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A Review on Impacts of Grid-Connected PV System on Distribution Networks

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Abstract**—**This paper aims to investigate and emphasize the importance of the grid-connected photovoltaic (PV) systems regarding the intermittent nature of renewable generation, and the characterization of PV generation with regard to grid code compliance. The development of Photovoltaic systems and expansion plans relating to the futuristic in worldwide is elaborated. The most important impacts of grid connected photovoltaic systems on distribution networks as well as the Penetration level of PV system was investigated.

Keywords**—**Grid-connected photovoltaic system, distribution network, penetration levels, power quality.

I. Introduction

NOWADAYS, we get approximately 80% of our energy from non-renewable energy sources, e.g. fossil fuels. Greenhouse gases and pollutants increase when fossil fuels are converted into electricity or heat. Therefore, atmosphere is damaged. Global warming is also threatening our world's delicate ecosystems and could easily relegate many animal species to extinction. To prevent the global warming calamity, the global warming should be kept to less than 1.5 centigrade degree above pre-industrial temperatures. For this target, the global greenhouse gas emissions should be reduced, and by 2050, these emissions should be reduced worldwide by 80% from their 1990 levels. Presently, the world annual energy consumption is 10 terawatts (TW) and by 2050 this amount will be about 30 TW. The world will need about 20 TW of non-CO_2 energy to stabilize CO_2 in the atmosphere by mid-century. The simplest scenario to stabilize CO2 by mid-century is renewable sources are used for electricity (10 TW), hydrogen for transportation (10 TW), and fossil fuels for residential and industrial heating (10 TW). Fortunately, as the resources are limited, our dependence on fossil is close to its end [1]-[5].

Utilizing renewable sources energy such as solar and wind to generate electricity provides a feasible solution for the previous dilemma as these renewable are clean, emission-free sources of energy that can be used to generate electricity and at the same time protect our environment for future generations. A simple calculation reveals that the amount of solar energy received in 1 hour by the earth is equivalent to the world's annual energy consumption [6].

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Solar energy, in particular, PV arrays, can fulfill all the electricity needs of mankind. Photovoltaic systems have been installed to provide electricity to the billions of people that do not have access to mains electricity. Power supply to remoter houses or villages, irrigation and water supply are important application of photovoltaics for many years to come. In the last decade, PV solar energy system has shown its huge potential. The amount of installed PV power has rapidly increased. Perhaps the most exciting new application has been the integration of solar cells into the roofs and facades of buildings during the last decade [7], [8].

It was thought that integrating photovoltaic systems into electrical networks would not be a difficult task; however, when the penetration level of photovoltaic systems started to increase, utilities began to face new non-traditional problems mainly due to the discontinuous nature of solar energy; PV array output is highly dependent on environmental conditions such as illumination intensity and temperature. The presence of dust on the surface of the solar panels deteriorates their performance. Concentration of dust and velocity of wind and cloudy days also reduces the current and power of solar cells. Thus, the power system has to deal with not only uncontrollable demand but also uncontrollable generation [9]-[11].

In this paper, the development and rapid growth in PV electricity worldwide is expressed. The possible impacts of solar PV arrays on existing electrical systems are reviewed. As well as the threshold penetration level of PV electricity that can be safely connected into electrical network is analyzed.

II. Development in PV Electricity Worldwide

In the last decade, PV solar energy system has shown its huge potential. The amount of installed PV electricity has rapidly increased. Nowadays, approximately 100 GW of PV power is installed worldwide. Global PV electricity installed capacity has experienced an annual growth rate of about 45% as shown in Fig. 1. This is because that electricity generation from renewable sources will be the only available option to satisfy the growing demand for electricity when all fossil fuel resources are consumed. Another reason for that is the anticipated benefit of PV electricity sector on national economy. Despite its high initial cost, cost of jobs created by PV electricity is 4–6 times less than the cost of jobs created by nuclear, natural gas, or coal. A million dollar investment in solar PV will create only 30%–42% of the energy produced by other power plants but 2.4–6.4 times more jobs [12]-[15].

