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A REVIEW ON HARMONIC REDUCTION TECHNIQUES IN THREE-PHASE POWER GENERATION IN PV SOLAR PLANTS

P. S. Pawar

Research Scholar, Department of Technology, Shivaji University, Kolhapur, India

ABSTRACT

There are a variety of techniques available for harmonic removal techniques. The methods have their own performance with respect to application. Also, cost of implementation of particular harmonic removal technique depends on the discrete and semiconductor components used while developing filters. Due to higher demands of electricity, power generations with low cost are most essential needs of the world. Photovoltaic-based power plant implementations are cost effective for long-term power generations due to technological advancements. While generating power from PV solar cells due to variations in the solar radiations, harmonic effect is seen. The harmonic reduction is the most important need while establishing grid-connected PV solar power plants. This paper introduces the review of various techniques for removing harmonics in PV solar power plant developed by various researchers. The addressed techniques are studied based on their robustness, implementation complexities and performance characteristics.

KEYWORDS: *Photovoltaic Solar Power Plant, Harmonic Reduction, Harmonic Filters*

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INTRODUCTION

Nowadays, installations of utility-scale solar photovoltaic power plants along with distributed power generation applications are rapidly growing. Effective cost reductions in solar photovoltaic cells and technological advancements and opportunistic market demands are the main factors in increment in demand. Solar power inverters are the main components of the generation plants for conversion of solar power to feed the existing grid system. The semiconductor components nowadays provide reliable life span for operational period, thereby increasing the overall system reliability and operational time along with silent operation and low environmental impact as added benefits.

In solar power plant, line frequency transformer is used to isolate the PV panels from the grid. Use of transformer provides facilitations for reduction in electromagnetic interference (EMI) noise along with step-up or step-down voltage levels. Transformer installation leads to increment in weight due to line frequency requirements and along with these additional switching circuits will be required for conversion stages, which reduces overall system efficiency along with increment in costs. To avoid cost increasing factors, efficiency factors and transformers are avoided by using transformerless inverters. In photovoltaic power generation systems, when no transformer is used, common mode voltage appears between PV panels and ground, which leads to additional leakage currents in inverter circuits. This increment in current leads to electromagnetic interference, harmonics and losses in the system [1], [2], [3].

LITERATURE REVIEW

Variety of techniques are invented for harmonic reduction in transformerless inverter circuits. Few of them are addressed in this paper.

Hussein A. Kazem [4] have given harmonic suppression technique-based review of various methods applicable for power distribution networks. The techniques are enlisted based on the combination of components and implementation feasibilities.

P. Jyothi Bhaskara Rao [5] has given the technique for harmonic reduction useful for solar power plant power generation station. The causes of harmonics are discussed by relating the effects of transformer operations. In this paper, authors have given the method for the reduction in harmonics, Space Vector Pulse Width Modulation (SVPWM). The method is implemented in MATLAB for simulation and compared with sinusoidal pulse width modulation (SPWM). The simulation results of three-phase three-level SPWM and three-phase three-level SVPWM inverter are compared in terms of Total Harmonic Distortion (THD) rate. The method consists of the pulse width modulation technique to control the switching of IGBTs. Total 6 gate-controlled IGBTs are used to control harmonics in three phase current and voltage. The graph-based analysis is given, which shows the optimum results.

Nishant Kumar *et al*. [6] have introduced a single sensor-based maximum power point tracking (MPPT) based C battery charging for solar photovoltaic (PV) power plant along with harmonic reduction by using normal harmonic search (NHS) algorithm. Based on the music composition technique, the NHS algorithm is an improved version of the harmony search. Its searching ability is improved by using the normal probability distribution factor. This results in NHS reaching the global maximum point (GMP) very quickly. The objective of the NHS algorithm is the maximum extraction of the power from a PV array and efficiently charging the battery through maximizing the charging current of the battery. Due to the single sensor, the cost of the MPPT is reduced as well as the algorithm complexity and computational burden are very less, so it can be easily implemented on the low-cost microcontroller. NHS algorithm is tested using MATLAB-based simulation. The performance evaluation is done for the NHS algorithm under variable irradiance and temperature.

Nishant Kumar *et al*. [7] have given the method for control of voltage source control (VSC), the proposed PNKLMS control technique is used, which maintains the power quality. The performances of NHS-based MPPT and PNKLMS-based control technique with reduced sensor approach are tested on a developed prototype. The performances of the PNKLMS algorithm without using DC-link voltage sensor are demonstrated during over-voltage, under-voltage, harmonics distortion and load nonlinearity condition, the results of which have satisfied the objective of the proposed system and the IEEE-519 standard.

