SIMULATION OF BACK STEPPING SLIDING MODE CONTROL FOR GRID CONNECTED DG UNITS WITH HARMONIC CURRENT COMPENSATION

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Abstract: The increased application of nonlinear loads such as computers, variable-speed drives, and compact fluorescent lamps, as well as power-electronics-based distributed generation (DG) systems may lead to distribution system harmonic pollutions. This project presents a new nonlinear current control strategy based on back stepping control and high-order sliding mode differentiator in order to employ distributed generation (DG) unit interfacing converters to actively compensate harmonics/inter harmonics of local loads. The converter-based DG unit is connected to a weak grid (with uncertain impedance) and local load (that can be parametrically uncertain and topologically unknown) through an LCL filter. The proposed strategy robustly regulates the inverter output currents and delivers pure sinusoidal, three-phase balanced currents to the grid. The new controller demonstrates the robust performance and robust stability of the DG unit system with respect to the filter parameters uncertainties, grid impedance, grid frequency, and grid voltage as well as the unknown load dynamics that include unbalanced loads and nonlinear loads with harmonic and inter-harmonic currents. We should remark that the local compensation of the loads with inter-harmonic current using a DG unit system is first proposed in this proposed work. When compared with the popular parallel proportional resonant (PR) control technique, the proposed controller offers smoother transient responses and a lower level of current distortion. The performance of the proposed control strategy is verified in MATLAB-Simulink.

Keywords: PR, LCL, SMC, Back Stepping, DG Unitetc.

I. INTRODUCTION

In order to protect the natural environment on the Earth, the development of clean energy without pollution has the major representative role in the last decade. By accompanying the permission of Kyoto Protocol, clean energies, including fuel cell, photovoltaic, and wind energy, have been widely applied for distributed generation (DG) installations [2]. In traditional power systems, power stations with fossil combustion engines that are located far from the consumers require the building of long transmission lines, which are very expensive. Moreover, estimates by the World Bank state that as much as 40% of the world’s population lives in villages not tied to any utility grid. Therefore, the DG units are often taken as a prime candidate in the building of a small-scale stand-alone generation plant for household electric supply. However, the DG units often cannot directly support the electrical appliances with the same power qualities of the grid in terms of frequency and amplitude. Thus, a high-performance inverter with the abilities of both stand-alone operation and utility-grid connection is necessary to ensure efficient utilization of DG units.

Developments in microelectronics and power devices have made the widespread applications of pulse width-modulation (PWM) inverters to industries. The basic mechanism of a PWM inverter is to convert the dc voltage to a sinusoidal ac output through the inverter–LC-filter blocks. The performance is evaluated by the total harmonic distortion (THD), the transient response, and the efficiency. In the past decade, much attention has been paid to the closed-loop regulation of PWM inverters to achieve good dynamic response under different types of load, e.g., linear control, passivity-based control, Lyapunov-based control, and sliding-mode control (SMC). The increasing application of nonlinear loads can lead to significant harmonic pollution in a power distribution system. The harmonic distortion may excite complex resonances, especially in power systems with underground cables or subsea cables [2] and [3]. In fact, these cables with nontrivial parasite shunt capacitance can form an LC ladder network to amplify resonances. In order to mitigate system resonances, damping resistors or passive filters can be placed in the distribution networks [1]. Nevertheless, the mitigation of resonance propagation using passive components is subject to a few well understood issues, such as power loss and additional investment. Moreover, a passive filter may even bring additional resonances if it is designed or installed without knowing detailed system configurations. To avoid the adoption of passive damping equipment, various types of active damping methods have been developed. Among them, the resistive active power filter (R-APF) is often considered as a promising way to realize better performance. Conventionally, the principle of R-APF is to emulate the behavior of passive damping resistors by applying a closed-loop current-controlled method (CCM) to power electronics converters. In this control category, the R-APF can be simply modelled as a virtual harmonic resistor if it is viewed at the distribution system level [2]. By increasing the requirement to electrical energy consumption, renewal of power industry, enhancing the completion, the need to improve and hence the future of environmental issues, developing the intelligent power systems, opportunities for advancement and growth of new technologies, such as solar cells, micro turbines and wind turbines have been provided. On the other hand, for the
better quality, increasing the reliability, the power industry was directed toward distributed generation. Distributed generators such as PV cells are renewable resources that have high reliability but require high investment costs, but due to environmental conditions in recent years, much tendency and attention have been done to them. Also, a lot of works are carried out in order to reduce costs and increase efficiency. In systems with distributed generation sources, it is possible that anti protective case occurs called islanding.

