Forecasting Solar Power Generation to Develop Prediction Module for Optimizing Energy Storage in Smart Grids

MURTAZA Hashmi[1, a], KARI Mäki[2,b], RIKU Pasonen[3,c] and ATTE Löf [4,d]

[1,2,3,4]Energy Systems Knowledge Centre, VTT Technical Research Centre of Finland, P.O.BOX 1000, FI-02044, Finland

[a]murtaza.hashmi@vtt.fi, [b]kari.maki@vtt.fi, [c]riku.pasonen@vtt.fi, [c]atte.lof@vtt.fi

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Abstract. In this paper, the weather data necessary to forecast solar power generation from solar panels has been described in the form of solar irradiation, panel temperature, and cloud cover percentage. The solar power generation forecast in Finland is carried out using Meteonorm software. It is possible to get azimuthal and inclinations angles values for solar panels installed in Finland using solar angle calculator. The generation forecast for six different locations in Finland is carried out and it is revealed that average maximum global radiation over the whole year is obtained at azimuthal angle of 0° and inclination angle of 40°. The load forecasting for three different loads, i.e., single family house, large office building with own transformer and urban town suburb connected to the MV grid is carried out. The studies will be useful to develop prediction module for optimizing energy storage size in the future mart grids.

Introduction

The weather data necessary to forecast power generation from the solar panels can be solar irradiation, panel temperature, and cloud cover percentage (in terms of effect of clouds on the power generation quantity). However, the satellite irradiance data obtained includes the effect of cloud on power generation and consists of irradiation and air temperature. The weather forecasting can be carried out based on available satellite irradiance data in Europe by one of the following ways:

- Available monthly-based meteorological databases, e.g., Meteonorm, WRDC, NASA-SSE, SolarGIS iMaps, PVGIS-ESRA and Retscreen
- Available daily-based meteorological databases, e.g., WRDC
- Available hourly-based meteorological databases, e.g., Meteonorm, Satel-Light, Helioclim-2 and SolarGIS climData
- Available quarterly-based (15 minutes) meteorological databases. e.g., Helioclim-3 (SoDA)

The sampling time or the frequency of capturing data is affecting on the accuracy of generation forecast. The shorter the sampling time, the more accurate is the generation forecast. However, it will cost more to obtain shorter sampling time as compared to longer sampling time. In this analysis, the month or hourly sampling time based data is taken into account. In this study, the Meteonorm database system is used to obtain the irradiance data.

The prediction module consists of the following sub-modules, i.e., generation forecasting based on Meteonorm weather data [1], load forecasting, calculation of array size and trade price forecast. The prediction module will be applied to optimize the size of energy storage system (ESS) in the future smart grid.

Solar Power Generation Forecast in Finland

While conducting generation forecast, the azimuthal and inclination angles for the solar panels to calculate the radiation components on the inclined plane should be accurately inserted in the Meteonorm software to get the maximum output.

The optimal azimuthal and inclinations angles for solar panels installed in Finland can be calculated using available solar angle calculators. The inclination angle varies to some extend during summer and winter season. However, azimuthal angle is varying along the whole day so an approximate value should be used in the calculations.

Generation Forecast at Different Locations in Finland

With the Meteonorm V7 (used in this research project) database, it is possible to simulate solar energy systems in all parts of the world on a consistent basis. The interpolation errors are mostly within the variations of climate from one year to the next. The six locations data can be retrieved in Greater Helsinki region in Finland.

The global irradiation (kWh/m2) on tilted plane is depending upon the magnitude of azimuthal and inclination angles. It is revealed from the calculations using software that average maximum global radiation over the whole year is obtained at azimuthal angle of 0° and inclination angle of 40° (although solar angle calculator gives the results that optimal inclination in summer is 40° while in winter is 83°). The effect of snow has been taken into account using Albedo-Automatic option. In Table I, different types of irradiation and air temperature data are given. Please note that irradiation of global radiation for tilted plane (referred as H_Gk) is the total amount of irradiation falling on the solar panel that should be taken into account to estimate the total power generated by the solar panel. The Figure 1 depicts monthly global and diffused radiation data in Helsinki downtown. The global irradiation values are calculated for six different locations in Finland and are given in Table 2. It is revealed that HELSINKI MALMI location has maximum global irradiation (1198 kWh/m2). However, the difference in global irradiation values is not significant because all these six locations are not far apart from each other and are located in the Greater Helsinki area.

Tab. I. Global and diffused irradiation at horizontal and tilted plane in Helsinki downtown

Month	H_Gh	H_Dh	H_Gk	H_Dk	H_Bn	Ta
	[kWh/m2]	[kWh/m2]	[kWh/m2]	[kWh/m2]	[kWh/m2]	[C]
January	8	5	24	8	22	-3,3
February	24	14	48	20	40	-4,6
March	65	31	104	39	89	-1,3
April	112	52	143	58	132	5,4
May	164	70	178	74	176	11,2
June	169	81	171	82	158	15,0
July	171	79	179	82	169	18,6
August	125	58	145	61	137	16,9
September	75	42	106	48	85	12,0
October	33	22	54	26	39	6,3
November	10	7	23	9	20	1,9
December	5	4	14	5	13	-1,5
Year	957	465	1188	513	1082	6,4

H_Gh: Irradiation of global radiation horizontal
H_Dh: Irradiation of diffuse radiation horizontal
H_Gk: Irradiation of global rad., tilted plane
H_Dk: Irradiation of diffuse rad., tilted plane
H_Bn: Irradiation of beam
Ta: Air temperature

