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Improving Transient Performance of VSG based Microgrids by Virtual FACTS' Functions

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***Abstract*— This report presents a transient proportional controller which is augmented on virtual inertia's topology. The concept of virtual synchronous generator (VSG) is inspired by the behavior of the synchronous generators and researchers map this behavior on microgrids to mimic the power system's dynamics on microgrids. The added characteristic is based on FACTS' functions such as: STATCOM swing damping capability for large-signal disturbance damping at transient times, for VSG based microgrids. This capability is added to the VSG structure by a bang-bang controller. The proposed bang-bang controller is used to improve transient response of VSG based microgrids just in large signal disturbances, including: islanding, three-phase faults, and huge variation of loads. Simplicity and capability to improve the transient response are the main features of the added configuration. Simulation results verify the improvement of the introduced manner by the represented augmented VSG control strategy.**

***Index Terms*—AC microgrids, FACTS, transient performance improvement, virtual inertia, virtual synchronous generator.**

I. INTRODUCTION

Immense use from renewable energy sources (RESs), in Electric power generation system especially microgrids has been obvious. The lack of RES inertia in islanded microgrids, leads to increment of variations in system frequency. Thus recently virtual inertia (VI), has drawn great attention, which VSG is one of its most prominent examples as a solution [1], [2].

In conventional power systems which used synchronous generator (SG), due to the inertia of SG, fluctuation in active and reactive power may be occurred. Resolutely, power system stabilizer (PSS) is used in SG to solve this problem. In conventional power systems, the PSS is responsible for damping of plausible fluctuation in active and reactive power caused by the inertia of SG. Due to complex and vague nature of power system, specifying, tuning and an appropriate control parameters by PSS is difficult. Define the appropriate control parameters for VSG in the case of VSGs is not so easy too.

With the advent of VSGs, the challenge of improving the transient state in systems based on VSG remains. This subject was explored by several papers. Transient state improvement in microgrids by VSG, have been addressed in a more last publication [3], [4]. In [5], the online optimization manner determines optimum damping coefficient and VI's parameters in swing equation. Reactive power sharing strategy in VSG based microgrids, is provides by virtual capacitor algorithm in [6]. Reduction of reactive power sharing error, and rectification of the voltage control accuracy meantime, without communication and system parameters detection are achieved by mentioned algorithm. In [7], a virtual inertia control strategy for DC microgrids through the introduced bidirectional grid-connected converters analogized with the virtual synchronous machine in AC microgrid is proposed to enhance the inertia of the DC microgrid, and to restrain the dc bus voltage fluctuation. In order to elevate the inertia of the DC microgrid and to harness the dc bus voltage oscillation, two topics of presence of virtual synchronous machine in AC microgrids and DC microgrids through the introduced bidirectional grid-connected converters are compared by a virtual inertia control strategy.

In [8], using the VSG based on linearizing method which works out the output power fluctuation, transient state fluctuation is developed for a DG, but active and reactive power sharing not investigated. In fact by using the VSG concept for a distributed generator, the grid oscillations is damped. Finally a damping control manner consists of the system linearized equation, decoupling the voltage deviation, damping factor and linear control theory is proposed.

In [9], by regulation of the virtual stator reactance, fluctuation damping and appropriate transient active power sharing are achieved. Also by V–Q droop control and common ac bus voltage estimation, suitable reactive power sharing is achieved. In [10], analogy of dynamic specifications between VSG and droop control in inverter-based distributed generators is proposed. But the discrepancy on inertia, transient frequency, and reactive power control issue are not considered. In [11], usual VSG control based modular multilevel inverters are equipped with dependence-based parity procedure. In [2], and [12], principal notion of VSG and their task to backing the power grid control, several significant VSG topologies and basic technical challenges are reviewed. In [12], the notion of acting an inverter to imitate a synchronous generator (SG) is

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expanded. The both dynamic equations of inverter and SG are the identical; merely the mechanical exchanged power with the prime mover is substituted with the exchanged power with the DC bus. The small signal modeling of VSG, parameters scheme of the power loop of the VSG and the inner capacitor voltages loop and dynamic performance improvement are discussed in [13]. Protection of the VSG output voltage to stay in fixed range is achieved by the VSG power loop analysis and its bandwidth.

In order to equip AC microgrid to further moment of inertia and damping under the transient state, the consensus-based droop control for VSG is offered. Also, secondary control of islanded AC microgrids is discussed in [14].

