Parallel Operation of Virtual Synchronous Generators in a Microgrid

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1. Introduction

A New Concept of **Inverter Control** in **AC Microgrid**

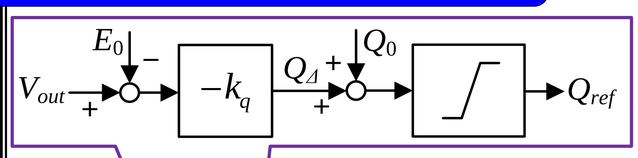
Conventional Droop Control + Swing Equation Imitation → **Virtual Synchronous Generator (VSG) Control**

- Load Sharing
- Smooth Transition between Islanding and Grid-connection
- $P_{in} - P_{out} = J\omega_m \frac{d\omega_m}{dt} + D(\omega_m - \omega_g)$
- Inertia Support

Issues to Solve

1. Active power oscillation during a disturbance
2. Inappropriate transient load active power sharing
3. Sharing errors in reactive power

2. Basic VSG Control



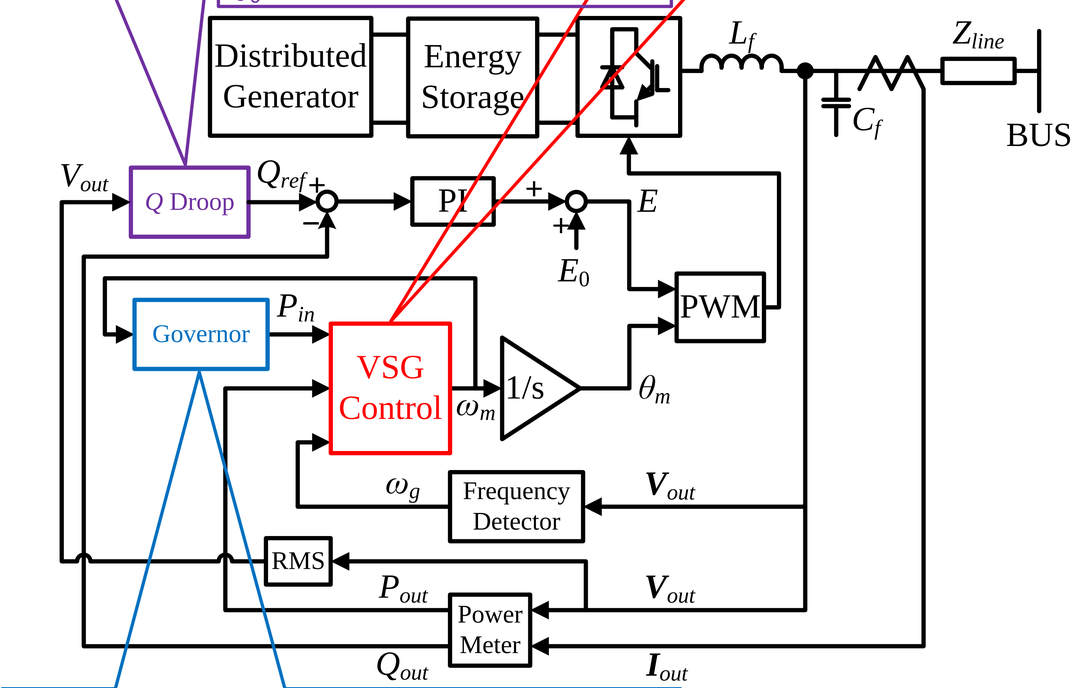
$P_{in} - P_{out} = J\omega_m \frac{d\omega_m}{dt} + D(\omega_m - \omega_g)$

