hourly values for solar and wind energy, noted for last 30 years were used. On the other hand Markvart drove a graphical technique for hybrid systems on monthly basis.

B. Probabilistic Approach

In that approach, the variations of wind and solar energies were taken into account. Storage energy variation, in Bucciarelli method [12], was treated as a random walk. For the variations of storage, the probability density was approximated on daily basis using a two event probability distribution.

C. Iterative Technique

A Hybrid Solar-Wind System Optimization (HSWSO) model was designed by yang [13] based on the Levelised Cost of Energy model (LCE) and Loss of power supply probability (LPSP) model for system cost and power reliability respectively, that model used the iterative optimization technique. A similar model was proposed by Kellogg [14]. In that model, iterative procedure was used to select the turbine size and module number for wind and PV respectively for which the difference between the power generation and demand was minimum.

D. Artificial intelligence

Many purposed Artificial intelligence methods were discussed in [9] and the goal of all these methods was to optimize the hybrid energy systems. Some of the examples of artificial intelligence methods discussed were Ant Colony Optimization (ACO), Artificial Neural Networks, Fuzzy Logic, Genetic Algorithm and Particle Swarm Optimization (PSO). Kalogirou [15] optimized a solar system using the artificial intelligence methods of Artificial Neural Networks and Genetic Algorithm.

E. Software based Approach

HOMER software was discussed to design and analyze the hybrid systems in Ref. [9].

In Ref. [16], Tito, R., T.T. Lie, and T. Anderson optimized a wind and solar systems using a simple iterative method. In first step, hourly solar and wind power generation was calculated of the site under exam. Different combinations of wind and solar energy were used to the hourly load. The combination for which the storage size was minimum, was selected.

In Ref. [17], Heide, D., et al. designed a seasonal optimized hybrid solar and wind energy model for Europe. It used two different approaches to discover the optimal combination of the solar and wind energy. In first approach it used the standard deviation method. In that method it calculated the standard deviation for different combinations of solar and wind energy to find the optimal combination for which the standard deviation of mismatch energy was minimum. In second approach, the author constructed a simple storage model. The base of that storage model was the mismatch energy. Author constructed storage model for different energy mix and determine for which mix, the storage requirements were minimum.

In Ref. [18], Dedinec, A., I. Tomovski, and L. Kocarev made a optimization model for variable renewable

energy sources generation for Macedonian. In that research work, author used the first approach from [17].

In Ref. [19], Huber, M. and C. Weissbart calculated the optimal mix of solar and wind energy for china. The research used the second approach used in [17] (finding the solar and wind energy mix for China for which the storage requirements are minimum). The author modified the approach so it could be used to find the optimal mix for different wind and solar energy share scenarios in the total energy system.

It is evident from the above studies that various attempts have been made to study and analyze optimization of hybrid renewable energy systems. However none of these studies had offer such approach for Sindh Province. To optimize a hybrid renewable energy system, various techniques had been proposed. In this study, iterative technique will be used to optimize a hybrid solar and wind system for Sindh.

