Energy Reports 2 (2016) 1–7

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

A verification analysis of power quality and energy yield of a large scale PV rooftop

B. Plangklang *, N. Thanomsat, T. Phuksamak

Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi, Rangsit-Nakhonnayok Rd., Klong 6, Thanyaburi, Pathumthani 12110, Thailand

ARTICLE INFO

Article history:
Received 4 August 2015
Received in revised form
30 November 2015
Accepted 9 December 2015

Keywords:
Large PV rooftop
Distribution grid
PV energy yield

ABSTRACT

The power quality and energy yield of a large scale PV rooftop power plant in Samut Songkhram province are analyzed and presented in this paper. The power quality is examined and analyzed from the measured data to comply with the Provincial Electricity Authority (PEA) standard in Thailand. The measured parameters used in this study are as follows: the RMS Voltage, Frequency, Total Voltage Harmonic Distortion (THDv), and Voltage ripple. Certain parameters of measured data are used to calculate the distributed power yield and then compared with the Homer program simulation respectively. The investigated PV rooftop system has the installed capacity of 987.84 kWp. From the monitoring results, it found that the highest power yield was 778.125 kW while the simulation result was 783 kW. Moreover, based on the PEA standard EN 50160 with the cumulative percentile at 95% for PV rooftop power plant, the measured data showed that the power quality of this power plant passed the PEA regulations for its distribution network connecting system.

1. Introduction

The renewable energy production in Thailand especially for PV systems is increasing continuously as in other places, the growing up of PV rooftop installations has been resulted by renewable energy schemes at either domestic or commercial building premises (Eke and Senturk, 2013; Sun et al., 2012; Menoufi et al., 2013; Muhammad-Sukki et al., 2014; Hachem et al., 2014). There are many reasons for this impact such as technology developments, the lower costs of technology, the higher subsidization from the government in renewable energy sources, and environmental concerns. Thus this paper presents a large scale PV rooftop power plant which is the first large scale PV rooftop system in Samut Songkhram, Thailand under 1 MW installation capacity. Before generating into the grid, this power plant must pass the Provincial Electricity Authority (PEA) regulations for its distribution network and connecting system inspections.

Several researchers have studied the designs and the economy of PV rooftop system (Fernandez-Infantes et al., 2006; Ren et al., 2009a,b; Wittkopf et al., 2012; Ko et al., 2015; Miranda et al., 2015; Gong and Kulkarni, 2005; Ioannou et al., 2014; Acquaviva et al., 2000; Ayompe et al., 2011). They found the problems associated with protection systems and its safety. The grid interface and power quality in particular are created by a large number of grid-connected PV rooftop systems at present (Aiello et al., 2006a).

There are many different types of power qualities. The goal is to create a sinusoidal of received current as an output of the grid connected to the PV rooftop plants. Nevertheless, harmonics are found in the output PV current because the inverter and variable power are used in the PV system to flow into the grid. Furthermore, the flowing of currents through the impedances of the distribution system (variable with frequency) results in voltage distortion of system (Grady and Santoso, 2001).

The subjects of this research paper (Aiello et al., 2006b; Papaioannou et al., 2008) are also involved the practical interaction of installed PV system and distribution grid. Since only few literatures and researchers have discussed power quality disturbances and the contribution of PV system for grid harmonic level utilization in particular (Grady and Santoso, 2001; Papaioannou et al., 2008; Batrinu et al., 2006; Menti et al., 2011; Chicco et al., 2005; McNeil and Mirza, 1983; Schlabbach, 2008), the need to further such study becomes significant. The subjects of several international standards of power quality (IEEE Standard, 2003; EN 50160, 0000) describe that voltages and the level of harmonic distortion in grid currents result from grid-connected PV systems. The limit of Total Voltage Harmonic Distortion (THDv) is 8% based on the European standard EN50160 (EN 50160, 0000), and this can increase up to the 40th

* Corresponding author.
E-mail address: boonyang.p@en.rmutt.ac.th (B. Plangklang).

http://dx.doi.org/10.1016/j.egyr.2015.12.002

Table 1
The minimum and the maximum voltage level standards of PEA.

Voltage level	Steady state		Emergency	
	Max. (kV)	Min. (kV)	Max. (kV)	Min. (kV)
115 kV	120.7	109.2	126.5	103.5
33 kV	34.7	31.3	36.3	29.7
22 kV	23.1	20.9	24.2	19.8
380 V	418	342	418	342
220 V	240	200	240	200

harmonic. In Thailand, harmonic limits are considered the THD factor. In addition, when PV plants or PV rooftops are connecting to the public electrical grid, the regulatory requirements in the document (Provincial Electricity Authority, 0000) edited by Provincial Electricity Authority (PEA) must be considered. The maximum voltage or THD factor from the individual power generation must not exceed 3%.

