Energy for Sustainable Development 21 (2014) 20–29

Contents lists available at ScienceDirect

Energy for Sustainable Development

Solar energy from Negev desert, Israel: Assessment of power fluctuations for future PV fleet

Gábor Halász *, Yair Malachi

Planning Development and Technology Division, Israel Electric Corporation Ltd., POB 10, Haifa 3100, Israel

ARTICLE INFO

Article history:
Received 20 August 2013
Revised 24 April 2014
Accepted 25 April 2014
Available online 20 May 2014

Keywords:
PV
Negev-desert
Smoothing effect
Irradiation fluctuation
Rank

ABSTRACT

Power output fluctuations have a potentially negative effect on utility grid stability, especially in isolated power systems such as that of Israel. Thus for the successful large scale application of photovoltaic power (PV) in an isolated system it is of particular importance to have a proper selection of photovoltaic sites together with an appropriate distribution of installed power.

The Negev desert in Israel is an ideal location for utility scale PV plants, where the average annual global horizontal radiation is above 2000 [kWh $*$ m^{-2} $*$ year^{-1}]. In spite of the 10% goal of renewably energy production by year 2020, in 2013 less than 1% of Israel's electric energy needs are supplied by PV and now is the best time to propose a proper spatial distribution of PV fleet in Negev that will limit the extreme fluctuations originated from the fleet without significantly reducing the utilized solar energy.

This paper presents a method of comparing different PV development scenarios by ranking them according to expected power fluctuations.

The irradiation fluctuation rank formulated in this paper was calculated using data of global irradiation measured during one and a half year with a 1 minute sampling time on seven sites in Israel's Negev desert. This rank values were compared for a large number of different possible geographical distributions of PV power plants.

Results show that the rank decreases with distribution of the same PV power over an increasing number of sites. The rank shows similar trends for the period of a year as well as for different seasons. Allocating PV power with different weights between a fixed number of sites influences the number of extreme power fluctuations. The PV fleet configuration with the minimum rank value shows the minimum number of extreme power fluctuations that will affect system frequency.

Introduction

Over the past decades, there has been an increasing interest in exploiting renewable energy sources. Photovoltaic (PV) technology offers a promising method of power generation and meets the criteria of clean energy and sustainability (Pearce, 2002).

The Negev desert in Israel is an ideal location for utility scale photovoltaic (PV) plants, where the average annual global horizontal radiation is above 2000 kWh m^{-2} year^{-1} (Faiman et al., 2004), which is very favorable in comparison with European sites of 1000–1500 kWh $*$ m^{-2} year^{-1} (Ineichen, 2011). The Ministry of National Infrastructure of Israel (2010) has set a goal of 10% of the country's electricity needs to be supplied by renewable energy sources by the year 2020. Germany and Denmark, for example, already passed this threshold which is a great challenge for the control and stability of the electric power system (Macedo and Zilles, 2008). Up till now the electric power system of Israel is forced to operate in island mode and it is relatively small (installed capacity of around 14000 MW in 2013), serving about 8 million consumers. Irradiation fluctuations may rapidly change the PV fleet power output. In an island system the power fluctuations may disturb the balance of generation versus load. The indicator of this imbalance is the frequency deviation that activates the frequency control systems of dedicated conventional power plants (Kirby et al., 2002; NERC Resources Subcommittee, 2009) and other backups. The response time of different systems is varying from a few ten seconds to several minutes. Power fluctuations above a certain MW level or ramp rate (MW/min) cannot be compensated by the load-frequency control of conventional generation units. As a result of this, power quality will be impaired and, in more serious cases, under-frequency load shedding could be necessary in order to restore the power balance and avoid system collapse. Therefore, even a small number of dangerous events per year caused by PV fleet power fluctuation would be painful.

The common solution to keep good power quality is to install fast response backup (spinning reserve) capacity to compensate for large or rapidly changing power imbalances caused by renewable sources. Backup capacities are expensive and they complicate the system's operation. In order to reduce or even avoid these drawbacks, one could exploit solar energy in the broadest sense of sustainability, by taking full advantage of the different climate conditions of available sites.

* Corresponding author. Tel.: +972 4 8183789; fax: +972 4 8185176.
E-mail address: kandurhalasz@gmail.com (G. Halász).

http://dx.doi.org/10.1016/j.esd.2014.04.005
0973-0826/

Table 1
Location of measurement stations.

ID	Location	Longitude	Latitude
1	Ketura	35°03′34″E	29°58′03″N
2	Ramat Negev	34°42′26″E	30°58′56″N
3	Revivim	34°43′13″E	31°02′44″N
4	Sde Boker	34°46′48″E	30°51′25″N
5	Tlalim	34°46′20″E	30°59′29″N
6	Yahel	35°00′50″E	29°40′22″N
7	Yotvata	35°01′39″E	29°50′49″N

Table 2
Basic statistics of 2012 year.

