ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Design of Non Linear Power Damping Of Integrating VSCS to Weak Grids with Self Synchronization Capability



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Abstract:

The ever increasing progress of high-voltage high-power fully controlled semiconductor technology continues to have a significant impact on the development of advanced power electronic apparatus used to support optimized operations and efficient management of electrical grids, which, in many cases, are fully or partially deregulated networks. Developments advance both the HVDC power transmission and the flexible ac transmission system technologies. Here PI controller is mainly used to reduce the steady state error. Regarding, the system retaliation and overall stability of the system, it has a negative impact.

This paper presents a new control topology to enable effective integration of voltage source converters (VSCs) in weak grids. The controller has two main parts. The first part is a linear power-damping and synchronizing controller which automatically synchronizes a VSC to a grid by providing damping and synchronizing power components, and enables effective full power injection even under very weak grid conditions. The controller adopts cascaded angle, frequency and power loops for frequency and angle regulation.

The controller emulates the dynamic performance of synchronous machines, which eases grid integration and provides a virtual inertia control framework for VSCs to damp power and frequency oscillations. Although the linear controller offers stable and smooth operation in many cases, it cannot ensure system stability in weak grids, where sudden large disturbances rapidly drift system dynamics to the nonlinear region. The configuration process for the straight and nonlinear parts has been carried out in MATLAB/Simulink and the results are situations were exhibited to accept the controller viability.

Index Terms:

Distributed generation, nonlinear control, power damping, voltage source converter (VSC) control, weak grid.

I. INTRODUCTION:

The utilization of power electronic technology in power system applications has been steadily increasing during the last decades. The continuous improvement of semiconductor device technology and the availability of digital control systems with continuously increasing performance have reinforced this development. Power electronic converter technology has also been an important enabling factor for the recent developments in distributed generation and renewable energy systems, especially with respect to wind power and photovoltaic systems. A large variety of controllable power electronic converter topologies are currently being utilized in grid connected applications. The range of well known applications span from large thyristor-based line-commutated converters for classical high-voltage DC (HVDC) transmission systems, to small single-phase power-factor-correction circuits used for low power domestic loads. In between these examples, a wide range of topologies have been developed and optimized for various applications. However, only a few of the available three-phase topologies have reached widespread deployment and mass production. During the last couple of decades, the Voltage Source Converter (VSC) has emerged as the dominant topology for actively controlled three-phase applications. This development has been supported by the widespread use of VSCs in variable speed electric drive systems. VSCs operating as active rectifiers have also become a relevant option for replacing diode rectifiers or line-commutated converters due to the Pulse Width Modulated (PWM) operation, which ensures limited current distortion and reduced

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harmonic filter requirements together with the ability to control power factor and DC-link voltage. Thus, almost identical VSC modules connected in a back to-back configurations have become the most common solution for regenerative motor drives and variable speed generator systems. Various configurations based on three-phase VSCs are also used for distributed energy resources like photovoltaic's and fuel cell systems which naturally provide a DC output and depend on power electronic converters for integration to the AC grid. Other well-known applications of grid integrated VSCs include operation as grid interfaces of energy storage systems, reactive power compensation when configured as a Static Synchronous Compensators (STATCOM), and active filter systems. Motivated by the aforementioned challenges, a hybrid nonlinear control of VSCs in weak grids is proposed in this paper. The controller adopts a power synchronization loop with additional cascaded damping and synchronizing loops. The main characteristics of the proposed controller are summarized as follows: 1) the hybrid nonlinear power damping controller enables self-synchronization of a VSC in weak grids. This means that the controller does not need a separate synchronization unit and it automatically synchronizes itself with the grid. Self-synchronization is a new concept, and its importance is more pronounced in weak grids.

