Grid Connected Renewable Energy Sources and Net Metering: A Review

Swapna Bhuyan

Department of Electrical and Electronics Engineering, Assam Don Bosco University,
Airport Road, Azara, Guwahati -781017, Assam, INDIA.
swapnabhuyan16@gmail.com

Abstract: ***In this paper, the constraints of a grid connection are presented along with some of the solutions to the problems as proposed by various researchers. Non-renewable energy sources are getting exhausted day by day. There is a need for alternative sources of energy. In this paper, various constraints in the incorporation of grid-connected renewable energy sources and the required solution are discussed. The concept of net metering and associated challenges are presented in this paper.***

Keywords: Renewable Energy Sources, grid, net metering, grid connection

1. Introduction

Renewable energy (RE) is the energy that can be used again and again. With the increase in the demand of energy, the prime concern today is the availability of the source of energy, which is reliable. Conventional energy sources are nonrenewable and will be completely exhausted someday. Therefore the need for utilization of renewable energy is felt. About 80% of the world's total energy depends on fossil fuels. Use of fossil fuel is expected to rise by 1.5% annually by 2030 leading to 2.2% CO_2 emission [1]. However, fossil fuels are going to deplete soon [2,3]. Renewable energy contributes to energy system de-carbonization, security of energy in the long run, and expansion of energy to new energy consumer [4]. RES contributes 14% of the world's total energy demand [5]. RE can be used as an alternative energy source. It is primary, domestic and clean energy source [6,7]. By 2100, the contribution of energy by RES is expected to increase to 30%-80% [8]. Proper energy harnessing techniques are to be developed to achieve more energy from Renewable Energy Sources (RES). RES can be followed by net metering to achieve the process of utilization of electricity in a more economic manner. Energy generated from RES can be used to meet the household electricity demand for that duration of time or period when RES are available to produce energy. For the remaining period when RES cannot be used, electricity can be drawn from the grid. Electricity pays to the consumers, who feedback the surplus electricity produced from RES back to the grid. This process not only reduces electricity bills but also saves electricity that can be used some other consumer in need.

2. Grid Connected Renewable Energy Sources

A) Optimal Power Flow

Electricity generated from renewable sources may be needed to be transported over some distances, as they are not location specific. They lack the flexibility needed in balancing supply and demand. RES cannot be considered as an isolated node of energy network as it requires coordinated efforts from planning stage to power generation, distribution, storage and consumption [17]. Various constraints have to be solved in order to achieve optimal power flow between grid and RES.

B) Constraints in incorporation of RES

Factors that affect the integration of RES in the grid are [17,29,30]:

- Stability and Timing,
- Voltage imbalance,
- Effect of reactive power regulation,
- Flicker effect,
- Harmonic and inter harmonic voltages and currents,
- Voltage fluctuations in the point of common coupling,
- Need for power factor improvement,
- Intermittency, storage and capacity factor,
- Infrastructure for RES and suitable location,
- It requires a large amount of conventional backup,
- It requires huge energy storage to compensate for the natural variation in the power generated.

The role of government in uplifting RES through energy policies and supporting policies for deploying renewable energy on a large scale is observed [17]. Direct policies promote renewable energy, indirect policies influence incentives and barriers for renewable energy [31].

3. Solutions to the Problems of Grid Connection

Synchronization can be defined as minimization of aby variance in voltage, phase angle and frequency between the RES generator and grid supply.

Grid synchronization methods are as follows [35-48]:

(i) Zero crossing detection
(ii) Kaman filter
(iii) Discrete Fourier Transform
(iv) Nonlinear least square
(v) Adaptive Notch Filter
(vi) Artificial Intelligence
(vii) Delayed Signal Cancellation
(viii) Phase Locked Loop
(ix) Frequency Locked Loop

Some of the recommendations to achieve synchronization are [22]:

- Development of an efficient method for variation in phase angle and frequency with fair dynamic performance during voltage depression and harmonic variation.
- A synchronization scheme based on the estimation of grid voltage and frequency should be given more attention.
- A robust method with advanced features for efficiently injecting power into the power grid with low total harmonic distortion of current is needed.
- A method to achieve uninterrupted operation of the RES in abnormal utility voltage conditions is to be developed.