Due to high subsidies in Germany, Span, and Italy the market has shown an exponential increase in the capacity.

Thus, approximately 22 GW have been installed within the Europe in 2011 alone, hence being by far the largest market in the world. The tendency of the market is to move to new large market like USA, India, and China. These countries will play a very important role in the near future of PV [16].

The increase in the capacity installed yearly has been coupled with a strong decrease in the components price. Since 2006, the PV system price has shown a reduction of more than 50%, e.g. the standard final price in 2006 was around 5500-6000 €/kW for a residential system, whereas in 2011 the standard final price was 2400-2700 €/kW. The industry still has capacity to reduce the margins and further PV system price reductions are expected [17].

In addition to these futuristic expansion plans, there are already many photovoltaics systems installed worldwide with high penetration levels of PV electricity. Most of these projects are being monitored in order to provide practical insight into the anticipated impacts if similar penetrations are to be installed in existing networks. Examples of such projects include the Gunma Project in Japan (starting up in 2002), which contains 550 houses with rooftop grid-connected PV systems. The total capacity is estimated to be 2.2MW in a 1 km^2 area, which corresponds to an 85% penetration level of PV electricity. In Germany, the PV settlement project in Freiburg consists of 50 condominium apartments with PV systems installed for each apartment. This amounts to 300kW total capacity, which corresponds to an 80% penetration level [18]-[20].

III. Photovoltaic (Effect, Environmental Dependency and Grid- Connected)

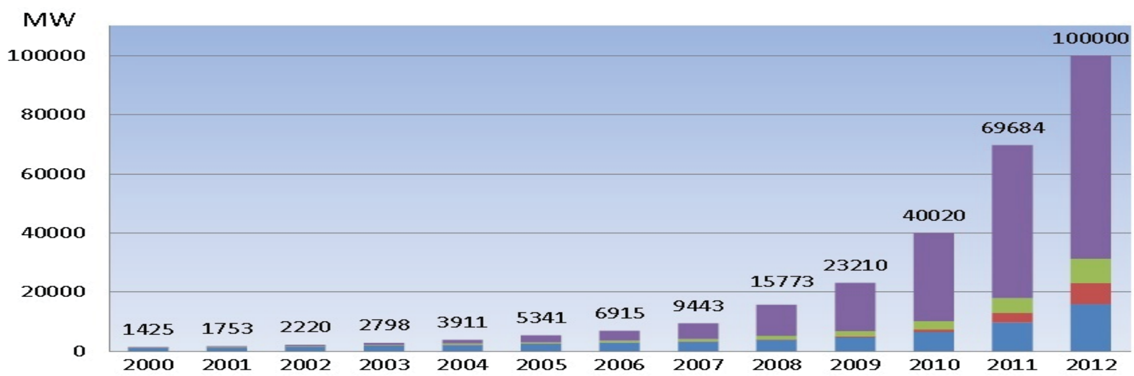
A. Photovoltaic Effect

The photovoltaic effect is the direct conversion of light into electricity in solar cells. When solar cells are exposed to sunlight, electrons excite from the valence band to the conduction band creating charged particles called holes. In one PV cell, typically the upper or n-type layer is crystalline silicon doped with phosphorus with 5 valence electrons while the lower or p-type layer is doped with boron, which has 3 valence electrons. By bringing n and p type silicon together, a p-n junction serves for creating an electric field within the solar cells, which is able to separate electrons and hole and if the incident photon is energetic enough to dislodge a valance electron, the electron will jump to the conduction band and initiate a current coming out from the solar cells through the contacts [21], [25]. Fig. 2 shows this process.

B. Effect of Environmental Condition

Temperature has an important effect on the power output. The most significant is the temperature dependence of the voltage which decreases with increasing temperature. the voltage decrease of a silicon solar cell is typically 2.2 mV per ^{o}C. As well as reduction in the output power per ^{o}C increase in Environmental temperature is 0.005 mw [11].