It should be noted that the process in still needs the inception time of synchronization and some information from the remote grid, thus it cannot realize a true plug-and-play operation. Moreover, its performance and stability in weak grids have not been investigated. It is noticeable that during islanding, an MG may usually face permanent frequency drop representing considerable frequency and angle mismatch at the moment of reconnection, however, with the proposed controller system does not need any initial synchronization with grid and it realizes a plug-and-play system. Therefore, better stability margin and damping characteristics can be achieved. This is a continuation where the concept of cooperative droop has been proposed. However, the method in demands accurate tuning of load angle and real power references, and lacks voltage regulation. In this paper, this problem is resolved by using a frequency loop as a first controller, therefore, the frequency reference is easily set equal to the grid nominal frequency. This is the first time the concepts of plug-and-play and nonlinear self-synchronization in VSCs are introduced. 2) The controller has cascaded frequency, angle and power loops.

3) Since the controller has a dynamic behavior similar to conventional SGs, it can be connected to very weak grids with SCR without loss of stability. 4) To guarantee system stability in all operating conditions especially when load angle drifts to the nonlinear region, a nonlinear supplementary controller is developed. 5)The controller is applicable to both modes of operation, i.e., islanded and grid-connected modes; therefore the need for islanding detection and system reconfiguration is automatically eliminated. 6) It provides fault-ride-through capability by proper adjustment of frequency, load angle and voltage amplitude, which in turn results in limiting current flowing into the interfacing circuit. It also automatically tracks and damps disturbances in main grid. The proposed control topology is general as it can be easily applied to VSC-based high-voltage dc (HVDC) transmission systems and DG units; however the main focus of this paper is on DG applications.

II. PROPOSED LINEAR CONTROLLER TOPOLOGY:

This paper focuses on the development of a nonlinear power damping control strategy for VSC units in weak grids with applicability to both grid-connected and islanded modes of operation. Fig. 1 shows the schematic view of a grid-connected VSC supplying a local load.

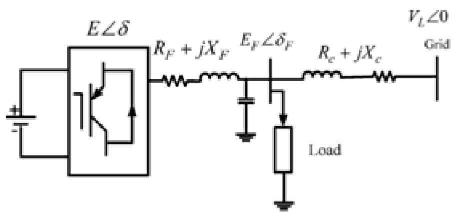

Fig.1. Circuit diagram of a grid-connected VSC

The most critical issue for controller design is the complexity of the system due to nonlinear behavior of the power transfer dynamics. Usually, linear controllers are developed based on small-signal linearization; however, the control performance inherently depends on specific operating points. In this paper, a two-level topology with cooperative nonlinear and linear controllers is developed. The first level is a power synchronizing-damping controller. The second level is a nonlinear controller supporting the linear part to enhance system stability in weak grids or during self-synchronization where load angle is large and system works in the nonlinear region.

ISSN No: 2348-4845
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The voltage generation principle is similar to an SG where the voltage frequency and load angle are tuned by power damping-synchronizing loop, whereas the voltage amplitude is given by voltage regulation loop similar to an automatic voltage regulator (AVR).

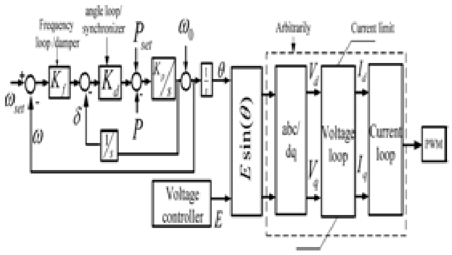

Fig.2. Proposed linear control scheme

The VSC's output real power is controlled directly by adjusting the load angle using the power-damping loop, whereas the reactive power (or alternating voltage) is controlled by adjusting the voltage magnitude. Since the VSC is voltage-controlled one, an inner current loop is not necessary except during large transients such as faults where the control strategy should be changed to current control mode to limit the current amplitude. It should be noted that the proposed outer-loop controller can be also integrated with cascaded voltage-current control loops to ensure high power quality injection and inherent current limitation during faults. In this case, the synchronization angle for dq-frame transformation is obtained from the proposed outer-loop controller instead of a PLL as shown in Fig. 2.