Carlos D. Fuentes *et al.* [8] have addressed the need to lower the weight of power converters without compromising efficiency and reliability. Authors have given a method to enhance performance and the ability to switch faster with lower losses alongside outstanding thermal characteristics for the semiconductor devices in inverters. A design methodology considering grid-connected PV converters and with special focus on weight, efficiency and rated power is presented. MATLAB-based simulation analysis is done and the corresponding results are provided.

Hamed Nademi *et al*. [9] have presented a study of photovoltaic grid connected generators. This study presents a new circuit topology of the Modular Multilevel Converter (MMC), which is deployed for photovoltaic grid applications. In the conventional MMC, two arm inductors are placed in each phase to limit the circulating current. Authors have given

topology and the inductors are replaced by a transformer. The circuit given by authors gives a 50% reduction of the voltage rating of the power devices and the capacitors in comparison with the conventional MMC. The required dc-link voltage, which is fed directly by PV panels is also reduced by half. The paper presents a PWM method to control the solar inverter output voltage. The concept is confirmed through simulation and experimental results.

C. S. Kiruba Samuel *et al* [10] have given a method for multilevel inverter using hybrid Photovoltaic (PV)/wind power system in order to simplify the power system and reduce harmonics and the cost effect. Multilevel inverter using combination of solar and wind was implemented by PWM modulation technique. This method shows minimization of the total harmonic distortion based on MATLAB simulations. The seven-level output voltage of inverters are tested.

Dr. M. Chakravarthy *et al*. [11] have given a detailed case study on design, erection, testing and commissioning of 200 Kwp solar power plant at Vasavi College of Engineering, Ibrahimbagh, Hyderabad. This paper deals with sizing of various equipments, specification of PV modules, inverters, MCCB, cables and associated protective equipment. Problems encountered during erection, testing, commissioning and operation and solutions adopted for these problems are discussed. The plant is generating on an average 25,000 units per month resulting in better revenue generation. Problems faced such as cable heating, reverse power to DG set is dealt. The details of reduction in the efficiency of the plant due to various causes and methods for improvement are also discussed. One protective scheme, namely, PLC-based power balancer protection scheme for DG protection is dealt. The monitoring of the PV plant is also discussed in detail in this paper.

Ramanuja Panigrahi *et al*. [12] have given review and summarize all the aforementioned aspects of a grid-integrated PV system. Various standards, power stage architectures, grid synchronization methods and control methodologies pertaining to small-scale PV plants are discussed at length. This paper provides a one-stop reference for practicing engineers and introduce the vast research in the field of solar PV integration to the new generation of researchers.

Albert Alexander *et al*. [13] have discussed the design of control circuit for a solar-fed cascaded multilevel inverter to reduce the number of semiconductor switches. The design includes 'binary', 'trinary' and 'modified multilevel connection' (MMC)-based topologies suitable for varying input sources from solar photovoltaics (PV). In binary mode, 2Ns +1 −1 output voltage levels are obtained, where Ns is the number of individual inverters. This is achieved by digital logic functions, which includes counters, flip-flops and logic gates. In trinary mode, 3Ns levels are achieved by corresponding look-up table. MMC intends design in both control and power circuits to provide corresponding output voltage levels by appropriate switching sequences. Hence to obtain a 15-level inverter, the conventional method requires 28 switches and in binary mode 12 switches are needed. In trinary mode with the same 12 switches, 27 levels can be obtained, whereas in MMC only 7 switches are employed to achieve 15 levels. The advantage of these three designs is in the reduction of total harmonic distortion by increasing the levels. All the three topologies are experimentally investigated using MATLAB-based simulations for a 3 kWp solar PV plant and power quality indices were measured.

Nagaraj, C. *et al*. [14] have presented analysis of shunt active filter (SHAF) using a PI controller with and without the incorporation of intermittent hybrid renewable sources under different grid conditions. An instantaneous real and reactive current (id-iq) control scheme for SHAF is given for reduction in harmonic levels. The MATLAB/Simulink simulation studies validates the performance of id-iq control method.

Mohammad Taufiqul Arif *et al*. [15] have given the impacts of high penetration of storage and solar PV by evaluating different case scenarios on a small distribution network in Rockhampton, Queensland, Australia. It was found

that storage introduces bidirectional power flow in the network and has impacts, such as voltage regulation, phase unbalance and harmonics. The model is used to evaluate the performance of the power plant and total harmonic distortion estimation practically.

