Droop Control Methods for PV-Based Minigrids

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Introduction:

Droop control method is the most widely used in PV power systems to enable automatic load sharing between different distributed PV systems and to extend operating range of active (P) and reactive (Q) power ratings of a given inverter [1,2]. For easy analysis, consider a two bus synchronous generator connected to a high volatge (HV) transmission netwrok as shown below.

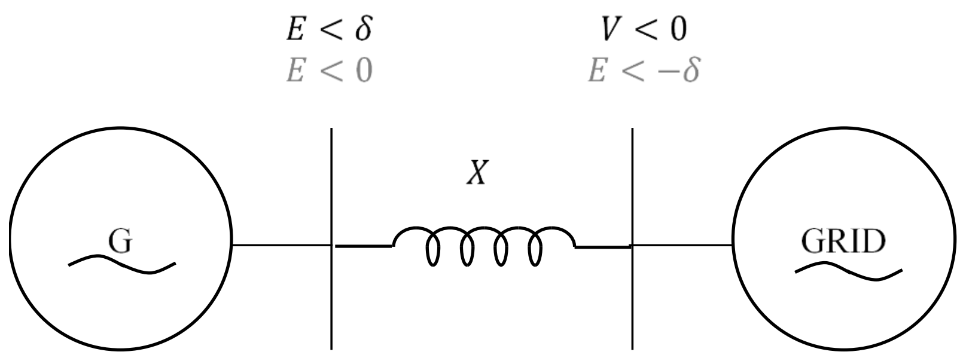

Fig. 1: Generator Connected to Grid

The power produced at the generator terminal is expressed as [3]

$$P = \frac{E}{R^2 + X^2}\left[XV \sin\delta + R(E - V\cos\delta)\right]$$

$$Q = \frac{E}{R^2 + X^2}\left[-RV \sin\delta + X(E - V\cos\delta)\right]$$

where δ is the voltage angle.

Methodology:

Consider a communal grid with two-feeder distribution systems as shown in figure 2 below.

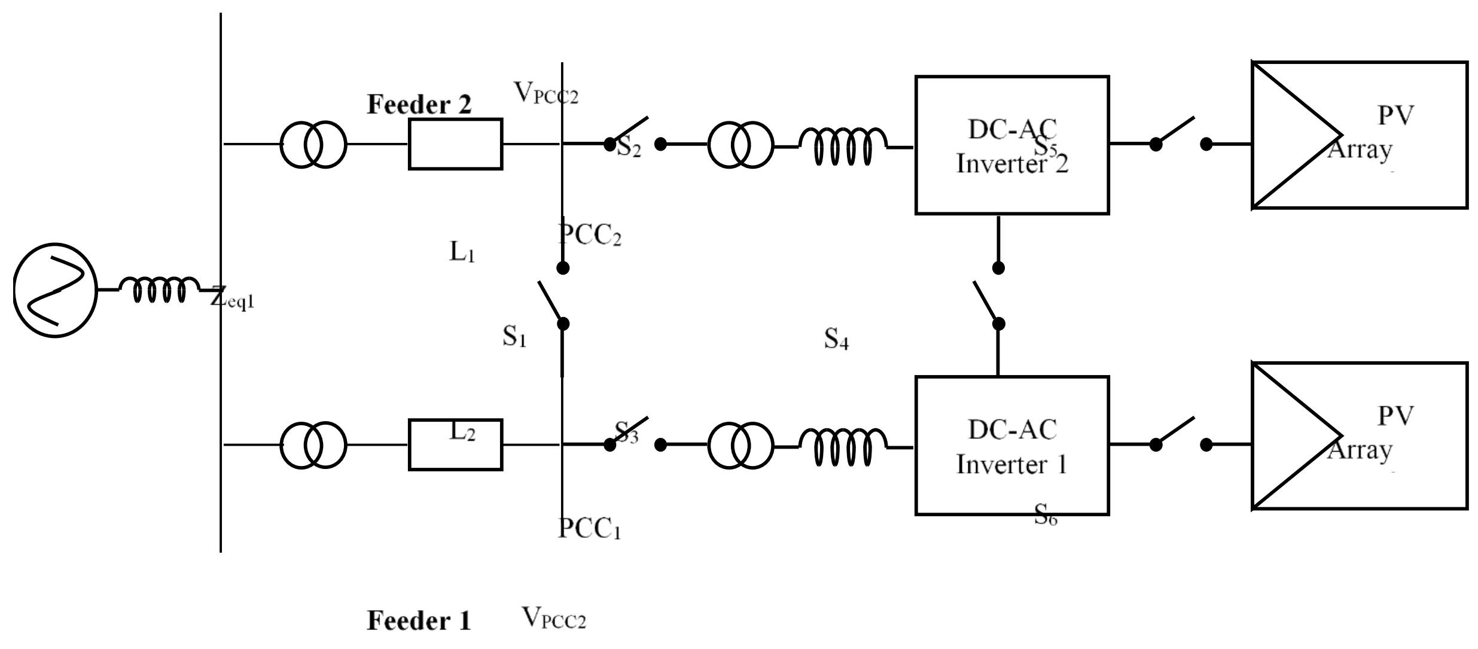

Fig. 2: Interline-PV (I-PV) System Configuration

Figure 3 shows a Thevenin equivalent of feeder 2 connected to inverter 2. The figure represents a power source ($E_{PV}\angle\phi$) where Z_{th} represents the feeder as well as inverter coupling impedance, ∅ is the phase angle difference between PCC and grid voltages, while θ is the impedance angle due to Z_{th}.