Using proportional control for a VSG with alternating moment of inertia is introduced in [15]. Appling transient energy analysis, the damping efficacy of the alternating inertia is studied. In every phase of swing and considering VSG's virtual angular velocity and acceleration/deceleration the appropriate amount of the moment of inertia of the VSG is adopted by mentioned algorithm.

In order to frequency response betterment in microgrid the optimum VSG which equipped to PSO algorithm is presented in [4]. Collection of deflection of frequency and voltage is defined as the cost function. By minimizing the cost function, both the inertia and damping factors are optimized.

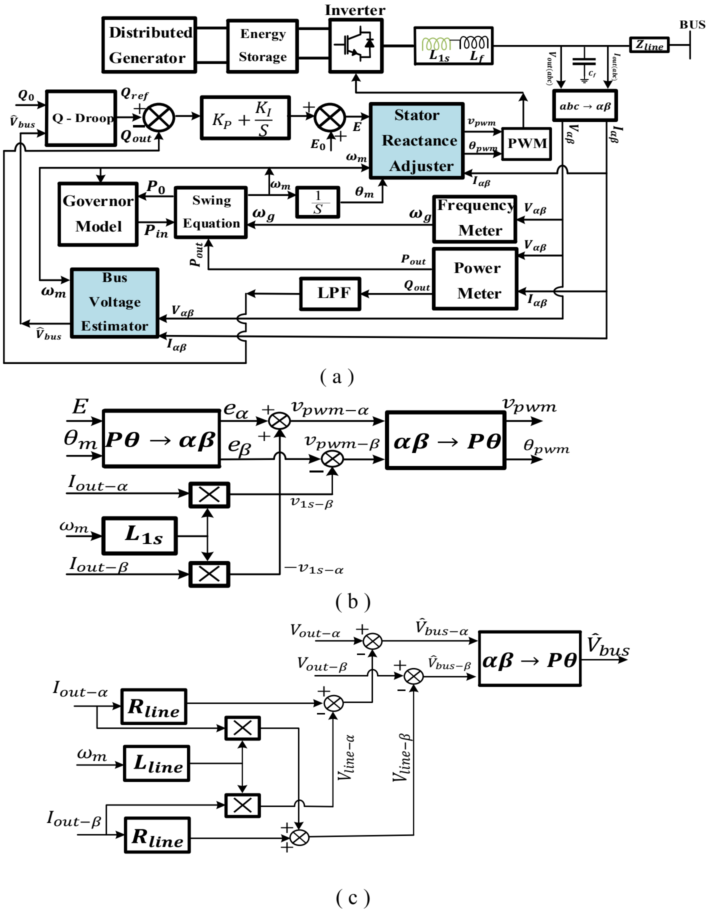
Motivated by the previous works, the notion of aggregating of VSG with flexible AC transmission systems (FACTS) controllers can be a novel solution to improve the VSG based systems' response in this paper. Due to specific application of some FACTs devices to increasing the stability and performance of the system as a matured technology will be more and more. Here in, more and more said why inverter based distributed resources are not augmented by the FACTs functions. Reactive power control [16], power oscillation and swings damping [17], power system fault tolerance and holding the stability of the system in the power system scale are interesting features by STATCOM [18]. However, in the distribution systems, D-STATCOM is presented [19] for power quality improvement, harmonic cancelation, unbalanced load compensation and so on [20]. Later, applications of STATCOMs and its flexible control features to control wind farms have been presented [21]. But, there are no study which closed the functions of the FACTs on the inverters in the inverter based microgrids as a separate loop so far.

The organization of this paper is as follows. The mathematical model of the swing equation and the notion of the BSG presented in Section II. Section III is devoted to the concept of the phase-angle regulators and how they can improve the transient stability in power systems and consequently on autonomous microgrids. The notion of active power oscillation damping by reactive power injection is reviewed and given in Section IV. Section V is illustrated and discussed around the simulation results. Finally, Section VI concludes this paper.

II. FUNDAMENTAL OF VSG

Any distributed energy resource such as fuel cell, photovoltaic panel and gas engine which called primary source, have an intrinsic uncertainty and fluctuation in their output power is inevitable. Thus in absence of rotating mass in DGs, existence of energy storage is obligatory to attract or offer excess /deficiency mentioned fluctuation especially in transient state. Control layout of the inverter was investigated in [8][11][12]. In Fig. 1, the iterative procedure is applied to the swing equation (1), as a result, ω_m is obtained.

$$P_{in} - P_{out} = J\omega_m \frac{d\omega_m}{dt} + D(\omega_m - \omega_g) \qquad (1)$$



(a)

(b)

(c)

Fig. 1. Block diagram of (a) the basic VSG control, (b) the "Governor Model" block and (c) the "Q Droop" block.