Bhim Singh *et al*. [16] have presented a single-stage solar photovoltaic (PV) grid interfaced power generating system using two-level 12-pulse double bridge voltage source converter (VSC) with improved sinusoidal signal integrator PLL (SSI-PLL)-based control algorithm for large capacity plants with improved power quality. The maximum power is tracked with modified perturbation and observation (P&O), maximum power point tracking (MPPT) method, and the maximum power obtained is transferred to the grid. Multipulse VSC results in reduction of grid current and grid voltage total harmonic distortion (THD) which is in accordance to the IEEE 519 standard without performing high frequency switching control. The design validation is done using simulations and control algorithm of the proposed system configuration under varying conditions.

T. Ilakkia *et al.* [17] have given a method for a hybrid solar and windmill system, which makes use of a DC/DC (SEPIC) converter for each of the two sources, with a common converter stage. It is advantageous that input current have fewer ripples. Here, multilevel (5-level) inverter is used to make total harmonic reduction. The DC/AC inverter is capable of bidirectional power transfer. The LC filter is used in series with the multilevel inverter for filtering the harmonics. The fuzzy controller is implemented in closed loop with multilevel inverter for better results. The simulation results are shown in this paper. Using fuzzy logic controller in closed loop with the multilevel inverter, the harmonics is reduced to low value. A system using a combination of these different sources has the advantage of balance and stability that offers the strengths of each type of sources that complement one another. Hybrid energy system is an excellent solution for electrification of remote rural areas, where the grid extension is difficult and not economical.

Anjeet Verma *et al*. [18] have given a charging station (CS) that uses a solar photovoltaic (PV) array, a battery energy storage system (BES), the grid and a diesel generator (DG) set to provide uninterruptible charging of electric vehicles (EVs). However, these energy sources are utilized in a way that minimizes the operational cost of the CS. Therefore, it reduces the charging cost of the electric vehicles (EVs). To achieve uninterruptible charging and to minimize the charging cost, a charging strategy is proposed that prioritizes the use of energy sources. Based on this, the solar PV and BES energy are used as a priority. After that, the grid is used and finally a DG set is used when all energy sources are not accessible. This strategy is based on the cost of electricity per kWh. Normally, the rooftop solar PV array offers power at INR 4.5-5/kWh. The grid offers power at INR 10/kWh and DG set offers at INR 17-20/kWh. To further minimize the charging cost, the single-phase two winding self-excited induction generator (SEIG)-based DG set is operated at the single point of saturation characteristic to generate much high power than its rated power. Moreover, a single two-leg voltage source converter (VSC) does multiple tasks such as

- generation of sinusoidal voltage in standalone mode,
- regulation of generator voltage and frequency,
- management of power flow,
- reactive power compensation and harmonic current elimination, and it also reduces the initial cost of the CS.

To obtain ceaseless charging while connecting the grid/DG set to the CS, the point of common coupling (PCC) voltage is synchronized with the grid/DG set voltage. The CS provides both AC and DC output ports for charging the EVs. To charge the EVs on AC port, the CS uses solar PV array and BES energy to generate a sinusoidal voltage of 220V and

50 Hz. Moreover, with both grid and DG, the CS draws power at unity power factor (PF) with current total harmonics distortion (THD) less than 5% as required by an IEEE 519 standard.

Abla Abd El-moety Gado *et al*. [19] have discussed the key major barriers to the integration of roof-top solar PV systems, which are the uncertainties in the performance of the low voltage distribution network due to the intermittent nature of solar PV sources. Also, a model developed is given to investigate the potential technical impacts of integrating roof-top solar PV systems into the low voltage distribution network in Egypt and the uncertainties, such as voltage fluctuations, phase unbalance, distribution transformer overloading, reactive power compensation and harmonic injections that detract the overall power quality of the typical distribution subtropical climate.

Soenke Rogalla *et al*. [20] have given some theoretical considerations about the correlation between voltages, currents and impedances for a Thevenin equivalent description of an inverter-grid system. A method of Thevenin modeling based on sets of independent measurements is presented. The impedance-based stability criterion will be applied to a real measured resonance in a 44 MW PV power plant. In conclusion, the paper discusses methods, which are suitable to get a better understanding of the harmonic behavior of inverters, which can help to avoid power quality problems in advance.

CONCLUSIONS

In this paper, we have studied various techniques of harmonic reduction developed by various researchers. The techniques are studied on the basis of implementation feasibility, operations methods and performance in harmonic reduction. By studying these techniques, we can conclude that the passive techniques are responsible to reduce harmonics efficiently, but overall losses on overcoming harmonics reduce system efficiency. Active harmonic filters are capable of reducing harmonics without affecting system efficiency, but the implementation cost is so high. Hybrid systems, which are a combination of passive and active harmonic filtering systems are reliable and robust in terms of performance, implementation cost and complexity is also low.

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