$$P = \frac{E}{R^2 + X^2}(XV_L \sin\delta + R(E - V_L \cos\delta)).$$

The base of power damping control of a grid-connected VSC is that the controller provides active damping and synchronization power to attenuate power, frequency and load angle oscillations, and synchronize the VSC with the grid during steady-state operation. By changing the control strategy of VSCs to comply with the power damping characteristics, VSCs can be integrated to weak grids and also cooperate with SGs in power grids.

$$SCR = \frac{short\ circuit\ capacity}{rated\ dc\ power}$$

Fig. 2 demonstrates the basic principle of the proposed controller in the polar system. It has three cascaded loops, namely frequency, angle and power loops. Based on the frequency error, the reference of the load angle is determined and the real power reference is obtained as a function of the load angle error.

Finally, the power synchronization loop adjusts VSC's instantaneous frequency and load angle. The synchronization and damping powers attenuate load angle and frequency fluctuations around equilibrium point and synchronize the VSC with the grid. Beside the inherent synchronization with the grid in steady-state, it is important to take into account that the VSC's frequency and angle are internally available; therefore, there is no need for a PLL in steady-state operation and several transient conditions.

III. SIMULATION RESULTS:

Fig. 3 shows the configuration of the simulated system. The system is composed of a 7.0 MW VSC, filter, local load, transformer and an interface line connecting the VSC to a grid. It is worth to mention that the impedance is the equivalent impedance of the stiff source referred to the distribution level. The simulation study was conducted in MATLAB/SIMULINK environment. The controller parameters are presented. The DG unit supplies the local load at its output terminal and is connected to a stiff grid through a very weak interface with total impedance. Since the connecting line is almost inductive, the power capacity of the interface line is approximated. The DG works as a PV bus aiming at keeping the filter output voltage constant during grid connection. A wide variety of scenarios have been applied to verify the effectiveness of the proposed hybrid nonlinear controller. System performance at low- and high-power references, transition to islanding, self-synchronization, sudden deviation in grid angle and three phase fault is studied. The advantage of the proposed controller is its flexibility to work in different conditions, i.e., grid-connected and islanded modes without reconfiguration whereas the nonlinear grid synchronizer enables the plug-and-play feature.

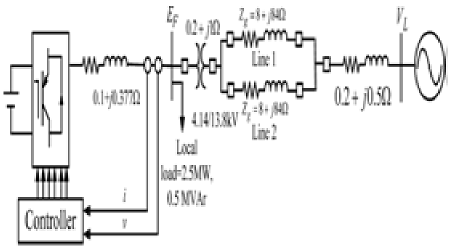

Fig.3. Simulated system

In this case, the supplementary nonlinear controller preserves the self-synchronization capability with large-signal stability.

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International Journal & Magazine of Engineering, Technology, Management and Research
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The controller without supplementary nonlinear control cannot offer self-synchronization capability under large-signal disturbances. Fault-ride-thorough is another advantage of the proposed controller and it will be shown that although the VSC works as a P-V bus, the current flowing in the power circuit during a three-phase fault is limited because of proper load angle adjustment.

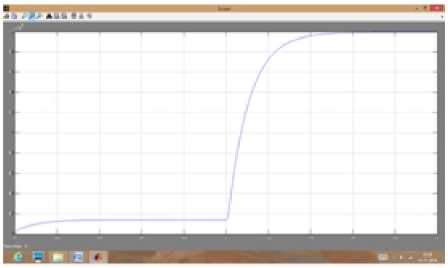

Fig 4 Real power

Fig 4 shows the wave form of low power injection which is varied from 2 to 6MW. Fig. 5 shows the real power waveform and Fig. 6 and 7 shows the frequency and phase voltage amplitude variation, respectively.

