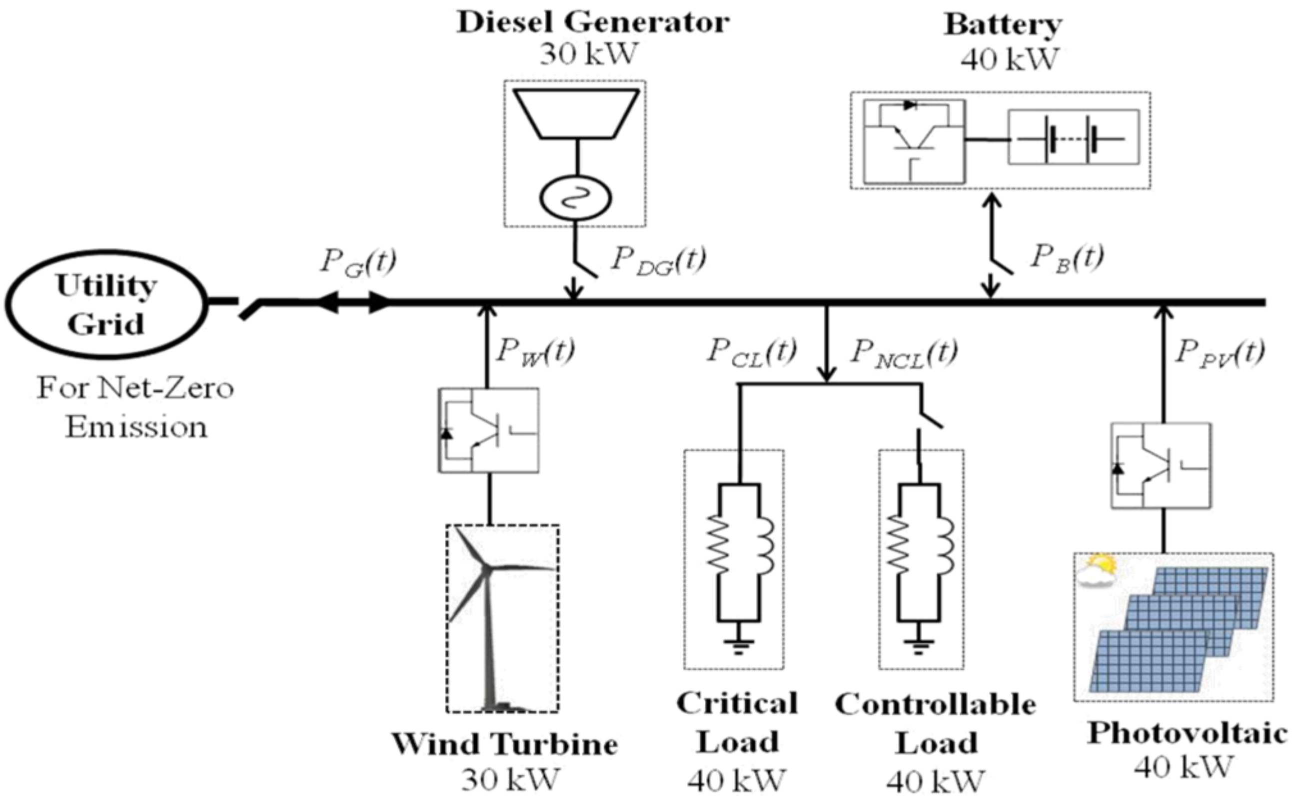
CLEMSON UNIVERSITY

ECE 802, Electric Motor Control

Synchronous Machines in Micro Grids

Micro Grids

- Generally, any stand-alone system with “finite” generation is considered to be a micro grid
- Examples, Army forward operating base, Naval ship power system, etc.
- Can be operated in grid-connected or islanded mode
- Sometimes seen as a bridge between the traditional power system and the future power system which will involve more renewable energy sources



Synchronous Machine Droop Control

- Control for paralleling synchronous machines including cases where the machines are of different power rating
- Typically, frequency is reduced or "drooped" with increasing generated real power
- Typically, voltage is drooped with increasing generated reactive power
- Droop control is usually used in micro grids in conjunction with a higher-level control to set the grid frequency

Synchronous Generator Control Options

Connection to the utility (an infinite buss)
- Utility frequency sets machine steady-state speed
- Torque is controlled to supply real power
- Field voltage is controlled to supply both positive and negative reactive power

Connection to passive loads
- Speed control adjusts frequency
- Field control adjusts voltage

Multiple machines supplying passive loads
- Speed is drooped depending on real power from generator
- Field voltage is drooped depending on reactive power from generator

Frequency Droop Equations

Typically, machine runs at rated frequency with no load and droops according to

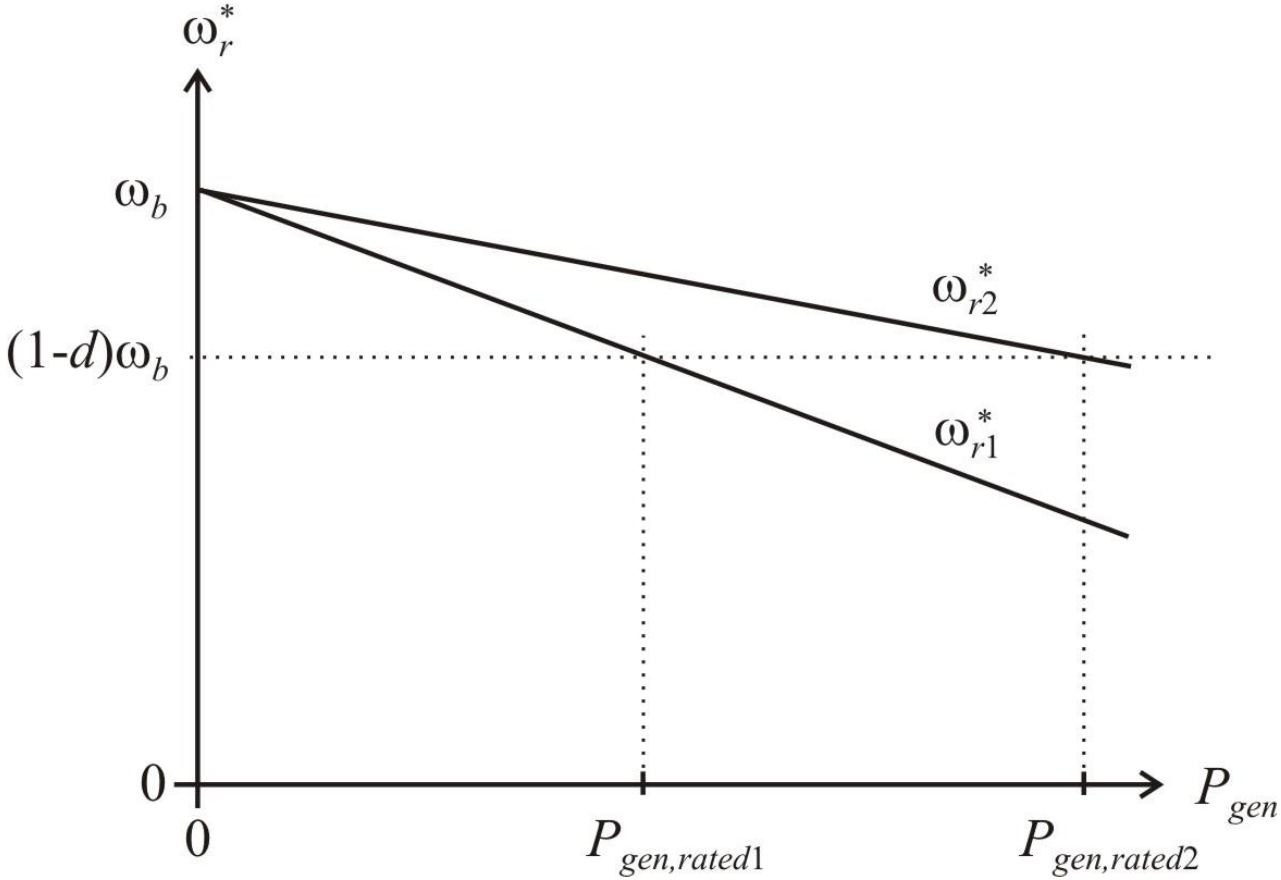
$$\omega_r^* = \omega_b \left(1 - d\,\frac{P_{gen}}{P_{gen,rated}} \right)$$

ω_b - base speed (rad/s)
P_{gen} - generator output real power (W)
$P_{gen,rated}$ - rated generator power (W)
d - droop factor

