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A Review Article Novel Approach to Design of Solar Plant with Connected to a Non- Linear Motor Load

Dheeraj Kumar, Professor Arun Pachori
Department of Electrical Engineering,
Jabalpur Engineering College,
Jabalpur, (M.P.) India

Abstract- The increasing application of nonlinear loads may cause distribution system power quality issues. This work presents a control of Single-phase Grid Interactive Inverters with nonlinear loads and a technique for Harmonic compensation and power factor correction of nonlinear loads employing Current Controlled Voltage Source Inverter. This work will focus on the design methodology and the analysis of control strategy which allows the compensation of harmonics and phase displacement of the input current, for non-linear loads. The Utility-Connected Inverter should operate at both Stand-alone and Grid-Connected modes. However, the waveform qualities of the grid current in GridConnected mode and the output voltage in Stand-alone mode are poor under the nonlinear critical load with the conventional control. The impact of the nonlinear load on the grid current is analyzed. Harmonics problem in industrial power systems with non-linear loads are presented. By adding the load current into the filter inductor current loop, the influence of the nonlinear load on the grid current can be eliminated, and the waveform quality of the output voltage in stand-alone mode can be improved. The control method is simple and easy to be achieved. Simulation results from a Full-bridge Grid-Interactive Inverter with a Diode Rectifier load verify the theoretical analysis.

Keywords- Power quality, Grid connected inverter, Maximum Power Point Tracking, Distributed generation System.

I. INTRODUCTION

Photovoltaic (PV) system has played very important role in the renewable energy (RE) technologies because PV systems are environment friendly, clean, and secure energy sources [1]. The PV based RE technologies has received a lot of attentions for stand-alone (SA) and grid-connected (GC) systems [2]. In the SA mode the inverter should be able to generate high quality power to the loads. An inverter is required to connect the load to the PV where the latter generates DC power [3].

The output waveforms, voltage and current, under the SA mode of operation of the inverter should be controlled based on the reference values. Therefore, a voltage source inverter (VSI) and a suitable voltage control approach are required [4]. The main feature of a good power inverter is its capability to provide constant amplitude sinusoidal voltage and frequency regardless the typing of the load it is connected to. The power inverter must also have the capability to quickly recover from transients affected by the disturbances without causing power quality problems.

However, the large-scale use of PV generators raises many challenges, such as harmonic pollutions, low efficiency of energy conversion, fluctuation of output power, and reliability of power electronic converters [5]. Various inverter control techniques have been suggested by many researchers and discussed in [6]. FLCs have become increasingly popular in designing inverter controls because it includes an advantage over the traditional controller by reducing the dependence on the mathematical model [7, 8].

Nonetheless, the performance of FLCs depends on the rule basis, number of rules, and MFs. These variables are determined by a trial and error procedure, which is time consuming [9, 10]. Thus, to overcome these limitations in FLC design, an optimization method was suggested in [11]. The method uses particle swarm optimization (PSO) algorithm and FLC for maximum power point tracking.

However, PSO is prone to premature convergence and hence there is a need to find a better way to optimize the FLC. In a related work [12–14], the problem of adaptive fuzzy tracking control for a class of uncertain multipleinput–multiple-output pure-feedback nonlinear systems with immeasurable states was considered. In this work, fuzzy logic systems were first used to approximate the unknown nonlinear functions, and then a fuzzy state observer was designed to estimate the unmeasured states.

II. RESEARCH MOTIVATION

Renewable energy resources are utilized in distribution networks based on an Active Front End (AFE) technology as a bidirectional power flow energy conversion system. Low and high frequency harmonics generated by

switching pattern of the power electronics converter should be reduced by an appropriate output filter. According to international regulations, harmonics injected to the grid by Pulse Width Modulated (PWM) power converters must be handled to maintain power quality indices within standard limits. LCL filters with passive damping resistors are the most reliable and renowned devices to fulfil the standards. The main objectives in the design of an efficient LCL filter are to reduce the cost and weight of the filter, as well as to increase the robustness and stability of the power electronics converter.

In this paper, a comprehensive and mathematical approach is proposed to calculate the maximum current ripple of a PWM-based inverter, which helps to precisely calculate the size of the inverter-side inductors in the LCL filter. The mathematical approach to solve the problem of optimal damping is presented, which can be implemented analytically in different configurations of the LCL filters. The proposed method also works to solve the optimal damping problem for any type of filter.

