2
Review of Literature

2.1 INTRODUCTION

Nowadays renewable energy sources are also playing a key role in the power system operation like grid integration and energy imbalance market issues. Renewable energy integration into electrical grid is assuming an important role in several countries. The importance of the social economic issues in the growth of renewable energy market has been reported [Steffel *et al.,* 2012]. This research focuses on energy produced by grid integrated small and large-scale solar photovoltaic power plants. Among all the renewable energy sources, solar energy is one of a major source of future energy supplies. The solar power generation variability may have a great impact on grid integration because of variability in solar irradiation and weather parameters. Forecasting of solar power generation is hence a major shortcoming because of the variability of solar irradiation which is needed for power generation. However, compared to the conventional source of energy, solar energy has its advantages.

Solar power generation forecasts play an important role in renewable power system operation, planning, scheduling, and dispatching operations [INCREASE, 2014]. An accurate solar power generation forecasts provide vital information to decision-makers on the generation of energy and purchase. It can also help to reduce instant load shedding problem [Ashraf *et al.,* 2013]. In modern electricity markets, power scheduling is also an important issue. If plant owner does not follow the schedule and proper dispatch of the power supply, then he will be heavily penalized [Wood and Wollenberg, 2012]. Due to this, development of solar power generation forecasting approaches are introduced for energy imbalance market [GoI, 2016]. Among various issues in grid integration, power system and energy imbalance operations, power generation forecasting problem constitutes a major part [GoI, 2016]. In this chapter, detailed literature survey is done for solar power generation forecasting approaches.

2.2 SOLAR POWER GENERATION FORECASTING: A REVIEW

This study mainly focuses on the topic 'Solar power generation forecasting'. Solar power generation forecasting can be performed for the different time intervals. Forecasting of solar power generation is classified into following time scale [Wan *et al.,* 2015; INCREASE, 2014; GoI, 2016; Kostylev and Pavlovski 2011]:

i. Short-term forecasting (An hour to 2 days)
ii. Medium- term forecasting (One day to one week)
iii. Long- term forecasting (More than a week)

Short term (Day-Ahead) forecasting is a general concern with an hour to the 48-hour time scale. It provides necessary information for the system management of day to day and the unit commitment. Medium term forecasting is generally for few days to a week time scale. It will help in scheduling generation and the unit maintenance. Long term forecasting provides electric utility management companies with forecasting of future needs of expansion of equipment purchase, policy making, and yearly planning. The reason behind day-ahead time scale is that the generated power needs to be sold against a day-ahead spot price.

2.2.1 Factors Affecting Solar Power Generation

As a matter of fact, the forecasting of solar power generation is not easy since its dependence on several parameters. The transformation process of solar radiation to electricity generation is mainly affected by deterministic and stochastic variables. Deterministic variables generally considered are PV system parameters but stochastic variables such as solar radiation are non-linear and dynamic in nature. The PV power generation is rated under the standard test condition (STC) with respect to PV cell temperature at 25° C, the solar intensity of 1000 W/m^2. It is also found that a number of factors affect the solar power generation and forecasting results and these factors are [Chen *et al.,* 2011; Shi *et al.,* 2012]:

i. Solar Radiation:

Solar radiation is one of the most important factors for the solar energy research. Here solar radiation is one of the independent variables in solar power generation. Solar radiation can be transformed directly into electricity using the photovoltaic system.

ii. Time:

Duration of the day is a basic factor of time frame. Solar radiation is available only in the day time so , Indian power system is scheduled for a 15-minute time interval. So here, measured solar radiation is for a 15-minute interval.

iii. Weather:

Meteorological conditions like temperature, wind, cloud cover and humidity are responsible for significant variation in the solar radiation pattern.

iv. Photovoltaic system parameters:

These are basically PV system parameters which are considered as system losses and are called deterministic parameters. Here, thermal losses (Module Temperature) is considered as one of the important variables for this study. PV module is giving highest efficiency at 25° Celsius ambient temperature and because of ambient temperature, module temperature also varies with time.