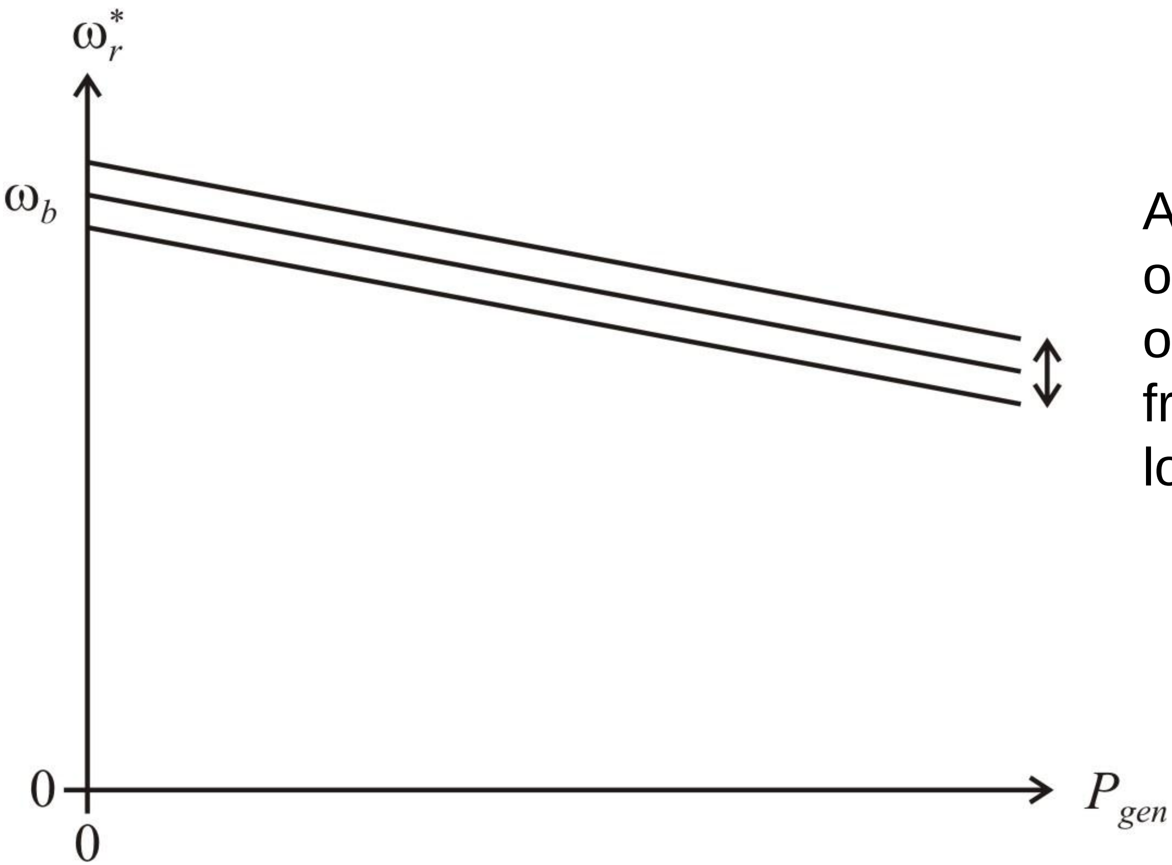
Alternatively, the machine speed can reach rated value at rated power according to

$$\omega_r^* = \omega_b \left[1 - d \left(\frac{P_{gen}}{P_{gen,rated}} + 1 \right) \right] = \omega_b - \frac{d\,\omega_b}{P_{gen,rated}} \left(P_{gen} - P_{gen,rated} \right)$$

Two Generators Sharing Power



Higher-Level Control to Adjust Micro Grid Frequency



Adjust base frequency of droop controllers up or down to set system frequency for a given load

Voltage Droop Equations

Droop voltage based on generator reactive power

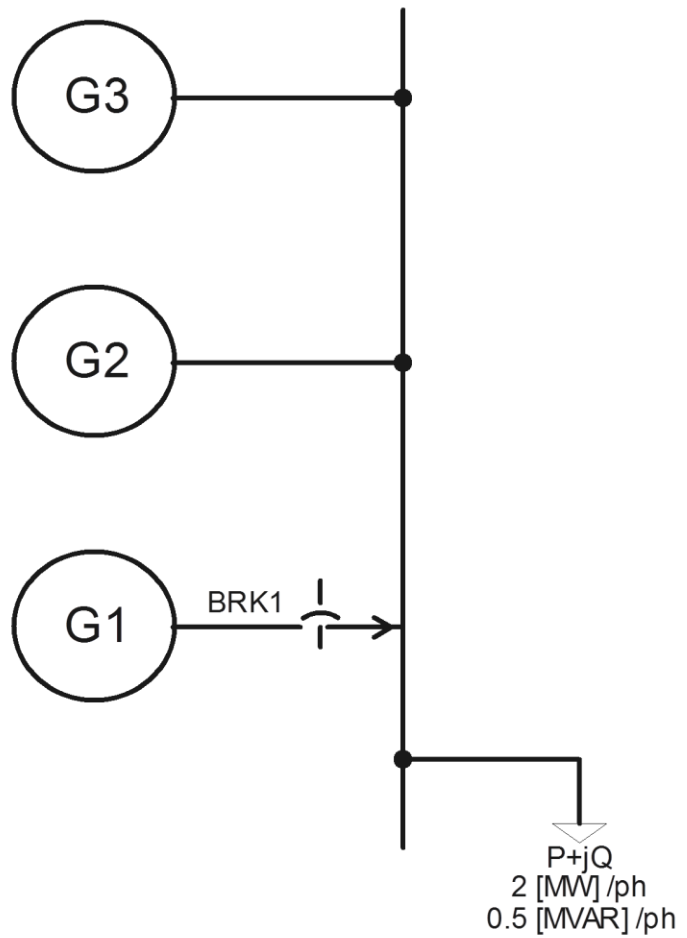
$$V_s^* = V_B \left(1 - d \, \frac{Q_{gen}}{Q_{gen,rated}} \right)$$

ω_b - base speed (rad/s)
Q_{gen} - generator output reactive power (VA)
$Q_{gen,rated}$ - rated generator reactive power (VA)
d - droop factor