II. RESEARCH GAP &OBJECTIVES
The increased application of nonlinear loads such as computers, variable-speed drives, and compact fluorescent lamps, as well as power-electronics-based distributed generation (DG) systems may lead to distribution system harmonic pollution. This project presents a new nonlinear current control strategy based on back stepping control and high-order sliding mode differentiator in order to employ distributed generation (DG) unit interfacing converters to actively compensate harmonics/ inter harmonics of local loads. The converter-based DG unit is connected to a weak grid (with uncertain impedance) and local load (that can be parametrically uncertain and topologically unknown) through an LCL filter. To compensate for the local load harmonic current, many types of harmonic extraction approaches have been suggested including instantaneous power (PQ) theory, second order generalized integrator (SOGI), the delayed-signal cancellation-based detection, and Fourier transformation based detection. To reduce the computational burden of DG unit controllers, the harmonic detection less method has been proposed in later on developed controlling techniques.
The main grid current commonly needs to be free of harmonic distortion. To improve the power quality of the grid current, the DG unit compensates for the harmonic current drawn by the nonlinear loads through injecting harmonic current. Therefore, the grid current will become free of distortion and the result will be good voltage quality at the point of common coupling (PCC). It becomes more important for a weak grid, where the harmonic current flowing through high grid impedance may cause more voltage distortions at the PCC. As a result, the improvement of the distribution system power quality through the proper control strategy of DG is an issue with high potential for engineering solutions.

- This project presents a new nonlinear current control strategy based on back stepping control and high-order sliding mode differentiator in order to employ distributed generation (DG) unit interfacing converters to actively compensate harmonics/ inter-harmonics of local loads. The converter-based DG unit is connected to a weak grid (with uncertain impedance) and local load (that can be parametrically uncertain and topologically unknown) through an LCL filter.

- The proposed strategy robustly regulates the inverter output currents and delivers pure sinusoidal, three-phase balanced currents to the grid. The new controller demonstrates the robust performance and robust stability of the DG unit system with respect to the filter parameters uncertainties, grid impedance, grid frequency, and grid voltage as well as the unknown load dynamics that include unbalanced loads and nonlinear loads with harmonic and inter-harmonic currents.

- We should remark that the local compensation of the loads with inter-harmonic current using a DG unit system is first proposed in this project. When compared with the popular parallel proportional resonant (PR) control technique, the proposed controller offers smoother transient responses and a lower level of current distortion.

III. POWER QUALITY
A Power Quality problem can be defined as deviation of magnitude and frequency from the ideal sinusoidal waveform. Good power quality is benefit to the operation of electrical equipment, but poor power quality will produce great harm to the power system. Most of the electronic equipment such as personal computers, telecommunication equipment, microprocessors and micro controller, etc. is responsible for power quality problems. Harmonics are defined as sinusoidal wave form having a frequency equal to an integer multiple of the power system fundamental frequency. It is a component of a periodic waveform. If the fundamental frequency multiple is not an integer, then we are dealing with inter harmonics. Most of the electronic equipment such as personal computers, telecommunication equipment, microprocessors, and microcontrollers etc.; are generally responsible to Power Quality problems. A poor power quality has become a more important issue for both power suppliers and customers. Poor power quality means there is a deviation in the power supply to cause equipment malfunction or may failure.

