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Review

On recent advances in PV output power forecast

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ABSTRACT

In last decade, the higher penetration of renewable energy resources (RES) in energy market was encouraged by implementing the energy polices in several developed and developing countries due to increasing environmental concerns. Among wide range of RES, Photovoltaic (PV) electricity generation get higher attention by researcher, energy policy makers and power production companies due to its economic and environmental benefits. Therefore, a large PV penetration was observed in energy market with rapid growth in the last decade. The PV output power is highly uncertain due to several meteorological factors such as temperature, wind speed, cloud cover, atmospheric aerosol levels and humidity level. The inherent variability of PV output power creates different issues directly or indirectly for power grid such as power system control and reliability, reserves cost, dispatchable and ancillary generation, grid integration and power planning. Therefore, there is need to accurately forecast the PV output over the spectrum of forecast horizon at different chronological scales. In this paper, a comprehensive and systematic review of PV output power forecast models were provided. This review covers the different factors affecting PV forecast, PV output power profile and performance matrices to evaluate the forecast model. The critical analysis regressive and artificial intelligence based forecast models are also presented. In addition, the potential benefits of hybrid techniques for PV forecast models are also thoroughly discussed.

Contents

Abbreviations: AI, artificial intelligence; AM, air mass; ANN, artificial neural network; AR, auto-regressive; ARIMA, Auto-Regressive Integrated Moving Average; ARIMAX, ARIMA exogenous; ARMA, Auto-Regressive Moving Average; ARMAX, ARMA-exogenous; DR, Demand response; BP, back propagation; CPV, concentrated PV; DHI, diffuse horizontal irradiance; DNI, direct normal irradiance; GA, genetic algorithm; GHI, global horizontal irradiance; HS, hybrid system; IEA, International Energy Agency; ISO, independent system operator; LMS, least means square; MA, moving average; MAE, Mean Absolute Error; MAPE, mean absolute percent error; MBE, Mean Bias Error; MLP, multi-layer perceptron; NAR, non-linear AR; NARMAX, non-linear ARMA exogenous; NARX, non-linear AR exogenous; NWP, numerical weather prediction; PV, Photovoltaic.

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1. Introduction

In last decades, the global energy demand increased steadily with rapid growth in world population. The energy demand is at the higher level ever before and most of the fossil resources are the edge of depletion due to excess usage. Therefore, "how to meet the 21 century energy demand" is the hot topic of discussion among the governments, researcher, scientists and energy policy makers in developed and developing countries. In addition, other concern is rapid changes in environmental and climatic conditions (i.e. global warming, depletion of ozone layer, etc.). Keep in view the energy issue, International Energy Agency (IEA) raised the concerned namely energy security, economic efficiency, and environmental protection, which are known as "3Es" ((IEA), 2007). Therefore, concentrated efforts have made to reduce the emission of CO_2 and minimum reliance on fossil fuels in order to achieve the 3Es objectives. Serval countries have been made efforts to meet the 3E objectives which are align with IEA guidelines and their national energy targets.

European union (EU) was decided to meet the energy targets by 2020 (Council, 2010). First target is to reduce the EU Green House Gas (GHG) emission by 20% below the level of 1990. Secondly, the contribution of renewable energy resources (RES) raise up to 20%. Thirdly, reduction of energy usage by 20% in contrast with projected levels through energy efficiency measures. European Union renewable energy directive set the RES production targets. It states that, 30% total energy will be produced from RES generation by 2030. The target of RES generation contribution will be climbed up to 100% by 2050 (Zervos et al., 2010). In addition, a high RES contribution in existing power grid network is also expected by the energy regulators of USA, Canada, Australia, China and India. Among number of RES resources, solar and wind power generation are more promising sources. They have higher potential for penetration in energy market with greater degree of success. However, solar generation get much more attention by the energy player, investors and Government funding agencies in the last decade because of its economic and environmental benefits.

Solar energy is feasible solution in order to meet the world energy demand. A research study highlights that, earth received approximately $1.8 * 10^{11}$ MW power from solar radiation at instant (B.M. Shah et al., 2015). However, the present world energy consumption requirement is less than the amount of energy received from solar (Wengenmayr and Bührke, 2011). Fig. 1 depicts the world solar energy map with solar hotspots. A huge potential for solar power generation in different countries can be observed those are above 45°N or below latitude 45°S. It can also be observed, the Middle East, Mojave Desert (USA), the Chilean Atacama Desert, the Sahara and Kalahari Deserts (Africa) and North-western Australia are potential locations for large power generation from solar PV technology.

Another research study (R. Shah et al., 2015) highlights that, the electricity demand of Mediterranean, North African region and entire Europe can be fulfilled by developing solar plants in Sahara Desert. The red sea including different areas of Saudi Arabia and Egypt are also among the highest potential sources for solar energy. In addition, United States and Australia also have greater potential to get benefit form solar energy than the world average. Due to potential of solar energy, large penetration of solar PV is expected in Australian energy sector in terms of rooftop PV, large and small scale solar PV units. In last decade, the higher penetration of PV technology in energy market of different countries is observed due its environmental and economic benefits (Photovoltaics, 2012). These benefits are reduction in CO_2 emission, minimum refinance of fossil fuel resources and Solar Photovoltaic (PV) plants consist of solar panels, which directly convert the sunlight into electricity unlike power generation using rotating generators. PV becomes more popular due to different promising features such as modularity, low maintenance and operational cost, longer lifetime, CO_2 reduction and environmental cleanliness. The energy generation capacity of solar plant varies due different factors such as PV plant site, meteorological variables, solar technology and installation capacity.

Fig. 2 highlights the growth of world solar PV capacity in the last decade. An exponential growth can be observed in global solar PV capacity from 2004 to 2014. Global capacity was increased from 3.7 GW to 7 GW in three years (2004–2007). In contrast, it was increased from 7 to 40 GW in next three years. In addition, a huge growth in global solar PV capacity was observed in next couple of years. For example, global was more than double in 2010 as compared to 2008. Overall, global PV energy capacity was increased from 3.7 to 177 GW in the last decade. A research study reports that, the PV module have individual capacity from 100 W to 320 W (Omran). The PV technology still facing lot of challenges for large penetration, in which intermittent and uncertain nature of solar PV is more prominent. The PV output power is variable mainly due to variations in solar radiations and amount received solar by the solar panels.

With a remarkable growth of PV in last decade, the integration of photovoltaic plants in current power network raise the different technical and stability issues for the power system directly or indirectly. These distress arises due to continuous change in solar resource, temperature, PV output power, high energy storage cost, grid reliability, seasonal and environmental changes (Denholm and Margolis, 2007; Dixon et al., 2010). The implementation of PV