The solar cells current is directly proportional to the illumination intensity while voltage is logarithmically proportional with light intensity. Partial shading due to passing clouds and radiation random variations are all factors that will affect photovoltaics system production, resulting in rapid fluctuations in its output power. Fig. 3 shows the power characteristics of a PV arrays at different temperature and sun radiation [21].



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Total	1425	1753	2220	2798	3911	5341	6915	9443	15773	23210	40020	69684	100000
Europe	154	248	389	590	1297	2299	3285	5257	10554	16357	29777	51716	68716
America	146	177	222	287	379	496	645	856	1205	1744	2820	5053	8253
China	19	30	45	55	64	68	80	100	145	373	893	3093	7093
ROW	1106	1298	1564	1866	2171	2478	2905	3230	3869	4736	6530	9822	15938

Fig. 1 Global cumulative installed PV power 2000-2012 [12]

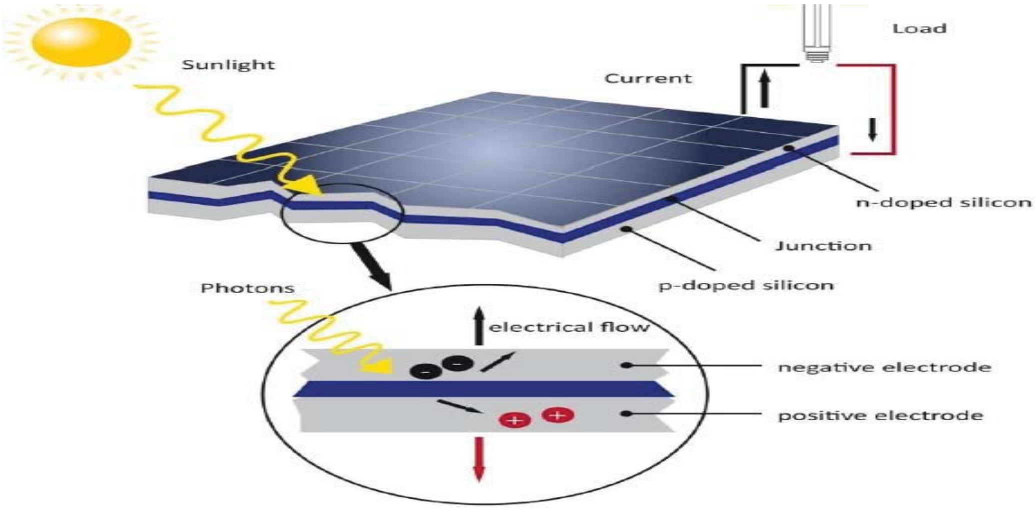


Fig. 2 Photovoltaic effect principle

The orientation and tilt of the photovoltaic panels determine the amount of light intensity that the panel surface receives. If the panels installed in northern hemisphere, they must be oriented facing south side, also facing north in the southern hemisphere [22]. In regions near the equator, the orientation is not considerable but a minimum of 10 degree tilt is necessary for that evacuate water in rain condition. The optimum tilt angle of panels depends on installation location. As a general rule, Tilt of panels should be equal to the latitude minus 10 degrees [23], [28].

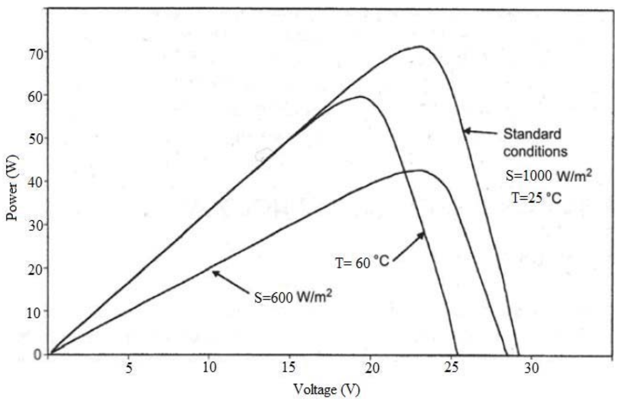


Fig. 3 Effect of temperature variation and illumination intensity on the output power of a PV array