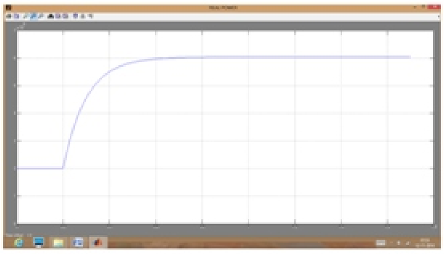

Fig 5 Real power

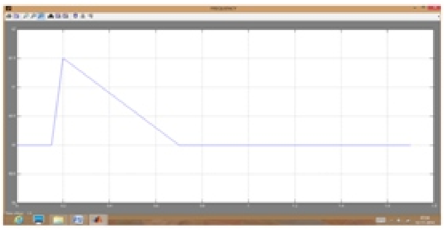

Fig 6 Frequency

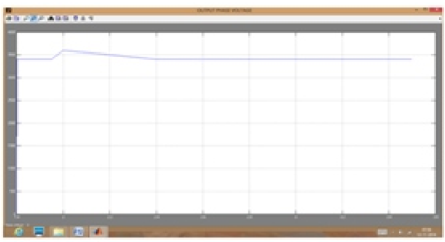

Fig 7 Phase voltage amplitude

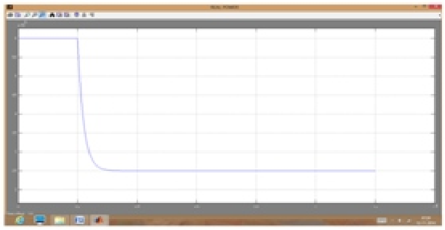

Fig 8 Real power during transition to islanding

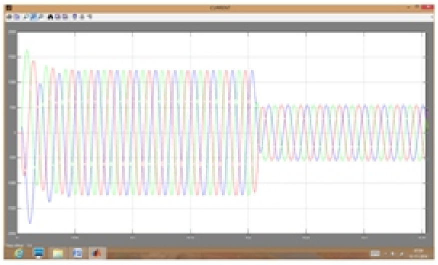

Fig 9 Current waveforms subsequent to islanding

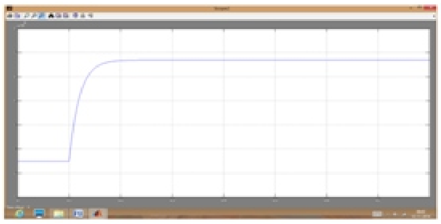

Fig 10 Real power with nonlinear supplementary controller

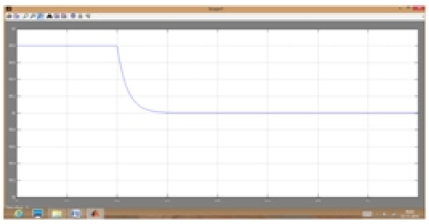

Fig 11 Frequency

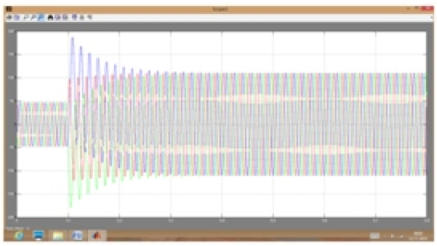

Fig 12 Current waveforms subsequent to self-synchronization with supplementary control

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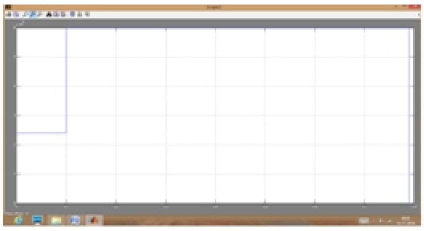