As [9] discusses Fig. 1(a), is final version of Previous basic VSG control structures, which was equipped with two significant amendment. the bus voltage estimator and the stator reactance adjuster are shown in fig.1(b) and Fig.1(c), respectively. the stator reactance adjuster which achieved by adjusting of virtual stator inductor l_{1s}, plays the role of virtual impedance and tunes the output reactance of the DG independently. Sharing the transient load without fluctuation and incrementing active power damping ratio are the result of above approach.

$$X_i = S_{basei}\,\omega_{mi}(L_{1si} + L_{fi} + L_{linei}) \Big/ E_0^2 = 0.7\,PU \qquad (2)$$

As illustrated in Fig.1(c), in a similar process with stator reactance adjuster, the bus voltage estimator is expressed. First by line impedance data and measured output current, the voltage drop is calculated in stagnant frame. Difference of output voltage and calculated line voltage drop, estimates the bus voltage. As discussed in[9], to clarify the explication for the cases with different power ratings, per unit values are considered based on respective power ratings of DGs. In order to share the active and reactive powers according to the ratings of DGs without communication.

III. IMPROVEMENT OF TRANSIENT STABILITY WITH PHASE ANGLE REGULATORS

Based on [21], [22] , power oscillation damping is achieved by varying the active power flow in the line(s) so as to counteract the accelerating and decelerating swings of the disturbed machine(s). That is, when the rotationally oscillating generator accelerates and angle δ increases ($\frac{d\delta}{dt} > 0$), the electric power transmitted must be increased to compensate for the excess mechanical input power. Conversely, when the generator decelerates and angle δ decreases ($\frac{d\delta}{dt} < 0$), the electric power must be decreased to *balance* the insufficient mechanical input power. The requirements of output control and the process of power oscillation damping by transmission angle control are illustrated at Fig. 2. Waveforms show the undamped and damped oscillations of angle δ around the steady-state value δ_0. Waveforms at (b) show the undamped and damped oscillations of the electric power P around the steady-state value P_o. The momentary drop in power shown in the figure represents an assumed disturbance that initiated the oscillation.

As illustrated, a "bang-bang" type control (in which the output value of controller is varied between minimum and maximum values) is the simplest and most effective if large oscillations are encountered. However, for damping relatively small power oscillations, continuous variation of the angle may be preferred.

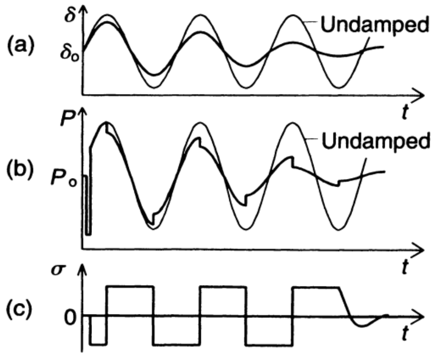


Fig. 2 Waveforms illustrating power oscillation damping by phase angle control: (a) generator angle, (b) transmitted power, and (c) phase shift provided by the Phase Angle Regulator [22].

IV. POWER OSCILLATION DAMPING BY REACTIVE POWER INJECTION

Fig. 3 shows that how we can damp the active power oscillation by injecting reactive power. As it is shown, the reactive power output is controlled in a "bang-bang" manner (output is varied between the minimum and maximum values). This method of control is generally considered as the most effective and simplest manner, particularly if large oscillations are encountered. However, for damping relatively small power oscillations, a strategy that varies the controlled output of the compensator continuously, in sympathy with the generator angle or power, may be preferred. This manner, is

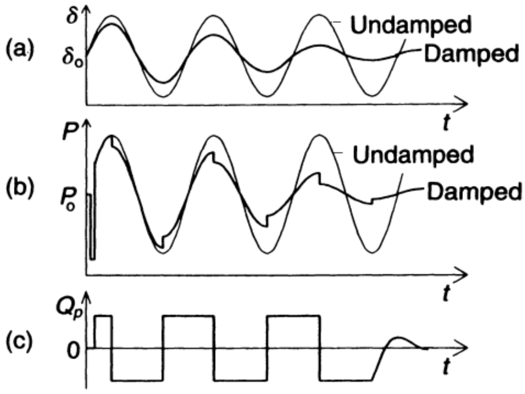


Fig. 3 Waveforms illustrating power oscillation damping by reactive shunt compensation: (a) generator angle, (b) transmitted power, and (c) variable output of the shunt compensator [22].

