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Stability Improvement of Weak Grid Integrated System with Voltage Source Converter

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ABSTRACT: ***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. To overcome this difficulty, a supplementary nonlinear controller is developed to assist the linear controller and enhance system performance under large-signal nonlinear disturbances, such as self-synchronization, disturbances in grid frequency and angle, high power injection in very weak grids and fault-ride-through conditions.***

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

I. INTRODUCTION

Consistent development of renewable distributed generations (DG) resources, such as wind turbines and photovoltaic (PV) arrays, has resulted in significant tendency toward optimal control, operation and grid integration of DG units Seamless integration of DG units is a major driving force in the context of smart grids. Voltage source converters (VSCs) are the main enabling technology for interfacing renewable and clean energy resources in modern grids. The main control topologies of VSCs are vector control and direct power control. To obtain current and voltage components in a synchronously-rotating reference frame, a phase-locked loop (PLL) is required. Furthermore, the PLL is necessary to extract grid-frequency and initial angle to guarantee smooth converter-grid connection via a synchronization process. However, the PLL dynamics, during transients, adversely affects overall system stability especially in weak grids. Despite the advantages of the vector control technique, there is considerable tendency toward developing new control topologies which eliminate the need for a PLL (i.e., self synchronization. To overcome difficulties associated with vector control of VSCs connected to very weak grids, the concept of power synchronization has been presented in and to provide an inherent synchronization with grid in steady-state similar to a synchronous generator (SG). Nevertheless, the proposed methods are synthesized based on small-signal dynamics and cannot guarantee large-signal stability.

Existing System:

To evaluate system dynamic performance in a weak grid, a small-signal stability analysis of a grid-connected VSC is presented in this section. The three-phase power system involves a converter and its controller, RL filter, connecting line and infinite grid. Assuming an ideal VSC, the VSC local voltage is equal to the controller command, thus it is possible to model the VSC and PWM block by an average voltage approach The system parameters are given in Table I. The augmented model of the VSC and its controller can be developed as follows.

First, the load angle dynamic equation is given by Equations and represent a sixth order system and involve all the eigen values of the multivariable multi-input multi-output controller and the related power system. Figs. 4 and 5 show the loci of the eigen values as a function of the real power control loop parameters and, respectively. The sixth eigen value is not shown here because it appears far away from the imaginary axis. The dominant poles are highly dependent on these parameters. Equations and introduce two eigen values (eigens 4 and 5) which are contributed to the electric circuit and are independent of controller parameters.

Proposed System:

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. 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

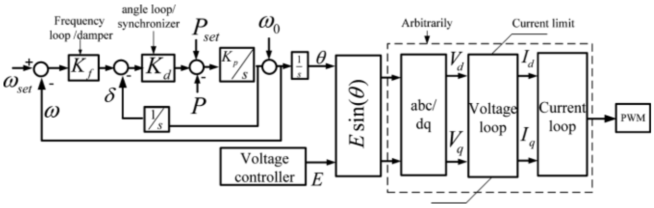


Fig.1 Proposed System

Nonlinear Power Damping Controller

In weak grids with SCR less than 4, the load angle is usually large and approaches the steady-state stability limit; accordingly, in the case that a DG unit is required to supply its rated power, power stability may be significantly degraded. The proposed cooperative angle-frequency droop control can enable higher load angles. However, as a linear controller, it cannot guarantee large-signal stability in all operating conditions especially when system dynamics drifts to the nonlinear region. This is more pronounced in sudden large transients such as self-synchronization where any large mismatch between frequency and angle of both sides across the connecting breaker (or re closer) may contribute to poor performance and even instability To overcome this issue, a nonlinear back stepping power damping controller is proposed and augmented with the linear controller Since the nonlinear controller is a supplementary one providing an additional signal for the linear controller, the designs of the controllers are decoupled.