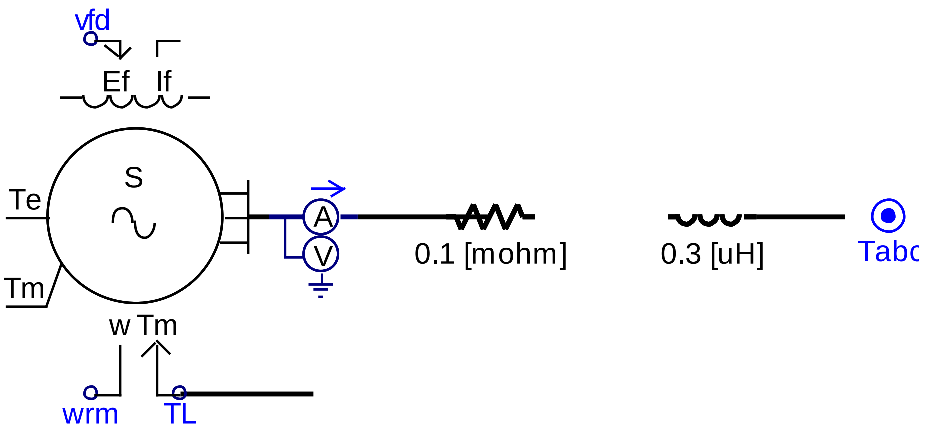
Simulation Example

Generator ratings
G3 - 4MW max
G2 - 2MW max
G1 - 2MW max

Total load
6 MW
1.5 MVAR

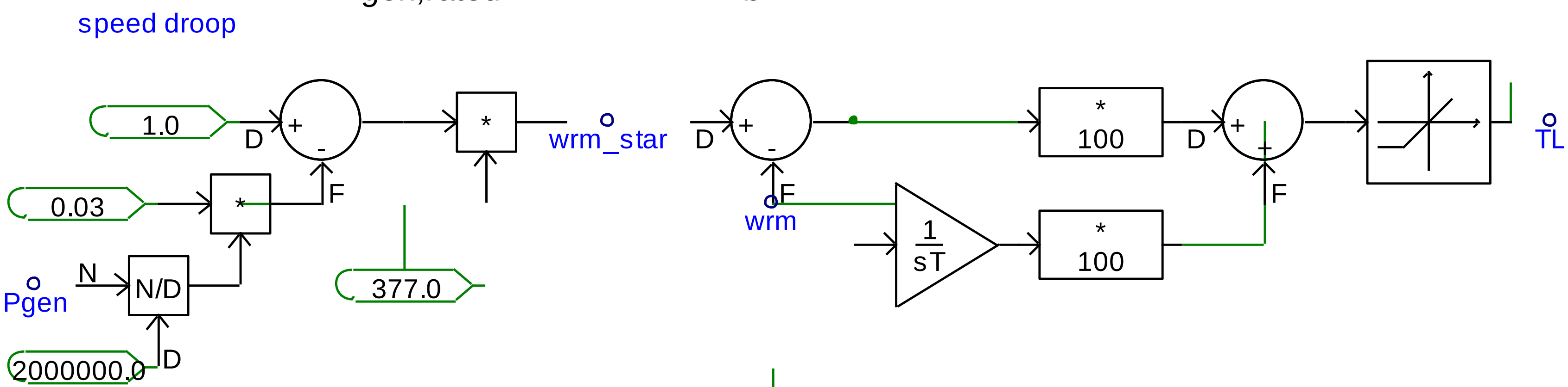


Generator G1

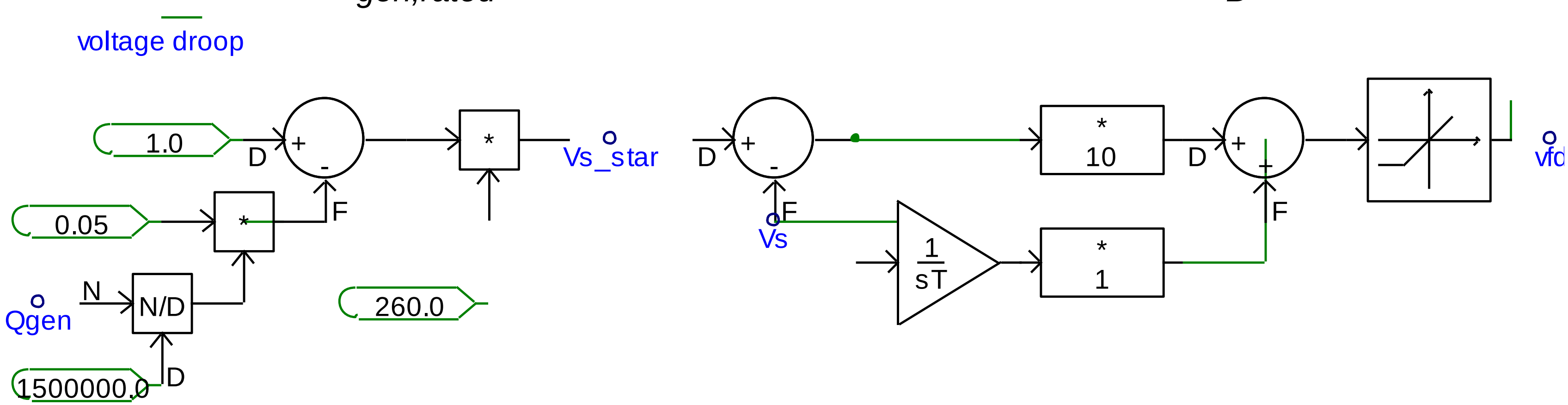


Generator G1 Droop Controls

$$P_{gen,rated} = 2\text{ MW},\ \omega_b = 377\text{ rad/s},\ d = 3\%$$

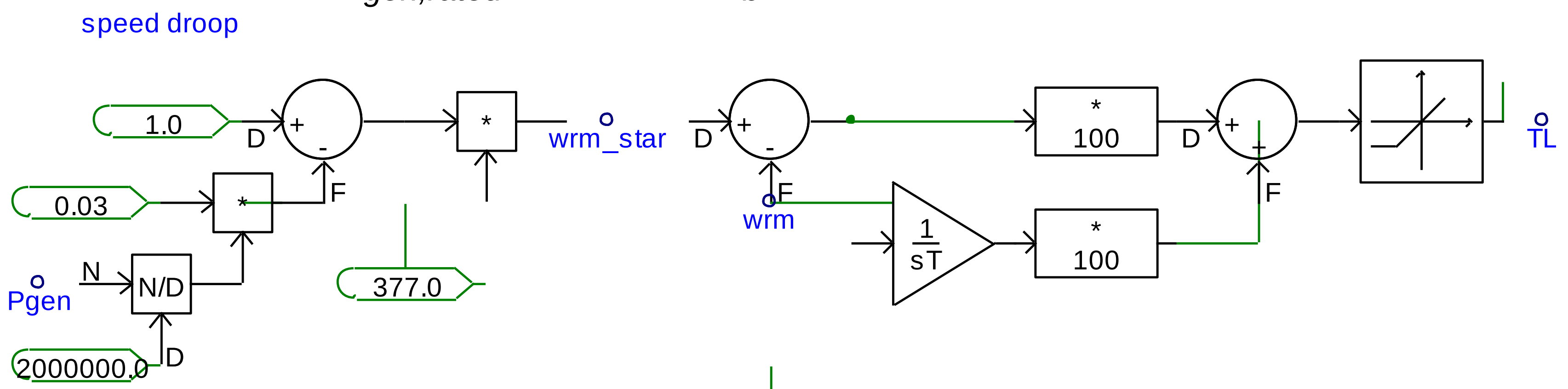


$$Q_{gen,rated} = 1.5\text{ MVAR (assuming 0.8 pf)},\ V_B = 260\text{ V},\ d = 5\%$$

