Power Flow Control of Grid Feeding Converter Based on VSG Emulator

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***Abstract*—The widespread integration of renewable energy sources with the traditional power systems causes a considerable impact, such as the decrease of total inertia, damping properties and large frequency deviation. In this paper, the virtual synchronous generator (VSG) concept in grid feeding structure is investigated within a week grid in order to bring support capabilities to the frequency and amplitude deviation. The frequency at the point of common cohesion (PCC) can be reduced when more active power is required whereas the voltage amplitude is reduced with reactive power demand. The small signal modeling of the VSG is addressed taking into consideration parameters variation to obtain a smooth power flow transition and then low frequency nadir. In order to validate the theoretical concepts, simulation tests have been carried out using PSIM platform.**

***Index Terms*—VSG controller , frequency deviation, small signal analysis, micro grid, distributed generation.**

I. INTRODUCTION

Nowadays, renewable energies sources such as wind, photovoltaic and energy storage systems has been attracted considerable attention in micro grid systems. Micro grid (MG) concept is considered as a potential solution to the technical energy management issues of smart grids [1], due to the high penetration of inverters based distributed generations DG_s. In the area of micro grid research, the optimum design of micro grid controllers is an essential topic that has to be addressed so that they can function properly in both grid connected and islanded modes. More precisely, it is critical to control the flow of real and reactive power flow from each DG in grid connected mode, whereas frequency and voltage of each power converter need to be maintained in islanded mode.

Considering the MG operation, power converters can operate in grid feeding and grid forming structure depending on the hierarchical control that they submitted. Grid feeding power converters can be adopted to operate in parallel, with other grid feeding in isolated grid connected mode [2].

Whereas, their operation in stand-alone mode requires other grid supporting/forming power converters to control the voltage and frequency of whole system. Regarding frequency control, a new power stability issue has evolved, this issue is the reduction and fluctuation of inertia in the power system, which is caused by the use of power electronics to integrate the DG_s into the system [3]. This power electronic converters has less inertia, because there is no rotating mass as a source of inertia. Where, their integration with the power system lead to decrease system's reliability and stability, especially frequency stability. Which, resulting in increased system uncertainty and the necessity for more complicated system operation and control. To ensure system stability and efficient use of renewable energies sources, the synthesis and control of virtual inertia should be a fundamental technology in future power systems.

As a solution to the potential power-stability issues [4], virtual synchronous generator (VSG) concept has been introduced from partnership of different European universities and companies. Which integrates synchronous generators model into the inverters control system. Moreover, to maintain system dynamic and frequency response under power fluctuation. It has considered as a promising idea to control micro grid system interfaced inverters, to make them behave as synchronous generators(SG) [5]. Several investigations have been presented, taking advantage of the VSG emulation concept for the micro grid system in both grid forming and grid feeding converters [6]. More detail is discussed as a review in [7].

The author in [8], has investigated a comparison of parallel inverters in grid feeding and forming structure, in order to improve power response and frequency nadir based on

modified virtual synchronous generator (VSG).
For the previous aforementioned services, several literature reports have been presented to handle the power flow while considering frequency stability of MG system. In [9], a real time hardware of VSG is tested to decrease the amplitude of frequency deviations in case of load variations.The grid services have been provided in [10], using grid feeding inverters based on comparison between virtual synchronous compensator and traditional current controller. In addition, multiple virtual synchronous machine have been studied in [11], to improve frequency stability and provide inertia support based on small signals modeling of power system. Even, [12] has analyzed, designed and tested the different parameters of VSG controller using system model under small signals.
This study considers the operation of a DC/AC converter in isolated grid feeding structure. the virtual synchronous generator (VSG) concept is investigated within a week grid in order to bring support capabilities to the frequency and amplitude deviation. The frequency amplitude at the point of common coupling (PCC) can be reduced, when more active power is required, whereas the voltage amplitude is reduced with reactive power demand. The small signal modeling of the VSG is addressed, taking into consideration parameters variation to obtain a smooth power flow transition and then low frequency nadir.
The rest of this paper is arranged as follows: section II briefly describes the structure of the three phases inverter in isolated micro grid. Section III, shows the design of VSG controller. Then, a small signal analysis is presented in section IV. The simulation tests are confirmed in section V, then section VI concludes this paper.