V. APPLYING TO VSG BASED MICROGRIDS

Now, by the variations of the angle of δ , we can propose a proportional controller which just applied only in transient times, in simple terms only when the angle of δ violates its bounds.

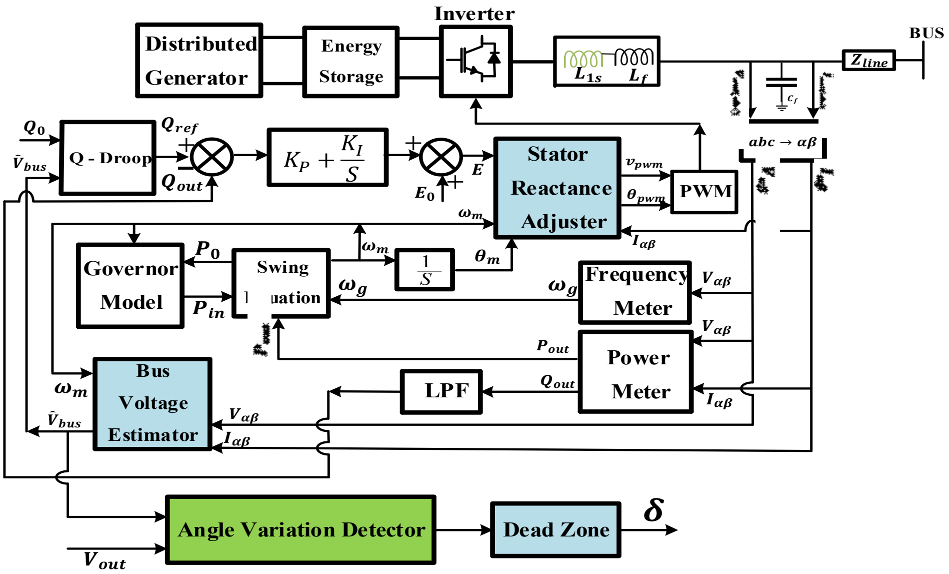


Fig. 4. Block diagram of a basic VSG control configuration with angle variation detection

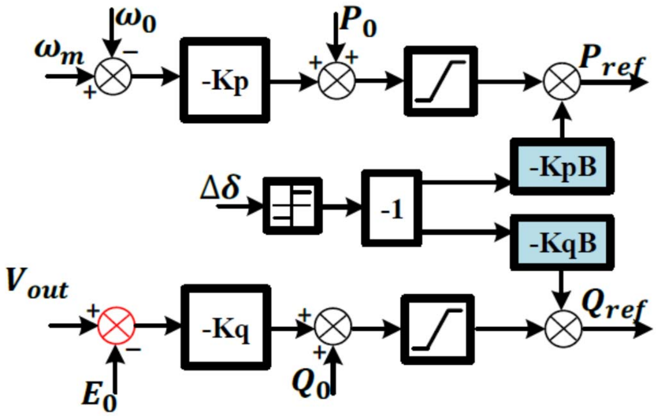


Fig. 5 The governor and the Q-droop blocks augmented by bang-bang proportional control

For this end, assuming that a basic VSG structure is fully notified, just by adding a block to detection of δ is needed which is shown in Fig. 4. Actually in this block (angle variation detector), two PLL is used to obtain δ. Also, a dead-bound block is used to filter the steady state small variation of δ. By obtaining variations of δ, i.e. $\Delta\delta$, based on section 1 and 2, a sign function needs to implement the bang-bang control like the Fig. 5, to inject active and reactive power in transient times when a large-scale change (Like islanding or huge load changes, and or when a fault occurs) occurs in microgrids.

VI. SIMULATION RESULTS

In order to test the designed proportional controller on the reactive and active power loops, it is enough to close the represented approaches on the VSG configuration. The case study and information about the VSG based test microgrid is addressed in [9]. All the simulation parameters and scenarios are like with [9], too.

