

Pavitra Shukl

Doctor of Philosophy (Ph.D.) Candidate

Department of Electrical Engineering, Indian Institute of Technology Delhi

Email: pavitra.shukl@gmail.com Ph.: +91-9990099486

ACADEMICS

Degree/Class	Institute/University/Board	Duration	%/CGPA
Doctor of Philosophy (Ph.D.)	Indian Institute of Technology Delhi (IITD), New Delhi, India	2016-present	8.75/10
Post-Graduation: Master of Technology (M. Tech.) in Electrical Power system and Management	Jamia Millia Islamia, New Delhi, India	2014-16	9.7/10
Under-Graduation: Bachelor of Technology (B. Tech.) in Electrical Engineering.	Uttar Pradesh Technical University (UPTU), BIET Jhansi, India	2009-13	81.34%
Class XII	St. Anthony Senior Secondary School, New Delhi (CBSE), India	2008-09	89.60%
Class X	St. Anthony Senior Secondary School, New Delhi (CBSE), India	2006-07	94.20%

RESEARCH

Ph.D. Topic of Research: Design and Development of Renewable Energy Based Microgrids with Grid Synchronization and Applications to EV Charging Infrastructure

- Design, control and implementation of various configurations of microgrids with grid synchronization capability along with their applications in EV charging system using MATLAB/SIMULINK software.
- Hardware-in-loop (HIL) simulations using (RT-Lab) OPAL-RT controller of distributed microgrids consisting of distributed energy sources such as solar, wind, battery and fuel cell sources for common DC/AC bus EV charging capabilities.
- Developed a laboratory prototype with solar simulator, voltage and current sensors, power electronic converters, three phase grid, nonlinear loads for validation and reliable operation under non-ideal grid conditions.
- Completed the project (RP03253) funded by OPAL-RT titled, "Design and Development of Advanced Research Modules in Power Electronics Applications to Power System".

M. Tech Dissertation Topic: Control Circuit for Bidirectional DC-DC Converter in Solar PV Applications

- Simulation of a novel control technique utilizing bidirectional DC-DC converter, solar photovoltaic energy conversion system with MPPT controller in standalone mode of operation using PSIM software.
- Developed a laboratory prototype for testing and validating the performance of the control technique.

COMMUNICATED PATENT

- [1] B. Singh and P. Shukl, "Implementation of AC-DC charging of Electric Vehicles (EVs) from Distributed Microgrids Based on Solar, Wind, Battery and Fuel Cell Sources," Ordinary Indian Patent (Under Process).

PUBLICATIONS IN JOURNALS

- [1] P. Shukl and B. Singh, "Combined IIR and FIR Filter for Improved Power Quality of PV Interfaced Utility Grid," *IEEE Transactions on Industry Applications*, vol. 57, no. 1, pp. 774-783, Jan.-Feb. 2021.
- [2] P. Shukl and B. Singh, "Recursive Digital Filter Based Control for Power Quality Improvement of Grid Tied Solar PV System," *IEEE Transactions on Industry Applications*, vol. 56, no. 4, pp. 3412-3421, July-Aug. 2020.
- [3] B. Singh and P. Shukl, "Control of Grid Fed PV Generation Using Infinite Impulse Response Peak Filter in Distribution Network," *IEEE Transactions on Industry Applications*, vol. 56, no. 3, pp. 3079-3089, May-June 2020.
- [4] P. Shukl and B. Singh, "Delta-Bar-Delta Neural Network (NN) Based Control Approach for Power Quality Improvement of Solar PV Interfaced Distribution System," *IEEE Transactions on Industrial Informatics*, vol. 16, no. 2, pp. 790-801, Feb. 2020.
- [5] P. Shukl and B. Singh, "Grid Integration of Three-Phase Single-Stage PV System using Adaptive Laguerre Filter Based Control Algorithm under Non-Ideal Distribution System," *IEEE Transactions on Industry Applications*, vol. 55, no. 6, pp. 6193-6202, Nov.-Dec. 2019.
- [6] P. Shukl, and B. Singh, "Proficient operation of grid interfaced solar PV system for power quality improvement during adverse grid conditions", *IET Generation, Transmission & Distribution*, 14, (25), p. 6330-6337, 2020.
- [7] P. Shukl and B. Singh, "Neural network-based quickprop control algorithm for grid connected solar PV-DSTATCOM system", *IET Renewable Power Generation*, 13, (14), p. 2522-2530, 2019.