The review of literature covers two types of solar photovoltaic technologies in which kilowatt (kW) to megawatt (MW) scale plants are considered. The solar PV technology is robust technology in nature and it has major advantages such as low maintenance, modularity, and simplicity. Photovoltaic modules cover more than 50% of the cost of PV power plant. Based on the basic difference between the implementation of kilowatt-scale (kW: Small Scale) rooftop PV system and megawatt-scale (MW: Large Scale), all PV systems can be categorized basically in two types of tariff applicability which is given in Table 2.1.

Table 2.1 Type of Solar PV Plant

S. No.	System size	System type	Evacuation specification
1	1 kW -5 kW	Rooftop	230 V, 1 Φ ,50 Hz
	5 kW -100 kW	Rooftop	415 V, 3 Φ ,50 Hz
2	100 kW-1 MW	Rooftop/ Ground –Mounted	11 kV, 3 Φ ,50 Hz
	1MW- 4 MW	Ground- Mounted	11 kV, 3 Φ ,50 Hz
	>4 MW	Ground- Mounted	66 kV, 3 Φ,50 Hz

In last few years, solar power generation forecasting is done for small and large scale photovoltaic system using conventional approaches. A few researchers [Chaouachi *et al.,* 2009; Lopez *et al.,* 2011; Francesco *et al.,* 2011; Maria *et al.,* 2013; Masa *et al.,* 2013; Ashraf *et al.,* 2013; Oudjana *et al.,* 2013; Fernando *et al.,* 2015; Fernandez *et al.,* 2015] have done forecasting for small and large scale using neural network approaches. Development of new approaches based

on artificial intelligence techniques is currently active research especially in solar power generation forecasting [Mellit *et al.,* 2008].

2.3 APPROACHES FOR SOLAR POWER GENERATION FORECASTING

The approach applied to forecast the photovoltaic plant power generation is similar to those already used for forecasting the solar irradiation. The following research work will focus generally on forecasting approaches dealing with PV power plant generation. The neural network based solar power generation forecasting approaches are explained in this section. In several studies about the artificial neural network in the field of photovoltaic applications are discussed in [Mellit and Kalogeria, 2008; Mellit *et al.,* 2005; Mellit and Pavan, 2010; Almonacid *et al.,* 2011]. Solar resource forecasting using neural network approaches is described in [Mellit *et al.,* 2005]. Mellit and Pavan have also done a study of the day ahead solar irradiance forecasting by using the artificial neural network having correlation coefficient in the range of 98–99%. The estimation of solar power generation using the artificial neural network is mentioned in [Almonacid *et al.,* 2011]. The work [Almonacid *et al.,* 2011] shows that artificial neural network provides much better results compared with the traditional approaches to forecasting problems.

In a study [Azedeh *et al.,* 2009] has shown that ANN comes with efficient approach to forecast the dependent parameter using other independent parameters which do not have any specified relationship. In [Rehman and Mohandas, 2008], the estimation of global solar radiation for Saudi Arabia using ambient temperature, number of days and relative humidity are considered to be input parameters for the neural network is considered. Multi-layer perceptron (MLP) neural network approach is introduced to forecast monthly global solar radiation by meteorological variables such as ambient temperature, relative humidity, duration of sunshine and wind speed with results of 6.70% and 94% as an average MAPE and absolute fraction of variance (R^2) respectively (Azadeh *et al.,* 2008).