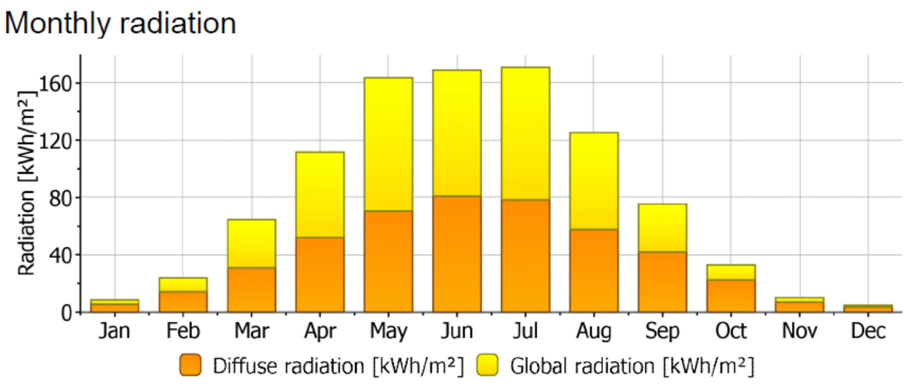

Fig.1. Monthly global and diffused radiation data in Helsinki downtown

Tab. 2. Global irradiation for six different locations in Finland

Location No.	**Location name (inclination angle=40°, azimuthal angle=0°)**	**Global irradiation for tilted plane (H_Gk, kWh/m2)**
1	HELSINKI FI	1188
2	**HELSINKI/MALMI**	**1198**
3	Helsinki-Airport	1192
4	Helsinki-Ilmala	1197
5	Helsinki-Kaisani	1182
6	Helsinki-Kaisaniemi	1171

Load Forecasting

Following three types of loads have been taken into account in this project provided that only linear loads (heating and lighting) are considered:

- Single family house: 30% of yearly energy will be supplied from PV panels. Lead acid batteries for surplus PV energy shifting to be usable later on the day. No reactive power cost, no power insert to grid is needed. Typical Finnish single family load curve with electric heating is an example of this type of load. A typical family house load profile is shown in Figure 2. Offices and Administration are the main consuming branches for these specific uses of electricity [2].

One family house 200 m2, electric heating, 5 persons.	January	February	March	April	May	June	July	August	Septembe	October	Novembe	Decembe	Total
Room heating	3605	2824	2080	1332	599	364	341	103	448	1497	1839	2798	*17830*
Household water heating	650	650	650	650	650	650	650	650	650	650	650	650	*7800*
Household electricity and other	773	640	515	533	554	526	782	536	590	720	707	792	*7668*
Total	*5028*	*4114*	*3245*	*2515*	*1803*	*1540*	*1773*	*1289*	*1688*	*2867*	*3196*	*4240*	*33298*

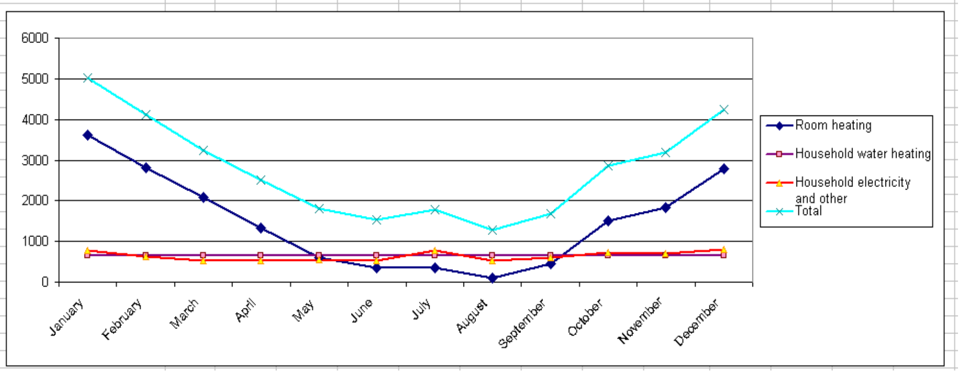

Fig.2. A typical family house load profile in Finland (Consumption in KWh/month)

- Large office building with own transformer: 30% yearly energy will be supplied from PV panels. Li-ion batteries for power shifting will be used. The cost for reactive power, grid delivery will be taken into account.
- Urban town suburb connected to the MV grid: 30% yearly energy will be supplied from PV panels. The NaS batteries delivery to the grid and storing according to the price. The cost of reactive power will be taken into account. By knowing the area covered by the urban town suburb, the peak load demand can be easily estimated [3].

There are algorithms available that can be used to calculate the DC output power of PV panel array [4]. Seasonality is normally explained by that prices are influenced by demand, business activities and weather conditions. The high volatility, price spikes, and non-normality behaviour is generally explained by that electricity is unstorable and the dominance of hydro power in the Nordic market [5].

Conclusions

The necessary weather data necessary to forecast solar power generation from the solar panels has been described in the form of solar irradiation, panel temperature, and cloud cover percentage. The solar power generation forecast for six different locations in in Finland is carried out using Meteonorm software. It is revealed that HELSINKI MALMI location has maximum global irradiation (1198 kWh/m2). However, the difference in global irradiation values is not significant because all these six locations are not far apart from each other and are located in the Greater Helsinki area. It is revealed that global irradiation increases by increasing the inclination angle, it goes up to the maximum value (1188 kWh/m2 at 40° inclination angle), then decreases by further increasing the value of inclination angle. It is also revealed that global irradiation is maximum at 0° of azimuthal angle, i.e., 1188 kWh/m2, it decreases by increasing the degree of azimuthal angles at both directions (clockwise and anti-clockwise from the south). The load forecasting for three different loads, i.e., single family house, large office building with own transformer and urban town suburb connected to the distribution grid is carried out. The outcome of this work will be further used to develop prediction module for optimizing energy storage size and control and exploiting the economic and technical benefits of incorporating an ESS in the future smart grid.

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