The active power quality can be improved by optimal usage of renewable sources and avoiding the usage of battery by replacing it with a solar energy unit. Dynamic active power filter fed by solar energy unit gives power to the load during power fluctuation from the grid side [20].

Maximum power point tracking is a technique used to improve the photovoltaic system efficiency [21]. MPPT are power electronic DC-DC converters [5,27] that enable the solar panels to operate with current voltage parameters that will always produce highest output power from the PV system to the load irrespective of external conditions [26,28].

Solar trackers are mechanical rotors that guide PV panels in such a way that the panels are constantly positioned at an angle that allows them to receive the most sunlight [4].

Transformer-less inverters are of small size and have light weight, more efficient and simple. By removing the transformer, efficiency of 96%-98% can be obtained. The drawback is ground currents are introduced here, and research can be done to obtain ways to remove ground currents [4].

Inverters must be designed in such a way that they operate at power factor equal to one, hence reducing the reactive power supplied to the grid. Inverters must also keep total harmonic distortion of the current supplied by grid-connected PVs to a minimum value. Algorithms for optimal power flow control in grid-connected PVs are:

- Feedback linearization control
- Phase lock loop control
- Extended direct power control
- Power factor control

A stable frequency is required for operation of grid-connected PVs and an inverter is needed to disconnect from the grid when its frequency becomes unstable. To restore nominal frequency real power must be provided to the grid as soon as possible. Frequency is constant when active power is equal to load demand at any given time. Shortage of active and reactive power must be compensated at least until energy supply and demands are balanced [16].

Fluctuation control in the output of wind and solar energy is provided by batteries. Batteries provide energy to the load during low power generation and store energy during excess power generation, and thus smoothen out the output of an irregular generation source. Some of the common battery technologies used are:

- Lead-acid technology
- Nickel Iron, redox flow and sodium Sulphur batteries
- Lithium-ion technology [19]

Lithium-ion batteries have the highest energy density and are costly. Work can be done to optimize the energy density of batteries and make them cost-effective. Lithium-ion batteries have high cell voltage, no memory effort, low cell discharge rate and flat discharge characteristics [32].

Conventional real-time optimal power flow method and day ahead optimal power flow method neglects the impact of variability. There are some modified methods that propose an evaluation of best fitting participation factors by considering minute-to-minute variability of solar and wind load for real time-optimal power flow and every 15-minute variation of the load for day-ahead optimal power flow for the scheduling time period. Voltage, reactive power and line flow constraints are included for all the intervals in both real-time optimal power flow and day ahead optimal power flow and voltage stability index is calculated.

4. Net Metering

Net metering uses a bi-directional meter that records the amount of electricity drawn from the grid or supplied to the grid. The electricity provider pays the consumer for supplying back the additional amount of electricity produced back to the grid. The consumers have to pay only for the amount of electricity taken from the grid in case the electricity from RES is not sufficient to meet the demand.

Buildings lead to the emission of CO_2 .Reduction of excessive use of energy and emission of greenhouse gases is needed. Installation of meters and sensors, for monitoring the use of energy and indoor environmental conditions, is needed. In the case of metering equipment, lots of work is done to enhance it. Many solutions are available which makes it difficult to select the best one. Accuracy, ease of development, communication protocol, granularity, cost and availability are some of the factors that affect the selection of sensing and metering solutions. Both wired and wireless technologies are used for data transmission in net metering. Wireless technologies are cheaper and wired technologies are more secured. Widely used communication and network technologies for net metering are Zigbee, power line carrier, Modbus, GPRS, GSM, Wi-Fi, M Bus, BACnet, Ethernet etc. Future challenges in this area being interoperability, lack of ICT infrastructure, cost, MEMS sensor Technology [23].

Test of the feasibility of net metering is very important. Simple net metering cannot serve diverse consumers. More scalable, feasible and economically acceptable net metering approaches serve the purpose [24]. Net metering is in its budding stage in India. Cities like Delhi, Bengaluru, Kolkata has drafted their initial net metering policy [25,9]. However, there is a need for change in energy policies to realize the benefits of the smart grid in its full potential [10]. Now-a-days, 110 KW standalone rooftop solar PV system with uninterrupted power supply covering a building is available, which provides total output to the grid of 1927.7 kW hour, an annual yield of 931.6 kW hour and an average output of 160.64 kW hour per month [11].