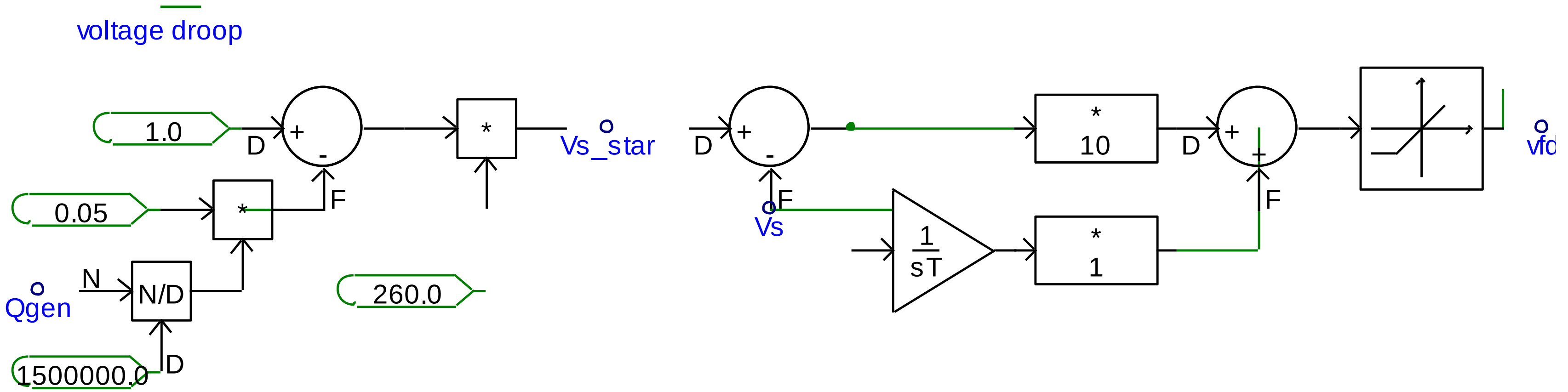


Generator G2 Droop Controls

$P_{gen,rated}$ = 2 MW, ω_b = 377 rad/s, d = 3%

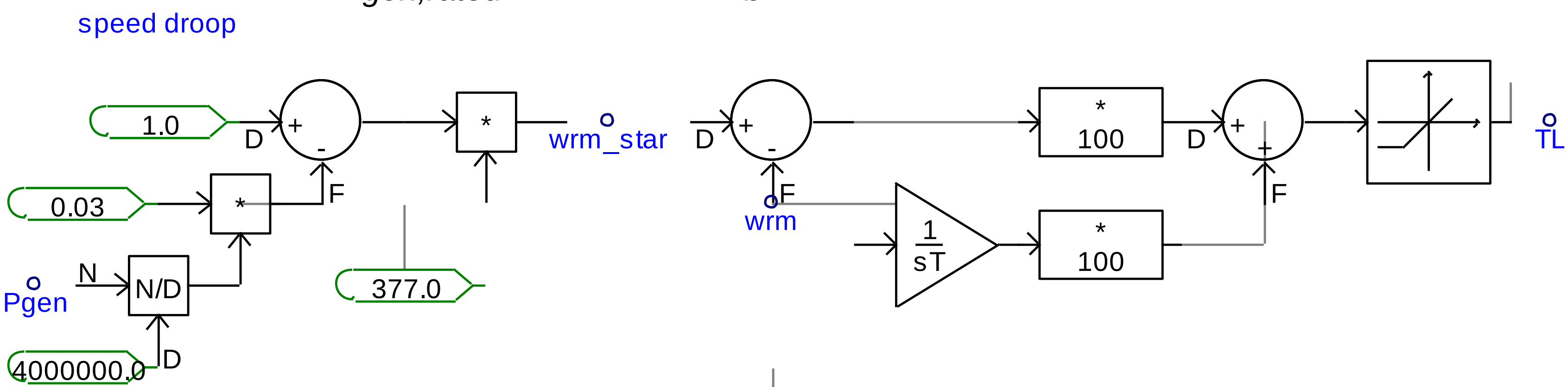


$Q_{gen,rated}$ = 1.5 MVAR (assuming 0.8 pf), V_B = 260 V, d = 5%

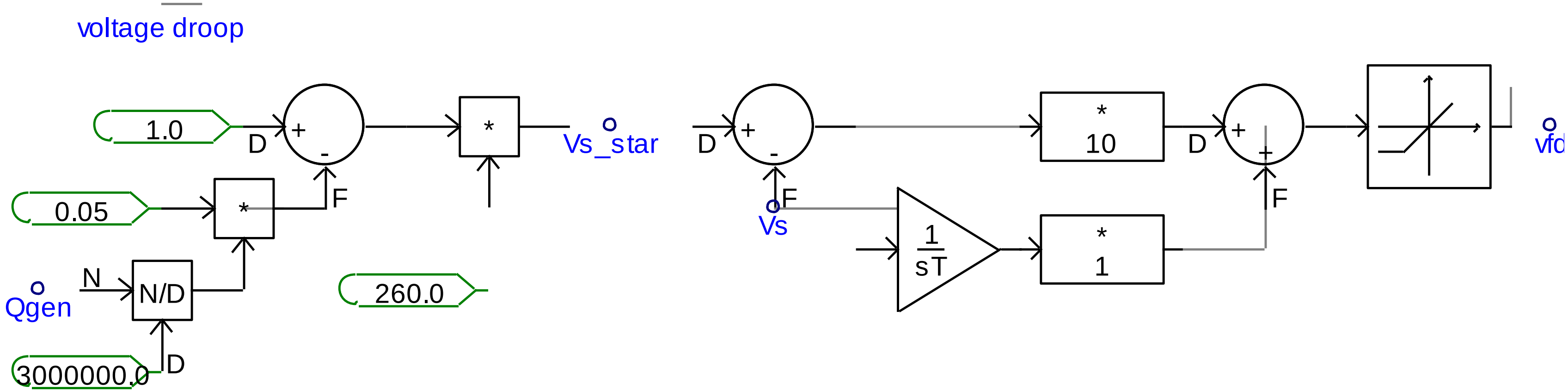


Generator G3 Droop Controls

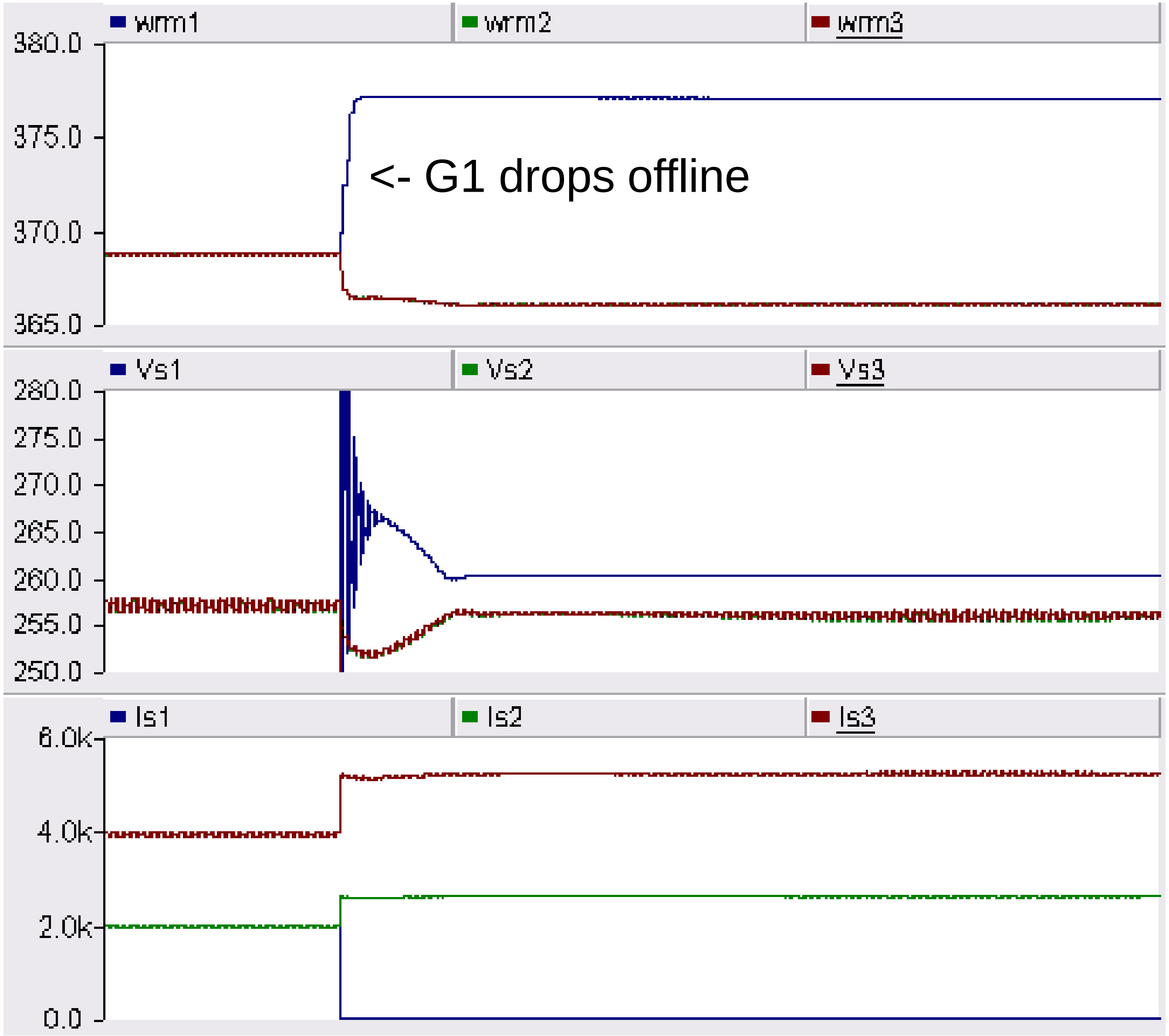
$P_{gen,rated}$ = 4 MW, ω_b = 377 rad/s, d = 3%



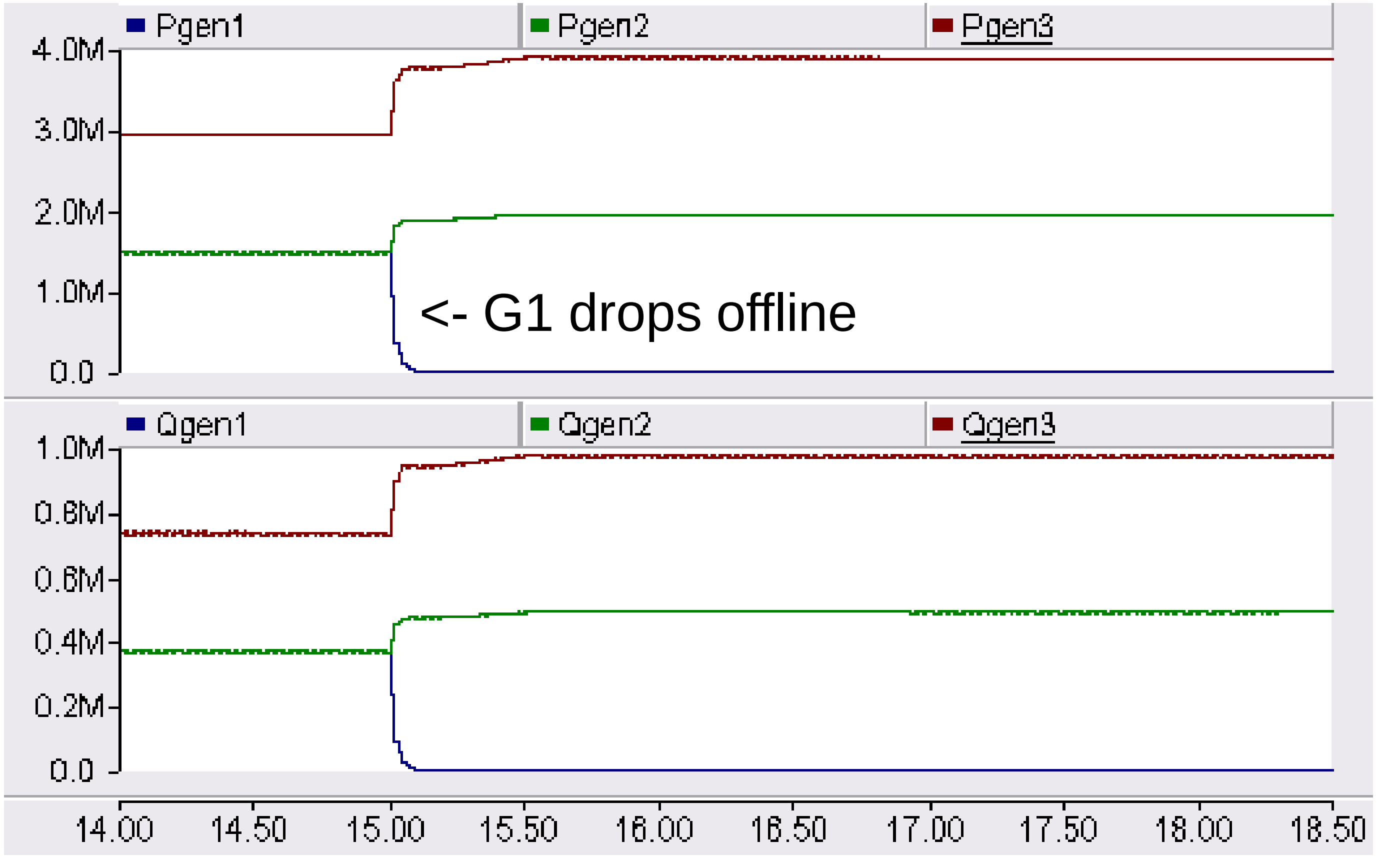
$Q_{gen,rated}$ = 3 MVAR (assuming 0.8 pf), V_B = 260 V, d = 5%