Designing processes for a large scale PV rooftop system, monitoring power quality, and comparing energy yield between simulation and actual value are clearly presented in this paper. The PV rooftop system is designed and the anticipated PV operational problems, i.e. harmonic effect, voltage fluctuation are discussed. Finally, the energy yield of this system is simulated and analyzed with actual value from monitoring. This paper also discusses the technical performance of the installations by using parameters such as performance ratio.

2. Methods and design

2.1. Power quality

In an ideal power system, generating electricity from power producer should invariably and perfectly display a sinusoidal voltage waveform at every customer locations even though it is hard to save such desirable conditions. The standard deviation of the current waveforms and the voltage from sinusoidal are described in terms of waveform distortion, such as, voltage fluctuation, and harmonic distortion (De La Rosa, 2006).

2.1.1. Voltage

The voltage must be controlled by power producer in the range of maximum and minimum standards as defined in Table 1.

2.1.2. Frequency

It must be controlled to 50 ± 0.5 Hz. If the frequency is in the range of 48.00–51.00 Hz in 0.1 s, it is considered as a fault.

2.1.3. Voltage fluctuation

It must be controlled and ensured that there is no ripple voltage at the connection point venture beyond the standard. In typical measurement, P_{st} is used to assess the severity of voltage flicker in a short-time period (10 min) and P_{lt} is used to assess the severity of voltage flicker in a long-time period (2–3 h) according to Eqs. (1) and (2).

$$P_{st} = \sqrt[m]{(P_{st_1})^m + (P_{st_2})^m + \cdots + (P_{st_3})^m} \tag{1}$$

$$P_{lt} = \sqrt[3]{\frac{1}{n}\sum_{j=1}^{j=n}(P_{st_j})^3}. \tag{2}$$

P_{st} is used to assess the severity of voltage flicker in a short-time period.

P_{lt} is used to assess the severity of voltage flicker in a long-time period.

The value m shows the nature of voltage fluctuations.

The value n shows the number of P_{st} at the time of measurement.

Fig. 1. The location of PV rooftop plant.

2.1.4. Harmonics

Equipment with nonlinear characteristics such as transformers, fluorescent lamps, and especially the power electronic components causes harmonics befalling (Schlabbach et al., 1999). Several researchers have described that harmonic in PV system is generated by the converter. Despite the fact that the converter uses switching signals, such signals are not perfect sinusoidal (IEEE Recommended Practice, 2000).

The waveform distortion is evaluated at the harmonic orders ($h = 2, \ldots, H_{\max}$) while $H_{\max} = 40$ (EN 50160, 0000; Stojkov et al., 2009) all of which are typical values. For example, individual harmonics can characterize a voltage waveform:

$$X_h = \frac{V_h}{V_1} \quad \text{for } h = 1, \ldots, H_{\max}. \tag{3}$$

Total Harmonic Distortion (THD) of voltage is defined as the ratio of the RMS value of all harmonic components of the Voltage (V_h), to the fundamental Voltage (V_1) based on the following Eq. (4)

$$THDv(\%) = \frac{\sqrt{\sum_{h=2}^{40} V_{h(rms)}^2}}{V_{1(rms)}} * 100\%. \tag{4}$$

$V_{h(rms)}$ is the value of the harmonic voltage number h.

$V_{1(rms)}$ is the voltage at the fundamental frequency of 50 Hz (see Table 2).

The standard deviation of harmonic that influences the distribution networks is not only initially visible, it also affects serious long-term outcomes; for example, resonant and stress conditions on power system, saturation effects in the core and increased heating of transformer affect another system and so on (Stojkov et al., 2009; Fekete et al., 2012).

2.2. Description of the PV rooftop site

The PV rooftop plant is located at latitude 13° 22 min North and 99° 58 min East in Samut Songkhram province, Thailand as show in Fig. 1.

The system has the installed capacity of 987.84 kWp which is composed of solar panels Poly Crystalline Module Size 245 Wp (Photovoltaic module Jinko Solar, 2015).

Array type 1 group: 4 array × 20 strings × 24 panels = 1920 modules.

Array type 2 group: 4 array × 22 strings × 24 panels = 2112 modules.

The PV arrays were installed on rooftop which the group 1–2–3–4 faced toward the North, the group 5–6–7–8 faced toward