No	Location	Yearly energy [kWh/m^2]	Yearly energy [%](*)	Maximum irradiation [W/m^2]
1	Ketura	2108	99	1392
2	Ramat Negev	2057	97	1307
3	Revivim	2122	100	1384
4	Sde Boker	2051	97	1276
5	Tlalim	2043	96	1275
6	Yahel	2104	99	1232
7	Yotvata	2120	100	1334

(*) Relative to the value observed at Revivim.

This involves selecting a proper distribution of the members of a fleet of PV installations in such a way that the number and extent of expected critical fluctuation events is minimized.

Numerous papers have been published dealing with PV power fluctuations. Hoff and Perez (2010) and later Perez et al. (2011) were pioneers in the development of a dispersion factor to quantify the relative power output variability for a fleet of identical PV systems. They showed that the relative output variability may be minimized for optimally-spaced PV systems on the Southern Great Plains (USA). The author's model was limited to a PV fleet of identical size members, orientation and spacing distributed in the direction of cloud motion at constant speed. An important conclusion was that the output variability of PV fleet of N member equals the output variability at any one system divided by the square root of the number of members of the PV fleet. In other words: increasing the number of members will reduce the overall

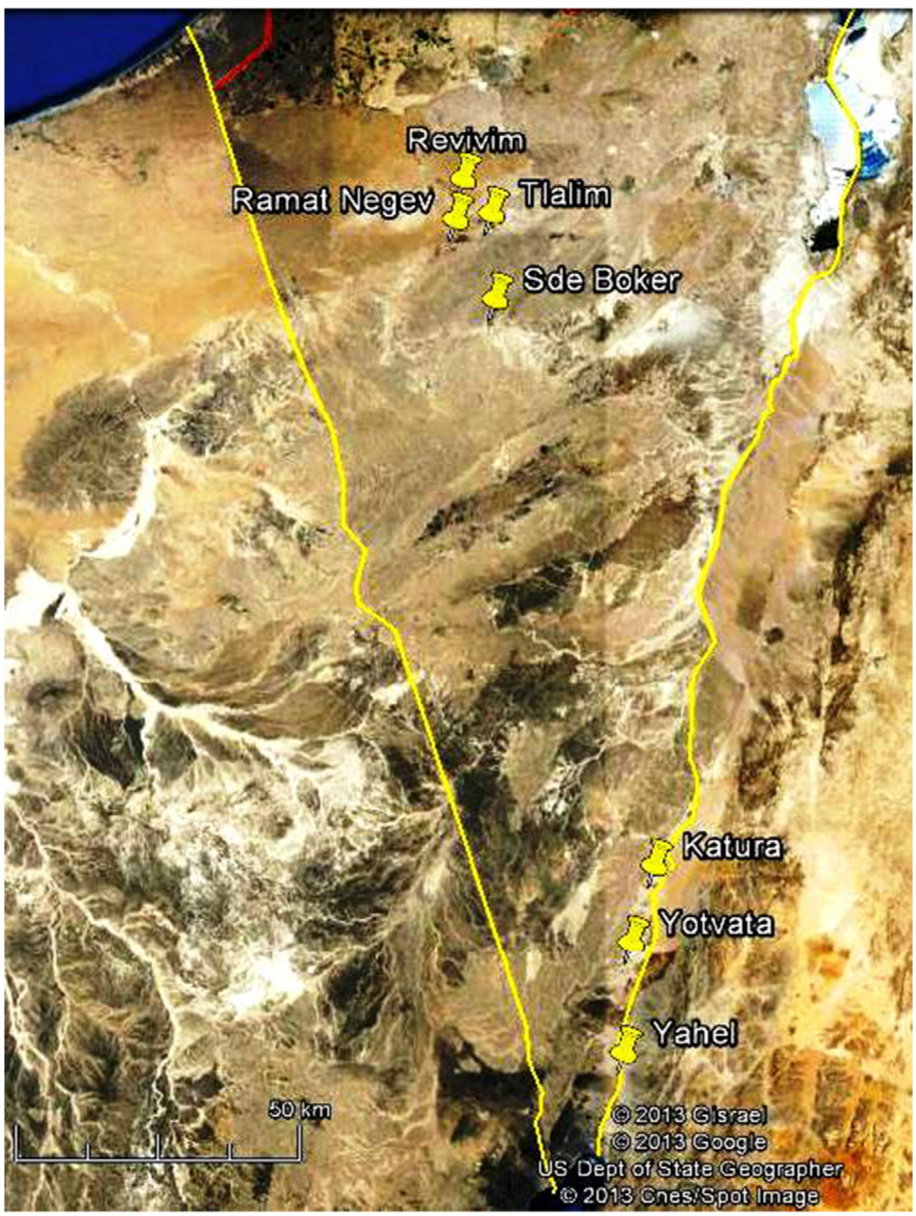

Fig. 1. Map of location of measurement stations.