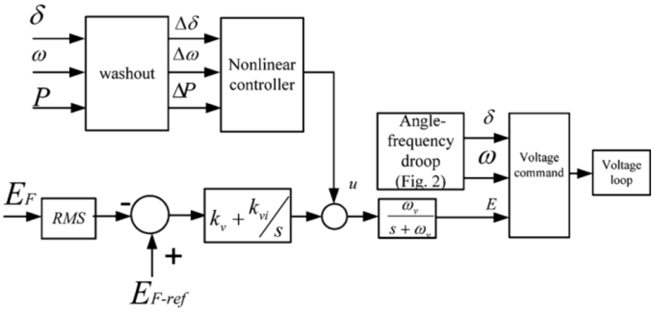


Fig.2 Nonlinear Control Structure

EVALUATION 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 in Table I. 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 of Since the connecting line is almost inductive, the power capacity of the interface line is approximated where the notations are defined in Fig. 1 and is the total reactance of the transformer, line and stiff grid Therefore, the maximum real power transfer capacity of the connecting line is equal MW. Since the local load power at the rated voltage is 2.5 MW, thus the VSC's maximum power capacity is about 7 MW. The DG works as a PV bus aiming at keeping the filter output voltage constant during grid connection.

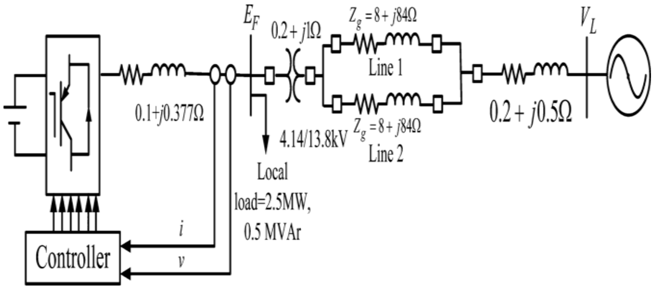
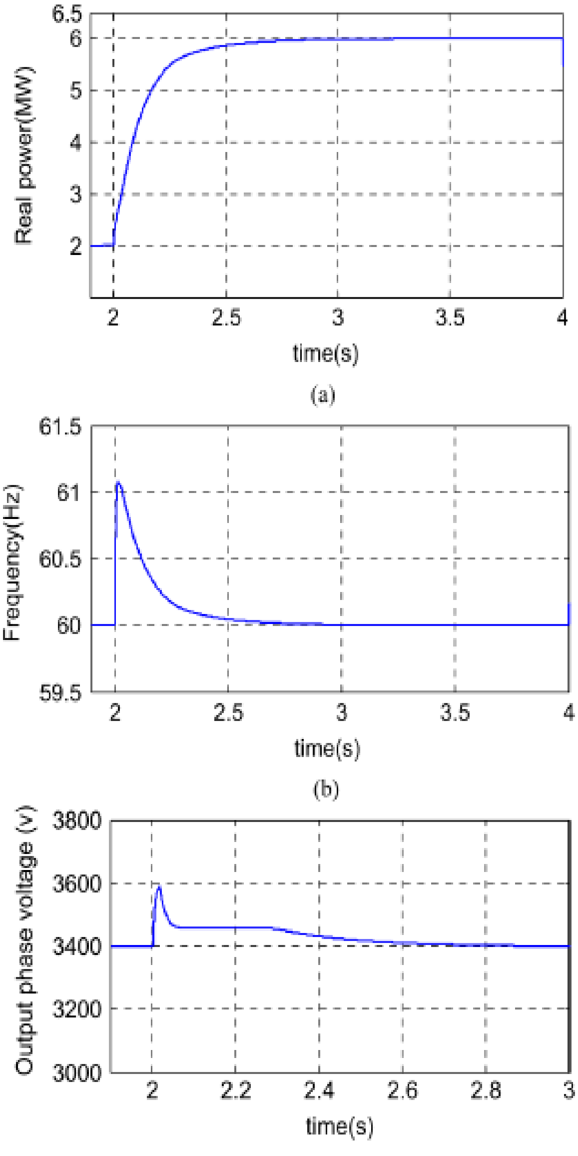


Fig.3 Simulated System



(a)

(b)

(c)

Fig. 4. Controller performance in high-power injection. (a) Real power. (b) Frequency. (c) Phase-voltage amplitude.

High-Power Injection With High Load Angles

At ,t=2sec the reference power is varied from 2.0 MW to 6.0 MW(0.86 p.u.) which is close to the VSC's maximum power capacity at constant voltage operation and a load angle more than 1.03 rad is expected. Fig. 4(a) shows the real power waveform and Fig. 4(b) and 4(c) shows the frequency and phase voltage amplitude variation, respectively. As it is observed, the response is smooth but with larger rise-time; however, it is still stable with damped response and the output power easily reaches 6.0 MW. The output voltage amplitude of the VSC during this transient is shown Fig. 4(c) presenting the controller action to boost VSC's voltage during load angle variation to enable high real power injection. This is in contrast with the natural behavior of the system which yields voltage sag subsequent to output power increment and consequently higher voltage drop.

