A Topology for High-Order Vector Control of Grid-Connected VSC with LCL-Filters

P. Anusha, Dr. B. Venkata Prasanth, Muzeeb Khan Patan

Abstract— **A new vector control topology for LCL-filter-based grid-connected voltage source converters (VSCs). The proposed control strategy is inherently capable of attenuating the resonance phenomenon of such systems. This is an advantage over the existing methods, which require additional damping techniques. Moreover, the proposed vector control strategy is able to fully decouple the direct (d) and quadrature (q) components of the current in a rotating reference frame. The design procedure comprises a constrained optimization-based loop shaping. It utilizes the multi-input multi-output (MIMO) nonparametric model of the system along with a high-order linearly parameterized MIMO controller to form an open-loop transfer function matrix. Minimizing the second norm of the error between the open-loop transfer function matrix and a desired one, the coefficients of the controller are optimally determined. Conducting several reference tracking scenarios, the performance of the proposed vector controller is evaluated both by means of time domain simulation studies in MATLAB/Simulink and experimental results.**

Index Terms— **multi-input multi-output (MIMO, voltage source converters (VSCs)**

I. INTRODUCTION

The rapid development of renewable energy related technologies, pulse width modulation (PWM) voltage-source converters (VSCs) are attracting significant interest and attention as the interfacing unit between such energy resources and the utility grid. Moreover, VSCs are utilized in various other power-electronic-based applications, e.g., power filters, electric drives, flexible AC transmission technologies, high voltage DC transmission systems. In all of these applications, the VSC is interfaced to the utility grid through either L- or LCL-filters. The filter is mainly responsible for attenuating the switching harmonic generated by the VSC. LCL-filters, however, are preferred due to their lower cost and superior harmonic attenuation capability compared to L-filters. Regardless of their application, grid-connected VSCs generally require a regulation scheme for controlling their current. In case of L-filter-based systems, the VSC current is regulated by well-known vector control strategies. For the vector control of LCL-filter-based VSCs, however, very limited specifically tailored vector control strategies exist. The conventional approach in such cases is to neglect the capacitor dynamics. Therefore, the vector controller is designed by considering the equivalent series connection of the LCL filter inductors, simplifying the control problem to that of a first-order system. As third-order systems, however, LCL-filters could potentially result in oscillatory and/or unstable dynamic behavior if the closed-loop system is not properly damped. Therefore, a damping strategy must accompany the vector controller.

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II. RENEWABLE ENERGY SOURCES:

A renewable source is a natural resource which can replenish with the passage of time, either through biological reproduction or other naturally recurring processes. Renewable resources are a part of Earth's natural environment and the largest components of its ecosphere.

Solar Energy: Solar power is the conversion of sunlight into electricity, either directly using photovoltaic's (PV), or indirectly using concentrated solar power (CSP). Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic's convert light into electric current using the photoelectric effect.

Wind Power: Wind power is the conversion of wind energy into a useful form of energy. Most modern electrical wind power is generated by converting the rotation of turbine blades into electrical currents by means of an electrical generator.

Hydropower: Hydropower is energy derived from the movement of water in rivers and oceans, originally used for irrigation and the operation of various mechanical devices. Since the early 20th century, the term is used almost exclusively in conjunction with the modern development of hydro-electric power.

Geothermal Energy: Geothermal energy comes from the Earth's crust and originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%). The available energy from the Earth's crust and mantle is approximately equal to that of incoming solar energy.

Biofuel: A bio fuel is a type of fuel whose energy is derived from biological carbon fixation. Bio fuels include fuels derived from biomass conversion, as well as solid biomass, liquid fuels and various biogases.

Fuel Cell: A fuel cell is an electrochemical device (a galvanic cell) which converts free energy of a chemical reaction into electrical energy (electricity); by products are heat and water/steam.

III. LCL-FILTER

LCL filters, which are particularly popular in the renewable energy industry today, are an efficient and economical way of ensuring and improving the quality of power fed from the energy source to the grid. Their purpose is to filter the inverter's switching frequencies. When the targeted distortion level is reached, the filter can create measurable cost savings. Small losses and small size and weight in relation to capacity are typical for LCL filters.