III. LITERATURE REVIEW

Ujjwal Kumar Kalla, An adaptive control of voltage source converter based scheme for grid connected solar PV - battery system: This paper presents an adaptive back propagation learning scheme for three phase four wire grid integrated solar PV - battery microgrid feeding three phase and single phase nonlinear loads simultaneously. The proposed power quality improved 3 phase 4 wire solar PV - battery micogrid is capable of delivering highly non-sinusoidal currents to nonlinear and unbalance loads of different types such that single and three phase industrial and domestic loads, while the source currents in all three phases remains balanced and sinusoidal.

An adaptive back propagation learning scheme is used to control the microgrid voltage control and power quality improvement under various loading conditions through mitigation of harmonic currents, reactive power compensation and active power balancing in the system. It also improves the system power factor in highly nonlinear and unbalanced loading conditions. The proposed scheme significantly improves the steady state and dynamic performances of the 3 phase 4 wire grids integrated solar PV - battery micogrid system.

W. Inwanna, Field Experience for Passive Power Filter for Grid-Connected Solar Rooftop Applications at Industrial Plants: This paper presents the solution of harmonic problem that caused by solar rooftop installation. The Passive Power Filter System (PPFs) is recommended for solving harmonic problem which produced from non-linear loads such as AC drive, SMPS and solar inverter. The PPFs is designed to eliminate the harmonic in the electrical system, result in the voltage and current distortion is reduced and avoid resonance problem. Moreover, it helps to compensate the reactive power and improve the power factor. The characteristic of PPFs is analyzed based on the simple calculation by the KMITL program. In practical, the PPFs is suitable for low voltage system which connected to the grid. There is high performance in solving harmonic problems in the electrical system.

S. Pramanick, Study on Power Quality Phenomena of Grid-connected AC Micro-grid: In recent electrical power system, there is a greatest interest on operation, control and performance of AC micro-grid by research community throughout the world. In this context, this paper investigates power quality issues of grid-connected AC micro-grid. The micro-grid consists of two wind farms (one is fixed speed type and other is variable speed type), a solar power plant and a mini hydel plant at point of common coupling (PCC). The grid is modeled as AC voltage source in series with impedance. The voltage and frequency at PCC are 600V and 50 Hz respectively.

All heterogeneous non-conventional energy sources are interfaced to the main grid through different types of power electronics converter(s) and a common transformer. In the study, PSCAD software is used to model the grid-connected AC micro-grid. Various responses of individual entities and at grid-side variables are observed. Here, various power quality problems have been monitored from the model of AC micro-grid under dynamic operating conditions like switching of non-linear load and power factor improving capacitor. This study will be helpful to develop strategy in future for mitigating or suppressing power quality problems in the AC micro-grid.

Bonginkosi A. Thango, On the Impact of Solar Photovoltaic Generation on the Thermal Ageing of Transformers: In the last decade, solar photovoltaic energy generation has emerged as one of the leading vanguards of renewable energy source generation in South Africa. The considerable growth in the deployment of solar photovoltaic plants has grabbed the attention of worldwide project developers, investors and stakeholders. In the way indicated, more devised efforts are essential to wield the guarantee that solar photovoltaic plant equipment operates to meet the requirement of solar photovoltaic environment and facilitate the generation of energy as required.

One such equipment susceptible to the harmonics and distortion generated by the connected inverters and resonances due to the non-linear loads is the step-up transformer. Harmonics and distortion are well known to introduce additional losses, hotspot temperature rise and reduction of the transformer service life. The rise in hotspot temperature yields abnormal levels of ignitable gases in the step-up transformer oil such that untimely failures may take place. The concentration of this gases suggests partial discharge and excessive heating. Recently reported studies evoke that the designing of solar

photovoltaic plant transformers be more robust. This paper intends to contribute additional knowledge towards understanding the adverse effects related to harmonic currents in the step-up transformer for solar photovoltaic application. The winding eddy losses and structural part losses are examined under a harmonic profile to compute the service losses and resultant thermal requirements.