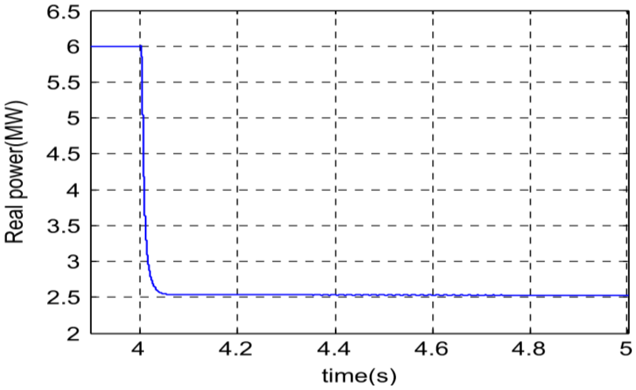


Fig. 5. Real power during transition to islanding.

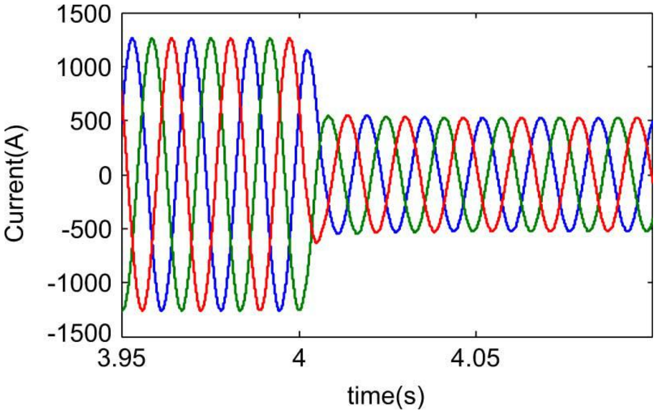


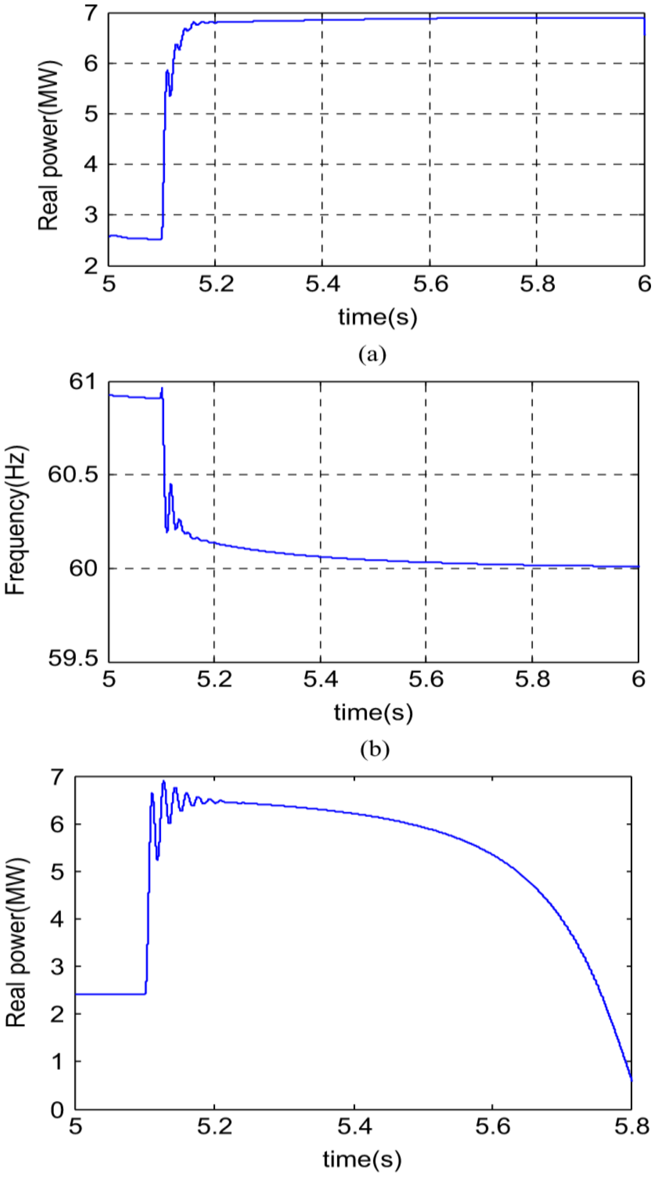
Fig.6. Current waveforms subsequent to islanding.