C. Grid-Connected PV System

Photovoltaic cells are connected in series or parallel in order to obtain the desired current and voltage value for the PV module. Modules are also connected in series or parallel in order to increase the output voltage or current respectively. There are two main different types of application for PV: Grid-connected and off-grid systems. Grid-connected PV systems feed their energy production into the grid. Off-grid PV systems refer to those separated from the grid. In the case, the produced energy is consumed locally such as water pumping, communication antennas, etc. Grid-connected PV system could be applied when large scale energy by PV plants produced [24].

In general, grid-connected PV systems are installed to enhance the performance of the electric network; PV arrays provide energy at the load side of the distribution system, reducing the feeder active power loading and hence improving the voltage profile. As a result, PV systems can delay the operation time of shunt capacitors and series voltage regulators, thus increasing their lifetime. PV systems can also reduce the losses in distribution feeders if optimally sized and allocated. PV systems can increase the load carrying capability, which is the amount of load a power system can handle while satisfying certain reliability criteria, of existing networks. To meet increased demand while satisfying the same reliability criteria, utilities have to increase their generation capacity. The load carrying capability can be increased further more if battery storage systems are installed in parallel with photovoltaics array [25].

The major elements of a grid-connected photovoltaics system are shown in Fig. 4. The inverter may simply fix the voltage at which the panel operates, or use a maximum power point tracking function to identify the best operating voltage for the panels. The inverter operates in phase with the grid and is generally delivering as much power as it can to the electric power grid given the available temperature and sunlight conditions. The inverter acts as a current source; it produces a sinusoidal output current but does not act to regulate its terminal voltage in any way. The utility connection can be made by connection to a circuit breaker on a distribution panel or by a service tap between the distribution panel and the utility meter. Either way, the PV generation reduces the power taken from the utility power grid, and may provide a net flow of power into the utility power grid if the interconnection rules permit [26], [27].

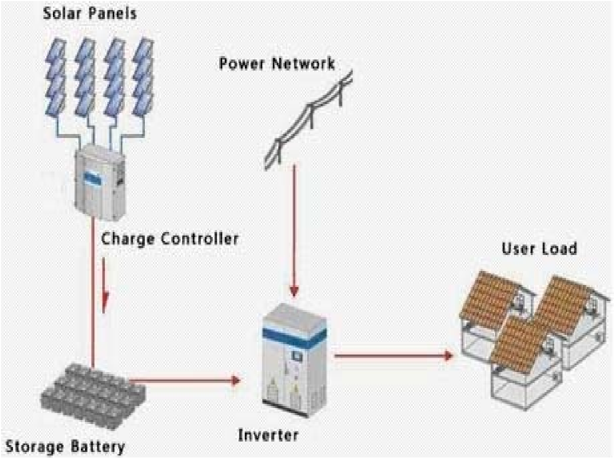


Fig. 4 Grid-connected photovoltaics system

IV. Impacts of Grid-Connected PV System on Electrical Networks

The photovoltaics systems can also impose several negative impacts on electrical networks, especially if their penetration level is high. These impacts are dependent on the size as well as the location of the photovoltaics system. Photovoltaics systems are classified based on their ratings into three different categorized: Small systems rated at 10kW and less, intermediate PV systems rated 10kW to 500 kW, and large PV systems rated above 500 kW. The first two categories are usually installed at the distribution system and the last category is usually installed at the transmission system. In This section the negative impacts of photovoltaics systems on distribution networks have been discussed [29].