II. Micro Grid Configuration

A. System Description

The typical scheme of three phases inverter based distributed generation is presented in figure 1. The inverter is designed to provide specified amount of active and reactive power, according to set-points to the grid through LCL filter. furthermore, a phase locked loop is necessary to synchronize the power inverter with the ac voltage at the point common coupling (PCC) in synchronously rotating dq frame.
The grid feeding converter contains two controller loops, power loop based on swing equation and current loop uses a PI regulator. VSG-VSYNC topology uses the concept of virtual inertia emulation to enhance system response and stability. It provides the current reference I^*_{d-q} allusive to the active and reactive power as a function of P^*, grid frequency ω and its rate of change $\frac{d\omega}{dt}$, and the PCC voltage. The provided reference I^*_{d-q} are compared to I_{d-q} components of measured current, then the upshot error added with a cross-coupling current term. Moreover, for fast dynamic response a feed-forward loop is added where is derived from the PCC voltage. The outcome of current loop are reference voltages V^*_{d-q}, which transformed to reference modulation V^*_{abc}.
The technique of pulse width modulation (PWM) is introduced, in order to generate the switching patterns of the DC/AC converter based on comparison between V^*_{abc} references modulation and triangular signal. In this structure, an isolated weak grid is considered, and simulated as three phases source in order to bring support capabilities to the frequency and amplitude deviation. Where it uses a primary droop control PF and QV, to obtain active and reactive powers average value.

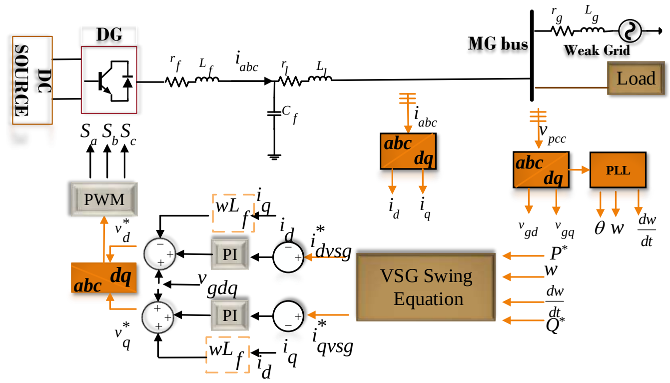

Fig. 1: Structure scheme of three phases inverter based distributed generation in MG system

III. VSG-VSYNC Controller

Due to the large growth of DG_s, VSG concept formed in 2007 [4], and it is considered as a promising strategy which integrates synchronous generators model into the inverters control system, allowing the static power electronic converter to function similarly to a rotating electrical machine [14]. By using the inertia emulation, it can effectively achieve frequency oscillations and damping of voltage, Even synchronization with the powerful grid. This project has focused to apply and develop the concept of Virtual Synchronous Generator (VSG) as a solution to the potential power-stability issues. The synthesis of an inertia emulating control has attracted significant interest to provide a practical scheme for micro grid systems based DG_s/RES [7], because it has the same operational mechanism as an SG. The general topology employed, controls the active and reactive powers of DG_s/RES_s based on equation below :

$$\begin{cases} P_{vsg} &= P_{set} + k_d(w - w_{ref}) + k_j \frac{dw}{dt} \\ Q_{vsg} &= Q_{set} \end{cases} \quad (1)$$

Where w represents the angular frequency of point of common coupling, and w_{ref} is the frequency reference. k_d is the damping factor while k_j represents the inertial constant. Whereas, $\frac{dw}{dt}$ is the change of frequency.
The controller involves measurements of grid frequency and its rate of change, for controlling the active and reactive power in bidirectional [15]. Moreover, k_j is adjusted so that the VSG provides its nominal active power when the maximum rate of change occurs (1 Hz/s). Whereas, k_d is chosen so that real power P is equal to the nominal value of P_{vsg} in case of frequency error is the largest.

Since the system uses the DC/AC converter as a current controlled source in synchronously rotating dq frame, the reference currents are generated from power controller using equation 2 below:

$$\begin{cases} I^*_{vsgd} &= \frac{V_{dpcc}P_{vsg}-V_{qpcc}Q_{vsg}}{(V_{dpcc}+V_{qpcc})^2} \\ I^*_{vsgq} &= \frac{V_{dpcc}Q_{vsg}-V_{qpcc}P_{vsg}}{(V_{dpcc}+V_{qpcc})^2} \end{cases} \quad (2)$$

Where $V_{d-q}$are the terminal voltages of PCC .

IV. Small Signal Modeling

The analysis of active power flow is presented in this subsection, based on equation 1 and considering small deviation of active power denoted by ΔP_{vsg}, which is given by equation below:

$$\Delta P_{vsg} = \Delta P_{set} + k_d(\Delta w - \Delta w_{ref}) + k_j \frac{d\Delta w}{dt} \quad (3)$$

Assuming ΔP_{set}=0, and Δw_{ref}=0, where represent a compensation terms, the new small signal model of equation 3can be expressed by :

$$\Delta P_{vsg} = k_d \Delta w + s k_j \Delta w \quad (4)$$

The simplified transfer function between real power and the angular frequency is given by :

$$\Delta w / \Delta P_{vsg} = \frac{1}{k_d + s k_j} \quad (5)$$

The active power at the output of the inverter can be defined by [16] :

$$P_{inv} = \frac{R V_g^2 - R E V_g cos(\theta) + X E V_g sin(\theta)}{R^2 + X^2} \quad (6)$$

