Integration of Solar PV Systems to the Grid: Issues and Challenges

Harish Kumar Khyani,
Associate Professor
Department of Electrical Engineering,
Jodhpur Institute of Engineering & Technology,
Jodhpur, Rajasthan, India
harish.khyani@jietjodhpur.com

Dr. Jayashri Vajpai,
Associate Professor
Electrical Engineering Department,
Faculty of Engineering, J.N.V. University,
Jodhpur, Rajasthan, India
jvapai@gmail.com

Abstract— *The small scale electricity generators such as solar photovoltaic (PV) systems are generally connected to the grid at the primary or secondary distribution and are considered as distributed generation (DG). Often, these small scale renewable generators cannot be directly connected to the grid. The generation technology or the operational characteristics require the use of some interface between the generator and utility distribution grid. This paper outlines the most common issues and challenges encountered during the grid integration of small scale solar photovoltaic energy systems. The major problems and suitable solutions have been also highlighted in this paper. These include the primary technical and power quality issues and the secondary economic and research related issues.*

Keywords—Small scale generation, Solar Photovoltaic, Distributed Generation, Grid Integration

I. INTRODUCTION

Electricity generation using renewable energy resources is presently at small scale due to the disperse nature of the resources. Integration of renewable energy into the grid can be at either the transmission level or distribution level, depending upon the scale of generation. The larger renewable energy generations such as wind farms are directly interconnected to the transmission system. Small scale distributed generation, such as small hydro, solar photovoltaics, biogas, biomass and small wind turbine, are generally interconnected to the medium or low voltage distribution systems. Both these types of interconnections present different issues and challenges that must be carefully analyzed, before grid integration systems are designed and deployed for commercial use. Solar photovoltaic systems are composed of PV arrays that convert incident solar energy into dc electricity and therefore, a power electronic based DC-to-AC converter is required between the generator and the grid.

Although small scale energy generation technologies with inbuilt system for frequency control, such as induction generator based small hydro or wind can be directly connected the AC grid, but starting transients, energy conversion efficiency and power quality issues make power electronic interface a better choice. [1]

The Table 1 summarizes some of the common types of generation and their preferred interfacing technology:

TABLE I. TYPE OF GENERATION AND IT'S INTERFACING

Type of Generation	***Interfacing Technology***
Wind	Variable frequency AC Power Electronic Converter for Induction Generator
Solar Photovoltaic	DC to AC Power Electronic Converter
Small Hydro	Fixed frequency AC Power Electronic for Converter Synchronous or Induction Generator

II. ISSUES RELATED TO GRID INTEGRAION

This paper focuses in delineating the grid integration issues associated with the solar PV generation systems. The exponential growth of the photovoltaic (PV) and wind energy systems has hence, thrown up many issues and challenges regarding the integration of these systems into utility networks at high levels of penetration. [2]. Most of the electric distribution systems are designed, operated and protected on the assumption that there is a single source of voltage on each distribution feeder. However, the interconnection of small scale renewable energy distributed generation to the distribution grid violates this basic assumption. Therefore, certain mandatory requirements is essential for meeting interconnecting distributed generation to the grid, in order to ensure safe and reliable operation.

Further, the past few years have seen many milestones in the development of streamlined, standardized requirements for utility interconnection of small-scale renewable generating facilities, particularly solar photovoltaic systems. [3] This paper studies the major issues thrown up by the wide development of PV systems and their grid integration.

III. PV SYSTEMS INTERCONNECTION ISSUES

The interconnection issues broadly cover the essential requirements for a small scale photovoltaic solar energy system connected in parallel to the utility grid. Interconnection issues refer to the Technical, Contractual, Metering and Rates, Research and Development and Certification & Warranty issues that must be settled between the system owners, a utility and local permitting authority before the system is connected to the grid.

A. Technical Issues:

The major technical issues associated with PV systems are as follows:

1) Safety: Research projects devoted to finding ways to reduce the inherent safety risks associated with PV systems have been under taken recently. Industrial customers have also recently focused on interconnecting PV generation systems to operate in parallel with the grid. Major safety equipment and periodic checks by utility personnel or professional engineers may be important and affordable for the safety of large generation sites, but these requirements are unreasonable for small PV systems.