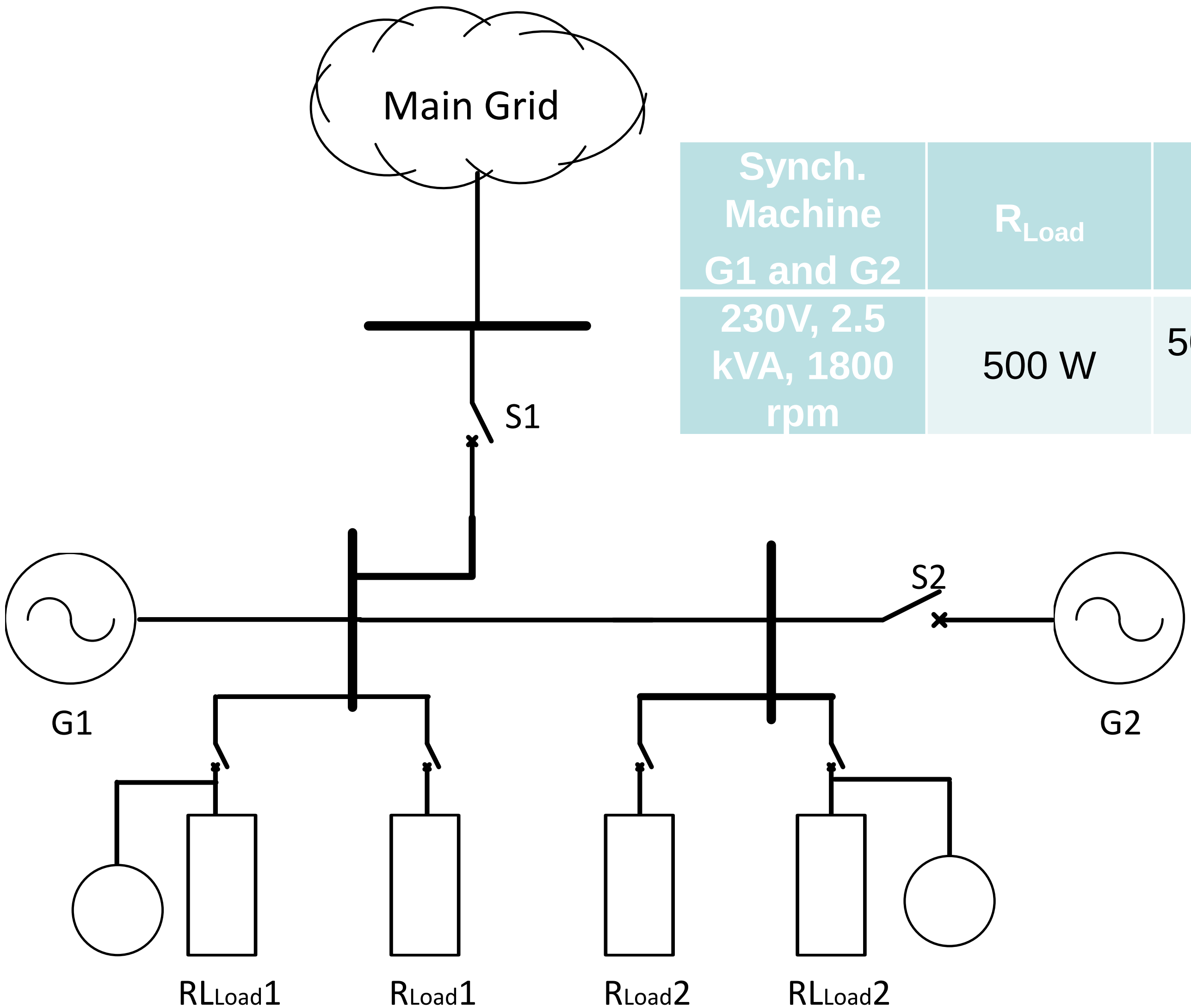
Generator Speeds, Voltages, and Currents



