

Droop Controller Limitation for Voltage Stability in Islanded Microgrid

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Abstract. The motivation to develop microgrids (MG), as a particular form of active networks is explained and presented as an effective solution for the control of grids. In MGs, with high level of penetration of Distributed Energy Resources, the stability becomes an important issue. Some control characteristics of elements such as droop coefficients in VSI highly affect voltage and frequency stability. In this paper, the changes in droop coefficient influencing the voltage stability of the microGrid are under investigation in islanded MG. The simulation results show the importance of the proposed limitation for the droop controller.

Key words

Microgrid, voltage stability, parallel inverters, VSI, conventional droop method

1. Introduction

The usage of Distributed Generation (DG) and Distributed Energy Resources (DER) in power systems has increased significantly in the last decade. Therefore the power system faces an increasing amount of small grid-connected generators, such as CHP units, wind turbines and photovoltaics at low and medium voltage levels. Actually, DG refers to the small electricity generators, which are located at LV or MV lines and usually near consumers. DER refers to all technologies which can be used to provide energy close to the consumers [1]. These technologies include besides generators, energy storage units, controllable loads and power control technologies.

The advantages of DG can be divided in three main groups: technical, economical and environmental. From technical point of view, the use of DG increases the service reliability. Moreover, it extends up the possibility of making the DG responsible for local power quality, voltage regulation, power factor correction, etc, in a way that is not possible with conventional centralized generators [2]. Unlike large generators, which are almost exclusively 50/60-Hz synchronous machines, DG units include variable frequency (variable speed) sources (such as wind energy sources), high-frequency (high-speed) sources (such as microturbines), and direct energy conversion sources producing dc voltages or currents (such as fuel cells and photovoltaic sources). The majority

of distributed resources are interfaced with the utility grid/loads via dc-ac inverter systems [3], [4].

Among several operating regimes possible for DG, microgrid is the most attractive one [5], [6], in which a cluster of DG units serviced by a distribution system is formed to maintain the reliability of critical loads, mainly when the utility supply is not available (Fig.1).

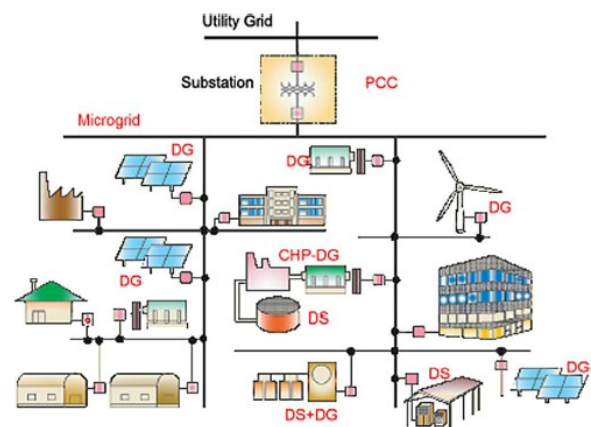


Fig. 1. MG architecture, comprising MS, loads and control devices

MGs can operate in two modes i.e. on-grid and off-grid [7]. In the first mode, MG is connected to an external network and this external network undertakes the role of frequency and voltage control for the MG. The external grid performs this role by compensation or absorption of power in the case of its deficiency or surplus. Inversely, when a MG operates in off-grid mode it is not connected to any other networks and thus DGs should be able to maintain the frequency and voltage in a satisfactory range.

Centralized control of a MG, based on a communication infrastructure, is investigated in [8], [9]. In this control structure, the elements operational information is transferred to microgrid central controller (MGCC). At MGCC, the amounts of control parameters are determined through stability calculation and finally the results are transferred to elements. However, in MGs, in remote areas with long connection distance between inverters, it is impractical and costly to distribute the dynamic sharing signals. Furthermore, reliability issues of the centralized control approach might counteract the positive reliability boosts gained by implementing DG microgrids.

To overcome these limitations, decentralized controllers are reported. Droop controllers, which emulate the droop characteristics of synchronous generators, are proposed as power sharing controllers for MG generators [10]–[13]. This kind of controllers is based on local measurement and there are no communication signals between units. Therefore, the stability studies must be considered in offline mode.

In this paper, the offline study for voltage stability is presented. As a result, some constraints are added to the system parameters to ensure that system operates in stable condition.