Depending on the system design, some utility-interconnected PV systems operate at DC voltages in excess of 300 volts before being inverted to standard alternating-current. The potential fire hazard of DC at these voltages is greater than that of standard AC, because it is more difficult to extinguish a DC arc than an AC arc at the same voltage. However, proper wiring ensures that any hazards related to DC power are significantly reduced.

2) Islanding: One of the most important safety issues for small customer-sited PV systems is a condition called islanding. Islanding occurs when a portion of the utility system that contains both loads and a generation source is isolated from the remainder of the utility system, but remains energized. When this happens with a PV system, it is referred to as PV-supported islanding.

The safety concern is that while a utility can ensure that its generation sources are either shut down or isolated from the area that needs work, an island created by PV system is out of their control. As a potentially undesirable result of islanding, a utility line worker can come into contact with a line that is unexpectedly energized. Inverters with built-in anti-islanding safety features are hence required. Grid-tied inverters monitor the utility line and can shut themselves off as quickly as necessary (in 2 seconds or less) in the event abnormalities occur on the utility system. [4]

3) Identification and Traceability: Each PV module of a solar power project is required to use RF identification tag. (Inside or outside the laminate, but must be able to withstand harsh environmental conditions.) The following information must be mentioned in the RFID used on each module: [5]

a) Name of the manufacturer of PV Module
b) Name of the Manufacturer of Solar cells
c) Unique Serial No. and Model No. of the module
d) Month and year of the manufacture (separately for solar cells and module)
e) Country of origin (separately for solar cells and module)
f) I-V curve for the module
g) Wattage, Maximum current (Im),Maximum Voltage (Vm) and Fill factor (FF) for the module
h) Date and year of obtaining PV module standard qualification certificate
i) Name of the test lab issuing standard certificate
j) Other relevant information on traceability of solar cells and module as per ISO: 9000

4) Measurement and Reporting: All grid solar PV power plants must install necessary equipment to continuously measure solar radiation, ambient temperature, wind speed and other weather parameters and simultaneously measure the generation of DC power as well as AC power generated from the plant. They are required to submit this data to the Ministry of Energy on-line and/ or through a report on regular basis.

Suitable measurement facility should be placed as close as possible to the solar plants. A common measurement facility may be used by the plants located within a radius of five kilometers from this facility. This is subject to the conditions that:

a) It is certified by the participating developers that the topography of the place remains similar in this range of distance;
b) Participating project developers agree on sharing of the data, maintenance of the facility, quality checks on the data, etc.

5) Power Quality: Power quality is another technical concern for utilities and customer-generators. Power should be consistently supplied at a standard voltage and frequency, because devices and appliances are designed to receive power at or near specified voltage and frequency parameters, and deviations may cause appliance malfunction or damage. Power quality problems can manifest themselves in lines on a TV screen or static noise on a radio, which is sometimes noticed when operating a microwave oven or hand mixer. A PV inverter can inject noise that can cause problems. In addition to simple voltage and frequency ranges, power quality standards also include harmonics, power factor, DC injection, and voltage flicker. [3]

a) *Harmonics generally refer to distortions in the voltage and current waveforms. These distortions are caused by the overlapping of the standard waves at 50 Hz with waves at other frequencies. Specifically, a harmonic of a sinusoidal wave is an integral multiple of the frequency of the wave. Total harmonic distortion (THD) is summation of all the distortions at the various harmonic frequencies. [3]*

b) *Power factor, the ratio of true electric power, as measured in kilowatts, to the apparent power, as measured in kilovolt-amperes (kVA), is required to be maintained close to unity. Otherwise it also contributes to utility system inefficiencies.*

c) *DC injection occurs when an inverter passes unwanted DC current into the AC or output side of the inverter.*

d) *Voltage flicker refers to short-lived spikes or dips in the line voltage. A common manifestation of voltage flicker is dimming of lights momentarily. Grid interactive inverters generally do not create DC injection or voltage flicker problems. [3]*

6) Codes and Standards: To address protection, safety and power quality issues, national codes and safety organizations have laid down the guidelines for equipment manufacture, operation, and installation. The major code and safety organizations that deal with photovoltaic systems are defined by the International Electro Technical Commission (IEC), the Institution of Electrical and Electronics Engineers (IEEE), the Bureau of Indian Standards (BIS), Underwriters Laboratories (UL), Deutsches Institute fuer Normung, German institute for standardization (DIN) and National Fire Protection Association (NFPA). IEC protocols are used all over the world and form the basis for developing indigenous protocols in different countries, due to their elaborate and modular nature. DIN protocols, however are the most exquisite and are used by developers and manufacturers. BIS protocols forms the Indian standards and are based on IEC and IEEE standards. These protocols are still under development.