Generator Real and Reactive Powers

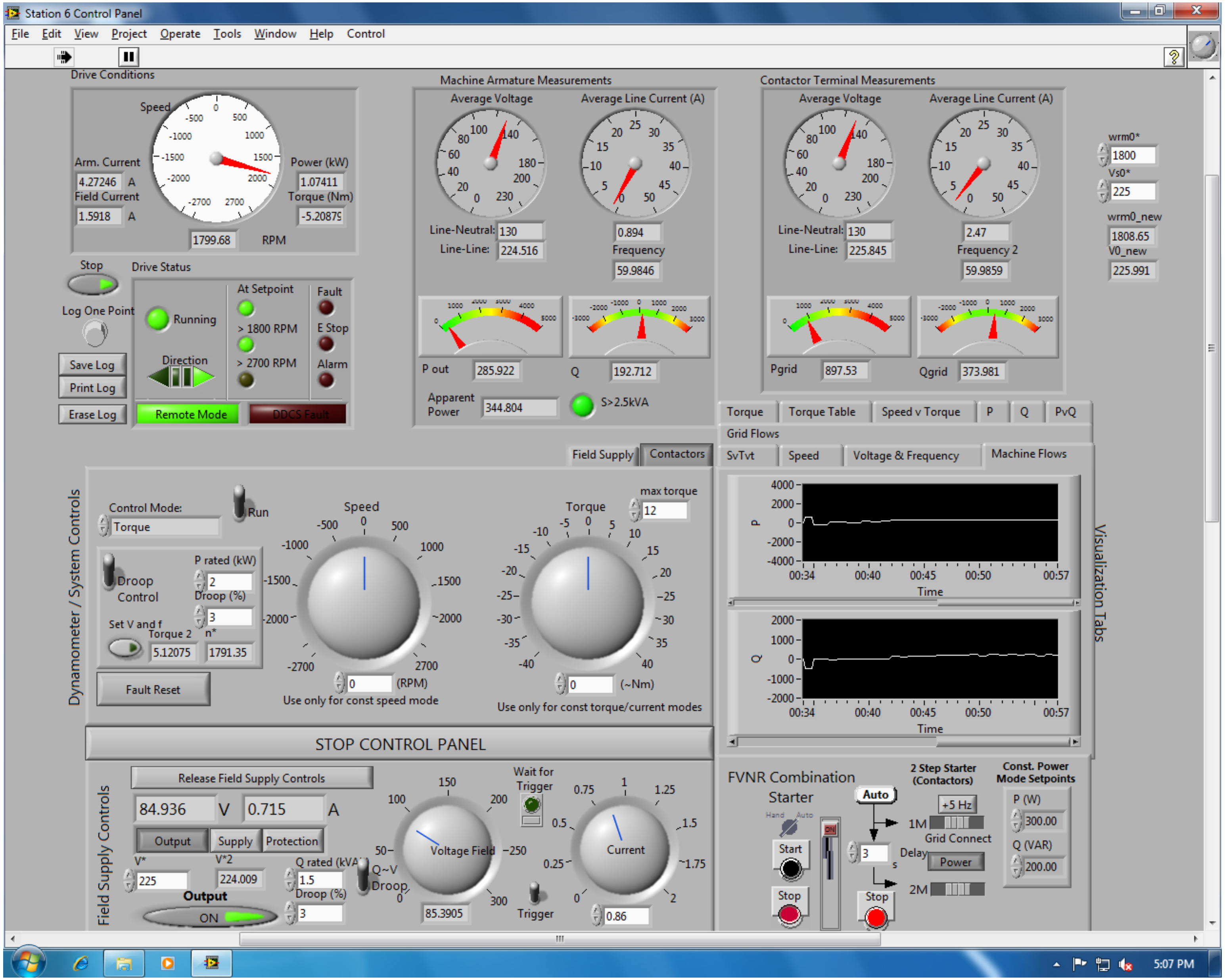


Laboratory Micro Grid

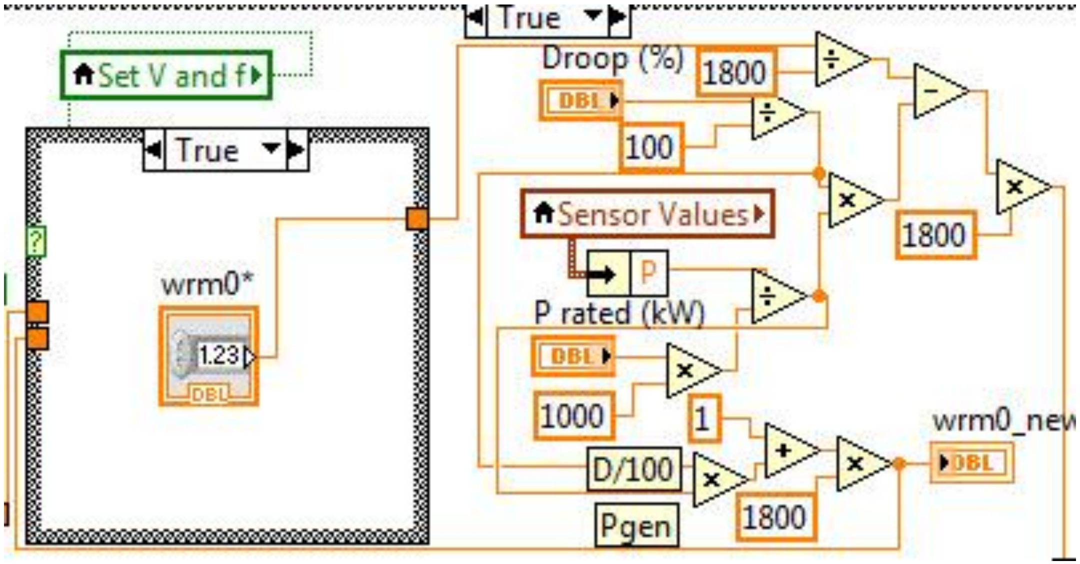


Synch. Machine G1 and G2	R_{Load}	RL_{Load}
230V, 2.5 kVA, 1800 rpm	500 W	500 W and 500 VAR