PUBLICATIONS IN CONFERENCES

- [1] **P. Shukl** and B. Singh, "Synchronization Control Based on Variable Fractional Delay Filter for Solar-PV-Battery System," in *Proc. of IEEE International Conference on Energy, Power and Environment: Towards Clean Energy Technologies (ICEPE)*, pp. 1-6, 2021.
- [2] **P. Shukl** and B. Singh, "Multifunctional Control of Weak Grid Intertie Solar PV System with Synchronization Capability," in *Proc. of IEEE International Conference on Power, Instrumentation, Control and Computing (PICC)*, pp. 1-6, 2020.
- [3] **P. Shukl** and B. Singh, "Performance of Biquad Filter under Weak Grid Conditions for Solar PV Interfaced Utility Grid," in *Proc. of IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE 2020)*, pp. 1-6, 2020.
- [4] **P. Shukl** and B. Singh, "Combined IIR and FIR Filter for Improved Power Quality of PV Interfaced Utility Grid," in *Proc. of IEEE International Conference on Computing, Power and Communication Technologies (GUCON)*, pp. 995-1000, 2019.
- [5] **P. Shukl** and B. Singh, "Neural Network Based Control Algorithm for Solar PV Interfaced System," in *Proc. of IEEE Energy Conversion Congress and Exposition (ECCE)*, pp. 2552-2559, 2019.
- [6] **P. Shukl** and B. Singh, "Power Quality Improvement Using Multilayer Gamma Filter Based Control for DSTATCOM Under Nonideal Distribution System," in *Proc. of IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, pp. 593-598, 2018.
- [7] **P. Shukl** and B. Singh, "Recursive Digital Filter Based Control for Power Quality Improvement of Grid Tied Solar PV System," in *Proc. of IEEE India International Conference on Power Electronics (IICPE)*, pp. 1-6, 2018.
- [8] **P. Shukl** and B. Singh, "Dual Mode Control of Grid Tied Solar PV-DSTATCOM by Utilizing Warped Digital Filter in Distribution System," in *Proc. of IEEE 8th Power India International Conference (PIICON)*, pp. 1-6, 2018.
- [9] B. Singh and **P. Shukl**, "Control of Grid Fed PV Generation using IIR Peak Filter in Distribution System," in *Proc. of IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, pp. 1-6, 2018.
- [10] **P. Shukl** and B. Singh, "Grid integration of three-phase single-stage PV system using adaptive laguerre filter based control algorithm under non-ideal distribution system," in *Proc. of IEEMA Engineer Infinite Conference (eTechNxT)*, pp. 1-6, 2018.

PROFESSIONAL EXPERIENCE (INDUSTRIAL TRAINING)

- **Central Electricity Authority (C.E.A.), 2012, India**
Study of Hydro Power Projects in C.E.A. - HETD Division, New Delhi (Summer industrial training of 6 weeks).
Guide- Mr. Sanjay Srivastava, Director (HETD)

Ph.D. SOFTWARE LAB SKILLS

- MATLAB/SIMULINK
- OPAL-RT
 - Real Time Simulation
 - Developed a laboratory hardware utilizing OPAL-RT as a controller.
- Basic understanding of C++ programming language.

ACHIEVEMENTS

- Project Fellowship beneficiary in Ph.D., 2016-present.
- Gold Medallist in M. Tech., Jamia Millia Islamia.
- Passed with first division with honours in B. Tech, BIET Jhansi.
- Scholarship for Securing 2nd position in school in class X, 2007.

