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# Advances and challenges in grid tied photovoltaic systems

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A B S T R A C T

Photovoltaic (PV) technology is gathering momentum around the word. Global PV energy harvest has been more than doubled since 2010. Grid connected PV (GCPV) systems can be found in different scales classified into three categories of small scale, medium scale and utility scale. Considering size of the system various configurations are suggested for the GCPV systems while each configuration might be assessed by factors such as efficiency, reliability, expandability and cost. Moreover, high integration of GCPV systems into the power system network creates several technical problems mostly coming from the intermittent nature of solar energy. In addition, to achieve a higher degree of power system reliability, GCPV systems are required to support the grid in abnormal condition such a faults and deviation from standard frequency. This paper provides a comprehensive review on GCPV systems. Various configuration proposed by the literature will be discussed. Cost study and impact of technical and environmental factors on the total expense and revenue of GCPV installation will be investigated. Different aspects of PV integration into the power network will be discussed. Problem and solutions will be studied as well. Finally grid requirements and active and reactive power support will be reviewed.


**Contents**



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## 1. Introduction

Among new ideas of extracting energy from renewable resources, photovoltaic (PV) has been becoming one of the most mature technologies in recent years. From the economical point of view, module prices are decreasing, emerging markets are increasing and investments on the manufacturing section are recovering. From the technical point of view, PV technology is developing as well. According to IHS, that efficiency of commercial module is expected to rise by 1.67% per year until 2017 [1]. As a result of the advanced technology, global PV installation is increasing unprecedentedly and is expected to exceed 40 GW by the end of 2014 as it is demonstrated in Fig. 1a. The contribution of different countries in the booming PV installation in 2014 is shown in Fig. 1b where the most significant shares belong to China, Japan, USA and Germany.

PV installation can be found in two types of stand-alone and grid connected. The former configuration might be aimed to supply local load located in a remote area far from any connection provided by the national power network [4,5], while the latter configuration, owned by individual or utility, supplies the power network. Based on size of the system, grid connected PV (GCPV) systems can be classified into three categories of utility scale, medium scale and small scale. With a capacity ranges in Megawatts, utility scale GCPV systems are normally connected to medium-voltage network via dedicated feeders. The 3-phase connections may involve several interconnected transformers. The plant itself is equipped with different means of protection (i.e. overcurrent protection, under voltage protection) as well as active anti-islanding schemes preventing power injection when the grid connection is lost. Medium scale configurations range from 10 kW to 1 MW. Smaller plants under this category, up to 100 kW, are connected to the secondary line (120/240 V) while larger plants have a connection same as utility scale GCPV systems. Finally, small scale with capacities up to 10 kW is usually installed at residence of costumers who normally own the system. Distributed small scale GCPV systems have a single phase connection to the secondary line [6].

The increasing deployment of GCPV calls for a study focusing on the big picture. It is necessary to consider not only GCPV's different types and benefits, but also rising issues in consequence of integration of this new equipment in power systems. This paper is aimed to provide a comprehensive review on the GCPV topologies and problems associated with it. Section 2 describes different possible GCPV configurations. A comparison among different configurations in terms of reliability, mismatch possibility, efficiency and expandability is also presented in this section. Section 3 discusses the cost study and different factors affecting the total expenses and return of investment of a medium or utility scale GCPV system. Negative aspects of high penetration level of GCPC connection on quality of power and voltage such as voltage rise, voltage fluctuations and harmonic injection are investigated in Section 4. The most recent solutions proposed by the literature are studied in this section as well. Grid codes applicable to large scale GCPV systems are reviewed in Section 5. Finally, active and reactive power controls to fulfill the grid codes are investigated in Section 6.

## 2. Cost study

High investment demand for renewable energy harvest is one of the most important barriers against development of these technologies. To incentivize individuals and companies toward renewable energy investments, governments usually define a Feed-in Tariff which offers higher rate of purchase for the power generated from renewable sources of energy. Yet, a careful cost study is necessary to select the most economical topology and ensure expected profit. To perform the cost study levelized cost of energy (LCOE) can be investigated. Characterizing how expensive the generated energy would be, this factor can be used to assess and compare the GCPV systems economically [7]. LCOE is defined as follows [7]:

$$\mathrm{LCOE} = \frac{\mathrm{TLCC}}{\sum_{n=1}^{N}[E_n/(1+d)^n]} \tag{1}$$

where TLCC is the total cost including investment cost and maintenance cost, $N$ is the analysis period, $d$ is the discount rate and $E_n$ is the energy yield in year $n$ which can be calculated as follows:

$$E_i = E_{dc,i} \times \eta_{conv} \tag{2}$$

where $\eta_{conv}$ is total converter efficiency which is multiplied efficiencies of all the power electronic converters located between PV modules and grid, and $E_{dc}$ is the available DC energy in the period of study [8]:

$$E_{dc,i} = R_i \frac{P_{PV}}{1000} k(1-\alpha_i N) \tag{3}$$

where $R_i$ is the average available radiation in period $i$ in kWh/m$^2$, $P_{PV}$ is the rated power of the PV array in kW, $k$ is the DC side derate factor representing efficiency reduction of power electronic component in the DC side and $\alpha_i$ is the degradation factor of PV modules representing efficiency reduction of PV cells [9].

Cost study helps designers to opt for the best configuration based on various factors affecting the LCOE. From the economical point of view the smallest LOCE is desired. Considering (1), TLCC and total energy yield affect LOCE directly and reversely respectively. Meanwhile, these two factors are related to other factors like maintenance cost and energy efficiency. In the next section we

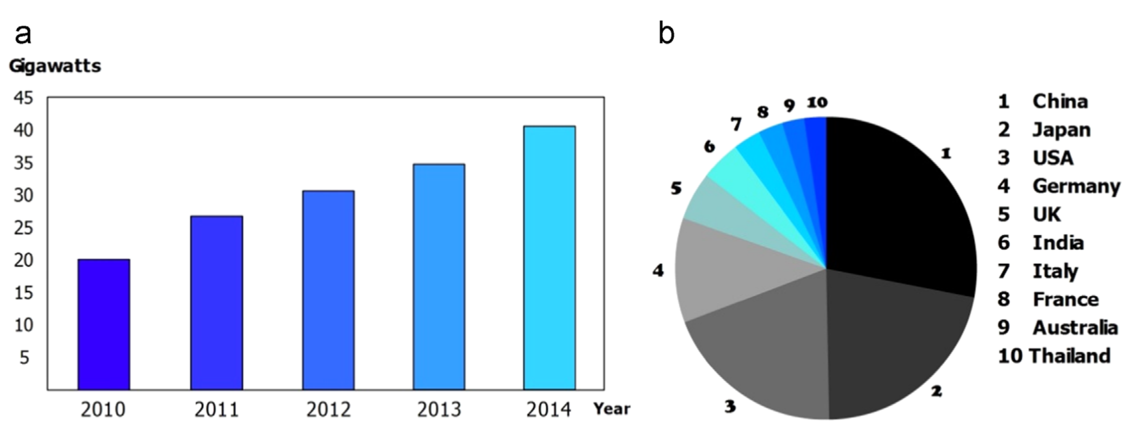


**Fig. 1.** (a) Global PV installation between 2010 and 2014 [2]. (b) PV installation by different countries in 2014 [3].