Where R and X are the resistance and reactance of line impedance respectively, E corresponds the output voltage of inverter and V_g is the grid voltage, θ is the phase-angle difference between PCC voltage and grid voltage.
By applying small deviation of active power, resulting from small perturbation of the input variable $\Delta\theta$ using equation 6. Then, assuming $sin(\theta) \simeq \theta$ and $V_g \simeq E$, the small signal model relating P_{vsg} as a function of the phase angle can be found as:

$$\Delta P_{inv} = K * \Delta\theta \quad (7)$$

Where $k = \frac{X V_g^2}{R^2+X^2}$, thus note that $\Delta\theta = \int \Delta w$.

By merging 7 and 5, the small signal closed loop transfer function relating P_{inv} as a function of the delivered active power is expressed below:

$$\frac{\Delta P_{inv}}{\Delta P_{vsg}} = \frac{k}{s^2 k_j + s k_d + k} \quad (8)$$

A step response of the obtained model is shown in 2, for diffident value of inertia and damping factors. According to this figure, it can be observed that the increasing of damping factor reduces the overshoot. Moreover, the decreasing of inertia factor also reduces the overshoot, whereas the settling time increases. The system stability is depicted in figure 3, using root locus method.

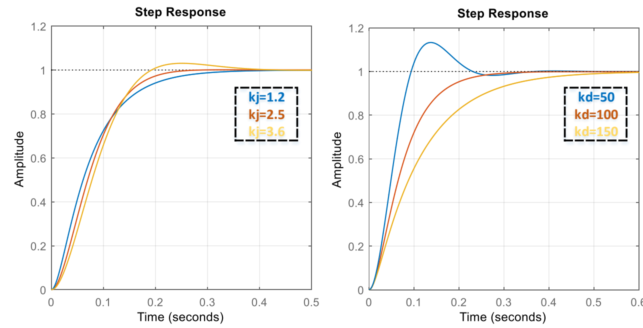

Fig. 2: Step response of the real power considering inertia and damping factors

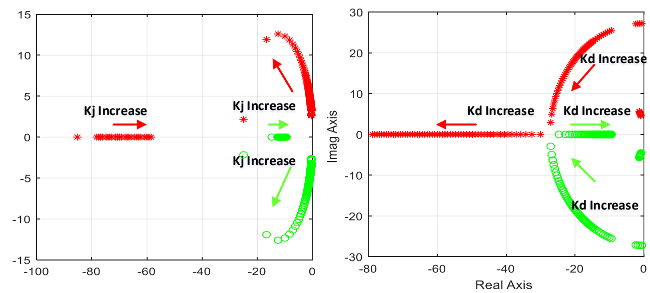

Fig. 3: Trajectory of system's poles under parameters variation

V. Simulation Results

In this part, a detail of simulation is executed in PSIM platform, the inverter based VSG controller is connected to week grid in order in order to bring support capabilities to the frequency and voltage amplitude. Even, to handle the active and reactive power flow between the VSG and power grid. For thus, two tests have been simulated:

- **Test 01:** At=0s, the set point of real power delivered from VSG is set zero. Then, a step change is happened to the rate value at t=0.5s. Whereas, a power demand is set by the connection of a second load at t=0.7s and t=0.9s.
- **Test 02:** The VSG provides 1KVAR to supply a small load. After that, the reference concerning reactive power is decreased to 0KVAR then increased again at t=0.35s and t=0.9s respectively, while a sudden load change is happened at=0.7s.

To evaluate the dynamic performance frequency deviation under load variation, the analysis of inertia and damping coefficients is investigated. The system is simulated using different values of inertia constant, whereas damping factor is remained unchanged. As well as vice versa.

TABLE I: Simulation parameters

Parameter	Value
Nominal real power	3kW
Nominal reactive power	1KVAR
DC bus voltage	500V
AC bus voltage	220V
Line inductance L_l	0.05mH
Filter inductance L_f	3mH
Filtre capacitance C_f	40uF
Filtre resistance r_f	10mΩ
System frequency	50Hz
Switching frequency	20kHz
Inertia factor J	$0.8kg.m^2$
Damping coefficient D	80

According to the obtained results, it is shown that the increase of active power demand has caused a frequency drop which can lead to a large frequency deviation. However, it is evidence to make judicious chose of coefficients mentioned above to reduce frequency nadir and minimize the over shoot resulting of the whole system. Moreover, a slow and smooth power response has been ensured.

When the reactive power is injected from the grid to supply a local load then a secondary load, the AC bus (PCC) voltage is decreased. Whereas, it can be increased when the inverter based on VSG control is the primary supply.

