Basics of Paralleling

Revised: February 1, 2017
Course Objectives

Participants will be able to:

– Discuss basic paralleling control functions to gain a better understanding of how paralleling is accomplished

– Explain the advantages of paralleling to enhance the overall system reliability, performance and flexibility

– Describe how generator set control functions are provided in a distributed logic architecture to improve paralleling reliability

– Recognize the common building blocks of a backup power system and their functionalities
Generator Set

- Skid
- Engine
- Alternator
- Cooling
- Control
Power System

Backup Power

Switchgear

Transfer Switches

Utility

Loads
Paralleling

- Synchronous operation of two or more generator sets connected together on a paralleling bus in order to provide power to common loads
Paralleling Operation

- Generators can be connected to a power plant or another generator source only when the following conditions are met:
  - Waveform
  - Phase Sequence
  - Speed difference (frequency)
  - Phase angle difference
  - Voltage amplitude difference
Synchronization

- Synchronization is the mechanism of matching frequency, phase and voltage of AC power sources.

- Electronic Governor
  - Maintains engine output speed

- Automatic Voltage Regulator
  - Maintains generator output voltage
Electronic Governor (GOV)
Automatic Voltage Regulator (AVR)

- The output voltage can be increased or decreased by altering the strength of the magnetic field

\[ \nabla \times E = -\frac{\delta B}{\delta t} \quad (\text{Faraday's Law}) \]
Synchronizer

- Match Frequency, Phase and Voltage

Closed feedback loop: Hz, Ø & V

Load Side → Line Side

_offset

Generator Set Control Synchronizer

Electronic Governor

Voltage Regulator

Sense line & load waves:
- Frequency Hz
- Phase Ø
- Voltage V

AC Network:
480 VAC, 60 Hz, 3Ø

Synchronized

Line Side Wave

Load Side Wave

Close signal

CB
Synchronizing: Phase and Frequency

- Adjusting the governor fuel set point
Synchronizing: Voltage Amplitude

- Adjusting the field excitation

![Diagram showing the process of synchronizing voltage amplitude.](attachment:image.png)

- Voltage Regulator
- Excitation System
- Electric Generator
- Voltage Sensor
- Output $V(t)$
- Setpoint 4.16kV
- Offset ($t$)
- Source-1
- Source-2
Rotor Position and Output Voltage

- Electrical Degrees = P/2 * Mechanical Degrees

P: Number of poles

Air Gap  Main Stator Coils in Slots

Alternator Shaft Position (Degrees)  One Wave Cycle
Controlling Speed, Phase and Voltage

Setpoint 1800 RPM

Electronic Governor

Fuel Actuator

Prime Mover

Shaft

Setpoint 4.16kV

Voltage Regulator

Excitation System

Generator Set

Output
Standby System Simulation: Isolated Bus
Parallel Sequencing of Operation: Isolated Bus

1. Remote Start
2. Engine Cranks & Builds Up To Rated Speed & Voltage
3. Ready to Load
4. Gen Bus Status
   - De-energized: First Start Arbitration
   - Energized: Synchronize
5. First Start Permission Won
6. Close Generator Breaker & Load Share
7. Sync Check Conditions Met
Load Sharing

- The proportional division of the kW and kVAR total load between multiple generator sets in a paralleled system
  - Load sharing is essential to avoid overloading and stability problems on the generator sets
- Load share can be Isochronous or Droop

Graph showing the percent load and percent Hz or Volts with labels for Isochronous and Droop. Diagram illustrates the load sharing distribution with one 2 MW, 2 MW, 1 MW, 1 MW, 0.5 MW, and 0.5 MW units.
Load Sharing

- The kW load sharing is achieved by increasing or decreasing fuel to the engines.
- The kVAR load sharing is achieved by increasing or decreasing the field excitation to the alternators.
Energy Management

- Peak Shave
- Base Load
Connecting to the Grid

- Base load, peak shave, extended paralleling
- Cannot change the grid voltage and frequency
- Drive generator sets to match the grid

<table>
<thead>
<tr>
<th>Infinite Source:</th>
<th>Match Grid</th>
<th>Synchronizer</th>
<th>kW Load Govern Lines</th>
<th>kVAR Load Govern Lines</th>
</tr>
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<tbody>
<tr>
<td>Frequency</td>
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<td>GOV</td>
<td>GOV</td>
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<tr>
<td>Phase</td>
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<tr>
<td>Voltage</td>
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</tbody>
</table>

Grid
Grid Connecting Example

- Peak Shave Mode - Extended Paralleling

Utility Import Setpoint:
e.g. 0.5 MW

Read Power

Grid

Controller

kW Load
Govern Lines

kVAR Load
Govern Lines

GOV

AVR

0.5 MW

2 MW

1 MW

2 MW

1 MW

2.5 MW Load
Typical Generator Protection Elements

- 15 – Synchronizer
- 24 – Volts/Hertz
- 25 – Synch Check
- 27 – Undervoltage
- 32 – Directional Power
- 40 – Loss of Excitation/Reverse kVAR
- 46 – Phase Balance Current
- 47 – Phase Sequence Voltage
- 50 – Instantaneous overcurrent
- 51 – Time Overcurrent
- 59 – Overvoltage
- 81U/O – Under/Over Frequency
Paralleling Control

- User Interface
- Configurations/Settings
- Alarms
- Start/Stop
- Manual Paralleling

- Paralleling
- Genset Protection
- Voltage Regulation
- Load Sharing
- Generator Metering

- Engine Protection
- Governing
- Engine metering
Generator Set Paralleling Controls Capabilities

- Without a Digital Master Control, generator set control can:
  - Parallel with each other
  - Synchronize with the grid (single genset) - Base Load/Peak Shave
  - Single Load Add/Shed Scheme
  - Perform Load Demand
Master Control

- Is required when:
  - Synchronizing multiple generator sets with the utility or multiple utility feeds
  - Load and capacity management
  - System monitoring and control
  - Complex sequence of operation
Digital Master Control
Digital Master Control
Summary

- Governor and AVR are the basic functions on every genset and the synchronizer, load share and load govern simply adjust the reference point to them.
- Paralleling enhances the overall system reliability, performance and flexibility.
- Distributed logic architecture in a paralleling system improves the overall reliability by eliminating single points of failure.
Thank You!

Please share your feedback by completing the Power Seminar evaluation form.
Load Demand

- Match generating capacity to the load to optimize fuel efficiency and prolong generator set life

Load: 0.55 MW

Capacity: 5 MW
Reference Material: Load Demand

- The load demand feature is used to match generating capacity to the load to optimize fuel efficiency and prolong generator set life while maintaining correct reserve capacity for the customer’s application.

- Shutdown sequence can either be a fixed sequence or can be based on running hours:
  - Fixed sequence: the sequence can be changed while the system is in operation.
  - Running hours: attempts to equalize generator set hours over time by exchanging stopped and running generator sets.

- To protect system integrity, load demand will restart all generator sets whenever an overload condition is detected.

- The minimum amount of capacity to maintain online is adjustable.