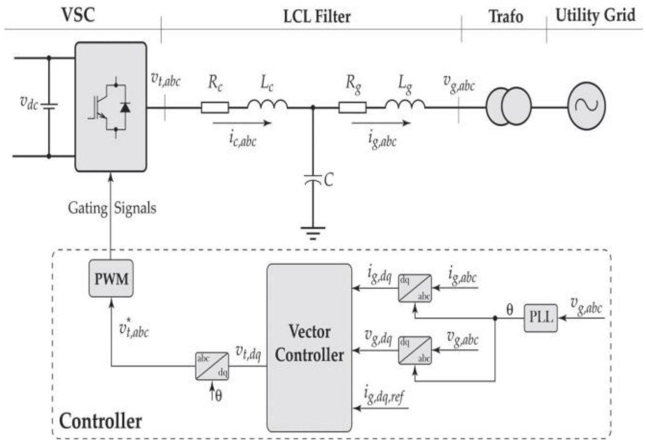

Fig. 1Single-line diagram of the three-phase test system.

A LCL filter is often used to interconnect an inverter to the utility grid in order to filter the harmonics produced by the inverter.

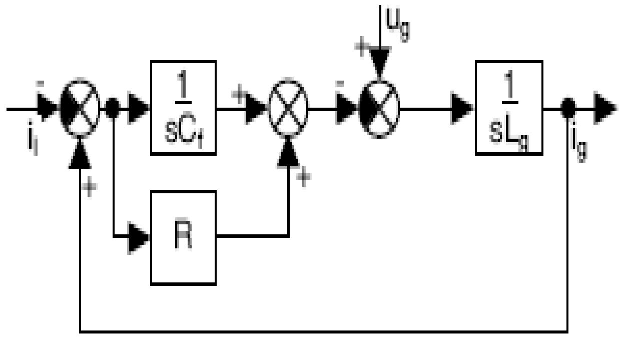

Fig. 2 Filter Model

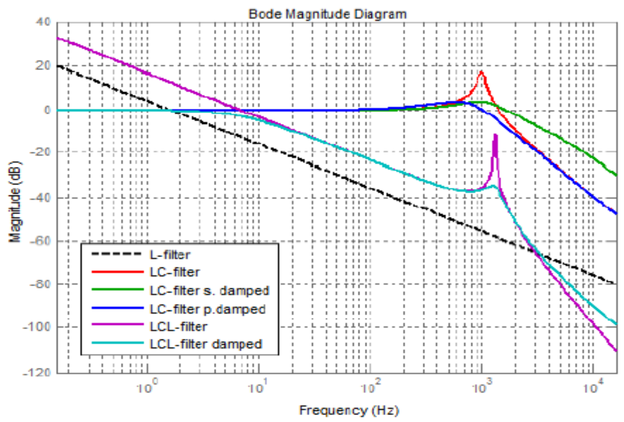

Fig. 3 Bode Plots of Different Filters

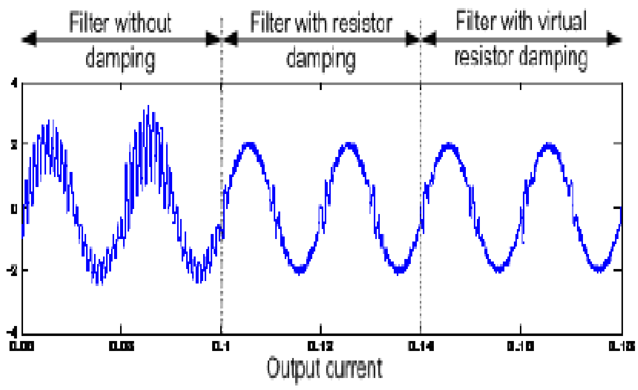

Fig. 4 Effects of Damping Circuit

IV. GRID CONNECTED VOLTAGE SOURCE CONVERTERS

A scheme of the main circuit of the VSC is shown in Fig. 5 . The valves are of the IGBT type. The VSC is connected to a symmetric three-phase load, which has the impedance *R*+jω*L* and the emfs *e*1(*t*), *e*2 (*t*) and *e*3(*t*). The neutral point of the star-connected load has the potential *v*0 (*t*), due to a floating ground. The phase potentials of the VSC are denoted as *v*1(*t*), *v*2 (*t*) and *v*3(*t*). The phase voltages of the VSC are denoted as *u*1(*t*), *u*2(*t*) and *u*3(*t*). The current flowing from the dc-link to the converter is denoted as *Iv*(*t*), the dc-link current is denoted as *idc*(*t*) and the dc-link voltage across the dc-link capacitor is denoted as *udc*(*t*).