III. Methodology

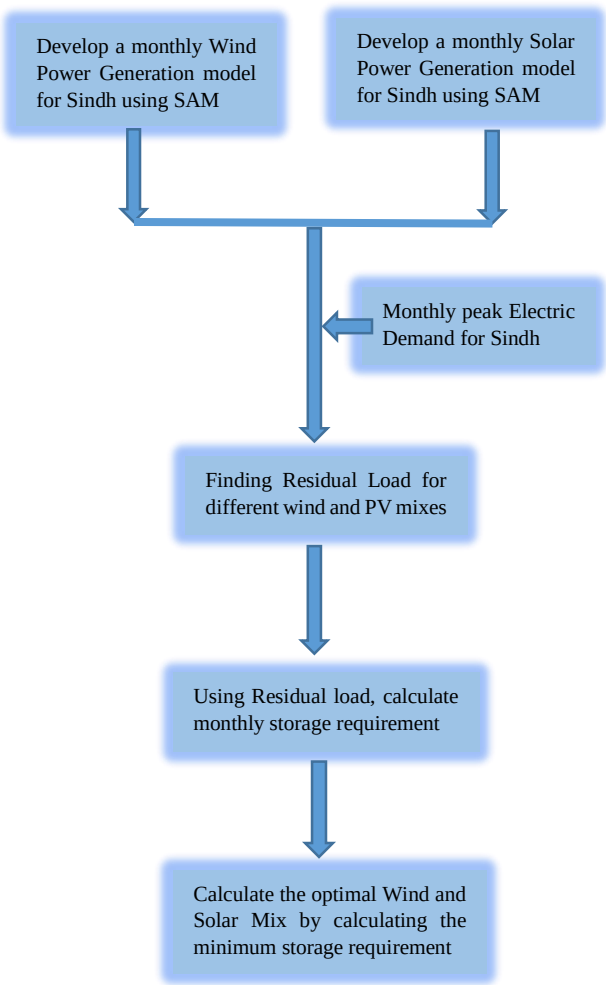

Fig. 2 Research Frame work

Separate solar and wind energy models for Sindh Province were developed using System Advisor Model (SAM). SAM is a performance and financial model software designed and developed by National Renewable Energy Laboratory (NREL). For solar energy model, data was gathered by NREL and other sources. For wind energy model, data collected by Pakistan Meteorological Department and World Bank, was be used.

The residual load on monthly basis for different combinations of solar and wind energy was calculated. Residual load is the difference of electricity demand and its production. In other words residual load is monthly mismatch energy.

Further, using residual load, the monthly storage requirement for different wind and solar energy combination was determined as per following relationship.

$$H(t) = H(t-1) + RL(t) \quad (1)$$

In this equation, *H(t)* is the storage requirement for month *t* and *RL(t)* is the residual load for month *t*.

The maximum monthly energy storage requirement, is the storage requirement for that particular solar and wind energy combination.

Finally, it was determined that for which solar and wind energy combination, the storage requirement is minimum.

$$E_H = \min(\max H(t)) \quad (2)$$

After the optimal combination of PV and wind energy is determined, eq.3 is used to calculate the share of PV and wind energy in the electricity system.

$$\beta = \frac{\sum_{t=1}^{t=12} P_{PV}(t)}{\sum_{t=1}^{t=12} P_{wind}(t) + \sum_{t=1}^{t=12} P_{PV}(t)} \quad (3)$$

In this equation, β is the percentage of PV energy in the electricity system and *P(t)* is the monthly power output, which equals the monthly energy generation.

IV. Results and Discussion

In this chapter, major results of this research are presented. Monthly capacity production for both PV and wind energy are evaluated along with residual load. Finally the most suitable combination of PV and wind is suggested.

A. Solar Power Generation Model

Solar energy potential of Sindh Province is very high. The annual average Horizontal Solar Radiation in Sindh is 5.34 kWh/m^2. But while developing PV energy model for Sindh Province, it's very important to take into account the importance of agriculture and the land used for agriculture in Sindh Province. Sindh's agriculture contributes 23% to national agriculture Revenue and to provincial GDP, its agriculture sector contributes nearly 24% [1]. So when the potential of solar energy for Sindh Province is calculated, the land used for agriculture must not be taken into the account and a much realistic PV Energy model can be developed for Sindh Province.