Solar PV systems on bright rooftops with 75 Wp solar modules are capable of generating about 1000 MW of electricity through standalone PV systems. With solar modules of high capacity (210 Wp), electricity generation can be greater than 1500 MW [15].

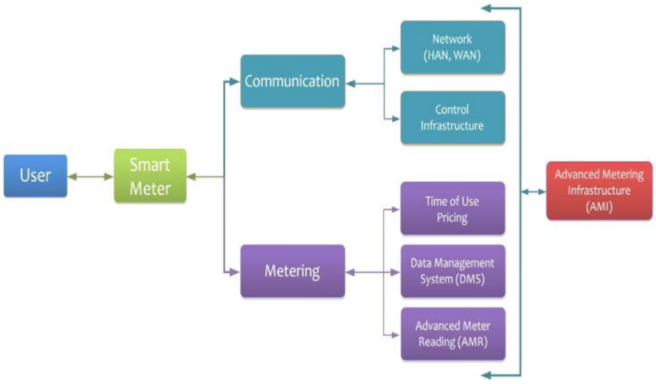

Fig. 1: Smart grid perspective with all components [12]

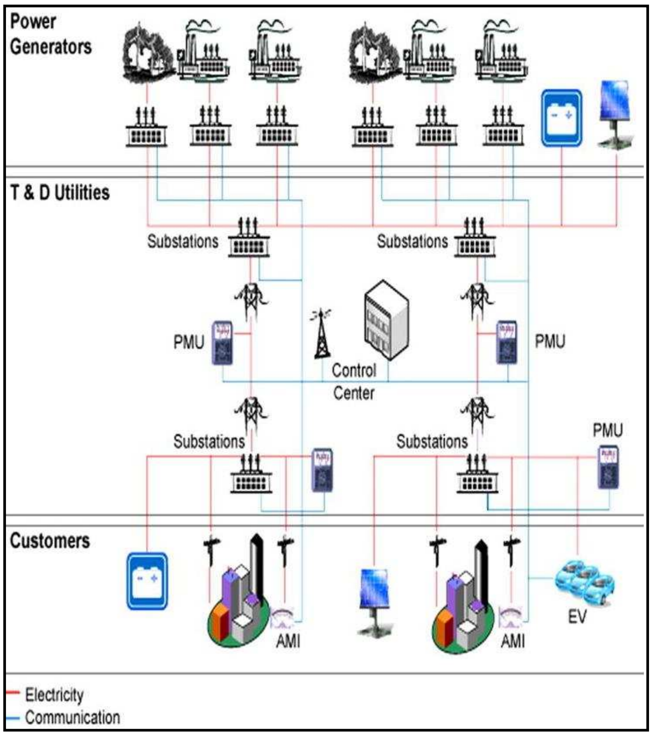

Fig. 2: Power generation, control, and measurement diagram across the distribution network and consumers [14]

5. Conclusion

It is observed that with the high increase in demand for energy the possibility of scarcity of energy in the future is increasing. Renewable energy sources can be cited as one of the solutions to meet the energy demand of diverse consumers. At present, the contribution of renewable energy sources as compared to the conventional energy sources is less. However, energy-harnessing methods from these sources are yet to be developed and are needed to be improved to a great extent. Production of energy from renewable energy sources, by maintaining optimal power flow is to be achieved.

References

[1] M. Hosenuzzaman, N. A. Rahim, J. Selvaraj, M. Hasanuzzaman, A. B. M. A. Malek and A. Nahar, "Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation", *Renewable and Sustainable Energy Reviews*, 41, 2015, pp. 284-297. Doi: https://doi.org/10.1016/j.rser.2014.08.046

[2] F. Blaabjerg, R. Teodorescu, M. Liserre and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems", *IEEE Transactions on Industrial Electronics*, Vol. 53, Issue 5, 2006, pp. 1398-1409.

[3] G. G. Pozzebon, A. F. Goncalves, G. G. Pena, N. E. M. Moçambique and R. Q. Machado, "Operation of a three-phase power converter connected to a distribution system", *IEEE Transactions on Industrial Electronics*, Vol. 60, Issue 5, 2013, pp. 1810-1818.