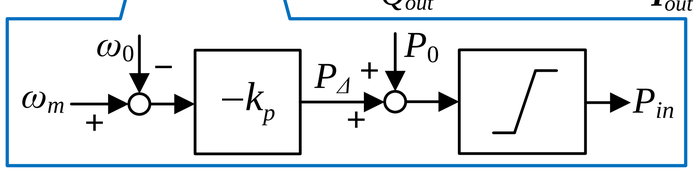
Swing Equation

J: Moment of Inertia
D: Damping Factor

V-Q Droop

k_q: *V-Q* Droop Coefficient
Q_0: Set Value of Reactive Power

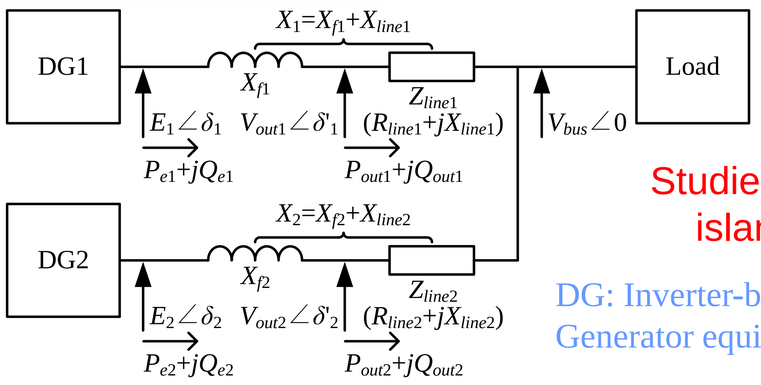




ω-P Droop

k_p: *ω-P* Droop Coefficient
P_0: Set Value of Active Power

3. Problem Analysis

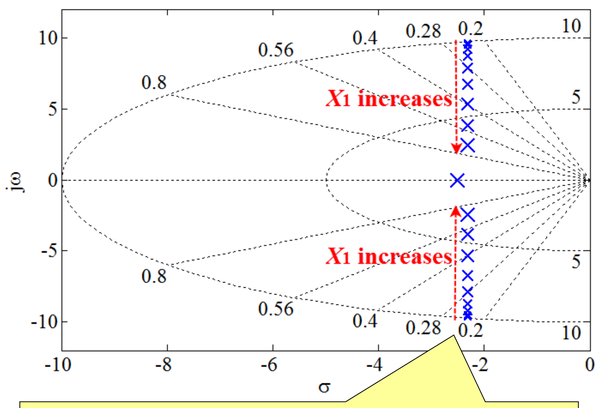


Studied Microgrid in islanded mode

DG: Inverter-based Distributed Generator equipped with VSG control

Active Power Oscillation

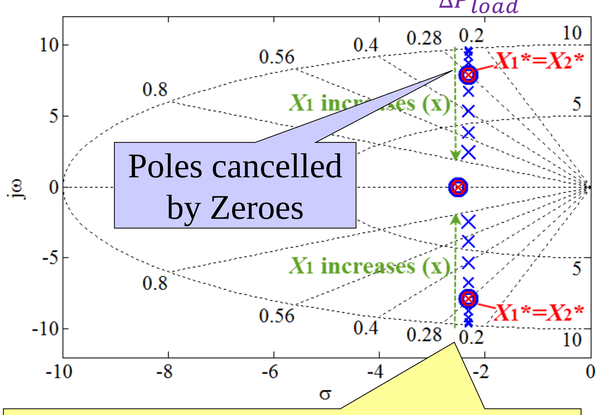
Eigenvalues of State Matrix



Damping ratio (indicated by the radial dash lines) can be increased by increasing output reactance