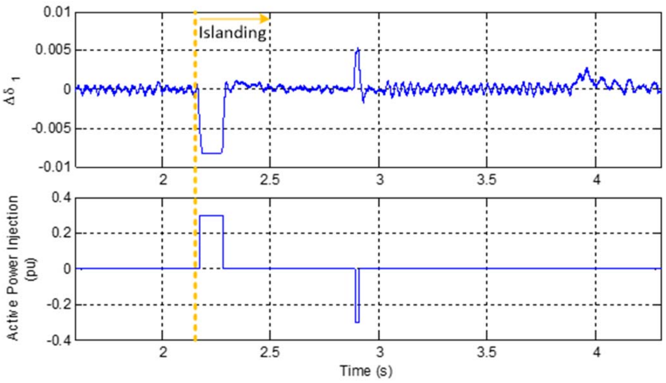


Fig. 6. Power angle detection in transient times and active power injection

As it is illustrated in Figs. 6, when the microgrid is islanded at 2.1 s, and when load 2 is connected at 2.8 s, oscillations on power angle can be observed in transient times. By detection of these oscillations, the bang-bang controller injects appropriates active and reactive power to reference values of active and reactive power, regarded as its K_p and K_q coefficients.

In active power, when the basic VSG control is applied for both DGs, this oscillation is almost eliminated by applying the proposed augmented VSG control with FACTS' functions shown in Fig. 7. However, the disturbance which is applied at 3.8 s caused by change of active power set value of DG1, is not a loading transition, and there are not any compensated signal to add on set points of active and reactive power.

Meanwhile, the oscillation periods become shorter, because the damped natural frequencies are decreased as it is discussed.

Note that the rate of change of frequency doesn't remain the same in transients, which suggests that the proposed augmented VSG control has a significance influence on the inertia support feature of VSG control, which it can change the system inertia.

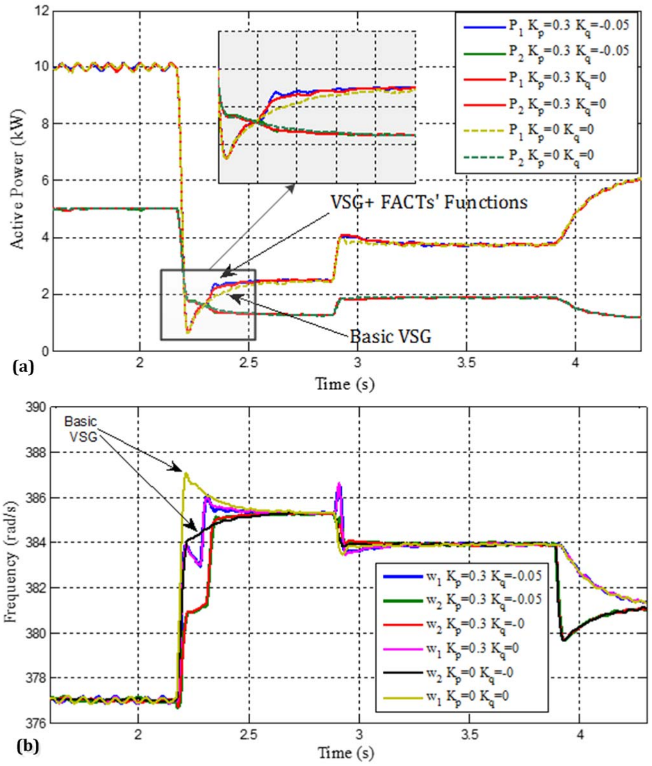


Fig. 7. Simulation results of active power (a), and frequency(b), when both DGs are controlled by the basic VSG control, and augmented by the coefficients of active and reactive power injection by the proposed controller.

VII. CONCLUSION

In order to appropriately integrate renewable energy to mimic the power system behavior with a favorable inertia, a virtual inertia topology is needed. The challenges faced in this case will be more if the transient performance will be bold. A control strategy based on FACTS' functions was augmented on VSG topology to take advantage of the transient performance improvement. Taking advantages of the better performance and the much greater flexibility attained by the tunable "virtual" parameters related to FACTS' functions in the proposed loop. Analysis of a simple bang-bang controller augmented on a VSG based microgrid was discussed and the comparison with previous works showed a better transient performance potential and preferable characteristic in the small signal stability. The proposed method was evaluated against the conventional VSG topology under frequency deviations, and active and reactive power fluctuations, where it showed a significantly improved regulation and damping performance. The stability and performance enhancement by the VSG-based microgrids will be an important issue under high penetration of renewable energy and will be further explored to augment them by inspiration with power system behavior in the future work.

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