The definition of power quality is different for the different uses. As per the Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 is “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” The effects on load and faulty condition occur in the system create the power quality (PQ) problem. The PQ problems will effect on electrical equipment like transformer, motors, generators and home appliances. A simple definition is that “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.” The above definition of power quality gives us two functions for electrical devices. The first one is performance and second one is expectancy. This chapter provides information regarding power quality. In this chapter we also discuss about how we can improve the power quality in the system.
The important things which are concerned regarding the power quality are given below:-

(1) Long duration voltage variation: -
Over voltage, under voltage, Sustained Interruption
(2) Short duration voltage variation: -
Interruption, Voltage unbalance, Sag, Swell, harmonics distortion, voltage fluctuation and power frequency
variations, etc.
In the electrical system there are two types of loads: -
1) Linear load: The load in which the voltage and current is related to each other and linearly varies. The examples of linear load are motors, heaters, incandescent lamp, etc.
2) Nonlinear load: The load in which the voltage and current is not related to each other and their value also not dependent to each other.
The examples of nonlinear loads are Arc furnace, welding, Resistance welding, etc. The nonlinear load uses high-speed electronic power switching devices for A.C to D.C conversion in internal circuits. Due to this harmonics are produced at the point of common coupling and some other problems of heating and line interference are also occurred. The different nonlinear loads which produce power quality problems like waveform distortion, harmonics are PC, fax machines, printers, Drives, UPS, lighting Ballasts etc.

IV. PROPOSED WORK
The robust hysteresis controller compensates harmonics in specific frequencies. Resonance mitigation in the grid connected converters has been investigated in literature papers. This project proposes a new nonlinear control strategy to control the current of a converter-based DG unit connected to a weak grid (with uncertain impedance) and a local load (that can be parametrically uncertain and topologically unknown) through an LCL filter. The proposed controller regulates the grid current in a robust way. In the proposed control strategy, the PCC voltage is considered a measurable disturbance signal. To effectively reject the impact of the disturbance signal on the performance of the system, this paper proposes a new back stepping control with an arbitrary order exact differentiator strategy. According to the separation principle, a controller and a differentiator can be designed separately. A differentiator rejects the impact of a disturbance signal and a back stepping control regulates the DG current.
The main salient features of the proposed method can be summarized as follows:
1) The use of a new back stepping control with an arbitrary order exact differentiator technique for control of the DG unit systems has not been proposed or investigated before.
2) To the best of our knowledge, local compensation of the load with inter harmonic currents, such as induction furnace, to the grid-connected DG unit has not been investigated before.
3) Unlike existing methods, if the harmonic/inter harmonic frequency of the local loads is changed, it is not necessary to change the control structure. This leads to a reduction in the steady-state error of the controller.
4) When compared with the popular parallel PR controllers, the proposed controller offers smoother transient responses with lower levels of current distortion.

Moreover, the new controller demonstrates the robust performance and stability of the DG unit system with respect to grid impedance, grid frequency, grid voltage, filter parameters uncertainties, and the unknown load dynamics.

Finally, the simulation results of the proposed controller are compared with those of the conventional parallel PR control method, which confirms the superiority of the proposed nonlinear current controller. Fig. 1 shows the block diagram of a three-phase, four wire, grid-connected DG unit, in which a common three phase voltage-source inverter (VSI) is connected to the grid via an LCL filter. The local loads are connected to the PCC, which are placed at DG unit terminals. As depicted in Fig. 5.6, the DG output currents are regulated by the proposed controller, while the harmonic extraction block extracts the loads harmonic/inter harmonic currents and produce the harmonic/ inter harmonic currents references to inject a set of pure sinusoidal balanced three-phase grid currents. Fig. 2 shows the circuit diagram of a three-phase four-wire DG unit in grid connected mode. L1 is the inverter-side inductor along with parasitic resistance; L2 is the grid-side inductor along with parasitic resistance; and C is the filter capacitor.
**Back stepping Control**