Jayasankar V N, Implementation of adaptive fuzzy controller in a grid connected wind-solar hybrid energy system with power quality improvement features: Energy demand increases rapidly, utilization of renewable energy resources plays an important role in narrowing down the supply-demand difference. Introduction of more power electronic devices and non-linear loads pollutes the grid and create power quality problems. Both the scarcity of energy problem and power quality problem can be simultaneously solved by using the grid interfacing inverter of renewable sources, as a shunt active filter.

A suitable control strategy has to be used for giving grid interfacing inverter, the power of power quality improvement. Conventional PI controller can be replaced with a fuzzy controller for better control, and thus improve the system performance. In this paper, a grid connected hybrid system of wind-solar with power quality improvement features is simulated with a PI controller, and then results are compared by replacing PI with fuzzy controller.

Jayasankar V N, A study on hybrid Renewable Energy Source interface to the non-ideal grid at distribution level with power quality improvements: Air pollution is one of the prominent issues that we are facing nowadays. The major contributor for air pollution is the waste output of power plants which uses fossil fuels to generate power. Urbanization and industrialization have changed the lifestyle of human society and the need for electrical energy has enhanced significantly. As the conventional energy sources are not capable of serving the purpose, the researchers have turned their face towards Renewable Energy Sources (RES). Energy sources are scattered across the globe, therefore the available green energy at the distribution level is also used to generate electricity. The hybrid combination of wind/solar systems has proved to be a reliable source to the utility.

For extracting maximum power from the RES, battery bank is connected across it. Due to the problem associated with the chemical batteries the wind/solar hybrid combination is directly connected to the grid. There are many issues related to the interconnection of RES to the grid which are addressed with the growth in power electronics field. However the power quality issue occurs due to the presence of non-linear loads at the point of common coupling. Shunt active filter has proved to mitigate the problems associated with the non-linear loads. Researchers have limited their work to interconnection of RES to ideal grid voltages which is not the practical case. In this paper the wind/solar hybrid system is modeled and is interconnected to the unbalanced and distorted grid. Also, RES interfacing inverter is added with shunt active filter functionality and hence overall cost curtailment of the project can be achieved.

Brook W. Abegaz, Optimal real-time integration control of a virtual power plant: This paper presents an optimal, real-time integration control mechanism for interconnecting hybrid energy sources into a virtual power plant. The implemented virtual power plant consists of distributed energy sources including ten solar panels providing 1 MW aggregate power, six wind turbines generating 9 MW aggregate powers, and ten grid connected battery energy storage systems which support the overall grid. Importantly, the capacity, the availability and the uninterrupted operation of the virtual power plant were identified as metrics to evaluate the real-time integration of distributed energy sources into the virtual power plant.

Furthermore, optimization techniques were developed using mixed integer linear programming in CPLEX (IBM ILOG optimization studio) to identify the optimal real-time operating margins for the aggregate virtual power plant. Using the optimal real-time integration control mechanism, the capacity factor of the virtual power plant was improved by 45 %, the system unavailability was reduced by 5.3 %, and the system interruption was reduced by 65.47 %, while the duration of the interruption decreased by 13 minutes per day as compared to non-optimal integration control strategies. The obtained results demonstrate that the optimal real-time integration control mechanism yields a more functional and reliable integration control of the virtual power plant, and thus increases the economic feasibility of distributed energy resources in the energy market.

Miguel Torres, Non-linear control of a grid-connected multi-cell photovoltaic inverter that operates under variable temperature and irradiance: This work evaluates the performance of a nonlinear control strategy of a modular photovoltaic (PV) plant that is used to support grid frequency control. The PV plant is designed based on a real study case and it has a modular structure consisting in several generating units. Each generating unit consists in PV arrays interfaced to the grid with a three-phase three-level cascaded H-bridge converter based on single-phase current-source inverters.

It is shown that, under changing temperature and irradiance conditions, the output dc currents of the PV arrays become unbalanced. A non-linear strategy is proposed to control the output voltages of the H-bridges and to overcome the problem of unbalanced dc currents. Additionally a control technique called virtual synchronous generator (VSG) is applied to the PV plant in

order to support the control of the grid frequency emulating an inertial response and providing damping and droop power. For the simulated cases, the nonlinear strategy was always capable of keeping the output voltages balanced. However, when the PV plant performed the VSG functions, the nonlinear strategy demonstrated a poor tracking capability of the output power reference. These results suggest that higher order controllers (instead of only gains) have to be tested in the nonlinear strategy in order to improve the tracking of the VSG power reference. Pooja Unnikrishnan, An efficient load sharing strategy among distributed generators in hybrid system: Efficient load sharing among distributed energy resources (DER) is not only an important way to realize the optimal operation of microgrid but also to maintain stability of system. Load sharing is done among DER and battery.