2. Modelling of MG Elements

In this section, modeling of different elements commonly used in a MG is presented. These elements are divided to three groups:

A. Voltage Source Inverter (VSI) Modelling

Most of MG systems are composed of a cluster of inverter-based DG units empowered by microsources, such as fuel cells, microturbines, dc storage, etc. A dc/ac VSI is commonly used as an interfacing module. Fig.2 shows a block diagram of a MG-connected VSI. Three control loops form the control structure. A droop controller is applied to set the magnitude and frequency of the fundamental output voltage of the inverter according based on active and reactive powers specifically. A voltage controller is used to synthesize the reference filter–inductor current vector (Fig.3); and a current controller is adopted to generate the command voltage vector to be synthesized by a pulse-width-modulation (PWM) module (Fig.4). In this paper, the resistance of inductor is considered in calculation. In Park's d - q frame rotating synchronously with the inverter output voltage angular speed ω , the current and voltage dynamics can be reasonably represented through the following equations:

$$\frac{di_d}{dt} = \frac{-Rf}{L_f} i_d + \omega i_q + \frac{1}{L_f} (u_d^* - v_{od}) \quad (1)$$

$$\frac{di_q}{dt} = \frac{-Rf}{L_f} i_q - \omega i_d + \frac{1}{L_f} (u_q^* - v_{oq}) \quad (2)$$

$$\frac{dv_{od}}{dt} = \omega v_{oq} + \frac{1}{C_f} (i_d - i_{od}) \quad (3)$$

$$\frac{dv_{oq}}{dt} = -\omega v_{od} + \frac{1}{C_f} (i_q - i_{oq}) \quad (4)$$

$$\frac{di_{od}}{dt} = \frac{-Rc}{Lc} i_{od} + \omega i_{oq} + \frac{1}{Lc} (v_{od} - v_{bd}) \quad (5)$$

$$\frac{di_{oq}}{dt} = \frac{-Rc}{Lc} i_{oq} - \omega i_{od} + \frac{1}{Lc} (v_{oq} - v_{bq}) \quad (6)$$

where u_d^* , u_q^* , i_d , and i_q are the d - and q -axis inverter's voltages and currents; v_{od} , v_{oq} , i_{od} , and i_{oq} are the d - and q -axis output voltages and currents; v_{bd} and v_{bq} are the d - and q -axis bus voltages, R_f , L_f , and C_f are the per-phase resistance, inductance, and capacitance of the LC filter, respectively; and R_c and L_c are the per-phase resistance and inductance of the coupling inductor, respectively.