Main Control Screen in LabVIEW



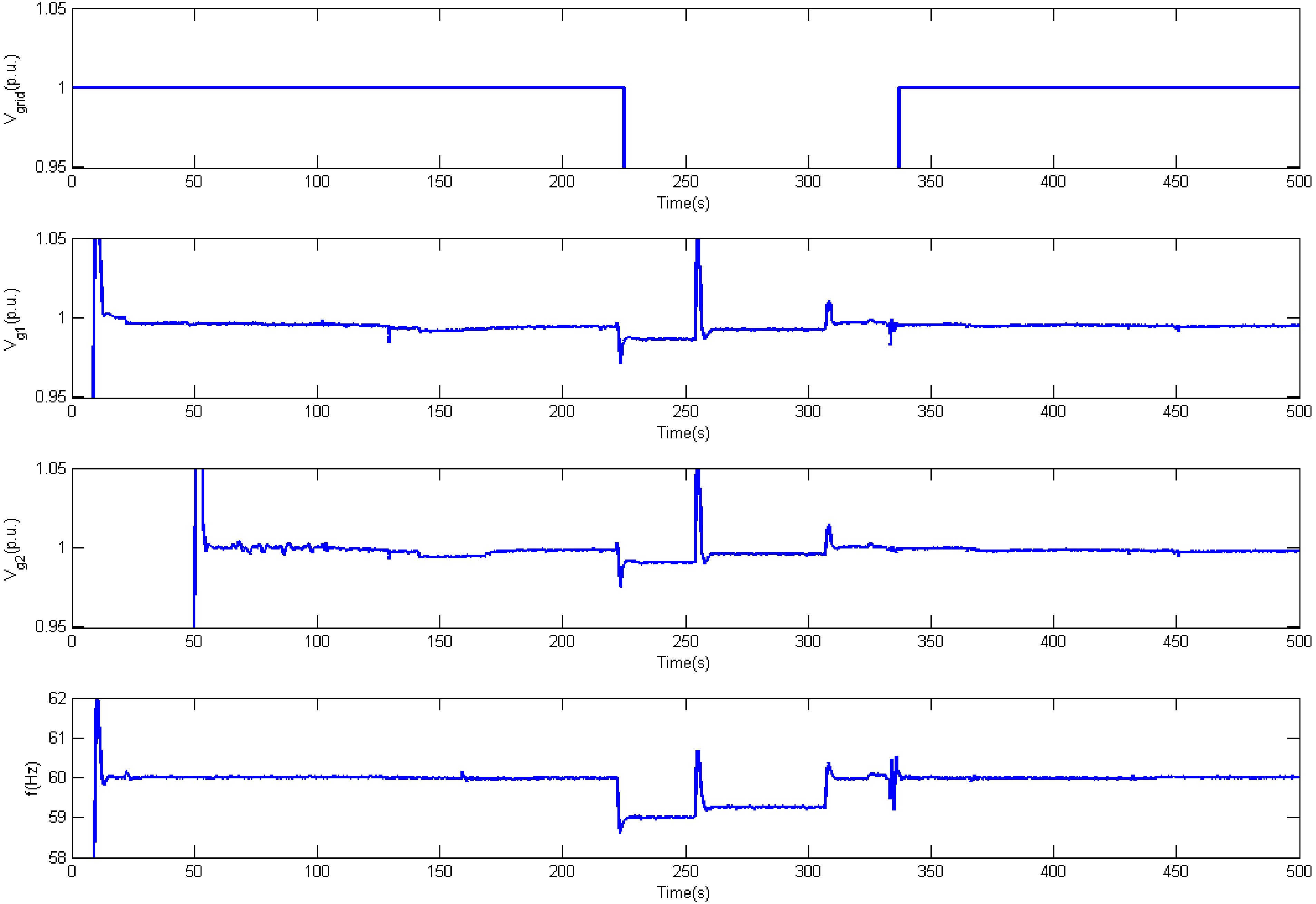
Speed Droop Control



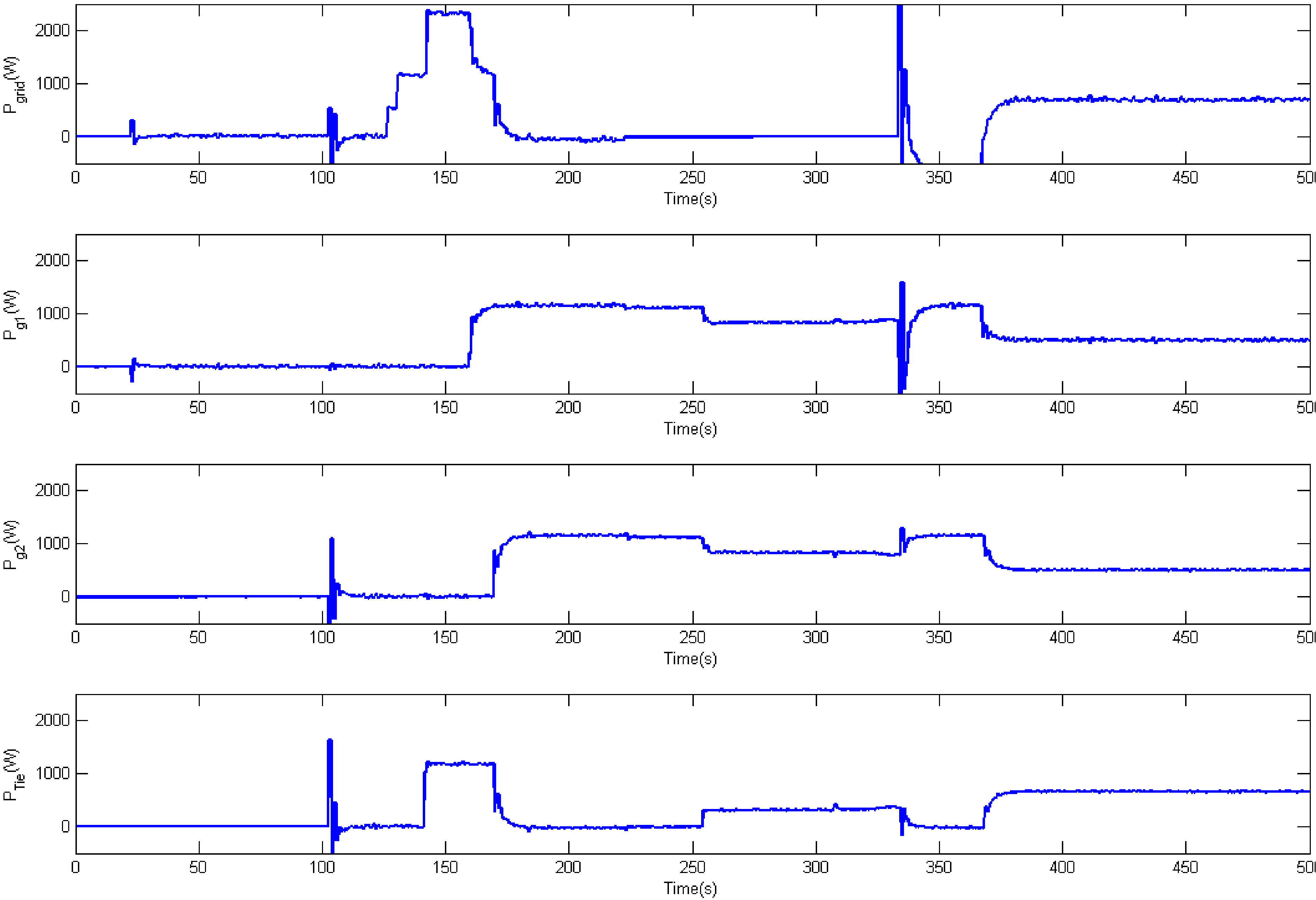
Micro Grid Study

25s	Synchronize generator G1 to the grid (close S1)
105s	Synchronize generator G2 to the grid (close S2)
125s	Switch on loads
175s	Adjust real and reactive power of the generators to match the loads
225s	Disconnect the grid and put generators in droop mode (open S1)
250s	Switch off RLLoad1
300s	Adjust droop controls so frequency and voltage to match the grid
325s	Synchronize the micro grid to the main grid (close S1)
375s	Command synchronous generators to generate less power
450s	Command generator G1 to supply zero reactive power

Voltage and Frequency

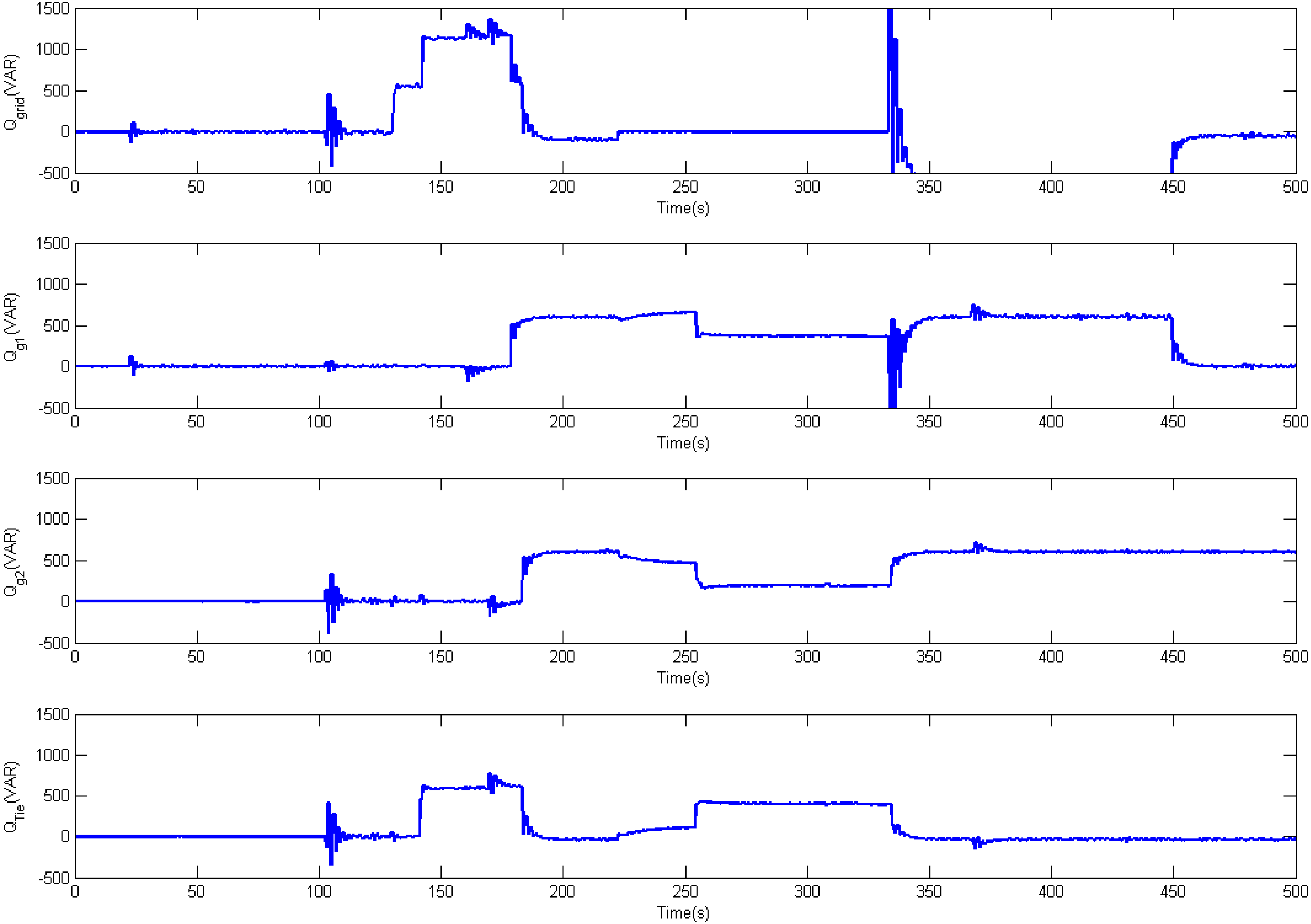


Real Power



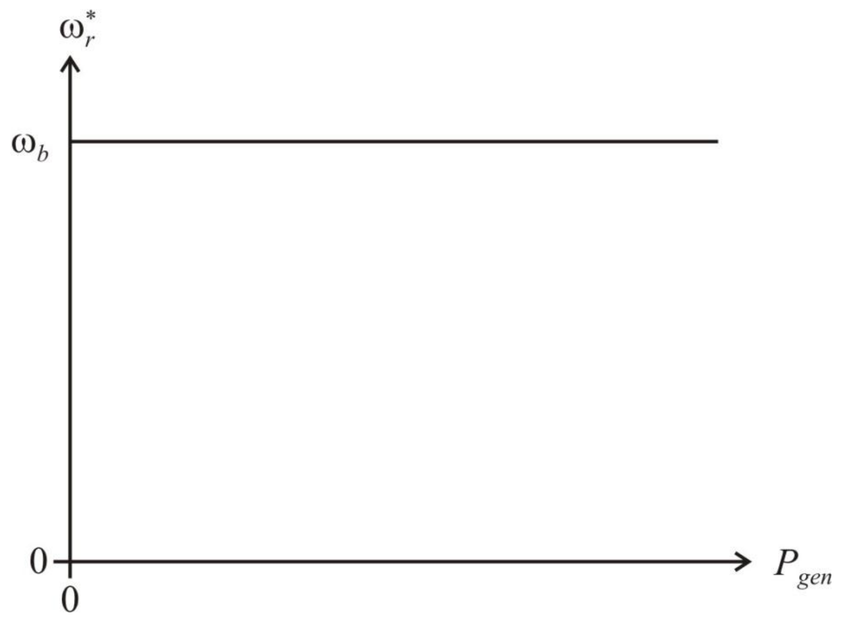
P_{grid}(W)
P_{g1}(W)
P_{g2}(W)
P_{Tie}(W)
2000
1000
0
0
50
100
150
200
250
300
350
400
450
500
Time(s)

Reactive Power



Synchronous Machine Isocronous Control

- Regulates voltage and frequency to set values
- Requires additional communication between generators for power sharing (paralleling generators)
- Similar to droop control with d=0