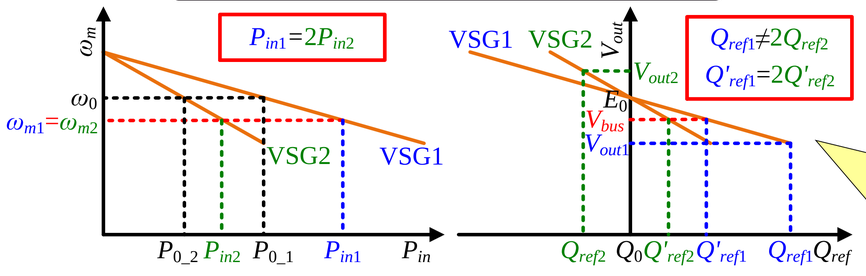
Transient Load Sharing

Poles and Zeroes of $\frac{\Delta P_{out1}}{\Delta P_{load}}$



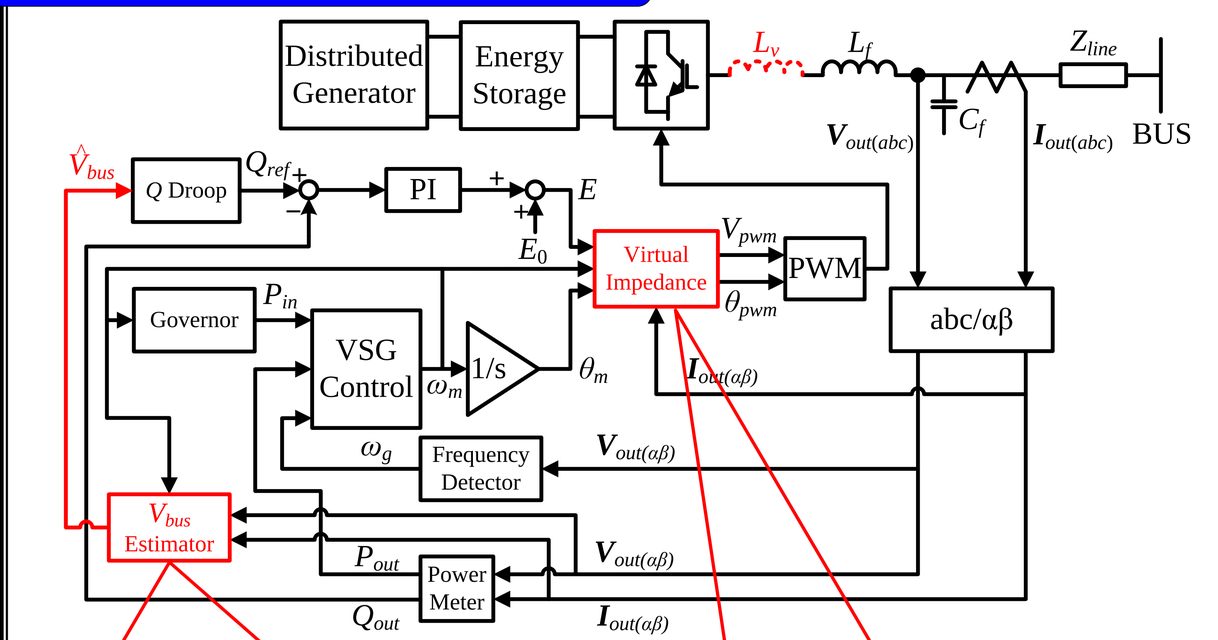
Transient load can be properly shared without oscillation if output reactance of each DG is of the same per unit value

Reactive Power Sharing Errors



For proper reactive power sharing, voltage used for *V-Q* Droop of each DG should be equivalent

4. Proposed VSG Control

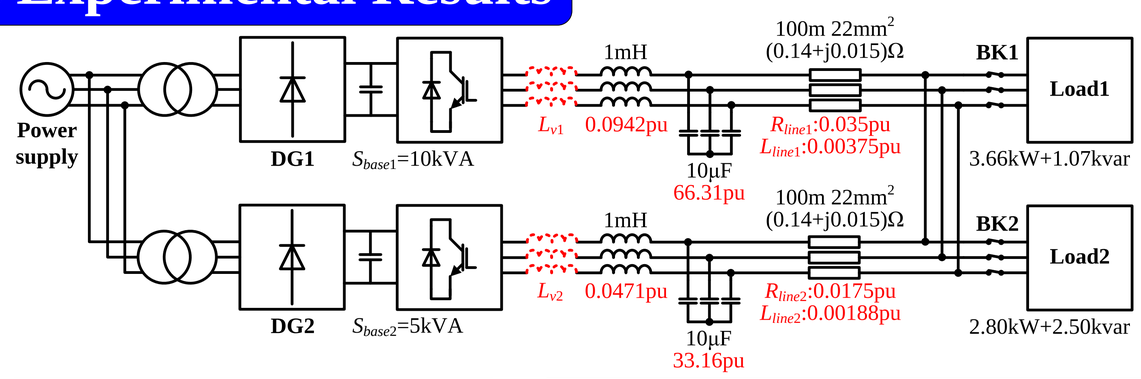


Using local voltage and current to estimate bus voltage for proper reactive power sharing

$X_i^* = \frac{S_{base\_i}}{E_0^2}\omega_{m\_i}(L_{v\_i} + L_{f\_i} + L_{line\_i}) = 0.7$ pu