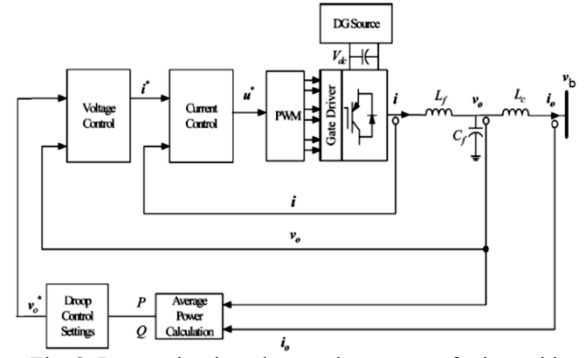


Fig. 2. Power circuit and control structure of microgrid-connected VSI

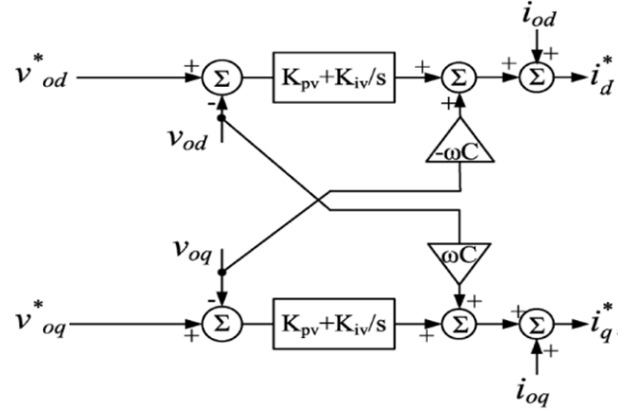


Fig. 3. Voltage controller

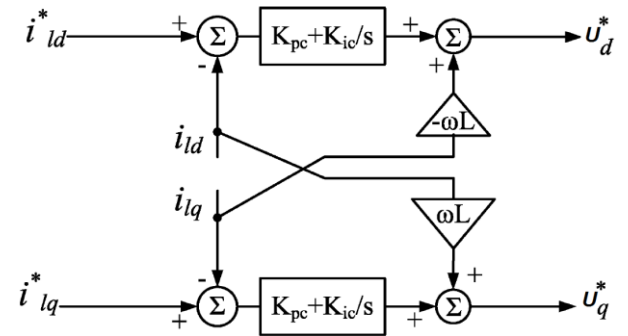


Fig. 4. Current controller

Voltage and current controllers have insignificant effect on VSIs stability while droop controller can highly affect stability. Consequently, the equations of droop controller are focused here.

Using the two-axis theory, the injected instantaneous active and reactive power components, p and q , are given by:

$$p = v_{od} i_{od} + v_{oq} i_{oq} \quad (7)$$

$$q = v_{od} i_{oq} - v_{oq} i_{od} \quad (8)$$

To allow sufficient time-scale separation between the power and current control loops and to achieve high power quality, the average active and reactive powers corresponding to the fundamental components are subjected to control action, and they are obtained by means of a low-pass filter as:

$$P = \frac{\omega_c}{s + \omega_c} p \quad (9)$$

$$Q = \frac{\omega_c}{s + \omega_c} q \quad (10)$$

where ω_c is the filter cut-off frequency.

To realize a power sharing function, the conventional droop characteristics are usually used in paralleled inverter systems. In droop method, the fundamental frequency and magnitude of the output voltage are set as below:

$$\omega_o = \omega^* - m_p P \quad (11)$$

$$v_{od}^* = V^* - n_q Q \quad (12)$$

where ω^* and V^* are the nominal frequency and voltage set points, respectively, and m_p and n_q are the static droop gains. The set points in (11) and (12) act as a virtual communication agent for different inverters in autonomous operation.

B. Network Modelling

On a common reference frame, the state equations of line current of i -th line connecting nodes j and k are:

$$\frac{di_{line\ id}}{dt} = \frac{-R_{line\ i}}{L_{line\ i}} i_{line\ id} + \omega_o i_{line\ iq} + \frac{1}{L_{line\ i}} (v_{jd} - v_{kd}) \quad (13)$$

$$\frac{di_{line\ iq}}{dt} = \frac{-R_{line\ i}}{L_{line\ i}} i_{line\ iq} - \omega_o i_{line\ id} + \frac{1}{L_{line\ i}} (v_{jq} - v_{kq}) \quad (14)$$

B. Load Modelling

Although, many types of load can exist in MGs, a general RL load is considered in this paper. The state equations of the RL load connected at i -th node are as below:

$$\frac{di_{load\ id}}{dt} = \frac{-R_{load\ i}}{L_{load\ i}} i_{load\ id} + \omega_o i_{load\ iq} + \frac{1}{L_{load\ i}} (v_{id}) \quad (15)$$

$$\frac{di_{load\ iq}}{dt} = \frac{-R_{load\ i}}{L_{load\ i}} i_{load\ iq} - \omega_o i_{load\ id} + \frac{1}{L_{load\ i}} (v_{iq}) \quad (16)$$

3. Simulation Results

A complete model of the test system was obtained according to the procedure expressed in section 2. The test system is shown in Fig.5 and the parameters values are gathered in table I. In all of the simulations, the m_p is set equal to $1e-4$ and is kept to its value in all of the simulations and the effect of varying the n_q is investigated.

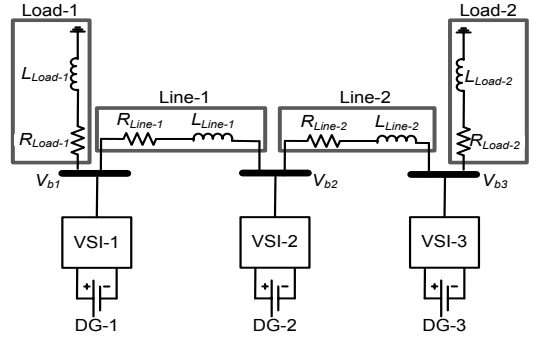


Fig. 5. Test system schematic

Table I. Test system parameters

Parameter	Value	Parameter	Value
L_f	1.35 mH	ω_0^*	314 rad/sec
R_f	0.1 Ω	V^*	380 V
C_f	50 μ F	R_{line1}	0.23 Ω
L_c	0.35 mH	L_{line1}	3.2 mH
R_c	0.03 Ω	R_{line2}	0.35 Ω
ω_c	31.4	L_{line2}	3.14 mH
K_{pv}	0.05	R_{load1}	25 Ω
K_{iv}	390	L_{load1}	1.5 mH
K_{pc}	10.5	R_{load2}	20 Ω
K_{ic}	16e3	L_{load2}	1.1 mH