PI controllers and parallel PR controllers are usually applied to the converter-based DG unit. Recently, however, the back stepping method has been applied to micro grid systems, which allows the designer to incorporate most system nonlinearities and uncertainties into the design of the controller. The back stepping method provides a recursive method for stabilizing the origin of a system or tracking the desired trajectory in strict-feedback form. Moreover, the adaptive back stepping method is applied to the hybrid micro grid to guarantee large signal stability and robustness against un-modelled dynamics, thereby enhancing the system performance. Recently, an adaptive back stepping sliding mode control method has been employed to design the nonlinear controller of a micro grid system. The proposed method can not only overcome the system nonlinearities and uncertainties, it can also improve the performance of robustness. The existence of parametric uncertainties and disturbances complicates the synthesis of back stepping controllers. In particular, mismatched disturbances limit the application of back stepping techniques.

**V. MODELLING AND SIMULATION**

![Fig 3 Main System of DG unit connected with Grid](image1)

![Fig 4 Structure of the proposed robust controller](image2)

![Fig 5- Back stepping Sliding Mode Control Matlab simulation](image3)

![Fig 6- Proposed Robust (PR) Controller Subsystem](image4)

![Fig 7- Non Linear Load subsystem](image5)
Fig 8 - load currents during Unbalanced Load

Fig 9 - DG currents during Unbalanced Load

Fig 10 - grid currents during Unbalanced Load

Fig 11 - control signals (Inverter Output Voltage) during Unbalanced Load

Fig 12 - tracking errors during Unbalanced Load

Fig 13 - load currents under Three-Phase Harmonic Load

Fig 14 - PCC voltages under Three-Phase Harmonic Load

Fig 15 - DG currents under Three-Phase Harmonic Load
Fig 16 - grid currents under Three-Phase Harmonic Load

Fig 17 - control signals (Inverter Output Voltage) under Three-Phase Harmonic Load

Fig 18 - tracking errors under Three-Phase Harmonic Load

Fig 19 - load currents under Connection of a Single-Phase Load with Inter harmonic Current

Fig 20 - DG currents under Connection of a Single-Phase Load with Inter harmonic Current

Fig 21 - grid currents under Connection of a Single-Phase Load with Inter harmonic Current

Fig 22 - control signals (Inverter Output Voltage) under Connection of a Single-Phase Load with Inter harmonic Current

Fig 23 - tracking errors under Connection of a Single-Phase Load with Inter harmonic Current

Fig 24 - load currents during single-phase nonlinear load is connected to the PCC at t = 0.35 s
Fig 25 - DG currents during single-phase nonlinear load is connected to the PCC at t = 0.35 s

Fig 26 - grid currents during single-phase nonlinear load is connected to the PCC at t = 0.35 s

Fig 27 - tracking errors during single-phase nonlinear load is connected to the PCC at t = 0.35 s

Fig 28 - load currents when the grid impedance is suddenly doubled at t = 0.45 s

Fig 29 - DG currents when the grid impedance is suddenly doubled at t = 0.45 s

Fig 30 - grid currents when the grid impedance is suddenly doubled at t = 0.45 s

Fig 31 - control signals (Inverter Output Voltage) when the grid impedance is suddenly doubled at t = 0.45 s

Fig 32 - tracking errors when the grid impedance is suddenly doubled at t = 0.45 s
VI. CONCLUSION
In this project, a new harmonic and inter harmonic compensation strategy is proposed for DG interfacing converters with LCL filters. The proposed method combines a backstepping control system based on a high-order sliding mode differentiator. The DG unit is connected to a weak grid (with uncertain impedance) and a local load (which can be parametrically uncertain and topologically unknown) through an LCL filter. The PCC voltage is considered a measurable disturbance signal. The aim of the controller is to regulate the grid current, irrespective of the load dynamics, grid impedance, grid frequency, and the grid voltage. To achieve the desirable performance and to reject any disturbance signal, a new backstepping control based on a high-order sliding mode differentiator is proposed. It is worth mentioning that the use of a new backstepping control with an arbitrary order exact differentiator technique for the control of DG grid-connected systems has not been proposed or investigated before.

REFERENCES