A. Reverse Power Flow

In distribution system, the power flow is usually unidirectional from the Medium Voltage system to the Low Voltage system. However, at a high penetration level of photovoltaics systems, there are moments when the net production is more than the net demand, especially at noon, and as a result, the direction of power flow is reversed, and power flows from the Low Voltage side to the Medium Voltage side. This reverse power flow results in overloading of the distribution feeders and excessive power losses. Reverse flow of power has also been reported to affect the operation of automatic voltage regulators installed along distribution feeders as the settings of such devices need to be changed to accommodate the shift in load center. Reverse power flow may have adverse effects on online tap changers in distribution transformers especially if they are from the single bridging resistor type [30].

B. Overvoltage along Distribution Feeders

Reverse power flow leads to overvoltage along distribution feeders. Voltage regulators and capacitor banks used to boost voltage slightly can now push the voltage further; above the acceptable limits. Voltage rise on MV networks is often a constraining factor for the widespread adoption of wind turbines. Voltage rise in LV networks may impose a similar constraint on the installation of PV systems. In the Gunma project in Japan, it was noticed that when the sun light intensity is more than 5 kWh/m^2, the voltage of individual inverters went up by 2%. Also, the difference between weekly household load and the weekends load demand could shift the voltage profile of the feeder by 1.5% to 2% above the maximum limit. A voltage analysis of distribution feeder in Canada showed that overvoltage along the feeder is highly sensitive to photovoltaics system penetration level as well as to the point of interconnection of the PV cluster to the feeder; at high penetration levels, during light load conditions the voltage at the point of interconnection may increase by 2%–3% above the no load voltages especially when the PV cluster is located far from the distribution transformer [31], [32].

C. Power Losses

Distributed Generation (DG) systems in general reduce system losses as they bring generation closer to the load. This assumption is true until reverse power flow starts to occur. A study showed that distribution system losses reach a minimum value at a penetration level of approximately 5%, but as the penetration level increases, the losses also increase and may exceed the no-DG system case [32].

D. Voltage Control Difficulty

In a power system with embedded generation, voltage control becomes a difficult task due to the existence of more than one supply point. All the voltage regulating devices such as capacitor banks and voltage regulators are designed to operate in a system with unidirectional power flow [31].

E. Phase Unbalance

Inverters used in small residential photovoltaics system installations are mostly single phase inverters. If these inverters are not distributed evenly among different phases, phase unbalance may take place shifting the neutral voltage to unsafe values and increasing the voltage unbalance [33].

F. Power Quality Problems

Power quality issues are one of the major impacts of high photovoltaics penetration level on distribution networks; power inverters used to interface PV arrays to power grids are producing harmonic currents; thus, they may increase the total harmonic distortion of both voltage and currents at the point of common coupling. However, voltage harmonics are usually within limits if the network is stiff enough with low equivalent series impedance. Current harmonics, on the other hand, are produced by high pulse power electronic inverters and usually appear at high orders with small magnitudes. An issue with higher-order current harmonics is that they may trigger resonance in the system at high frequencies. This situation occurred in the holiday park in the Netherlands where the 11th and 15th voltage harmonics exceeded the permissible limits due to resonance between the grid inductance and the inverter high capacitance [33]-[35].

G. Increased Reactive Power

Photovoltaics system inverters normally operate at unity power factor for two reasons. The first reason is that current standards, according to IEEE 929-2000, do not allow Photovoltaics system inverters to operate in the voltage regulation mode. The second reason is that owners of small residential PV systems in the incentive-programs are revenue only for their kilowatt-hour yield, not for their kilovolt-ampere hour production. Thus, they prefer to operate their inverters at unity power factor to maximize the active power generated and accordingly, their return. As a result, the active power requirements of existing loads are partially met by PV systems, reducing the active power supply from the utility. However, reactive power requirements are still the same and have to be supplied completely by the utility. A high rate of reactive power supply is not preferred by the utilities because in this case distribution transformers will operate at very low power factor. Efficiency of transformers efficiency decreases as their operating power factor decreases, as a result, the overall losses in distribution transformers will increase reducing the overall system efficiency [33].