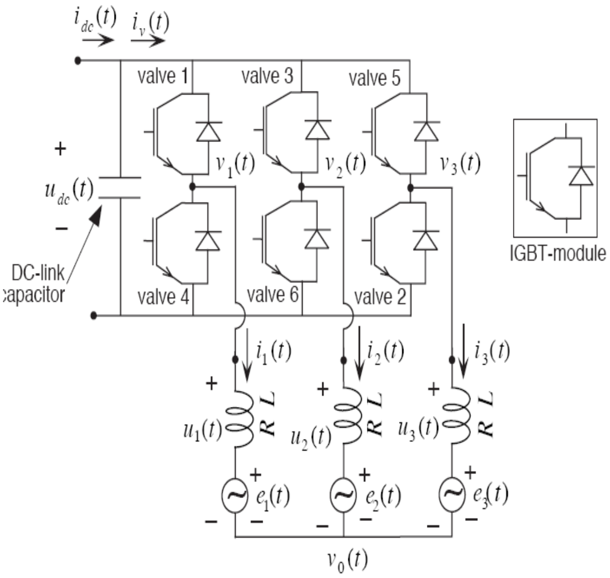

Fig. 4 Main Circuit of VSC

Two control principles are investigated for a VSC connected to a grid. They are the voltage angle control and the vector current control.

The voltage angle control is simple to implement in an analog controller or a microcontroller. However, the bandwidth of the system is low, since the controller is based on a steady-state model. The basic principle of the vector current controlled grid-connected VSC is to control the instantaneous active and reactive grid currents independently of each other and with a high bandwidth.

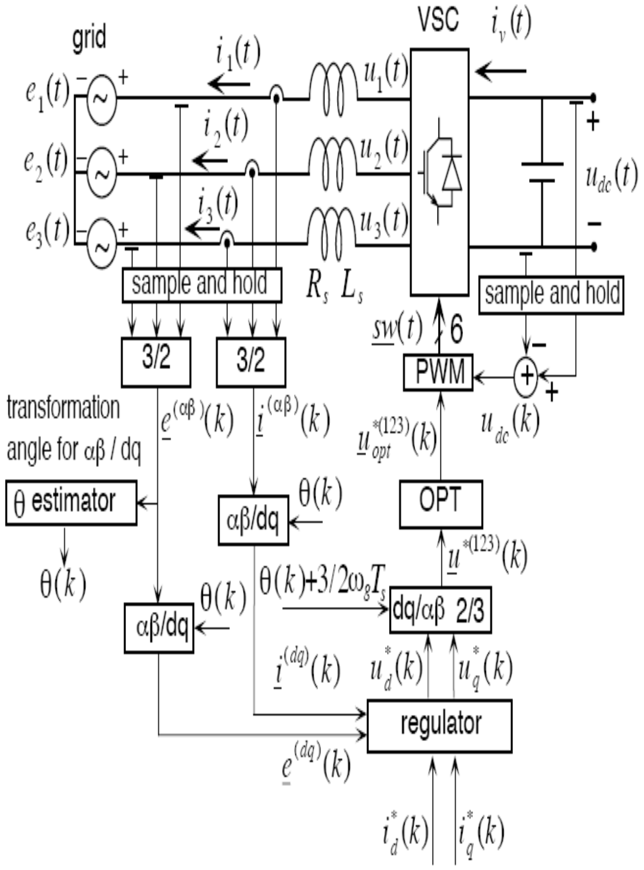

Fig. 5 Principle diagram for vector current controller

The dq0_to_abc Transformation performs the reverse of the so-called Park transformation, which is commonly used in three-phase electric machine models. It transforms three quantities (direct axis, quadratic axis, and zero-sequence components) expressed in a two-axis reference frame back to phase quantities. The following transformation is used