EXTRA CURRICULAR ACTIVITIES

- Participant in **IIT DELHI INDUSTRY DAY**, "Power Quality Improvement of Three-Phase Grid Tied Single-Stage PV System under Non-Ideal Distribution System", 2018.
- Organizing Member of **IEEE Encomium'16, Annual Techno-cultural Fest**, Jamia Millia Islamia, 2016.
- Member in organizing **International Conference 12th IEEE INDICON 2015**, Jamia Millia Islamia.
- Student Delegate in **IEEE Delhi student- Young Professionals-WIE Congress 2015**, Jamia Millia Islamia.
- Organizing Committee Member of **National Conference ETEEE**, Jamia Millia Islamia, 2014.
- Executive Committee Member of **IEEE JMI**, Jamia Millia Islamia, 2014-16.

Delta-Bar-Delta Neural-Network-Based Control Approach for Power Quality Improvement of Solar-PV-Interfaced Distribution System

Pavitra Shukl , Member, IEEE, and Bhim Singh, Fellow, IEEE

Abstract—A serious concern regarding deterioration in power quality has emerged with the increasing integration of solar photovoltaic (PV) energy sources to the utility primarily in the scenario of a weak distribution grid. Therefore, power quality improvement of the grid-tied solar energy conversion system is paramount by implementation of a robust control technique. This paper deals with a delta-bar-delta neural network (NN) control for operating optimally by feeding active power to the loads and remaining power to the grid as a function of distribution static compensator capabilities, such as mitigating harmonics, balancing of load, and improving power factor. The control algorithm provides the ability to adjust weights adaptively in an independent manner, and hence, it offers alleviation in model complexity predominant during abnormal grid conditions along with reduction in computational time. Moreover, the NN-based control technique offers enhanced accuracy due to the combinational neural structure in the estimation process. In addition, the system performance according to the IEEE-519 standard has been verified; hence, it is proficient in maintaining the power quality. The solar-PV-array-efficient utilization is accomplished through an incremental-conductance-based maximum power point tracking technique. For validating the behavior of the proposed system, its performance is studied using simulation results. Moreover, a prototype is developed for validation, and experimental results corroborate reliable operation under nonideal grid conditions comprising of a wide range of load variations, voltage sag, and varying solar insolation conditions.

Index Terms—Delta-bar-delta, distribution static compensator, neural network (NN), power quality, solar photovoltaic (PV) generation.

I. INTRODUCTION

THE energy has emerged as the backbone of the economic and technological development of the world during the past few years. In accordance with the reports, the population of the world is estimated to grow by 1% in the coming years.

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The authors are with the Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India (e-mail: pavitra.shukl@gmail.com; bhimsinghiitd61@gmail.com).

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However, the gross domestic product (GDP) rise is estimated to be around 3%. Moreover, considering GDP per capita as the global energy demand indicator, the escalating requirement of energy sources is prevalent [1]. Therefore, with an increase in the energy requirement of the world and the exhaust of fossil fuels (like coal, natural gas, and petroleum), the emphasis on renewable energy sources is predominant [2]. In addition, the increasing pollution level due to an increase in the carbon footprint is one of the main factors for the inclination toward utilization of renewable energy sources. In order to build a large energy base, there is a need to fully exploit the available renewable energy resources. Currently, the contribution by the renewable energy sources is around 18% of the world energy demand. However, according to an estimate by the International Energy Agency, the overall energy requirement of the world is expected to increase by 50% in the near future [3]. With the reduction in pollution and an increase in grid parity as the major benefits, solar energy is gaining popularity due to the encouragement given by the government, with an increase in government subsidies for their easy installation and operation [4].

The contribution of solar power in terms of meeting the global energy demand is increasing rapidly. During recent years, the major factors have included a sharp fall in the cost of silicon, which is the primary resource in the solar power production [5] and an upsurge in technical skill, thereby leading to a decrease in the overall solar photovoltaic (PV) cost. Villalva *et al.* [6] have presented the modeling of the PV array, where a simple, fast, and accurate method is given for realizing the solar PV array. On the other hand, the solar PV array characteristics depict the nonlinear behavior between its voltage and current. As a result, it is necessary to extract the maximum power from the solar PV array by utilizing a maximum power point tracking (MPPT) mechanism in order to ensure that the interfaced power converter is capable of self-adjusting its parameters during runtime based on the varying current/voltage levels of the PV source. The realization of MPPT controllers [7] can be based on different methods and algorithms. However, the prevalent techniques include perturb and observe [8] and incremental conductance (INC) techniques. Due to the reduced oscillations in the INC method while determining the maximum power point (MPP), it is preferred here, and it is also suitable for commercial purposes.