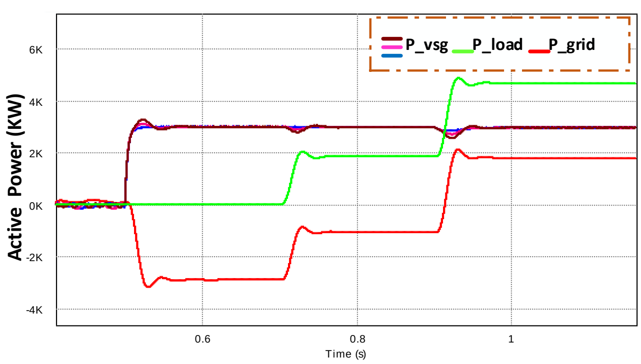

Fig. 4: Active power in response of test 01

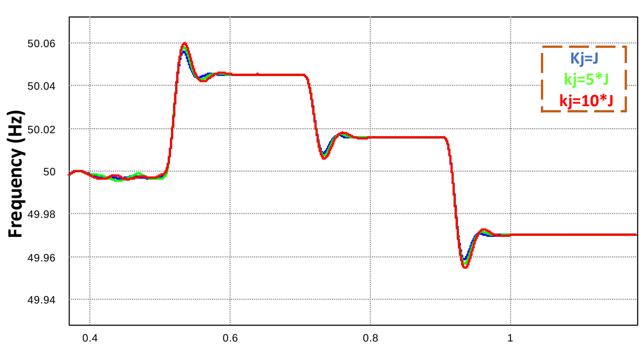

Fig. 5: Frequency response considering inertia factor variation to test 01

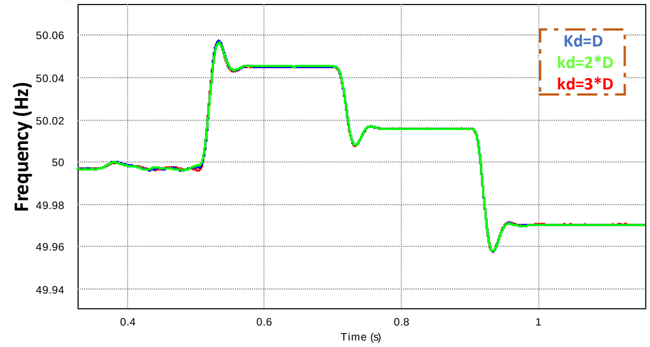

Fig. 6: Frequency response considering damping factor variation to test 01

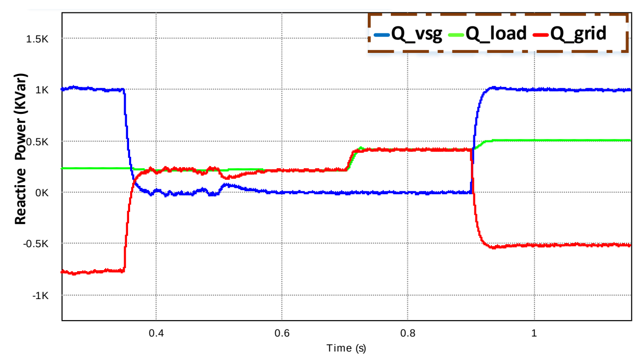

Fig. 7: Reactive power of MG system in case of test 02

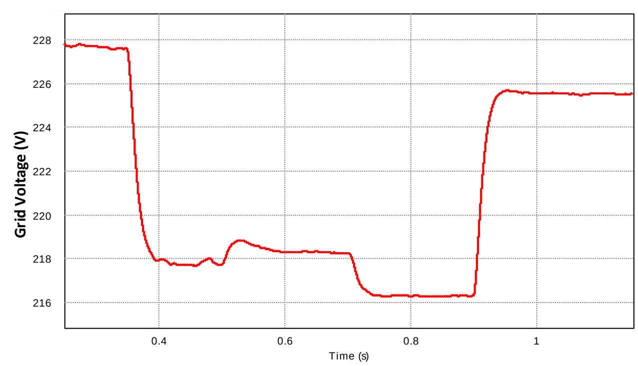

Fig. 8: Grid voltage in response to test 02

VI. Conclusion

In this paper, the control of real and reactive power flow in grid feeding converter considering frequency assessment has been studied. Virtual synchronous generator concept has proved the ability to reduce frequency nadir of an isolated micro grid, under active power demand, load variation. Based on system modeling, the judicious chose of inertia and damping factors can lead to minimize frequency amplitude of MG system. The theoretical concepts have been verified to highlight the desired results using simulation tests. Virtual synchronous generators emulator is suitable for a MG system, that includes renewable energy sources based distributed generating and energy storage systems.

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