The wind power generator and the solar power is incorporated to the grid and battery is developed for storing the energy when the load power is less than the total generated power of wind and solar power plant and to supply power when both solar and wind energy are not able to meet the demand. Thus continuous power supply is maintained. Harmonics are generated due to the presence of non-linear load. Harmonics to an extend causes no harm to the system. When large amount of harmonics are generated increased heating in conductors and equipment, misfiring of variable speed drives, torque pulsation in motors etc. are caused. The wind model, solar model, non-linear load and battery integrated to the grid are simulated in MATLAB/SIMULINK. Filter is placed to eliminate the harmonics caused due to non-linear loads. Active shunt filter connected in parallel with non-linear load is considered as linear load which will supply harmonic free current.

Bonginkosi A. Thango, Step-Up Transformers for PV Plants: Load Loss Estimation under Harmonic Conditions: In 2010, South Africa introduced the Renewable Energy Independent Power Producer Procurement Programme to invigorate low-carbon energy generation using renewable energy resources. Amongst the development of wind and hydro plants; solar photovoltaic plants then took off rapidly. The volume of solar PV plants connected to the grid in 2015 and 2016 was unparalleled.

However, the solar PV electric power distribution network is challenged with the presence of unacceptable harmonics and distortion content at the point of common coupling due to the switching action of inverters and operation of non-linear loads. It therefore essential to precisely estimate the resultant increased load losses in order to estimate the hot spot temperature and total losses during service.

In order to demonstrate the significance of these challenges, this paper provides a comprehensive harmonic analysis of an oil-filled transformer for the supplied geometrical data and harmonic spectrum of an oil-filled transformer. The load losses are evaluated under fundamental and harmonic conditions. The load losses are classified into I2R and stray losses. The I2R losses can be easily obtained by analytical calculations and also through practical measurement.

On one hand, analytical calculation of the stray losses cannot give an optimized estimation and practically their immeasurable. In this paper, a 2D FEM model that is dynamic to any transformer geometrical data is developed to produce pragmatic loss estimation by using knowledge of the magnetic flux density. Generally, analytical formulations neglect the radial magnetic flux density component. During operation, this component becomes predominant towards the winding ends and cannot be disregarded.

Rayappa David Amar Raj, Mitigation of Voltage And Current Harmonics In Double-Stage Grid-Connected PV Plant: Due to the escalating demand for electricity in recent years, there is a desperate need for renewable energy resources that can supply a large amount of power at less cost. The Grid-connected solar PV (GCSPV) system is known for its simplicity, less maintenance and operating expenses. Boost converter employed changes the fluctuating output to a steady output. Voltage source inverter (VSI) is used to change boosted DC voltage to AC voltage. A PWM technique is adopted to regulate VSI by proper switching. Because of the presence of these power electric devices and non-linear connected loads, the generation of harmonics in the system is inevitable.

These harmonics severely affect the operation of the PV system and power quality in the system. So an efficient passive LCL filter is needed to filter out the harmonics for better efficiency and power quality. The LCL filter designed in this paper decreases THD content in the grid output voltage and current to less than 1.17%. This filtered ac voltage is synchronized to the electric grid by a PLL system. The complete model a 100 kW double-stage three-phase grid-connected solar PV plant has been formulated in MATLAB, and a thorough investigation has been conducted on converter and inverter output parameters, electric grid voltage, current and power and THD percentage in inverter and grid output parameters.

Marcelo A. Perez, Asymmetric cascaded converter for solar PV applications: Solar photovoltaic energy systems have received increasing attention during the last years due mainly to the cost reduction of solar panels and the availability of power converters specifically designed for these applications. Small scale photovoltaic plants have been installed to fed houses and small business whether connected to the grid or stand-alone. In the latter case, the converter must provide a high quality output voltage even with non-linear loads. In this paper the design and control scheme of an asymmetric cascaded converter for small scale PV applications is shown. The converter proposed is

based on a main stage which provides the active power to the load and a secondary stage that generates the reactive power compensation. It is shown that this asymmetric converter can work with higher voltage ratios than previously published asymmetric converters and can generate high quality output voltages for both linear and non-linear three-phase loads. The proposed converter is analysed and design guidelines are given. Results that shown the performance of the converter and its control system are presented.