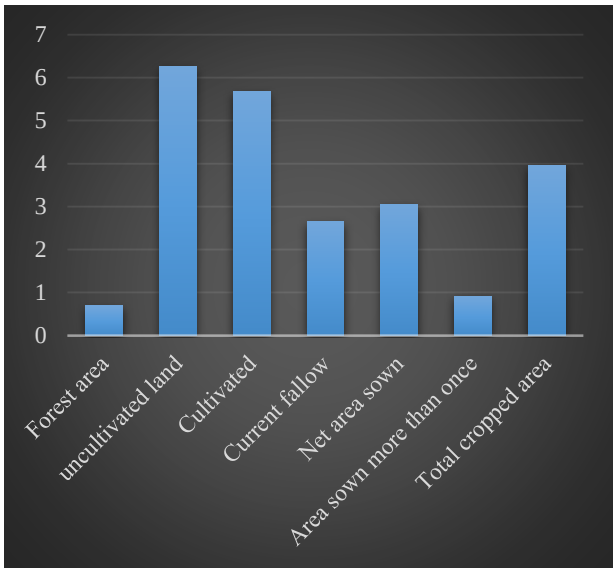

Fig. 3 Land usage of Sindh Province

It is important to mention that if new canals and irrigation channels are constructed and Sindh gets its due share from Indus River, out of 6.26 land not available for cultivation, upto 3.0 MHA can be brought under cultivation. So the area which is considered to be available for solar power generation is 3.26 MHA.

The module selected in SAM is Phono Solar Technology Co, Ltd. Poly PS325P-24/T. From Tier-1 PV module manufacturers (Phono Solar or equivalent), It is proposed to consider 325Wp polycrystalline modules. High transmission tempered glass covered with anodized aluminum alloy frame will be used to protect the module. The reason to select the module is because this module already has been used in Sindh in other solar power generation plants like Gharo Solar (Private) Limited.

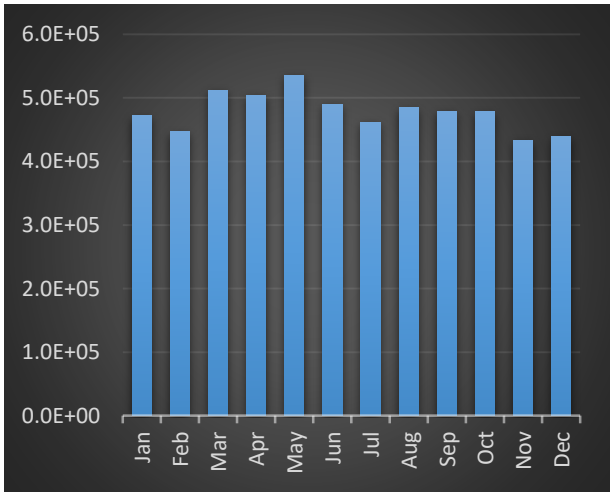

Fig. 4 Monthly PV Power Generation in MW

From Fig. 4, it can be observed that the highest value of power generation take place in the month of May.

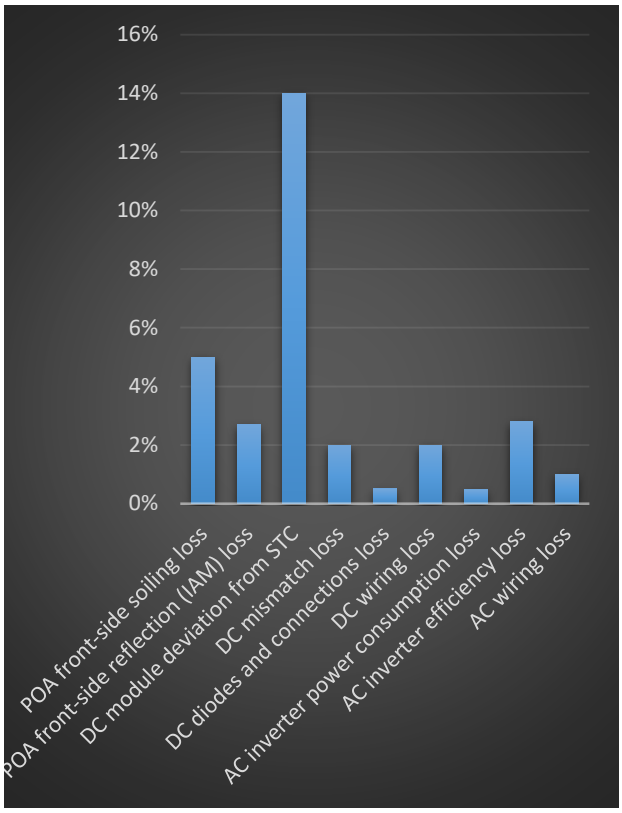

Fig. 5 Losses in PV Power Generation

Fig. 5 shows that the highest loss in PV power generation is due to the DC module Deviation from STC (standard test condition). The high temperature in Sindh Province in summer is the major cause of these losses.

