Dynamic Stability of a Microgrid with an Active Load

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***Abstract*—Rectifiers and voltage regulators acting as constant power loads form an important part of a microgrid's total load. In simplified form, they present a negative incremental resistance and beyond that, they have control loop dynamics in a similar frequency range to the inverters that may supply a microgrid. Either of these features may lead to a degradation of small-signal damping. It is known that droop control constants need to be chosen with regard to damping, even with simple impedance loads. Actively controlled rectifiers have been modeled in non-linear state-space form, linearized around an operating point, and joined to network and inverter models. Participation analysis of the eigenvalues of the combined system identified that the low-frequency modes are associated with the voltage controller of the active rectifier and the droop-controllers of the inverters. The analysis also reveals that when the active load DC-voltage controller is designed with large gains, the voltage controller of the inverter becomes unstable. This dependency has been verified by observing the response of an experimental microgrid to step changes in power demand. Achieving a well-damped response with a conservative stability margin does not compromise normal active rectifier design, but notice should be taken of the inverter-rectifier interaction identified.**

***Index Terms*—Microgrids; Small-Signal Stability; Inverters; Constant Power Loads; Active Loads; Rectifiers.**

I. INTRODUCTION

The presence of distributed generation (DG) in a distribution network creates the possibility of microgrid (MG) formation [1]. If a MG is formed, whether after a line outage or during planned maintenance, there is a need for the DG to respond to changes in load, and share the load such that the DG operate within their limits.

A MG will have to ensure small-signal stability due to small changes to the operating conditions or load perturbations. It is known that, in general, load dynamics interact with generation dynamics and may influence the stability of a network [2]. Therefore, when investigating the stability of a MG, both the generation dynamics and the load dynamics must be considered.

Typically, electrical power in MGs is generated by rotating machines or by power electronics. Rotating machines include synchronous machines and power electronics include voltage or current source inverters. This work only considers MGs with voltage source inverters.

The literature on control approaches that enable the DG to share the load and remain within their operating limits discusses either use of a communications link or use of a droop method. Communication approaches may involve a master-slave link, where the DG outputs are controlled using a dispatch signal [3]. If the master DG unit regulating the grid voltage is not functioning or does not have enough capacity, the MG may not satisfy voltage and frequency limits.

The use of a droop control method has the advantages of not requiring a communication link and allows DG to support MGs irrespective of which sources are available. The droop control method has been widely discussed, for example [4] [5] [6] [7]. However, inverter-interfaced DG operated with droop controllers have relatively complex and dynamic properties.

It is known that in droop controlled MGs, the low-frequency modes (oscillations that are represented by conjugate eigenvalue pairs) are associated with the droop controllers [7]. The low frequency modes are most likely to be poorly damped, and at a risk of instability during operating point or parameter changes. The droop controllers give rise to low frequency modes because of their use of low-pass filters to reject harmonic and negative sequence disturbances from the power measurements. The filtered power measurements are used to determine the frequency references for the AC-voltage controllers of the inverters.

Several strategies have been proposed to increase the damping of the low frequency modes during both steady-state operation and transient behavior. Improvements include adjusting the droop parameters while the MG is functioning by the use of either an energy manager [8] or a grid-impedance estimation strategy [9]. Feed-forward terms have been proposed in [10] and using an inverter to imitate a voltage source with a complex output impedance is proposed in [11]. Using proportional, integral, and derivative controllers within the droop calculation have been proposed in [12] [13] [14] [15].

For simplicity, this work will not consider the enhancements of droop-controllers to improve stability and will only consider the simple droop controller, as presented in [7]. This is so that, the influence of load dynamics within the MG can be more readily observed. One possibility to further simplify the MG model, is to represent the inverters by only their low-frequency dynamics as in [16] (which was extended to larger system sizes in [17]). This modeling technique is valid if the system is not sensitive to the mid-frequency or high-frequency dynamics.