B.A Thango, Service Life Estimation of Photovoltaic Plant Transformers Under Non-Linear Loads: South Africa has achieved a substantial amount in the country's energy generation capacity through distributed photovoltaic systems. A much-discussed hindrance on this development has been related to the rich penetration of harmonics and distortion in the connected transformers, which drives a temperature rise and generation of hotspots in the active part components. In this paper, the loss components of a 15MVA transformer that governs its performance under non-linear loads are examined. Finite Element Method is used as a method to evaluate the transformer losses under these conditions.

Subsequently, the generated hotspot temperature and remaining service life of the transformer are evaluated. In this paper, an effort is made to illustrate how a transformer manufacturer can predict the remaining service lifetime under various loads for solar photovoltaic application. Findings indicate that when the plant loading is gradually increasing during service, utility owners may contemplate replacing existing transformer with a higher MVA rating.

Dixitkumar P Pathak, Off-Grid Integrated Renewable Energy System Scheduling for an un-electrified remote area: The optimum utilization of alternative sources of energy are allied with supply of electrical power to the elected area of customers underneath grid connected or standalone mode. An alternative source of energy supports the high reliability in on-site generation. Consequently, it is found many hybrid schemes all ready existence like micro wind turbine, SPV panels, Small hydro, Biomass energy and Biogas energy systems. Moreover integrated renewable energy system (IRES) is further effective in comparison to grid extension which is too expensive.

The representation of IRES provides support to specific site which is located on the nearly accessible Non-conventional energy resources and load requirement. This article reveal that an optimal modeling of MHP, solar, bio-mass, wind and bio-gas energy scheme for un-electrified remote area in Gujarat. Considering this, the seven un-electrified clusters of villages in taluka, Limkheda and district, Dahod in Gujarat state have been selected as study region. The best possible daily scheduling approach for renewable energy sources (RES) like solar, wind, small hydro, biomass, and biogas system with using battery set storage system has been proposed in this paper. The proposed IRES model has been proposed that is more economical in terms of operating cost. The proposed model has been optimized using Primal-Dual Interior Point (PDIP) method in Linear Programming problem (LPP) technique. The proposed representation has been verified in MATLAB environment.

Igor B. M. Matsuo, An Optimized Frequency Scanning Tool for Sub-Synchronous Interaction Analysis of Non-Linear Devices: Frequency scan is a powerful and versatile approach for Sub-Synchronous Interaction (SSI) screening in power grids. Among different numerical and analytical frequency scan techniques, the harmonic injection method is well suited for the scan of black-box models with active elements, such as in wind farms and solar plants. The results can be used for SSI risk assessment, in which accuracy performs a decisive role. The ideal situation for this method, which leads to the most accurate results, is to perform one simulation per single-frequency harmonic injection.

However, for SSI studies with a wide range of frequencies and simulations with very small time steps (scale of μs), this comes at the expense of increased simulation time and financial costs. This paper proposes a technique to improve the accuracy of the harmonic injection method through the optimization of crest factor while injecting all frequencies at one shot, therefore increasing the efficiency of the method by a considerable decrease in simulation time while maintaining good accuracy. The proposed technique was tested on a 100 MVA wind farm connected to the grid through a series-compensated line. The frequency scan results were benchmarked with both Electromagnetic Transient Simulation (EMT) and the ideal multiple single-frequency injection case and compared with other techniques. The results are indicative of the accuracy and robustness of the proposed method.

IV. CONCLUSION

The objective of this paper was to present a comparative study on both approaches. The measurements were conducted for different nonlinear load types served from the same feeder at the same time. The study indicates that harmonics in the current waveforms strongly deteriorate the quality of the electricity.

The current harmonic pollution at PCC depends on the summation and/or cancellation effects in total current drawn from the grid by nonlinear loads. This should be a key factor used to determine the guidelines that limit current harmonic pollution in the distribution system. Another value of this work is the establishment of a framework for comparing the harmonic effect of various appliances consistently. The next effort is to increase the number of appliance types measured so a useful database can be established.

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