Using virtual impedance control to increase output reactance of each DG to a same large per unit value

5. Experimental Results



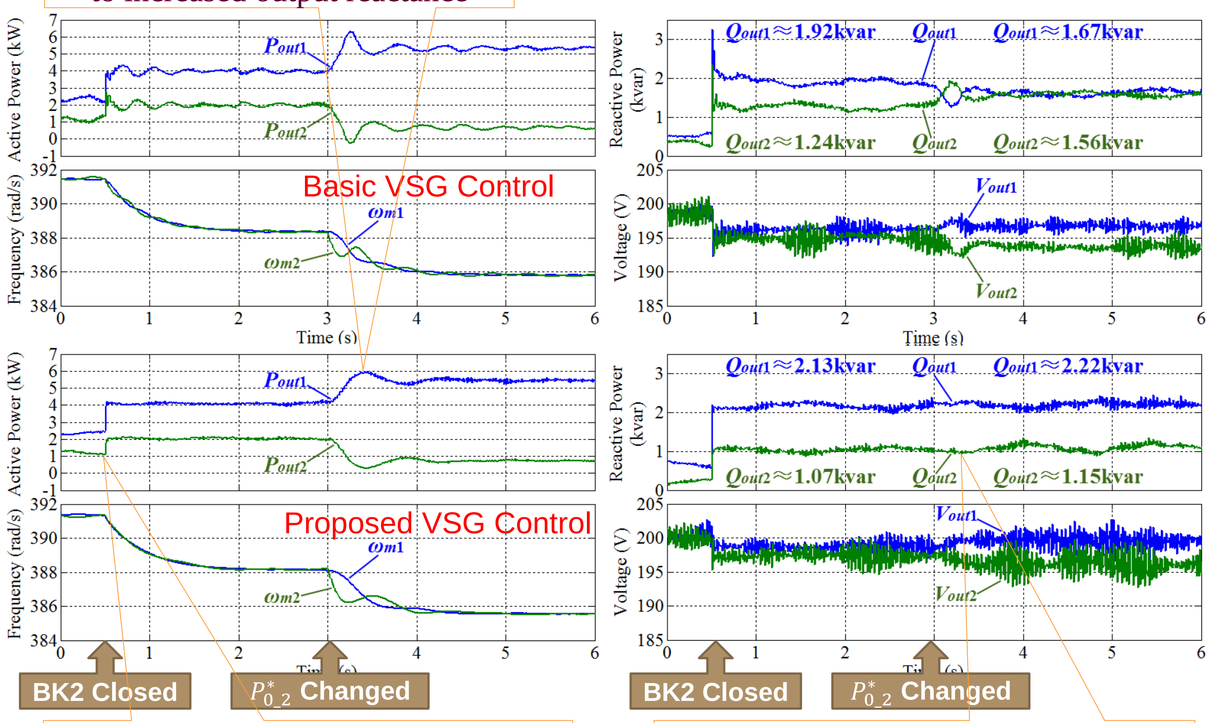
Experiment Sequence

Time	$P^*_{0\_1}$	$P^*_{0\_2}$	Load
t < 0.5 s	1 pu	1 pu	Load1
0.5 s ≤ t < 3 s	-	-	Load1+2
3 s ≤ t < 6 s	-	0.6 pu	-

Common Parameters

Parameter	Value	Parameter	Value
S_{base1}	10 kVA	M^*_i	8 s
S_{base2}	5 kVA	D^*_i	17 pu
E_0	200 V	$k^*_{p\_i}$	20 pu
ω_0	376.99 rad/s	$k^*_{q\_i}$	10 pu
$P^*_{0\_i}$	1 pu	$Q^*_{0\_i}$	0 pu

Oscillation being damped owing to increased output reactance



Transient load being properly shared owing to matched output reactance

Proper reactive power sharing achieved owing to equal *V-Q* droop reference

6. Conclusion

1. Virtual impedance control was proposed to increase output reactance and to adjust output reactance mismatch, in order to increase system damping and to properly share transient load
2. Bus voltage estimator was proposed to provide a common reference for the V-Q droop, in order to properly share reactive power
3. The effects of both virtual impedance control and bus voltage estimator were proved by experimental results