The utilization of solar PV systems can be grouped into single-stage or double-stage topologies. However, the benefits of the single-stage topology include reduction in cost as the

Combined IIR and FIR Filter for Improved Power Quality of PV Interfaced Utility Grid

Pavitra Shukl , Member, IEEE, and Bhim Singh , Fellow, IEEE

Abstract—For enhancing the power quality (PQ), an adaptive infinite impulse response (IIR) combined with finite impulse response (FIR) control is utilized for a grid connected solar photovoltaic (PV) system. The power obtained from a solar PV array is affected due to the seasonal and diurnal variability of the sun. Moreover, the utility distribution network is relatively weak for the developing and underdeveloped countries, exacerbating PQ deterioration issues. For the improvement in PQ indices, an adaptive combined IIR and FIR filter is utilized here, which exhibits adaptive control capability of the voltage source converter essential for smart grid operations. The major advantage regarding the utilization of adaptive control involves much less sensitivity to quantization errors. This new application of a combined IIR and FIR filter includes the mitigation of harmonics in the grid currents and the grid voltages, thereby improving PQ along with reactive power compensation. Due to a combination of IIR and FIR filters, the filtering is achieved with fewer coefficients, requiring minimum memory (as in the case of IIR filters) along with easy implementation and design capability (in the case of FIR filters). Test cases corroborate satisfactory performance during the weak grid conditions, such as voltage distortion, unbalance, and swell, and experimental results are obtained though assessment on a developed laboratory prototype. The PQ improvement is evident by observing the total harmonics distortion conferring to the IEEE-519-2014 Std.

Index Terms—Adaptive control, combined infinite impulse response (IIR) and finite impulse response (FIR) filter, distribution static compensator (DSTATCOM), photovoltaic (PV).

	NOMENCLATURE
IIR	Infinite impulse response.
FIR	Finite impulse response.
PV	Photovoltaic.
PQ	Power quality.
THD	Total harmonic distortion.

DSTATCOM

RESs

LMF

PLL

SOGI

NN

P&O

PCC

MPPT

i_{sa}, i_{sb}, i_{sc}

v_{sab}, v_{sbc}

v_a, v_b, v_c

v_{sa}, v_{sb}, v_{sc}

V_t

u_{pa}, u_{pb}, u_{pc}

u_{qa}, u_{qb}, u_{qc}

V_{dc}

V_{dc}^*

I_{pnet}

i_{La}, i_{Lb}, i_{Lc}

i_{fLa}

M

$T_f(z, a)$

φ_k

$I_{fpa}, I_{fpb}, I_{fpc}$

I_{pLavg}

V_{dce}

I_{loss}

w_{pv}

P_v

I_{pv}

$i_{VSCa}, i_{VSCb}, i_{VSCc}$

$i_{sa}^*, i_{sb}^*, i_{sc}^*$

Distribution static compensator.

Renewable energy sources.

Least mean fourth.

Phase-locked loop.

Second-order generalized integrator.

Neural network.

Perturb and observe.

Point of common coupling.

Maximum power point tracking.

Grid currents

Grid line voltages.

Distorted grid phase voltages.

Distortion-free grid phase voltages.

Terminal voltage.

In-phase unit templates.

Quadrature-phase unit templates.

DC link voltage.

Reference dc link voltage.

Load active power component.

Load currents.

Fundamental load current.

Order of filter.

Transfer function.

Scaling coefficients.

Active power components of grid current.

Average component of load current.

DC voltage error.

DC loss component.

Feed-forward term.

Solar PV power.

Solar PV current.

VSC currents.

Reference grid currents.