B. Wind Power Generation

The production of electricity from wind energy also depends upon meteorological conditions. In the case of wind energy, the distribution of electricity depends upon wind speed. Pakistan Meteorological Department (PMD) conducted a study from 2002 to 2005 at the coast areas of Sindh to calculate the wind energy potential. The study was conducted at 20 different places. Six most windy sites identified by PMD are Hyderabad, Jamshoro, Keti Bandar, Nooriabad, Thatta and Gharo. In this research work, the average monthly wind speed of these sites at the height of 80m has been used to calculate the monthly capacity electricity production. According to the findings of PMD's study Sindh Province can produce upto 11000MW annual electricity from wind energy.

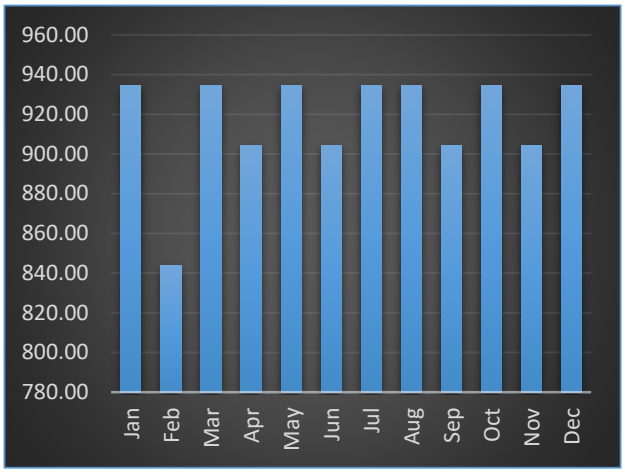

Fig. 6 Monthly wind Power Generation in MW

Fig. 6 shows the monthly electricity generation capacity from wind energy for Sindh Province. Variation in monthly power generation from wind energy is less than the variation in monthly power generation from PV.

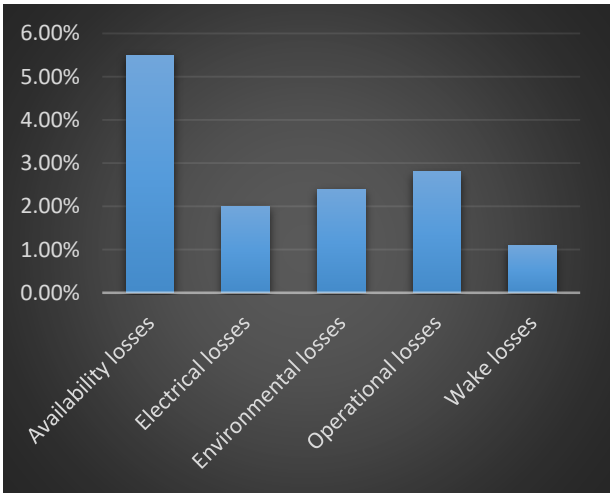

Fig. 7 Losses in Wind Power Generation

C. Optimal Combination

The main objective of this research paper is to determine the optimal mix between PV and wind generation in the power system of Sindh Province in future.