Most of the utilities all over the world have adopted the IEEE Standard 1547-2003 entitled “IEEE Standard for Interconnecting Distributed Resources (DR) with Electric Power Systems, 2003”, in formulating the guidelines and rules for interconnecting DG to their network. This standard is written considering that the DR is a 60 Hz source. A brief description of the salient features of IEEE standard 1547-2003 is given below: [1]

IEEE standard 1547-2003 recommends disconnection of distributed energy resources when voltage and/or frequency at the point of interconnection deviate from their base values due to faults and other disturbances. The allowable deviations are defined in Table 2 and Table 3 [1], respectively, as follows:

TABLE II. INTERCONNECTION SYSTEM RESPONSE TO ABNORMAL VOLTAGES

Voltage Range ***(% of nominal system voltage)***	***Clearing Time*** ***(In Sec.)***
V<50%	0.16
50% ≤V<88%	2.00
110% ≤V<120%	1.00
V≥120%	0.16

TABLE III. INTERCONNECTION SYSTEM RESPONSE TO ABNORMAL FREQUENCIES

Size of Distributed Resources (DR)	***Frequency Range (Hz)***	***Clearing Time (In Sec.)***
≤ 30kW	>60.5	0.16
	<59.3	0.16
>30kW	<{59.8-57.0} (adjustable set point)	0.16-300 (adjustable set point)
	<57.0	0.16

Also, for an unintentional island in which the DG energizes a portion of the network, the DG interconnection system must detect the island and disconnect the DG within two seconds of the formation of island.

B. Contractual Issues: While the technical barriers to interconnection have been reasonably solved with the recent updation of IEEE Std. 929-2000 and UL Std. 1741, there still remain significant contractual barriers to interconnection. [3] Among these are liability insurance requirements, fees and charges, etc.

1) Liability: Liability insurance is required to protect utilities and their employees, in the event of any accidents attributable to the operation of the customer’s PV system. Indemnity is another liability-related issue that refers to security against or compensation for damage, loss, or injury. In the case of contracts between utilities and PV owners, utilities frequently require the PV owner or other customer generator to indemnify the utility for any potential damages as a result of operation of the PV system. Where there are liability insurance requirements, indemnification requirements are somewhat redundant.

2) Fees and Other Charges: There are a variety of fees that utilities may impose on owners of grid-tied PV systems. These fees include permitting fees, interconnection-related fees and charges, metering charges, and standby charges. The imposition of even a modest fee can substantially alter the economics of grid-tied PV systems. [3]

3) Standard Agreements and Procedures: One of the most important interconnection issues is in the area of standardized agreement for customers interconnecting their PV systems. Even when the major technical and contractual rules are settled, if a lawyer is needed to read and interpret the utility-required paperwork, costs go up and plans are abandoned.

C. Metering and Rates Issues: The following metering and related issues are required to be considered for commissioning PV systems:

1) Net Metering: For those consumers who have their own electricity generating units, net metering allows for the flow of electricity both to and from the customer through a single, bi-directional meter. This arrangement is more advantageous to the customer in the emerging systems of availability based tariff, than the two-meter arrangements. Under the most common two-meter arrangement, referred to as net purchase and sale, any electricity produced by a consumer that is not immediately used by the customer flows to the utility through the second meter. This excess generation flowing through the second meter is purchased by the utility at the utility's avoided cost, while the customer purchases any electricity off of the grid at the retail rate. There is usually a significant difference in the retail rate and the avoided cost.

