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Paralleling Generators: Synchronization Design & Power Flow Analysis

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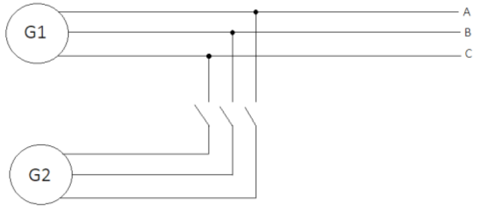


Abstract:

The standard for modern power system designs involves multiple generators operating in parallel to share a common load. This configuration has numerous advantages, including improved system redundancy and adaptability. For a generator to be inserted into an existing electrical network, a set of criteria must be met with regards to the generator voltage, phase angle, phase sequence, and frequency relative to that of the network. A device capable of measuring all of these quantities simultaneously is necessary for the synchronization to take place. This capstone project will investigate the topic of generator paralleling by addressing the design and implementation of a three-phase paralleling unit. The device will be used to integrate an experimental generator to the grid, and data will be collected regarding the power flow characteristics of the paralleled system. It will be demonstrated that the real and reactive power contributions from the generator can be controlled when operating in this configuration, indicating that parallel generators can be used for power factor correction purposes. The completed product will be used as a learning tool for future power systems classes at the University of Southern Maine.

Why Operate Generators in Parallel?

- Redundancy
- Resiliency
- Improved Efficiency
- Added Capacity
- Power Factor Control

Conditions for Paralleling:

1. Same Line Voltage → Voltmeter
2. Same Phase Sequence → Three-Lightbulb Test
3. Similar Frequency → Frequency Meter
4. 0° Phase Angle → Synchroscope

Paralleling Design:

The design aspect of this project involves the integration of a digital synchroscope and phase sequence test circuit into a 3D printed enclosure with all switches, terminals, and metering necessary to manually synchronize a generator with the grid. The circuit diagram and physical layout are shown in figures 1 and 2 below.

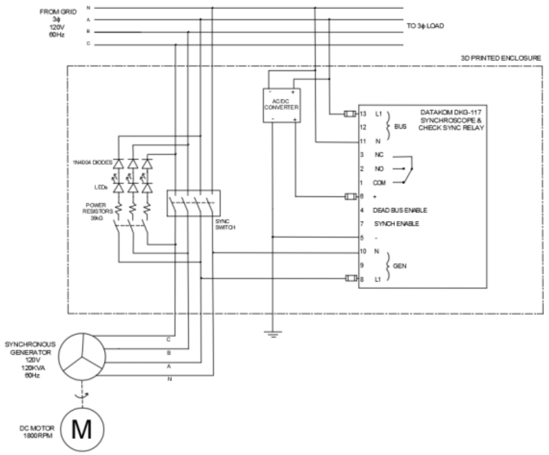
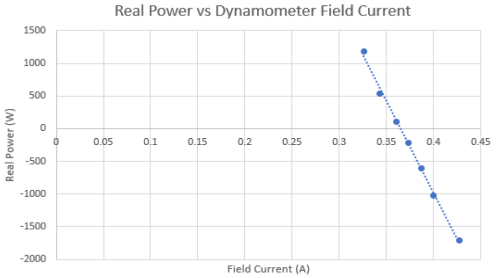


Figure 1 – Circuit Diagram (Top), Figure 2 – Device Layout (Bottom)

Testing & Data Collection:

A set of laboratory experiments was developed and carried out to further investigate the operation of parallel power systems. Figure 3 shows data that was collected under a wide range of excitation conditions. It was observed that motor excitation has a linear relationship with real power supplied by the generator, shown in figure 4. The same relationship also exists between generator excitation and reactive power flow, shown in figure 5.

Torque (N-m)	P (W)	Q (VAR)	S (kVA)	PF	Synchronous Machine Field Current (A)	Dynamometer Field Current (A)
	333	-270	428.71	0.78	0.52	0.361
	1620	-420	1673.6	0.97	0.52	0.343
0.9	3564	-810	3654.9	0.98	0.52	0.326
0.3	-657	195	685.33	-1	0.52	0.373
	1818	189	1827.8	0.99	0.52	0.387
-0.3	-5130	630	5168.5	-1	0.71	0.427
0	-2925	210	2932.5	-1	0.52	0.4
	-2907	720	2994.8	-1	0.69	0.4
0	-3060	1770	3535	-0.9	0.94	0.4
	-3033	1470	3370.5	-0.9	0.87	0.4
	-2970	1200	3203.3	-0.9	0.79	0.4



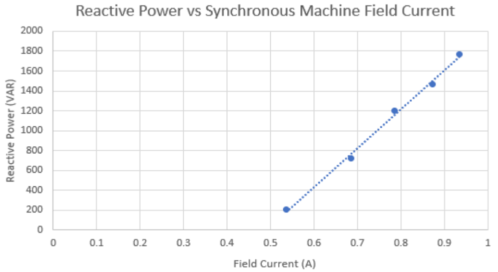


Figure 3 – Data Collection (Top), Figure 4 – Real Power Flow (Middle), Figure 5 – Reactive Power Flow (Bottom)