H. Electromagnetic Interference Problem

The high switching frequency of Photovoltaics system inverters may result in electromagnetic interference with neighboring circuits such as capacitor banks, protection devices, converters, and DC links leading to mal-function of these devices [33], [36-37].

I. Islanding Detection Difficulty

The North American Electric Reliability Corporation requires photovoltaics systems to be disconnected once the connection with the utility supply is lost, as they can enliven the utility system and impose danger on personnel and equipment. Similarly, IEEE Std. 929-2000 recommends that photovoltaic inverters should be disconnected within 6 cycles if an islanding condition is detected. Many techniques can be used to detect islanding, such as passive, active, hybrid, and communication based techniques. However, most of these islanding detection techniques are characterized by the presence of non-detection zones defined as the loading conditions for which an islanding detection method would fail to operate in a timely manner, and are thus prone to failure. Moreover, the inclusion of islanding detection devices increases the overall cost of integrating PV systems in electrical networks [38]-[52].

V. Conclusions

Photovoltaics systems are expected one of the most growing sources of electricity in the next decades. However, they have numerous negative impacts on electrical networks. There is no agreed upon maximum allowable penetration level for Photovoltaics electricity in a certain network as it depends on the network's characteristics as well as types, locations, and geographical distribution of Photovoltaics arrays within the network. Results in the literature the penetration level of PV system vary from 1.3% up to 40%. However, cloud transients and the mandatory increase in frequency regulation services are usually the bottleneck against the widespread adoption of PV system. The electrical power systems under the current circumstances are not yet ready to accommodate the anticipated increase in photovoltaic system penetration. More research work is clearly required to address these impacts and hence, stretch the allowable limits of Photovoltaics system.

References

[1] Razykov TM, Ferekides CS, Morel D, Stefanakos E and Ullal HS. 2011. Solar photovoltaic electricity: Current status and future prospects. Solar Energy. 85(8): 1580–1608.
[2] Singh GK. 2013. Solar power generation by PV (photovoltaic) technology: A review. Energy. 58(1): 1-13.
[3] Singh P. 2008. Temperature dependence of I–V characteristics and performance parameters of silicon solar cell. Solar Energy Materials and Solar Cells. 92(12): 1611–1616.
[4] Singh P and Ravindra NM. 2012. Temperature dependence of solar cell performance—an analysis. Solar Energy Materials and Solar Cell. 101: 36–45.
[5] Radziemska E. 2003. The effect of temperature on the power drop in crystalline silicon solar cells. Renew Energy. 28: 1–12.
[6] W. T. Jewell, R. Ramakumar, and S. R. Hill, "A study of dispersed photovoltaic generation on the PSO system," IEEE Trans. Energy Convers. 3, 473–478, 1988.
[7] Acharya YB. 2001. Effect of temperature dependence of band gap and device constant on I–V characteristics of junction diode. Solid-State Electron. 45: 115–119.
[8] Rustemli S and Dincer F. 2011. Modeling of Photovoltaic Panel and Examining Effects of Temperature in Matlab/Simulink. Electronics And Electrical Engineering. 109(3): 35-40.
[9] A. F. Povlsen, "Impacts of power penetration from photovoltaic power systems in distribution networks," International Energy Agency, February 2002.
[10] Cuce E. and Cuce PM. 2013. An experimental analysis of illumination intensity and temperature dependency of photovoltaic cell parameters. Applied Energy. 111: 374–382.
[11] Tobnaghi DM and Madatov R. 2013. The Effect of Temperature on Electrical Parameters of Solar Cells IJAREEIE. 2(12): 6404-6407.
[12] Bunea G, Wilson K, Meydbray Y and Ceuster D. 2006. Low Light Performance of Mono-Crystalline Silicon Solar Cell. 4th World Conference on Photovoltaic Energy Conference. Waikoloa: 1312–1314.
[13] California ISO, "2020 renewable transmission conceptual plan based on inputs from the RETI process," September 15,2009.
[14] Iijima A, Suzuki K, Wakao S, Kawasaki N and Usami A. 2013. A fundamental study of spectrum center estimation of solar spectral irradiation by statistical pattern recognition. Electrical Engineering In Japan. 184(1): 10–18.
[15] L. Solarbuzz, "German PV market 2006," January 2007.
[16] Chegaar M, Ouennoughi Z and Hoffmann A. 2001. A new method for evaluating illuminated solar cell parameters. Solid State Electron. 45: 293–296.
[17] Solar server, global solar industry website, Germany's PV installed capacity in 2011.
[18] F. Katiraei, K. Mauch, and L. Dignard-Bailey, "Integration of photovoltaic power systems in high-penetration clusters for distribution networks and mini-grids," National Resources Canada, January 2009.
[19] Lammert MD and Schwarts RJ. 1997. The integrated back contact solar cell: a siliconsolar cell for use in concentrated sunlight. IEEE Transactions on Electron Devices. 24: 337–342.
[20] H. Laukamp, M. Thoma, T. Meyer, and T. Erge, "Impact of a large capacity of distributed PV production on the low voltage grid," in 19th European Photovoltaic Solar Energy Conference, Paris, France, June (2004), pp. 7–11.
[21] Tobnaghi DM and Madatov R. 2013. Influence of Illumination Intensity on Electrical Parameters of Solar Cells" Tech J Engin& App Sci. 3(s): 3854-3857.
[22] Yadav AK and Chandel SS. 2013. Tilt angle optimization to maximize incident solar radiation: A review. Renewable and Sustainable Energy Reviews. 23: 503–513.