Fig.6 shows the complete eigenvalues places of the system for the $n_q=1.5e-4$. This diagram is obtained by linearizing the state equations which are expressed in section 2. In this case, the reactive output power and the voltage response of the VSIs are shown in Fig.7, Fig.8 and Fig.9, respectively.

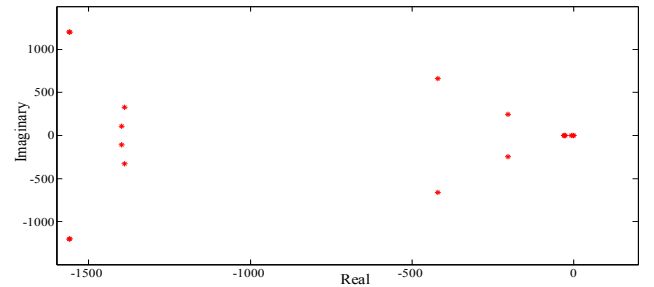


Fig. 6. All eigenvalues of system for $n_q=1.5e-4$

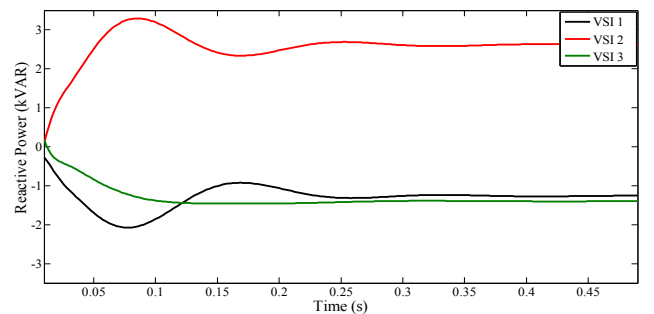


Fig. 7. Reactive output power response of the VSIs to a disturbance ($n_q=1.5e-4$)

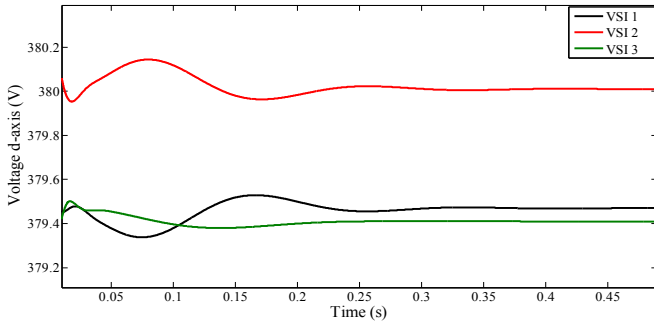


Fig. 8. Voltage magnitude in d axis after a disturbance ($n_q=1.5e-4$)

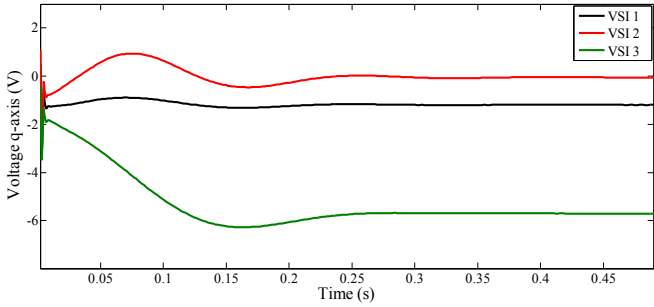


Fig. 9. Voltage magnitude in q axis after a disturbance ($n_q=1.5e-4$)

It should be noted that reactive power sharing isn't accurate between the inverters while active power sharing is precise. This inequality in reactive power sharing happens because of droop characteristics. In active power ω_0 is a global parameter in steady state and equal for all the inverters, so active power shares equally between them. In contrast, v_{d0}^* is a local value which differs for different buses and consequently, the inequality in reactive power sharing is normal.