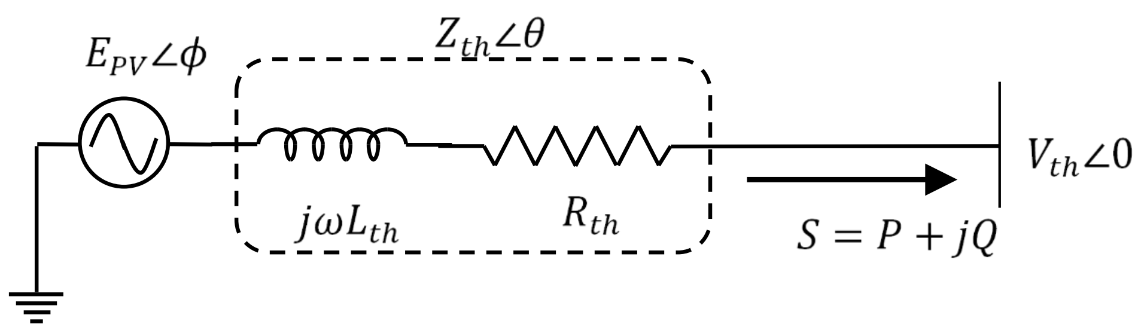

Fig. 3: Thevenin Equivalent Circuit of Feeder 2 Connected to Inverter 2

The following equations are used to control the active and reactive power flows (S = P +*j*Q) from inverter 2 (the power source) to feeder 2 (the grid):

$$P = \frac{V_{th}}{Z_{th}}\left[(E_{PV}cos\emptyset - \mathrm{V_{th}})cos\theta + E_{PV}\ sin\theta sin\emptyset\right]$$

$$Q = \frac{V_{th}}{Z_{th}}\left[(E_{PV}cos\emptyset - \mathrm{V_{th}})sin\theta - E_{PV}\ cos\theta sin\emptyset\right]$$

Results and Discussion:

Figure 4 shows the performance of feeder 2 at t_1, t_2, and t_3. The PCC voltage is regulated according to the P-f droop control method. The droop coefficient for this method is 0.02 *pu/MW* for all the operating conditions.

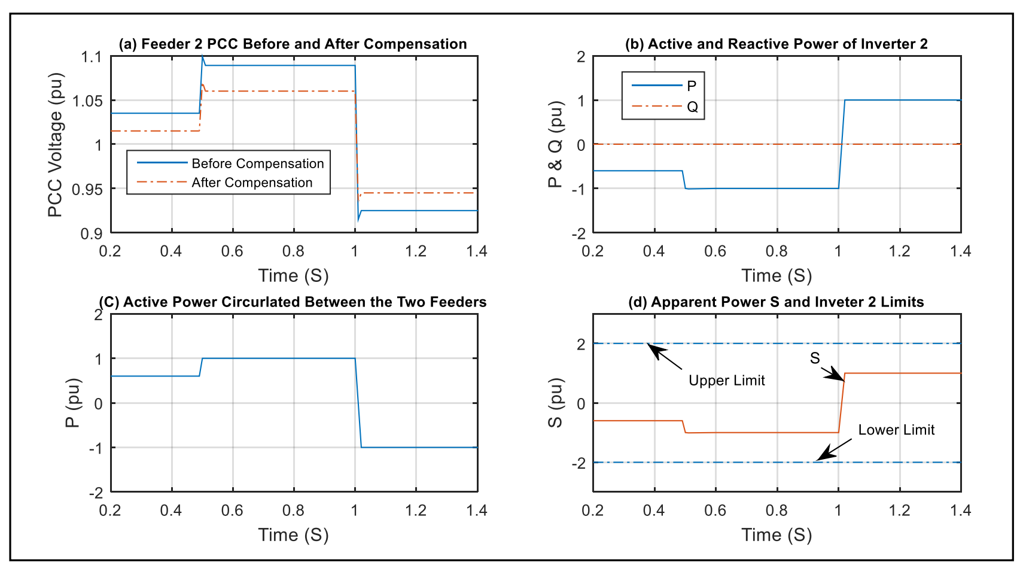

Fig. 4: Feeder 2 Performance Using P-f Droop Control Method

Figure 5 shows the performance of feeder 2 at t_1, t_2, and t_3 with Q-V droop control method. The droop coefficient for this method is 0.01 *pu/MVAR* for all the operating conditions.