I. INTRODUCTION

THE emphasis on utilizing renewable energy resources (RESs) is increasing due to the ever-increasing depletion of fossil fuel-based energy resources. Moreover, the abundant solar power, clean and pollution-free energy have attracted the attention toward its utilization for generating power in the distribution network [1], [2]. However, the solar PV array interfacing with the grid through a voltage source converter (VSC) causes major power quality (PQ) issues. The primary PQ issues observed are due to fluctuations and distortions in the grid voltage and grid currents, which lead to deterioration in performance of

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The authors are with the Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India (e-mail: pavitra.shukl@gmail.com; bsingh@ee.iitd.ac.in).

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Control of Grid Fed PV Generation Using Infinite Impulse Response Peak Filter in Distribution Network

Bhim Singh , *Fellow, IEEE*, and Pavitra Shukl , *Member, IEEE*

Abstract—An upsurge in the integration of renewable sources to the utility grid has resulted into escalating concerns regarding power quality (PQ) improvement. In order to provide efficient operation under weak grid conditions, the necessity of a competent control technique is dominant. Consequently, the implementation of an infinite impulse response (IIR) peak filter is used here for harmonics mitigation, power factor correction, and alleviating other PQ issues by providing distribution static compensator (DSTATCOM) capabilities. In addition, this control technique also works during conditions when solar photovoltaic (PV) power is not procurable. During day, the requirement of load is fed from the solar PV array and the stored grid power. On the other hand, at night when the power from solar PV array is unavailable, the requirements of load are fulfilled from the grid and DSTATCOM operation ensures power quality improvement. In order to validate this system, it is maintained according to the IEEE-519 standard. The considered weak grid conditions include load unbalancing, intermittent solar insolation, voltage sag, voltage swell, voltage distortion, and voltage unbalance conditions. The benefits of IIR peak filter include adaptive computation during filtering, thereby alleviating the computational complexity. Moreover, less memory space is required during execution guaranteeing fast performance during weak grid conditions. Simulated results are utilized to depict the behavior of the system during abnormal grid conditions. Moreover, its comparative performance with the existing control techniques, is also presented. For further substantiation and in order to observe reliable operation, a laboratory prototype is developed and tested during weak grid conditions such as voltage distortion, voltage unbalance, voltage sag, voltage swell, and load unbalancing.

Index Terms—Distribution static compensator (DSTATCOM), infinite impulse response (IIR) peak filter, maximum power point tracking (MPPT), photovoltaic (PV) array, power quality.

NOMENCLATURE

PQ Power quality.

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The authors are with the Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India (e-mail: bsingh@ee.iitd.ac.in; pavitra.shukl@gmail.com).

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IIR	Infinite impulse response.
DSTATCOM	Distribution static compensator.
VSC	Voltage source converter.
PV	Photovoltaic.
MPPT	Maximum power point tracking.
WEA	World Energy Assessment.
SECS	Solar energy conversion system.
POI	Point of intersection.
PLL	Phase locked loop.
FFPLL	Fixed frequency PLL.
SRF-PLL	Synchronous reference frame PLL.
LMF	Least mean fourth.
FIR	Finite impulse response.
P&O	Perturb and observe.
S&H	Sample and hold.
ZCD	Zero crossing detector.
PI	Proportional integrator.
UPF	Unity power factor.
ADCs	Analog to digital converters.
FPGA	Field programmable gate array.
DSO	Digital signal oscilloscope.
THD	Total harmonic distortion.

I. INTRODUCTION

IN ORDER to bring about the economic development of the world, a balance between the demand and supply of the energy, is of paramount importance. However, a huge challenge is being observed while implementing a fully sustainable system with respect to energy and material requirement [1]–[4]. The emphasis on the usage of distributed generation sources is increasing due to an increase in flexibility, reliability as compared to conventional central power stations [5]. Among the renewable energy sources, the solar PV energy is gaining importance due to improvements in manufacturing technology and enhancement in efficiency of solar cells [6]–[8]. In addition, the major benefits include zero pollution, minimum operating cost, zero fuel cost, static structure, and small size.