Fig 13 Real power without supplementary control

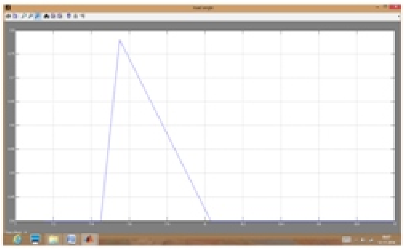

Fig 14 Load angle variation

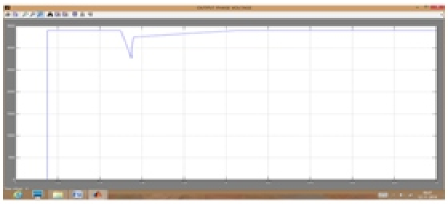

Fig 15 Output phase voltage

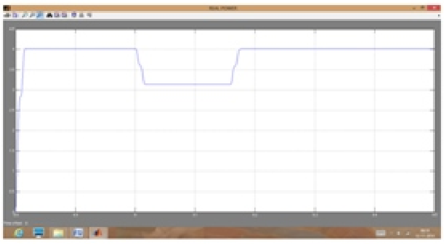

Fig 16 Real power

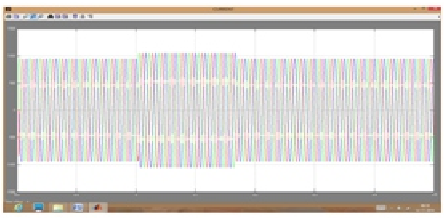

Fig 17 Instantaneous current waveforms

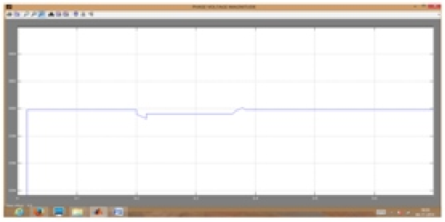

Fig 18 Amplitude of the phase voltage

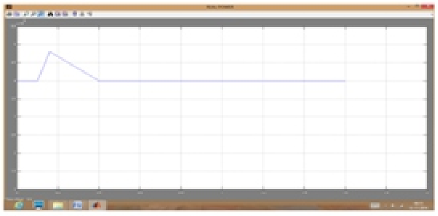

Fig 19 Real power

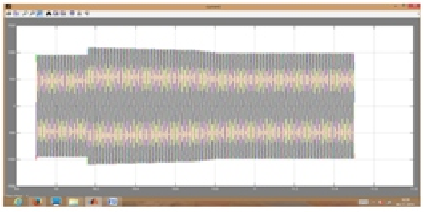

Fig 20 Instantaneous current

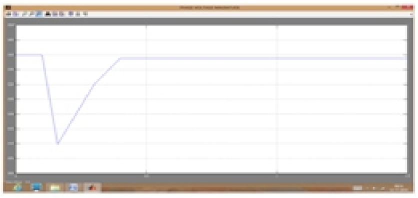

Fig 21 Output phase voltage

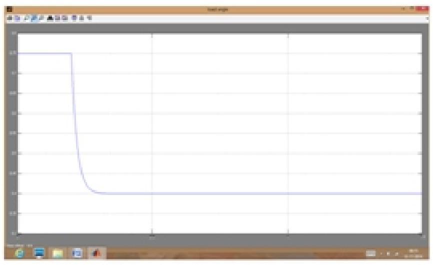

Fig 22 Load angle

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IV. CONCLUSION:

The controller has two sections, specifically the direct power damping controller and the nonlinear supplementary controller. The direct part emulates Sags with additional force damping-synchronization capacity giving synchronization toward oneself with lattice which wipes out the requirement for a PLL. In any case, in framework rebuilding situations, any substantial befuddle in the middle of VSC and matrix recurrence and point may cause poor execution and even insecurity. These cases are considered as vast sign aggravations, in this way the proposed nonlinear controller can upgrade framework execution in these cases. In addition, the controller has the capacity work in exceptionally frail matrices with SCR and supplies the appraised force due to its damping and synchronizing force qualities. The outline process for the straight and nonlinear parts has been introduced and various reproduction situations were exhibited to accept the controller viability.

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