Transition To Islanded Mode

Islanded operation is another scenario that may occur in DG applications to supply local critical loads. At t=4sec the VSC is switched to the islanded mode due to a fault in the grid. No controller-mode switching action or reconfiguration is required. The transition is again seamless without any instability Fig.5. Real power during transition to islanding. Fig.6.Current waveforms subsequent to islanding. as shown in Fig.5. To achieve faster response, should be reduced; nevertheless, it may cause larger steady-state error in the grid-connected mode. The corresponding current waveforms are shown in Fig. 6, which shows smooth and fast transition because of the generality of the controller in both modes.

Self-Synchronized Grid Restoration

It is common that a recloser automatically reconnects a DG unit to the main grid after a special time period (usually 1 s). This is due to the fact that most of faults are cleared after few cycles. In this case, connection occurs without synchronization which may lead to severe transients as a result of frequency and angle mismatch of both sides of the recloser at the moment of connection. Weak grids suffer more from the resynchronization transients due to the fact that load angle is inherently large and after grid restoration it may easily move to the nonlinear region and even pass where instability is expected. Fig. 7(a) and (b) shows the corresponding waveforms and clearly shows that the system with nonlinear controller provides smooth and fast grid connection. This excellent performance occurs under the fact that there is about 0.9 Hz frequency mismatch between the grid and VSC, and the reference power is equal to 6.8 MW corresponding a the load angle 1.32 rad. The system response without using the supplementary controller is demonstrated in Fig. 7(c), which shows that the weak grid conditions cause instability. The current waveform of the system with supplementary control is presented in Fig. 8, which shows the system well-damped behavior even in the out-of-phase reclosing scenarios, and verifies the plug-and-play feature of the proposed controller.



(a)

(b)

(c)

Fig.7. System performance during grid restoration, (a) Real power with nonlinear supplementary controller. (b) Frequency. (c) Real power without the supplementary controller.

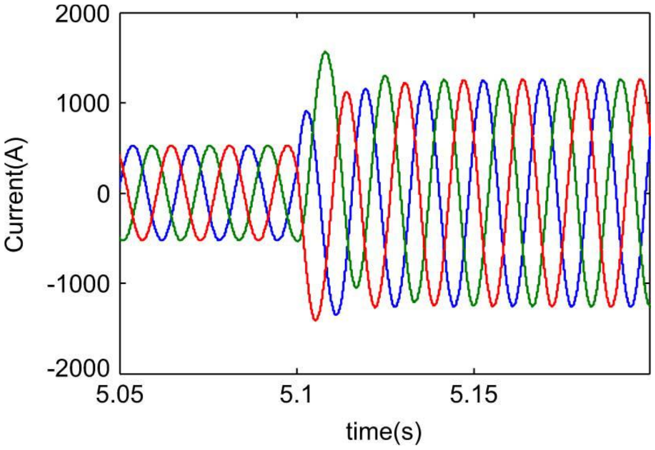


Fig.8. Current waveforms subsequent to self-synchronization with supplementary control

CONCLUSION

In this paper, a new control topology is presented to enable effective integration of VSCs to weak grids. The controller has two parts, namely the linear power damping controller and the nonlinear supplementary controller. The linear part mimics SGs with extra power damping synchronization capability providing self-synchronization with grid which eliminates the need for a PLL. However, in grid restoration scenarios, any large mismatch between VSC and grid frequency and angle may cause poor performance and even instability. These cases are considered as large-signal disturbances, thus the proposed nonlinear controller can enhance system performance in these cases. Moreover, the controller is able to work in very weak grids with SCR and supplies the rated power because of its damping and synchronizing power characteristics. The design process for the linear and nonlinear parts has been presented and numerous simulation scenarios were presented to validate the controller effectiveness.

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