Fig.10 shows the trajectory of sensitive eigenvalues as a function of the reactive power droop gain.

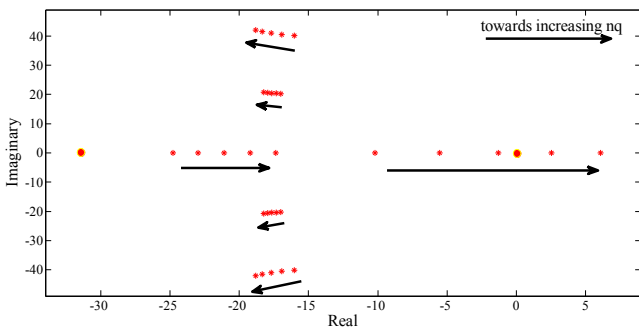


Fig. 10. Movement of eigenvalues

The movement of real part of the most sensitive eigenvalues as a function of the reactive power droop gain is shown in Fig.11.

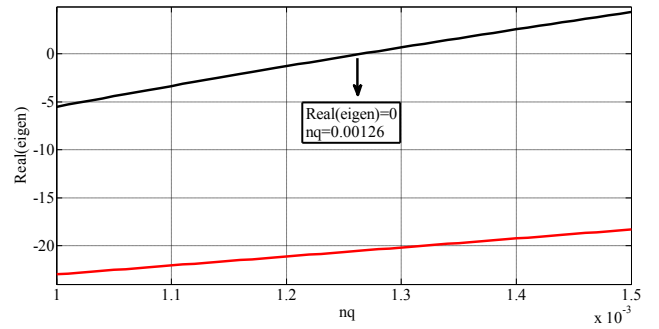


Fig. 11. Movement of real part of dominant low frequency eigenvalues

As shown in Fig.11, the stability margin of the system decreases when n_q is increased. For example, when n_q is set equal to 0.0015, the system is expected to be instable. To validate this phenomenon, consider Fig.12 and Fig.13. In these figures the unstable response of the system ($n_q=0.0015$) are shown.

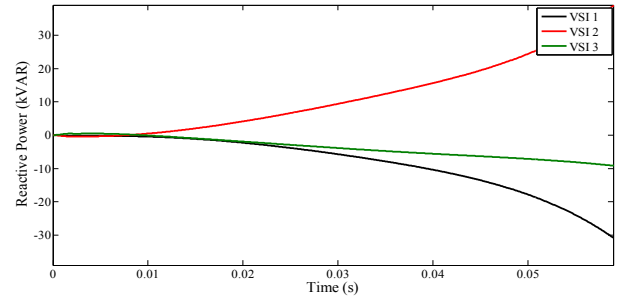


Fig. 12. Reactive output power response of the VSIs to a disturbance ($n_q=0.0015$)

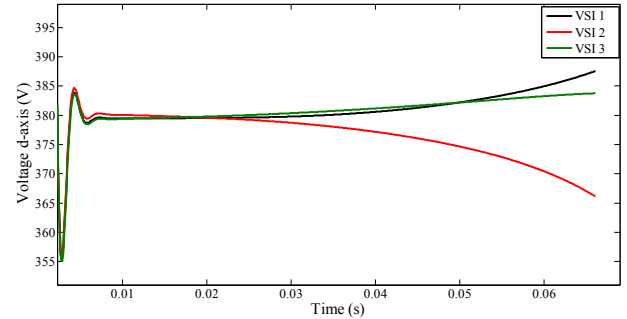


Fig. 13. Voltage magnitude in d axis after a disturbance ($n_q=0.0015$)

Considering Fig.11, the constraint $n_q < 0.00126$ should be added to every controller design or this constraint can be added after controllers output as the controller upper limiter.

4. Conclusion

In this paper, inverters, network and dynamic loads are modeled forming an islanded MG. In this process, a complete model of the MG is obtained through combination of individual models of all the sub-modules into a common reference. The eigenvalues of the derived model have been analyzed to find their sensitivity to changes in the reactive power droop gain. Then the offline study for voltage stability is presented. As a result, some constraints are added to some of the system parameters to ensure that the system operates in stable condition.

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