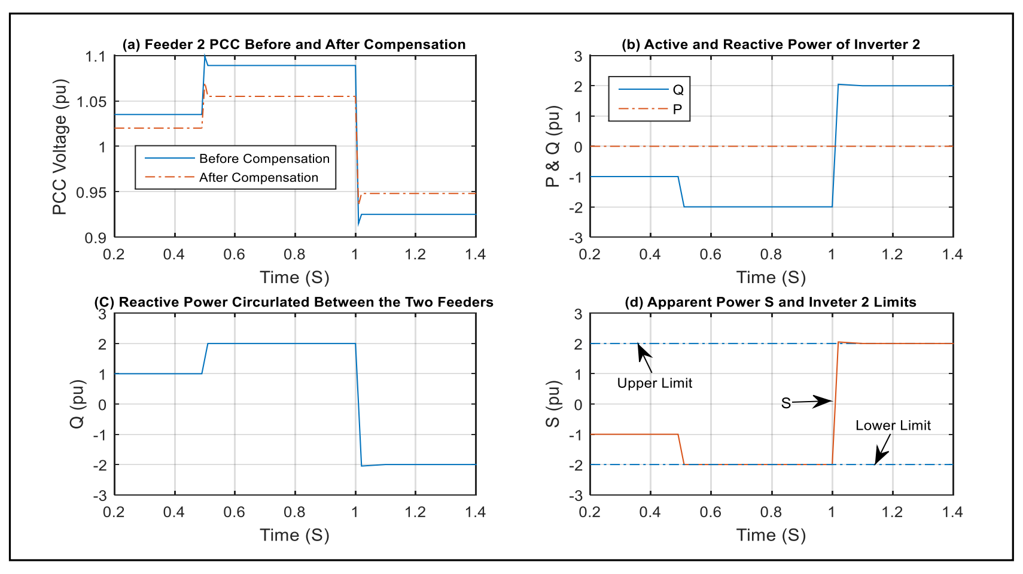

Fig. 5: Feeder 2 Performance Using Q-V Droop Control Method

Figure 6 shows the performance of feeder 2 at t_1, t_2, and t_3 with P-Q-V droop control method. The inverter capacity is efficiently utilized for voltage regulation with the P-Q-V method than with P-f or Q-V droop methods individually.

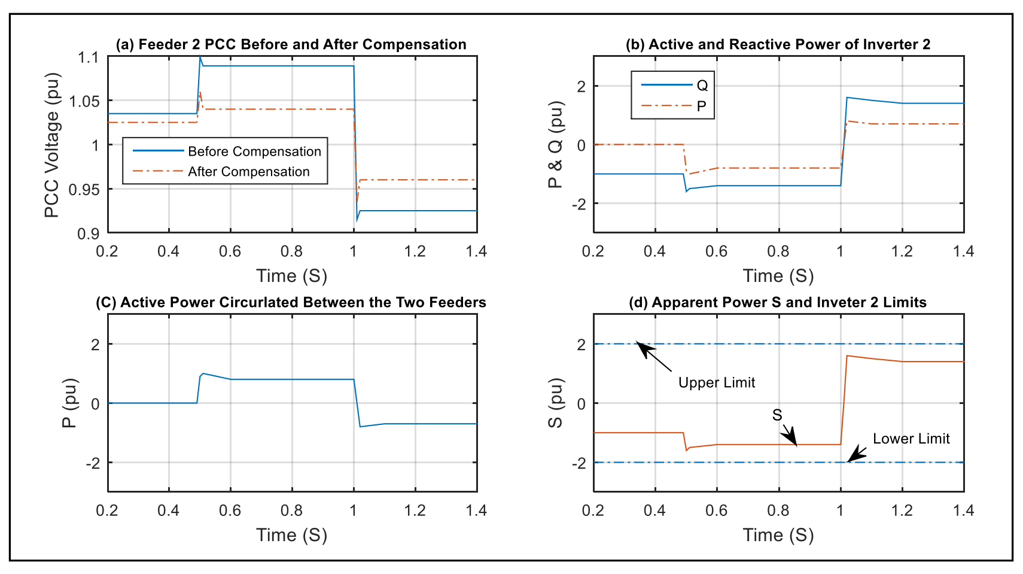

Fig. 6: Feeder 2 Performance Using P-Q-V Droop Control Method

Conclusion:

Active power-frequency (P-f) droop control method is the most efficient for low voltage transmission networks with low X/R ratios while reactive power-voltage (Q-V) droop control method is the most efficient for systems with high X/R ratios. Results also show that P-f or Q-V droop control methods cannot individually efficiently regulate line voltage and frequency that for systems with complex line resistances and impedances, i.e. near unity X/R ratios. For such systems, P-Q-V droop control method, where both active and reactive power could be used to control PCC voltage via shunt-connected inverters, is determined to be the most efficient control method.

Results also show that shunt-connection of inverters leads to improved power flow control of interconnected communal grids by allowing feeder voltage regulation, load reactive power support, reactive power management between feeders, and improved overall system performance against dynamic disturbances.

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