[23] Bakirci K. 2012. General models for optimum tilt angles of solar panels: Turkey case study. Renewable and Sustainable Energy Reviews. 16(8): 6149–6159.
[24] IEEE recommended practice for utility interface of photovoltaic (PV) systems. Project Authorization Request P929. Draft 10, February; 1999.
[25] Cronemberger J and Caamano E. 2012. Assessing the solar irradiation potential for solar photovoltaic applications in buildings at low latitudes – Making the case for Brazil. Energy and Buildings. 55: 264–272.
[26] Zhao Y, Wang S, Li X, Wang W, Liu Z, Song S. China renewable energy development project. Report on the development of the photovoltaic industry in China. NDRC/GEF/WB, August; 2006.
[27] D. M. Tobnaghi, R. Madatov, Recovery in the electrical parameters of the aging silicon solar cells by annealing, Journal of Optoelectronics and Advanced Materials, Vol. 16, No. 5-6, May - June 2014, p. 764 – 768.
[28] Santos IP and R. Ruther. 2014. Limitations in solar module azimuth and tilt angles in building integrated photovoltaics at low latitude tropical sites in Brazil. Renewable Energy. 63: 116–124.
[29] J. T. Day and W. J. Hobbs, "Reliability impact of solar electric generation upon electric utility systems," IEEE Trans. Reliab. R-31, 304–307 (1982).
[30] M. Thomson and D. G. Infield, "Impact of widespread photovoltaics generation on distribution systems," IET Renewable Power Gener. 1, 33–40 (2007).
[31] C. Whitaker, J. Newmiller, M. Ropp, and B. Norris, "Distributed photovoltaic systems design and technology requirements," Sandia Laboratories, 2008.
[32] N. Miller and Z. Ye, "Distributed generation penetration study," National Renewable Energy Laboratory, 2003.
[33] S. Cobben, B. Gaiddon, and H. Laukamp, "Impact of photovoltaic generation on power quality in urban areas with high PV population," PV Upscale, 2008.
[34] V. H. M. Quezada, J. R. Abbad, and T. G. S. Roman, "Assessment of energy distribution losses for increasing penetration of distributed generation," IEEE Trans. Power Systems 21, 533–540 (2006).
[35] F. Katiraei, K. Mauch, and L. Dignard-Bailey, "Integration of photovoltaic power systems in high-penetration clusters fordistribution networks and mini-grids," National Resources Canada, January 2009.
[36] Technical Interconnection Requirements for Distributed Generation: Micro Generation & Small Generation, 3-phase, less than 30 kW, Hydro One Networks Inc., 2010.
[37] Kroposki B. and Vaughn A., "DG power quality, protection, and reliability case studies report," Report No. NREL/SR-560-34635, National Renewable Energy Laboratory, Golden, CO, 2003.
[38] W. Wencong, J. Kliber, Z. Guibin, X. Wilsun, B. Howell, and T. Palladino, "A power line signaling based scheme for anti-islanding protection of distributed generators: Part II: Field test results," in Power Engineering Society GeneralMeeting, 2007 (IEEE, 2007), p. 1.