[4] B. Dunn, H. Kamath and J. M. Tarascon, "Electrical Energy Storage for the Grid: A Battery of Choices", *Science*, Vol. 334, Issue 6058, 2011, pp. 928-935. Doi: 10.1126/science.1212741

[5] J. Goldemberg (ed.), "World Energy Assessment: Energy and the Challenge of Sustainability", *United Nations Development Programme (UNDP)*, New York, Sept. 2000. Retrieved from https://sustainabledevelopment.un.org/content/documents/2423World_Energy_Assessment_2000.pdf

[6] P. Riley, J. A. Linker, Z. Mikić, R. Lionello, S. A. Ledvina and J. G. Luhmann, "A comparison between global solar magnetohydrodynamic and potential field source surface model results", *The Astrophysical Journal*, Vol. 653, Issue 2, Dec. 2006, pp. 1510-1516. Retrieved from http://www.academia.edu/download/44051211/2006_aj_1510.pdf

[7] S. Bilgen, K. Kaygusuz, and A. Sari, "Renewable energy for a clean and sustainable future", *Energy Sources*, Vol. 26, Issue 12, 2004, pp. 1119-1129.

[8] W. R. Fernandes, Z. Á. Tamus and T. Orosz, "Characterization of peltier cell for the use of waste heat of spas", *Proc. of 2014 55th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), IEEE*, 2014, pp. 43-47

[9] J. Thakur and B. Chakraborty, "Sustainable Net Metering Model for Diversified India", *Energy Procedia*, Vol. 88, 2016, pp. 336-340. Doi: 10.1016/j.egypro.2016.06.139

[10] J. Thakur and B. Chakraborty, "A study of feasible smart tariff alternatives for smart grid integrated solar panels in India", *Energy*, Vol. 93, 2015, pp. 963-975.

[11] A. K. Shukla, K. Sudhakar and P. Baredar, "Design, simulation and economic analysis of standalone roof top solar PV system in India", *Solar Energy*, Vol. 136, 2016, pp. 437-449.

[12] Y. Kabalci, "A survey on smart metering and smart grid communication", *Renewable and Sustainable Energy Reviews*, Vol. 57, May 2016, pp. 302-318.

[13] H. Zhang, A. Gladisch, M. Pickavet, Z. Tao and W. Mohr, "Energy efficiency in communications", *IEEE Communications Magazine*, Vol. 48, Issue 11, 2010, pp. 48-49.

[14] S. Y. Hui, C. K. Lee and F. F. Wu, "Electric springs- A new smart grid technology", *IEEE Transactions on Smart Grid*, Vol. 3, Issue 3, 2012, pp. 1552-1561.

[15] S. Y. Hui, C. K. Lee and F. F. Wu, "Electric springs- A new smart grid technology", *IEEE Transactions on Smart Grid*, Vol. 3, Issue 3, 2012, pp. 1552-1561.

[16] X. Tan, Q. Li and H. Wang, "Advances and trends of energy storage technology in microgrid", *International Journal of Electrical Power & Energy Systems*, Vol. 44, Issue 1, 2013, pp. 179-191.

[17] S. Mekhilef, S. Y. I. Abujarad, S. Ghazi and F. Shadman, "Technical issues of grid connected renewable energy sources: A new areas of research", *Proc. of 2014 World Renewable Energy Congress - WREC XIII*, Kingstone University, 3-8 August 2014. Retrieved from http://eprints.um.edu.my/id/eprint/11393

[18] S. S. Reddy and P. R. Bijwe, "Day-Ahead and Real Time Optimal Power Flow considering Renewable Energy Resources",

International Journal of Electrical Power & Energy Systems, Vol. 82, 2016, pp. 400-408.

[19] A. S. Subburaj, B. N. Pushpakaran and S. B. Bayne, "Overview of grid connected renewable energy based battery projects in USA", *Renewable and Sustainable Energy Reviews*, Vol. 45, 2015, pp. 219-234.

[20] S. Kasa, P. Ramanathan, S. Ramasamy and D. P. Kothari, "Effective grid interfaced renewable sources with power quality improvement using dynamic active power filter", *International Journal of Electrical Power & Energy Systems*, Vol. 82, 2016, pp. 150-160.

[21] M. Obi and R. Bass, "Trends and challenges of grid-connected photovoltaic systems - A review", *Renewable and Sustainable Energy Reviews*, Vol. 58, 2016, pp. 1082-1094.