Over the past few years, researchers mainly forecast the generated solar power from grid-connected PV system for grid operations and grid management. [A. Chaouachi *et al.,* 2009] applied ensemble neural network for 24 hours ahead short-term solar power forecasting of 20 kW grid-connected system and found that radial basis neural network model performs much better compared to the multi-layered neural network model. Real-time prediction and short – term PV power generation forecasted is done by [Chow *et al.,* 2012] using artificial neural network model and explained its advantage. It can give better results in complex, a nonlinear process without assuming the form of the relationship between dependent and independent parameters. [Jimenez *et al.,* 2012] describes performance analysis and power generation forecasting of 36 kW Grid connected PV system using national weather prediction (NWP) based parameters with standard neural network approach. Weather parameters are included as input parameters and back-propagation based neural network model is used in [Kou *et al.,* 2013]. Solar photovoltaic plant performance analysis for 190 kW and its forecasting of generated power is done by [Vikrant and Chandel, 2013]. The novel hybrid intelligent approach is presented by [Ashraf et. al., 2013] in which author utilized the combination of fuzzy based neural network model for 15 kW solar photovoltaic power generation forecasting. Forecasting of 36 kW solar photovoltaic power plant generation is done by [Monterio *et al.,* 2013] using statistical and soft computing approaches where the author mentioned that soft computing approaches perform better than statistical approaches and 1-day ahead forecasting of 2.1 kW grid-connected rooftop solar PV power is done by [Li *et al.,* 2014] using an autoregressive moving average model with exogenous inputs and the results shows that autoregressive moving average with exogenous input performs better than neural network model. A weather-based hybrid approach for the day ahead hourly power output forecasted by [Yang *et al.,* 2014] using support vector regression and artificial neural network where result shows that support vector regression with weather parameter has performed better than conventional neural network model. In [Ma *et al.,* 2014] performance analysis and power generation forecasting is

done for measurement of power generated from 5 parameter based Simulink model for 19.8 kW solar PV power system and field based measurement, in this study author, explained that model is in good agreement with field collected data and it will be helpful in enabling system designers/ engineers to understand the actual and forecasted power generation under operating conditions. In the study of [Wu *et al.,* 2014] authors introduce the genetic algorithm based regression and neural network models for power generated from three different locations based rooftop grid connected solar PV system where results show the high precision and efficiency of this combination of these models. Six hours ahead solar power generation forecasted using vector autoregression theory is explained in [Bessa *et al.,* 2014] for 4 kW solar PV system and the result shows that it will help in smart grid infrastructure. Grid integration can be improved with the help of short-term solar power forecasting and self-consumption mapping. In [Bote *et al.,* 2014] the demand side management (DSM) techniques which can help in power generation forecasting to schedule the local consumption for rooftop grid connected solar power plants are introduced. 264 kW solar PV power plant's hourly energy forecasting based on historical weather parameters was discussed by [Leva *et al.,* 2015]. The author explained in this paper that time interval of solar PV data and its pre-processing is also important for forecasting of PV power. Hybridization of regression and neural network approach is discussed for 24-h ahead solar power generation forecasting for 4 kW rooftop grid connected solar PV plant where results show that hybrid models perform better than their corresponding regression models.

Efforts have also been made to improve the accuracy of solar power forecast using the ANN technique by introducing the fuzzy concepts in a neural network by [Ashraf *et al.,* 2013]. They developed a Fuzzy –Neural Network for solar power generation forecasting considering the grid integration. In that paper, ANN creates a non-linear relationship between fuzzy inputs and outputs. [Li *et al.,* 2014] developed self-organizing fuzzy ARMAX model for forecasting hourly solar power generation. [Pedro and Coimbra, 2012] developed a local ANN solar power predictor by active selection of training data employing K-nearest neighbor concept.

Artificial neural network is also used for large scale 1 MW grid connected solar photovoltaic power generation forecasting without any exogenous inputs [Pedro and Coimbra, 2012] and result shows that ANN models provide better forecasting accuracy as compared to other regression models and further 1 MW grid connected solar photovoltaic power plant generation forecasting studied by [Giorgi *et al.,* 2014] using multilayered feed-forward neural network. [Polo *et al.,* 2015] also describes the use of the artificial neural network for energy forecasting of 6.1 MW grid-connected PV plants and its failure mode prediction. These authors claim that it will improve decision –making process in condition based maintenance and risk modeling.

2.4 SUMMARY

Above discussion shows that artificial neural networks (ANN) offer a reasonable alternative to the classical methods for forecasting of irradiance and solar power generation of solar PV plant. ANN approach provides a more general framework to solve regression analysis, time series prediction and classification problems than other classical statistical methods. The reason is that the input-output relationship in an ANN model provides more flexibility and can accommodate an increased level of complexity.

As far as the question of solar power generation forecasting is concerned, the main concern is to improve the accuracy of forecasting procedures. It has been mentioned that 1% improvement in accuracy of solar power forecasting can help in the wide range of power system applications like reliable power supply, better grid integration with grid stabilization, Energy imbalance market, and Day-ahead scheduling.

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