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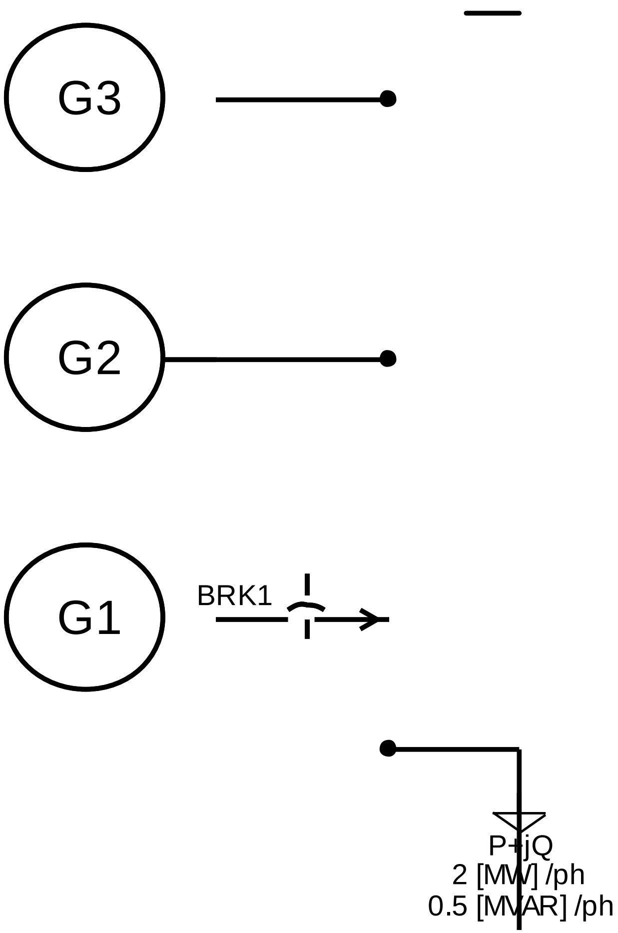
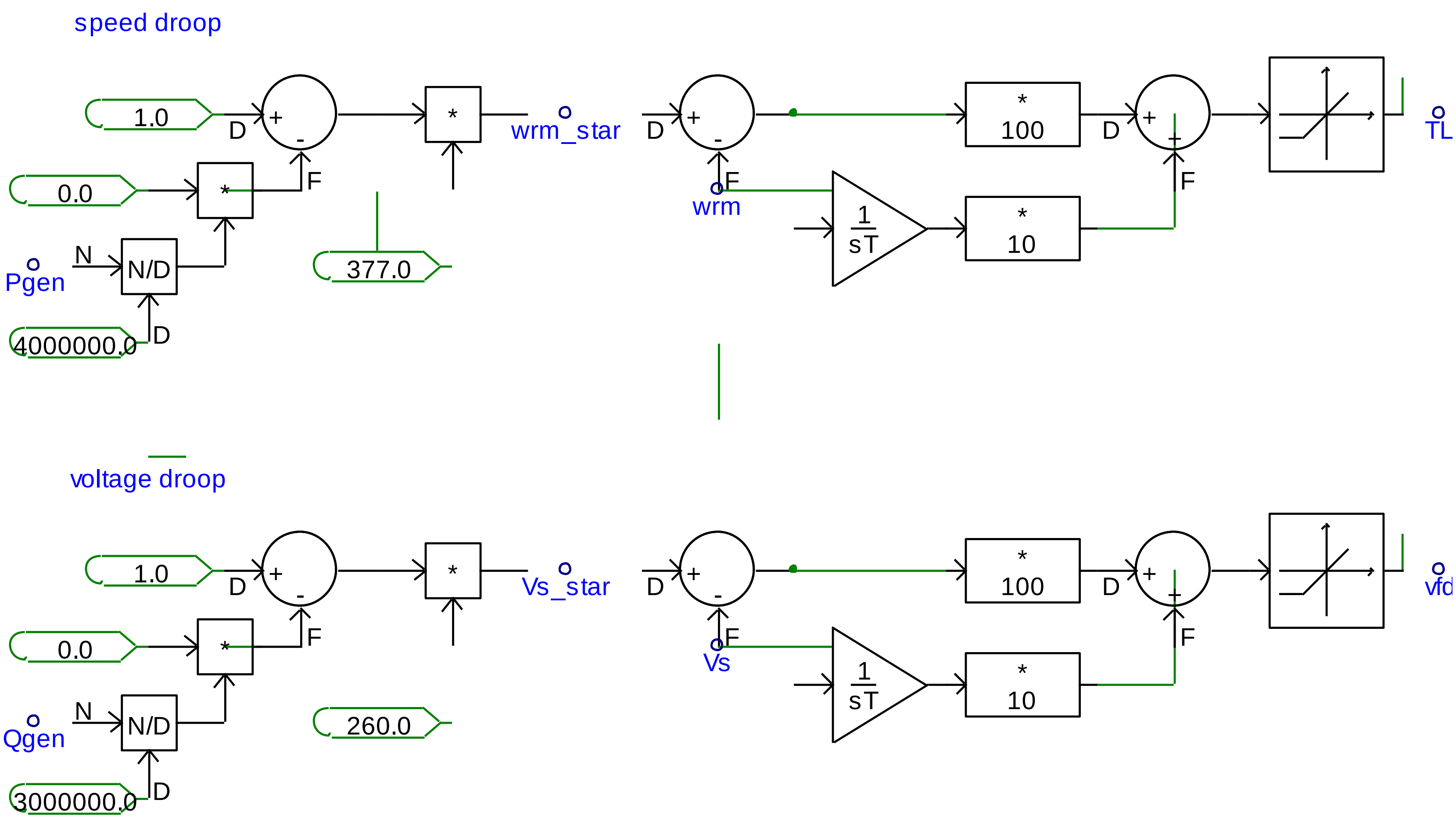


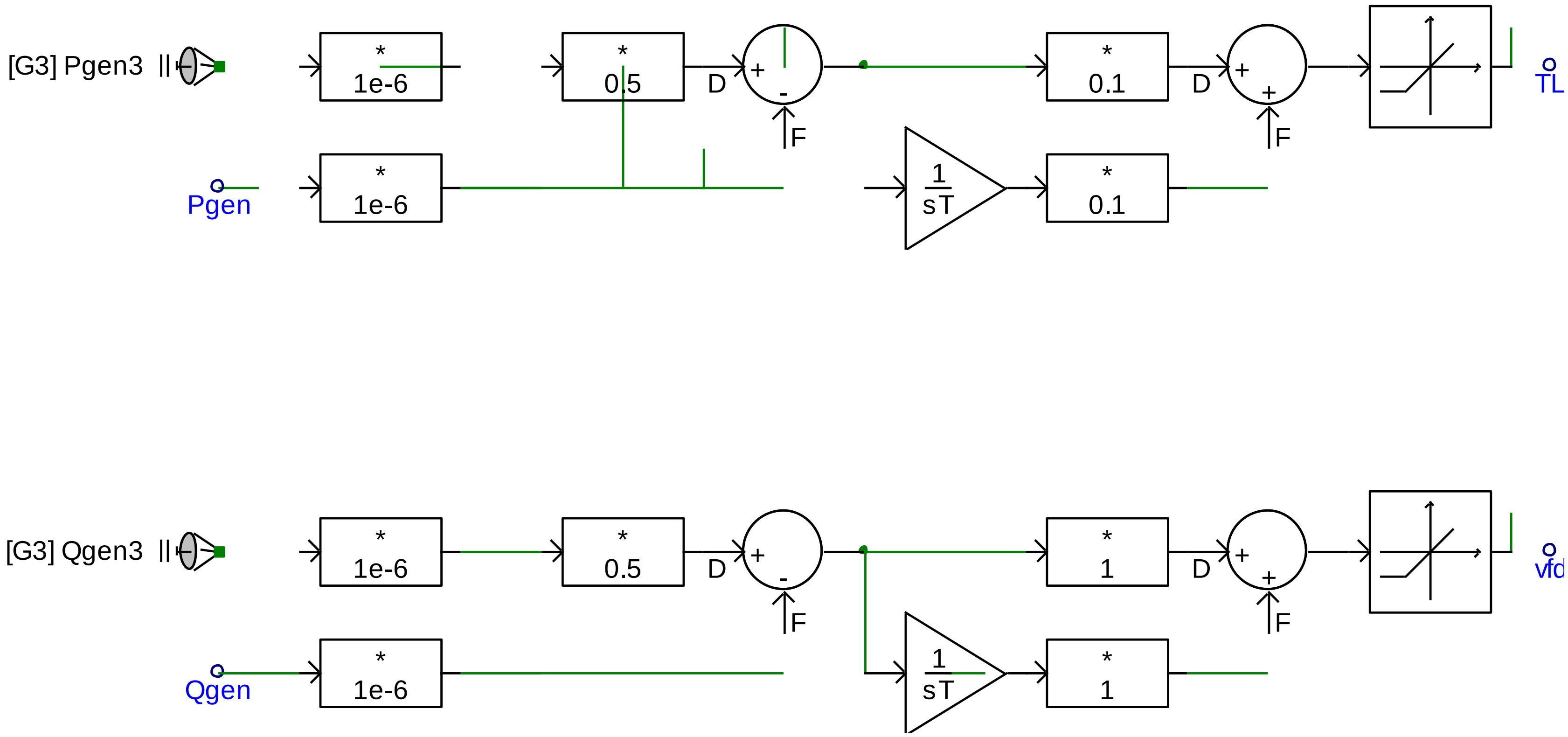
Generator G3 Isocronous Controls

Note: d=0



Generator G1 and G2 Controls

Torque commanded to control P, Field commanded to control Q
Reference values set to ½ of G3



Generator Real and Reactive Powers