[22] N. Jaalam, N. A. Rahim, A. H. Bakar, C. Tan and A. M. Haidar, "A comprehensive review of synchronization methods for grid-connected converters of renewable energy source", *Renewable and Sustainable Energy Reviews*, Vol. 59, 2016, pp. 1471-1481.

[23] M. W. Ahmad, M. Mourshed, D. Mundow, M. Sisinni and Y. Rezgui, "Building energy metering and environmental monitoring - A state-of-the-art review and directions for future research", *Energy and Buildings*, Vol. 120, 2016, pp. 85-102.

[24] J. Thakur and B. Chakraborty, "Sustainable Net Metering Model for Diversified India", *Energy Procedia*, Vol. 88, 2016, pp. 336-340.

[25] S. Ghosh, A. Nair and S. S. Krishnan, "Techno-economic review of rooftop photovoltaic systems: Case studies of industrial, residential and off-grid rooftops in Bangalore, Karnataka", *Renewable and Sustainable Energy Reviews*, Vol. 42, 2015, pp. 1132-1142.

[26] A. I. Dounis, P. Kofinas, C. Alafodimos and D. Tseles, "Adaptive fuzzy gain scheduling PID controller for maximum power point tracking of photovoltaic system", *Renewable Energy*, Vol. 60, 2013, pp. 202-214.

[27] D. Shmilovitz, "On the control of photovoltaic maximum power point tracker via output parameters", *IEE Proceedings-Electric Power Applications*, Vol. 152, Issue 2, 2005, pp. 239-248. Retrieved from https://ieeexplore.ieee.org/document/1425280

[28] I. Laird and D. D. C. Lu, "High step-up DC/DC topology and MPPT algorithm for use with a thermoelectric generator", *IEEE Transactions on Power Electronics*, Vol. 28, Issue 7, 2013, pp. 3147-3157.

[29] N. Phuangpornpitak and S. Tia, "Opportunities and challenges of integrating renewable energy in smart grid system", *Energy Procedia*, Vol. 34, 2013, pp. 282-290.

[30] K. Baker, G. Hug and X. Li, "Optimal integration of intermittent energy sources using distributed multi-step optimization", *Proc. of 2012 IEEE Power and Energy Society General Meeting*, San Diego, CA, July 2012, pp. 1-8. Doi: 10.1109/PESGM.2012.6344712

[31] B. J. M. de Vries, D. P. van Vuuren and M. M. Hoogwijk, "Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach", *Energy Policy*, Vol. 35, Issue 4, 2007, pp. 2590-2610.

[32] J. M. Tarascon and M. Armand, "Issues and challenges facing rechargeable lithium batteries", in *Materials for Sustainable Energy: A Collection of Peer-Reviewed Research and Review Articles from Nature Publishing Group*, V. Dusastre (ed.), pp. 359-367, Nature Publishing Group, UK, 2010.

[33] B. Gu, J. Dominic, J. S. Lai, C. L. Chen, T. LaBella and B. Chen, "High reliability and efficiency single- phase transformerless inverter for grid-connected photovoltaic systems", *IEEE Transactions on Power Electronics*, Vol. 28, Issue 5, 2013, pp. 2235-2245.

[34] J. C. Boemer, K. Burges, P. Zolotarev, J. Lehner, P. Wajant, M. Fürst, R. Brohm and T. Kumm, "Overview of German grid issues and retrofit of photovoltaic power plants in Germany for the prevention of frequency stability problems in abnormal system conditions of the ENTSO-E region continental Europe", *Proc. of 1st International Workshop on Integration of Solar Power into Power Systems*, Vol. 24, 24 October 2011, Aarhus, Denmark.

[35] O. Vainio and S. J. Ovaska, "Noise reduction in zero crossing detection by predictive digital filtering", *IEEE Transactions on Industrial Electronics*, Vol. 42, Issue 1, 1995, pp. 58-62.

[36] M. A. Pérez, J. R. Espinoza, L. A. Morán, M. A. Torres and E. A. Araya, "A robust phase-locked loop algorithm to synchronize static-power converters with polluted AC systems", *IEEE Transactions on Industrial Electronics*, Vol. 55, Issue 5, 2008, pp. 2185-2192.