Net metering is also a low-cost and easily-administered way of promoting direct customer investment in renewable energy. One of the major advantages of net metering is its simplicity; most customers can use their existing meter without any additional regulation or equipment. [3]

2) Annual vs. Monthly Netting: Recent net metering rules have called for month-to-month carry forward of any net excess generation or "annual netting." Under this provision, if over the period of a month, a customer generates more kWh than used, the excess kWh or "net excess generation" is carried over to the following month. In the event that there is excess generation carried over to the end of the year, any excess generation by the customer generator is granted to the utility with no payment to the customer generator. The provision for annualized netting reflects the fact that some renewable energy resources are seasonal in nature. For example, a solar system may produce more energy than a household consumes in the summer months but may also produce less than what the household uses in the winter. Under this scenario the excess from the summer months would roll over to the winter months. The advantage of this type of arrangement to the utility is that not only is the utility granted any net excess generation at the end of the year, but the utility does not incur the administrative costs of paying the customer. [3]

3) Time-of-Use Metering and Smart Meters: Time-of-use (TOU) metering refers to a metering arrangement where customers pay differential electric rate based on the time of day that they are consuming electricity. [3]

D. Research and Development Issues: Fast development of PV energy systems requires dynamic, innovative thinking and the flexibility to rapidly accommodate changing market demands. Coherent research and development (R&D) programmes for renewable energies are key elements in designing political strategies for further development of this area. Enhancing the dialogue between science and policy is essential to achieve a consistent global approach which takes into account the maturity of the different renewable energy technologies. [4] The solar photovoltaics industry has advanced significantly in recent years. The following research directions are critical for the development of PV:

1) Improved statistical and soft computing based tools should be developed for better forecasting of the unpredictable output of Solar PV. Better energy and weather forecasting tools are required to forecast the output of Solar PV plant well in advance so that it could be properly operated and integrated with the other power generating sources.
2) Modeling and simulation of overall PV plant is required so that the output of the plant could be predicted under different weather and partial shading conditions.
3) Reduction in the consumption of silicon and other materials in conventional crystalline silicon applications should be explored, so as to reduce material and associated costs.
4) Development of novel high efficiency silicon devices for thin-film modules based on silicon should be attempted.
5) A new class of nano-structured devices such as organic, organic/inorganic hybrid devices and dye cells are being designed as futuristic PV systems.
6) Better operation of existing PV systems requires design of improved power electronics circuits to enhance output quality and the compatibility with smart grid schemes.
7) Study of Grid integration issues for high levels of penetration, including large distance DC transport

has become necessary for improving overall system efficiency.

8) Design of high throughput, high yield and integrated processing systems with increased automation across all module types is expected to enhance system efficiency.

9) Attempts for improving sustainability of production by the use of recycled material, supported by life cycle assessment studies are becoming the need of hour.

Thus, enhancing R&D has a vital role to play if the potential of renewable energy is to be fully exploited. Policy measures, such as taxes, cap and trade schemes, obligations and feed-in tariffs, which take into account environmental impacts and, in particular, the social cost of carbon dioxide emissions, will contribute to faster deployment. However, investment in R&D will not be delivered by market alone; extensive support at the national and international levels is needed to accelerate the development of renewable technologies. [6]

E. Certification & Warranty Issues: Finally, it is important to impose certain third party testing and certification along with warranty.

1) Authorized Test Centers: The PV modules are tested and approved the IEC authorized test centers. In India PV module qualification test certificate as per IEC standard can be issued by Electronics Test & Development Centre (ETDC), Bangalore, or Solar Energy Centre at New Delhi. Ministry of Energy reviews the list of authorized testing laboratories/centers from time to time.

2) Warranty: The mechanical structures, electrical works and overall workmanship of the grid solar power plants must be warranted for a minimum of 5 years. PV modules used in grid connected solar power plants must be warranted for output wattage, which should not be less than 90% at the end of 10 years and 80% at the end of 25 years. [3]

Thus, a study of important grid integration issues, protocols and standards is an essential part of design and commissioning of solar PV systems.

IV. CONCLUSION

Various issues and challenges that need to be addressed in grid integration of solar PV systems have been discussed in this paper. Most of the legacy power grid systems are not designed to handle today's high electricity demand levels. It is important for governments and utilities to have a realistic understanding of the condition of their country's grid network connections and the maximum allowable penetration levels at current capacities. Although a certain amount of renewable energy may be integrated into the existing grid with no major issues, in some cases, a portion of the network will require upgrading in order to accommodate high amounts of renewable energy in the system. The major grid integration issues that impact system operation include technical, contractual and commercial issues. The most significant ones among these can be highlighted as:

1) Power Quality, Islanding and Certification
2) System integrity and stability
3) Safety and Protection
4) Economics and Metering

Finally, Research and Development in the grid integration of solar PV system is expected to play a major role in meeting the impending energy crisis.

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