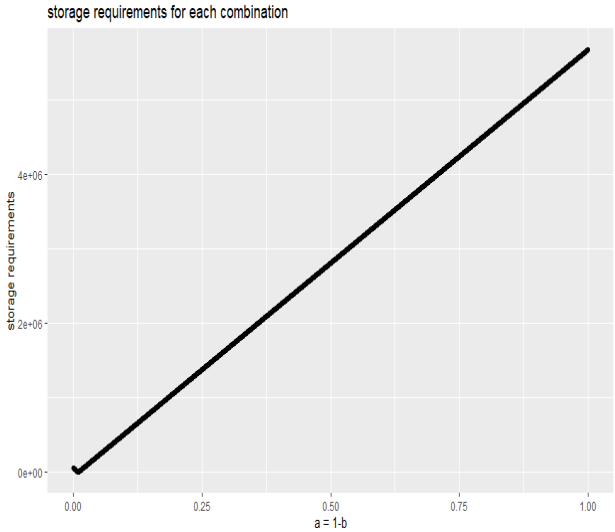

Fig. 8 Power Storage Requirements

Fig. 8 shows the storage requirements for different combination of PV and wind energy. In figure, 'a' represents the share of PV energy and 'b' represents the share of wind energy. Since the capacity production from wind is almost negligible as compare to the capacity production of PV. Therefore as the share of PV energy increases, the effect of wind energy decreases as shown by the straight line in the graph.

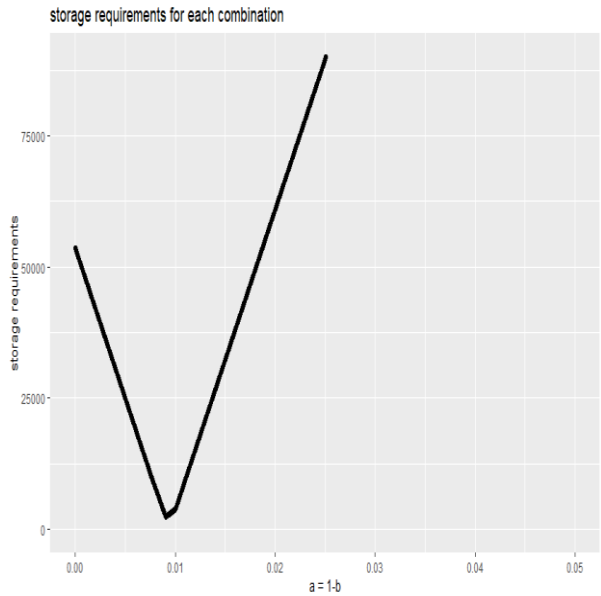

Fig. 9 Power Storage Requirements

If the curvy part of the Fig. 8 is closely observed as in Fig. 9, it can be seen that the combination of PV and wind energy for which the storage requirement is minimum is 0.00905% of capacity production of PV and 99.1% of capacity production of wind energy. When the values are put in the equation 4, it can be determined that an energy system of Sindh Province containing 82.65% PV energy and 17.35% of wind energy is the energy system for which the storage requirements are minimum so this is

the optimal mix of PV and wind energy for Sindh Province.

V. Conclusion and Recommendation

The results of this study conform the hypothesis that Sindh Province can be entirely powered by renewable energy sources. Results shows that the generation from PV is more than enough to fulfill the energy needs of Sindh Province on Annual bases. However, it turned out to be more difficult when considered the monthly timescale. Due to meteorological changes, monthly production and consumption of electricity cannot be matched every month. There is shortage or excess of energy each month. To overcome this difficulty, energy storage is used. This situation can be significantly improved if wind energy is also added to the system. This research concludes that the optimal combination of PV and wind energy in the electricity system of Sindh Province to meet energy demands is 82.65% and 17.35% wind energy.

In short, this research shows that large amount of storage will be required to ensure a reliable power supply on monthly basis even with a generation that equals the demand on a 'per year' base. To address this limitation and to ensure the continuous supply of electricity, energy storage is necessity. The size of this storage can be reduced to minimum if a specific combination of PV and wind energy is used. So as a result of our analysis, we suggest planners to pursue an electricity system with a combination of 82.65% PV and 17.35% of wind energy.

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