[39] G. Hernandez-Gonzalez and R. Iravani, "Current injection for active islanding detection of electronically-interfaced distribute resources," IEEE Trans. Power Deliv. 21, 1698–1705 (2006).
[40] A. Woyte, R. Belmans, and J. Nijs, "Testing the islanding protection function of photovoltaic inverters," IEEE Trans. Energy Convers. 18, 157–162 (2003).
[41] H. Zhenyu, W. Freitas, and X. Wilsun, "A practical method for assessing the effectiveness of vector surge relays for distributed generation applications," IEEE Trans. Power Deliv. 2005 (20): 57–63.
[42] Sung J. and Kwang K., "An islanding detection method for distributed generations using voltage unbalance and total harmonic distortion of current," IEEE Trans. Power Deliv. 2004 (19): 745–752.
[43] Smith G. A., Onions P. A., and Infield D. G., "Predicting islanding operation of grid connected PV inverters," IEE Proc.: Electr. Power Appl. 2000 (147): 1–6.
[44] OKane P. and Fox B., "Loss of mains detection for embedded generation by system impedance monitoring," in Sixth International Conference on Developments in Power System Protection. 1997 (434): 95–98.
[45] Jun Y., Liuchen C., and Diduch C., "A new adaptive logic phase-shift algorithm for anti-islanding protections in inverterbased DG systems," in IEEE 36th Power Electronics Specialists Conference, 2005: 2482–2486.
[46] Ropp M. E., Begovic M., and Rohatgi A., "Analysis and performance assessment of the active frequency drift method of islanding prevention," IEEE Trans. Energy Convers. 19991(4): 810–816.
[47] Jun Y., Diduch C. P., and Liucheng C., "Islanding detection using proportional power spectral density," IEEE Trans. Power Deliv. 2008 (23): 776–784.
[48] Wilsun X., Guibin Z., L. Chun, Wencong W., Guangzhu W., and J. Kliber, "A power line signaling based technique for anti-islanding protection of distributed generators: Part I: Scheme and analysis," in Power Engineering Society General Meeting, 2007, p. 1.
[49] M. Thomson and D. Infield, "Impact of widespread photovoltaics generation on distribution systems," IET Journal of Renewable Power Generation. 2007 (1): 33–40.
[50] W.N. Macedo and R. Zilles, "Operational results of grid-connected photovoltaic system with different inverter's sizing factors (ISF)", Progress in Photovoltaics Research and Applications 2007(15) :337–52.
[51] E.R. Michael, B. Miroslav, R. Ajeet, A.K. Gregory, Bonn Sr RH, Gonzalez S. "Determining the relative effectiveness of islanding detection methods using phase criteria and nondetection zones". IEEE Transactions on Energy Conversion 2000(15).
[52] Zeineldin H. H. and Kirtley J. L., "A simple technique for islanding detection with negligible nondetection zone," IEEE Trans. Power Deliv. 2009 (24): 779–786.