$$V_a = V_d \sin(\omega t) + V_q \cos(\omega t) + V_0$$

$$V_b = V_d \sin(\omega t - 2\pi/3) + V_q \cos(\omega t - 2\pi/3) + V_0$$

$$V_c = V_d \sin(\omega t + 2\pi/3) + V_q \cos(\omega t + 2\pi/3) + V_0$$

V. SIMULATION CIRCUITS & RESULTS

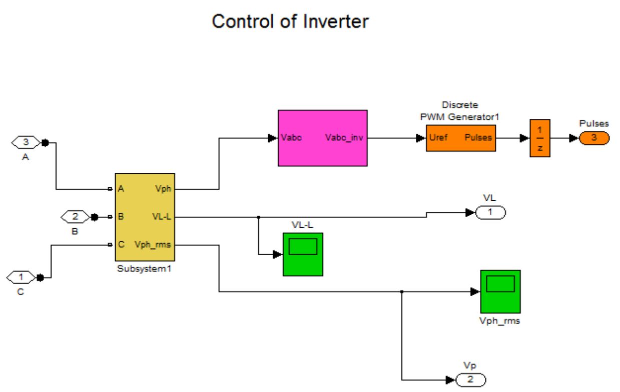

Fig. 6 Simulation circuit of inverter control with PI controller.