The rooftop solar PV array is the most popular mode of generation. However, due to variable behavior of environmental climate, the operation in standalone mode is not reliable due to varying solar power, as it is not always equal to load power [9]. When the power produced is more than the load requirement, a power sink is essential. However, when it is insufficient then

Recursive Digital Filter Based Control for Power Quality Improvement of Grid Tied Solar PV System

Pavitra Shukl , Member, IEEE, and Bhim Singh , Fellow, IEEE

Abstract—This article deals with the implementation of a control approach for an active power transfer between solar photovoltaic (PV) array and the grid/ load along-with power quality (PQ) improvement by eliminating harmonics and compensating reactive power required by the load in the distribution network. The PQ problems at the point of intersection, are increasing preeminently with respect to voltage and current harmonics due to integration of renewable sources. The recursive digital filter control implemented here for PV grid interfaced system is efficient in improving PQ indices by operating round the clock and ensuring power transfer between utility grid and connected loads. The prominence of the control algorithm lies in the efficient switching of voltage source converter (VSC), by generating reference grid currents, which are obtained through indirect current control technique. The recursive digital filter is utilized for processing the load currents and extracting the active power component of them. These active power components of load currents are used for generating the reference grid currents in this system. A prototype of the system is developed in the laboratory and its performance is studied for varying loads, changing solar insolation, and voltage swell, voltage sag and voltage distortion conditions.

Index Terms—Distribution static compensator (DSTATCOM), power quality (PQ), recursive digital filter, solar photovoltaic (PV) generation.

I. INTRODUCTION

THE issues with the usage of fossil fuels have been the prime highlight of Paris Climate Agreement in 2015, where the reduction in the usage of fossil fuel based energy sources, has been emphasized. As the electricity obtained from renewable energy sources [1] has no effect on the greenhouse gas emissions, it is termed as green power and is obtained commercially from solar, wind, biomass, geothermal, and hydro energy sources. Their requirement can be attributed to the need for minimization of carbon dioxide emission and the usage of oil. The usage of renewable energy is being emphasized due to the alarming levels of pollution created by conventional energy resources. The

renewable energy sources being exploited include solar energy, wind energy, tidal energy and biomass energy. The distributed generations (DGs) are focused on the usage of renewable energy sources, as they do not produce pollution, they are clean form of energy and are found in abundance in nature [2]. The demand for exploitation of solar energy, is increasing, with an increase in the government subsidies. The harnessing of solar energy is gaining popularity, as it is available in abundance and the solar power plants are not constituted of any moving parts. Among the fastest growing distributed energy sources is the solar photovoltaic (PV) distributed generation (PV-DG) system due to the abundant supply of solar power and the ease of installation. The reason of utilizing PV power in distribution network in place of usage in the transmission grid is primarily in regard with the regulatory and economic factors. The PV-DG system significantly affects the power quality (PQ) [3] and system operation due to intermittent availability of solar PV power caused by severe weather conditions. The primary constituent of solar PV system is PV arrays, in which the relationship of solar PV current and voltage is nonlinear leading to issues in utilization of maximum power. In order to force the solar PV system to operate at maximum power point (MPP) at all environmental conditions, techniques are recognized as MPP tracking techniques (MPPT). Extensive research has been reported in the literature as MPPT is an essential part of a PV system. Due to reduced complexity and ease of implementation, perturb and observe (P&O) technique is utilized.

The widespread adoption of solar power generation [4], [5] poses difficulties in steady-state and transient operation for issues such as weather-induced changes in generation, voltage unbalances and protective devices. The primary reason for the increase in usage of the grid connected PV system, is in regard with storage of excess power into the grid thereby minimizing the requirement of bulky and costly batteries. This becomes possible if sunshine is available in plenty, thus, the net power outflow to the grid can be achieved with local solar generation [6], which causes a reduction in the net demand on a distribution feeder. However, the increased penetration of the PV-DG system to the utility grid, leads to enhanced challenges in regard with the system operator and utilities. The intermittent nature of solar power requires the usage of energy storage, which can be classified as grid interfaced solar PV system or standalone solar PV system [7], [8]. The popularity of grid connected system can be attributed to the nonutilization of the battery for energy storage. The increasing inclination towards grid connected system is due to the usage of the grid for storage purposes, thereby improving the performance by reducing complexity and cost of the system.