Loads within an electrical network are either passive or ac-

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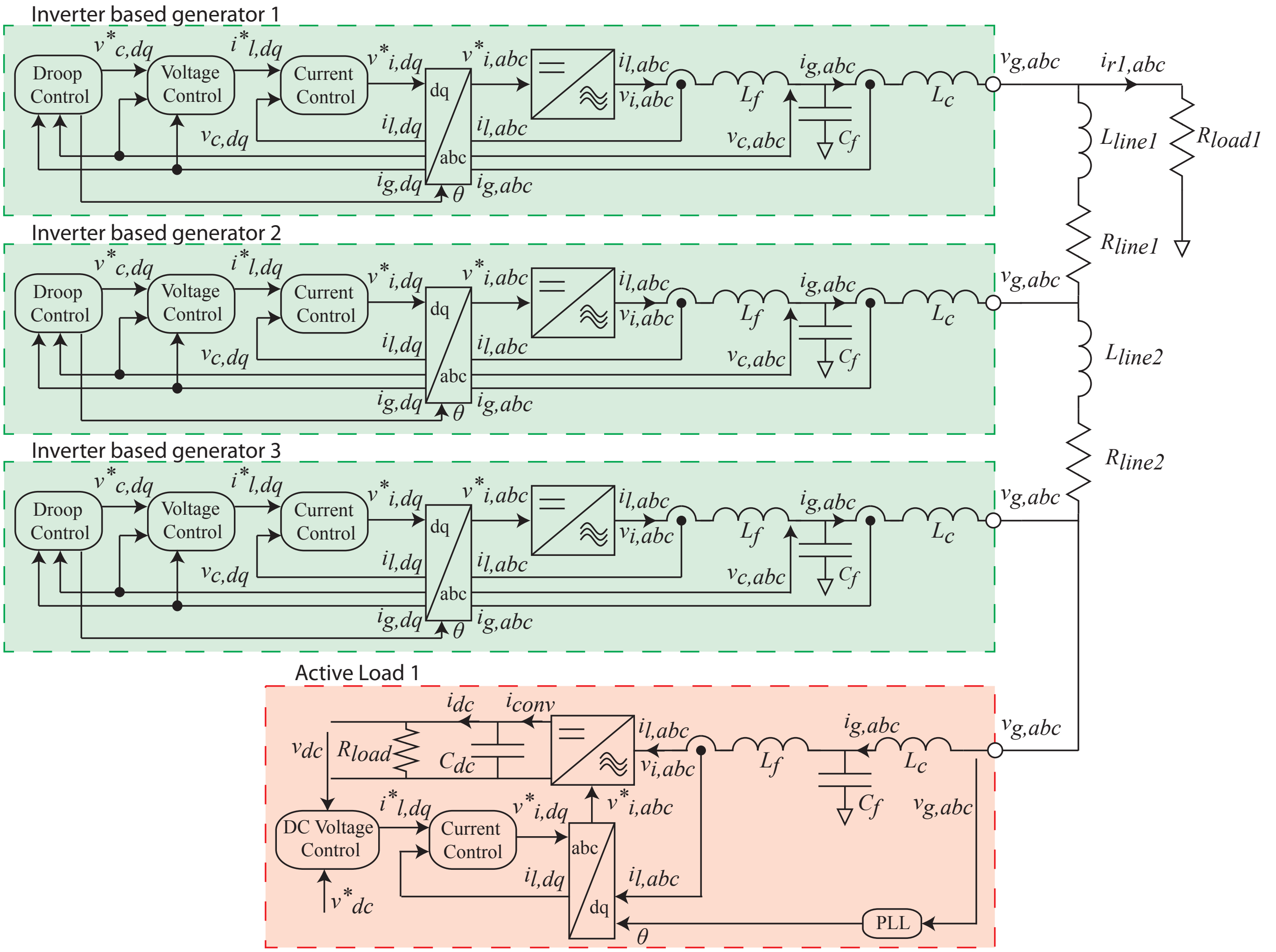

Fig. 1: Comprehensive figure showing all the DG's and loads with corresponding control

tive loads. Passive loads include devices such as incandescent lighting or resistive space heaters and are typically modeled by a resistor or an inductor-resistor network. Active loads include devices such as machine drives, back-to-back converter configurations, and consumer electronics with unity power factor correction. Over a small time period, these devices may be modeled as constant power loads (CPLs). This work considers inverter based generation with active and passive loads.

This work is important since published literature has mostly considered MGs with passive (i.e. impedance) loads, whereas MG implementations are likely to include significant proportions of loads with active front ends. Active front ends are used for providing regulated voltage buses to supply the final use equipment. By regulating the voltage bus, an active load may become a CPL.

Constant impedance loads generally increase damping whereas CPLs tend to decrease damping [18]. To understand how a network responds to different generation technologies, in this case DG, a range of load dynamics must be studied. The results produced from using only passive loads may be misleading, since they might not represent the type of loads connected to a network [19].

CPLs typically destabilize DC MG networks [20] [21] [22] and were shown to destabilize an AC MG in [23], which went on to conclude that CPLs are only stable if paralleled with constant impedance loads. The study used the small-signal representation of an ideal CPL, which exhibits a negative incremental resistance $\left(\Delta i = -\left(\frac{P}{V^2}\right)\Delta v\right)$ but did not consider the dynamics of the bus regulator. Many solutions have been proposed to overcome the problems of CPLs, including the solution discussed in [24] [25].

Large-signal stability of a MG, with various load types, was investigated in [26]. The conclusion from this was that constant PQ loads and impedance loads have no affect on stability but motor loads do. Although this work did not consider small-signal stability, it is important because it demonstrates that CPLs have the possibility of being stable without the need to be paralleled with constant impedance loads (contrary to the assertion in [23]).

Several approaches for determining network stability exist. Power electronic networks can be analyzed using impedance