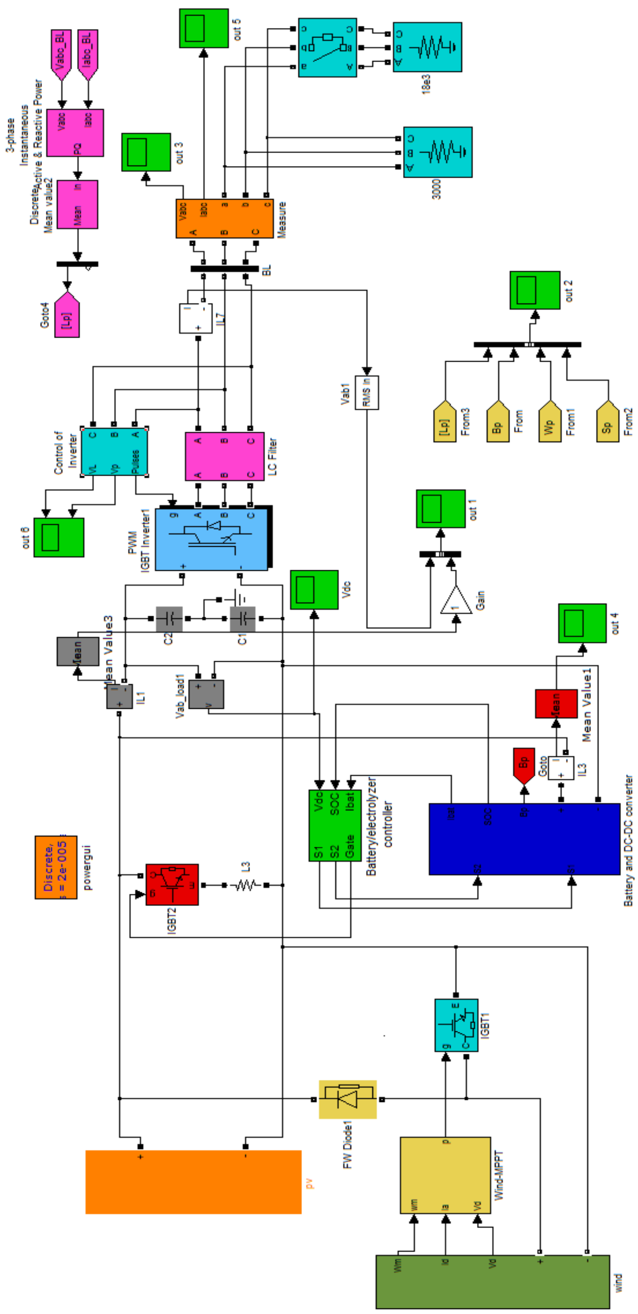

Fig. 7 Simulation circuit of VSC with grid of PV cell & Wind energy systems

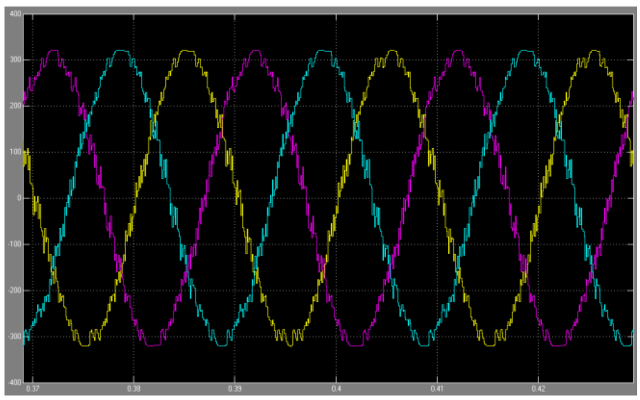

Fig. 8 Three phase grid voltage V_{abc}

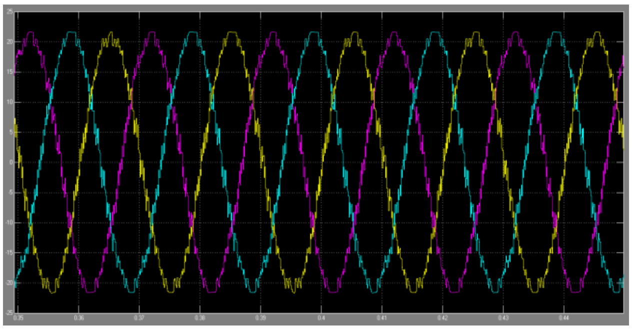

Fig. 9 Three phase grid current I_{abc}

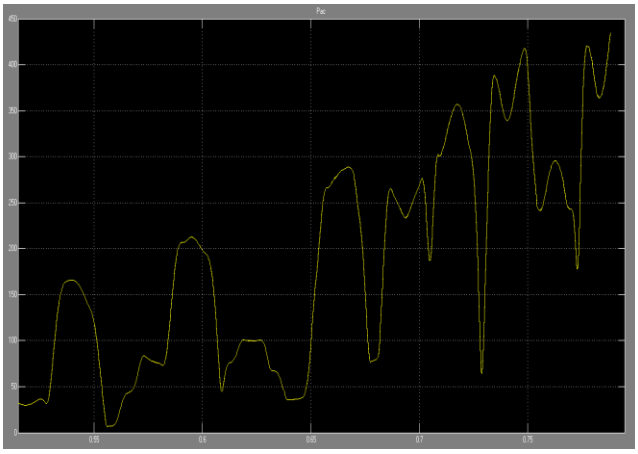

Fig. 10 Wind Power

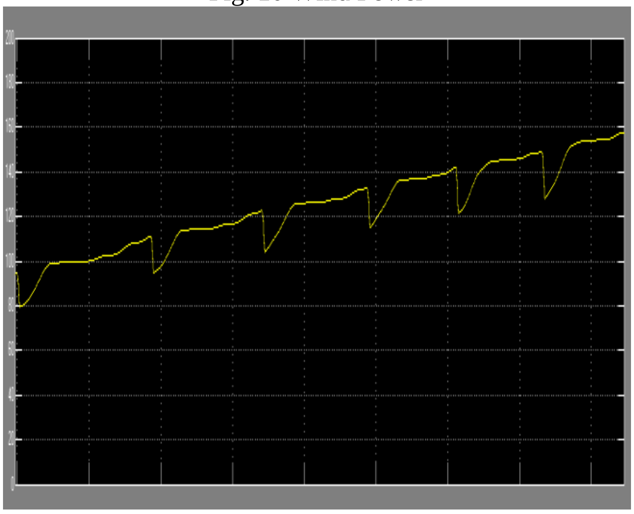

Fig. 11 Wind Voltage

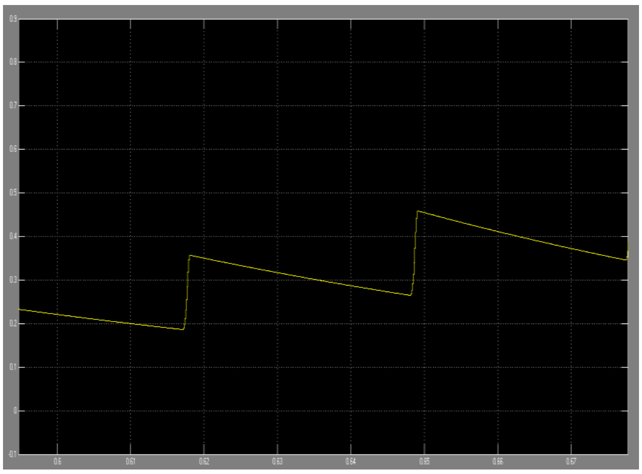

Fig. 12 Wind Current

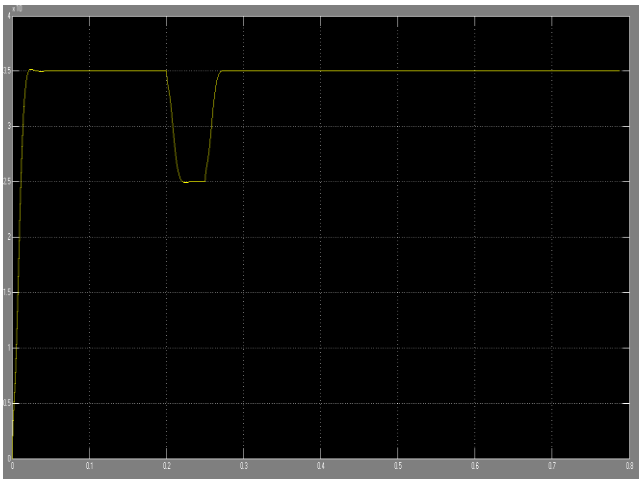

Fig. 13 PV Cell Power

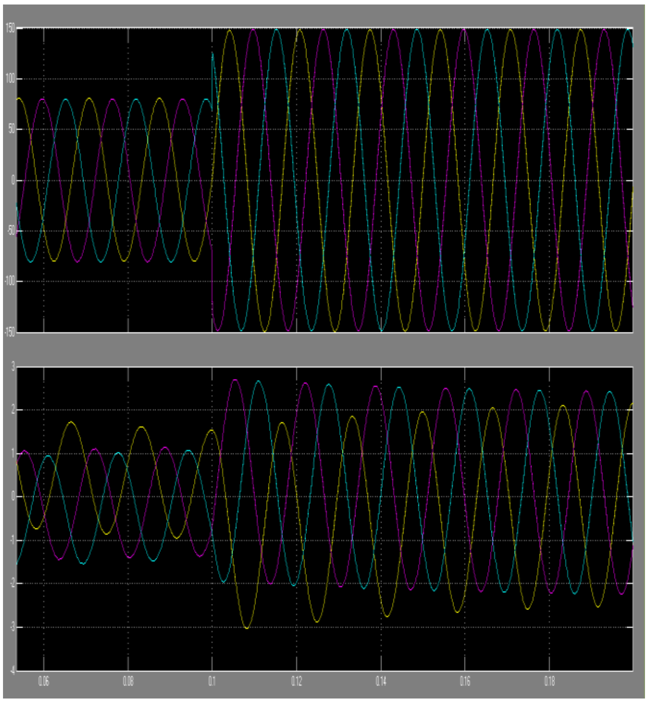

Fig. 14 Load Voltage & Current with effect LCL Filter.

VI. CONCLUSION

A vector control strategy for the LCL-filter-based grid-connected VSCs is proposed in this paper. To damp the resonance phenomenon of the LCL whose elements are linearly parameterized high-order controllers with integrators. Contrary to the existing vector control schemes for VSCs with LCL -filter, a MIMO controller matrix is adopted, filters, the proposed approach does not require extra damping methods. Moreover, the dynamic performance of the proposed approach is similar to the existing ones while its axis-decoupling capability is superior. The performance of the controller is evaluated for different sources. Based on simulation and experimental results, it is concluded that the proposed vector controller shows excellent dynamic performance in terms of reference tracking, axis-decoupling, and resonance attenuation, upon step-changes in the set-points of the *dq*-components of current. Moreover, despite uncertainties in the LCL-filter parameters, the dynamic performance of the controller is acceptable.

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