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The authors are with the Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India (e-mail: pavitra.shukl@gmail.com; bsingh@ee.iitd.ac.in).

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Grid Integration of Three-Phase Single-Stage PV System Using Adaptive Laguerre Filter Based Control Algorithm Under Nonideal Distribution System

Pavitra Shukl¹, *Member, IEEE*, and Bhim Singh², *Fellow, IEEE*

Abstract—The increasing integration of utility with renewable sources of energy has resulted into serious issues of power quality (PQ) deterioration primarily in a scenario of weak distribution grid. In order to improve the PQ, efficient implementation of a control algorithm for the solar energy conversion system interfaced to the grid is paramount. This article illustrates the usage of an adaptive Laguerre filter based control technique for optimal operation providing distribution static compensator capabilities along with load balancing, power factor correction and harmonics mitigation. Moreover, it provides the active power transfer to the grid together with feeding the nonlinear and linear loads. In addition, the system performance according to an IEEE-519 standard has been verified, hence it is proficient in maintaining the PQ. The Laguerre filter offers the benefits of reduced computational time in addition with the alleviation in model complexity predominant during abnormal grid conditions. By utilizing maximum power point tracking, the efficient utilization of solar PV array is accomplished with a perturb and observe method. For validating performance of the proposed system, it is examined through simulation results. Furthermore, a prototype is developed for validation and test results corroborate reliable operation under nonideal grid conditions comprising of wide range of load variations, voltage sag, swell, distortion, and unbalance conditions.

Index Terms—Adaptive Laguerre filter, distribution static synchronous compensator (DSTATCOM), maximum power point tracking (MPPT), photovoltaic (PV), power quality (PQ).

I. INTRODUCTION

THE industrialization has led to an increase in the deterioration of the environment due to the dependency on

fossil fuels, which have led to global warming, greenhouse gas effect, and acid rain, consequently causing pollution [1]. The International Energy Agency in November 2011 has cautioned that the efforts for the reduction of greenhouse gas effect are crucial in the coming years as the world is fast approaching a tipping point concerning climate change. In an effort through United Nations Framework Convention on Climate Change [2], countries have been warned to cut down their emissions of greenhouse gases. Through the Paris Agreement [3] in 2016, severity of the situation has become evident as its objective encompasses the constraint of limiting the increase in global average temperature to not more than 2 °C, which subsequently leads to reduction in the harmful effects and risks of climate change. Therefore, a paradigm shift is observed toward the usage of nonconventional energy sources [4]. The demand of renewable energy sources is emergent owing to the benefits acquired in terms of extracted energy being clean, abundant, and pollution free. In addition, the subsidies provided by the government are reassuring growth and utilization of renewable sources in the energy sector. Among various nonconventional sources like solar, wind, biomass, and geothermal energy, the prominence of solar energy based power generation is evident due to its abundance in nature [5]. The solar energy is being widely used in the distribution networks for consumption in industrial and residential applications due to the diminution in installation cost, static design, low maintenance cost, no fuel cost, and small size as a result of skill development, emerging technologies, and market penetration [6].

The solar energy is acquired by the usage of solar photovoltaic (PV) arrays. Villalva *et al.* [7] have presented the modeling scheme of the solar PV array, which provides accurate, fast, and simple method of implementing the solar PV array. On the other hand, the solar PV array characteristics depict the nonlinear behavior between its voltage and current. As a result, it is necessary to extract maximum power from the solar PV array by utilizing a maximum power point tracking (MPPT) mechanism. In order to obtain the maximum power, several MPPT techniques are present in the literature, namely perturb and observe (P&O) [8], incremental conductance [9], particle swarm optimization [10], and fuzzy logic and grey wolf optimization [11] MPPT techniques. The benefits of P&O technique include its simple

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P. Shukl is with the Indian Institute of Technology Delhi, New Delhi, Delhi 110016, India (e-mail: pavitra.shukl@gmail.com).

B. Singh is with the Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi, Delhi 110016, India (e-mail: bsingh@ee.iitd.ac.in).

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