[37] B. P. McGrath, D. G. Holmes and J. J. H. Galloway, "Power converter line synchronization using a discrete Fourier transform (DFT) based on a variable sample rate", *IEEE Transactions on Power Electronics*, Vol. 20, Issue 4, 2005, pp. 877-884.

[38] B. C. Babu, K. Sridharan, E. Rosolowski and Z. Leonowicz, "Analysis of SDFT based phase detection system for grid synchronization of distributed generation systems", *Engineering Science and Technology, an International Journal*, Vol. 17, Issue 4, 2014, pp. 270-278.

[39] G. Simon, R. Pintelon, L. Sujbert and J. Schoukens, "An efficient nonlinear least square multisine fitting algorithm", *IEEE Transactions on Instrumentation and Measurement*, Vol. 51, Issue 4, 2002, pp.750-755.

[40] M. Mojiri, M. Karimi-Ghartemani and A. Bakhshai, "Estimation of power system frequency using an adaptive notch filter", *IEEE Transactions on Instrumentation and Measurement*, Vol. 56, Issue 6, 2007, pp. 2470-2477.

[41] P. Tichavsky and A. Nehorai, "Comparative study of four adaptive frequency trackers", *IEEE Transactions on Signal Processing*, Vol. 45, Issue 6, 1997, pp. 1473-1484.

[42] L. L. Lai, W. L. Chan, C. T. Tse and A. T. P. So, "Real-time frequency and harmonic evaluation using artificial neural networks", *IEEE Transactions on Power Delivery*, Vol. 14, Issue 1, 1999, pp. 52-59.

[43] G. W. Chang, C. I. Chen and Y. F. Teng, "Radial-basis-function-based neural network for harmonic detection", *IEEE Transactions on Industrial Electronics*, Vol. 57, Issue 6, 2010, pp. 2171-2179.

[44] Y. F. Wang and Y. W. Li, "Analysis and digital implementation of cascaded delayed-signal-cancellation PLL", *IEEE Transactions on Power Electronics*, Vol. 26, Issue 4, 2011, pp. 1067-1080.

[45] M. Bongiorno, J. Svensson and Ambra Sannino, "Effect of sampling frequency and harmonics on delay-based phase-sequence estimation method", *IEEE Transactions on Power Delivery*, Vol. 23, Issue 3, 2008, pp. 1664-1672.

[46] P. Rodriguez, A. Luna, R. S. Munoz-Aguilar and I. Etxeberria-Otadui, "A stationary reference frame grid synchronization system for three-phase grid-connected power converters under adverse grid conditions", *IEEE Transactions on Power Electronics*, Vol. 27, Issue 1, 2012, pp. 99-112.

[47] J. Rocabert, G. M. S. Azevedo, A. Luna, J. M. Guerrero, J. I. Candela and P. Rodríguez, "Intelligent connection agent for three-phase grid-connected microgrids", *IEEE Transactions on Power Electronics*, Vol. 26, Issue 10, 2011, pp. 2993-3005.

[48] P. Rodriguez, A. Luna, I. Candela, R. Teodorescu and F. Blaabjerg, "Grid synchronization of power converters using multiple second order generalized integrators", *Proc. of The 34th Annual Conference of the IEEE Industrial Electronics Society (IECON 2008),* Orlando, FL, 2008, pp. 775-760.

[49] P. K. Dash, A. K. Pradhan and G. Panda, "Frequency estimation of distorted power system signals using extended complex Kalman filter", *IEEE Transactions on Power Delivery*, Vol. 14, Issue 3, 1999, pp. 761-766.

[50] P. K. Dash, R. K. Jena, G. Panda and A. Routray, "An extended complex Kalman filter for frequency measurement of distorted signals", *IEEE Transactions on Instrumentation and Measurement*, Vol. 49, Issue 4, 2000, pp. 746-753.

[51] L. R. Chen, "PLL-based battery charge circuit topology", *IEEE Transactions on Industrial Electronics*, Vol. 51, Issue 6, 2004, pp. 1344-1346.

[52] X. Du, Y. Liu, G. Wang, P. Sun, H. M. Tai and L. Zhou, "Three-phase grid voltage synchronization using sinusoidal amplitude integrator in synchronous reference frame", *International Journal of Electrical Power & Energy Systems*, Vol. 64, 2015, pp. 861-872.