Functions and Features of Generator Set Control Based Paralleling

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Course Objectives

Functions and Features of Generator Set Control Based Paralleling

This course provides a comprehensive overview of a typical paralleling emergency power system and dives into the fundamental key features needed to parallel generator sets. Throughout this course, the instructor will review critical control functionality for paralleling systems and will compare distributed logic architecture with traditional switchgear paralleling. System reliability will be explored while the instructor reviews the ability of paralleling and control strategies employed to eliminate potential single points of failure.

After completing this course, participants will be able to:

- Identify the advantages of paralleling as they relate to overall system reliability, performance and flexibility.
- Recognize basic generator set paralleling control components, functions and features.
- Describe common strategies employed by paralleling systems using distributed logic architecture.
- Discuss the benefits of distributed logic architecture as it relates to paralleling, system reliability and its ability to eliminate a single point of failure.
Power System Building Blocks
Generator Set

- Skid
- Engine
- Alternator
- Cooling
- Control
What is Paralleling?

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

\[ f(Hz) = \frac{nP}{120} \]

\[ n: \text{rpm}, P: \text{Poles} \]

Generator Sets

Point of Power Connection:
Switchgear, Collector Bus,…

Transfer Switches

- Emergency
- Legally Required
- Optional

NEC2017-700.10 (B) (5)
Why Parallel?

- Reliability
  - Not dependent on a single generator. If one generator fails, there are other generators to power the load

- Performance
  - A large generator bus capacity will act more like a utility. There will be less frequency and voltage variations during load steps

- Redundancy
  - Creating an N+1 or N+2 configuration is easier in paralleling designs

- Scalability/Expandability
  - Easy to add generators to a paralleling architecture as power demand increases

- Serviceability
  - A single generator can be serviced while the remaining generators are available to provide power
What To Specify For a Paralleled Power System

- Seamless operation if a generator set fails
  - During a start
  - While paralleled
- No single point of failure
  - Control architecture redundancy
  - Not dependent on a paralleling master control
- Capacity to load consumption optimization
  - Prolong generator sets life expectancy
  - Save fuel
- Ability of generator sets to self-protect
  - Overload, reverse power,…
  - Intelligent control with built-in protection
- Energy reducing maintenance switching
  - If there is a need to work on an energized generator set
- Comprehensive remote monitoring
  - Manage assets, monitor alarms, mitigate issues, etc. in real-time
Paralleling Control
Elements of Paralleling Controls

- Speed control – Governor (ECM)
- Voltage control – Automatic Voltage Regulator (AVR)
- Generator set arbitration
  - De-energized bus: which generator set closes its breaker first
- Synchronization (frequency, phase and voltage)
  - Energized bus
- Load sharing
  - (kW: governor and kVAR: voltage regulator)
- Protection: engine and generator
  - Reverse Power, Under/Over Voltage & Frequency, Sync Check,…
- Metering, faults, alarms
  - kW, kVA, V, PF, Hz, Battery Voltage, Engine Temp,…
A generator set output power can be connected to another generator source only when the following conditions are met:

- Waveform (2/3rd pitch or 5/6th pitch)
- Phase sequence
- Speed difference (frequency)
- Phase angle difference
- Voltage amplitude difference
Synchronizing

- Phase and Frequency: engine governor fuel
- Voltage: alternator field excitation
Concept Check

What are the advantages of paralleling generator sets?

- a) Scalability/Expandability
- b) Reliability
- c) Redundancy
- d) All of the Above
Traditional Paralleling Control Design

- Paralleling control in the switchgear
- Master paralleling control
  - Single point of failure
- Component based design
- PLC-based core
- Variability in the design
- Lots of wiring
- Nightmare to troubleshoot
Integrated Autonomous Paralleling Design

Integrated Generator Set Control

Human Machine Interface
Paralleling Control – Closer Look

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

- First Start Arbitration
- Synchronizing (Ø, V, Hz)
- Voltage Regulation
- Load Sharing (kW, kVAR)
- Generator Set Metering
- Generator Set Protection

- Governing
- Engine Protection
- Engine metering
Integrated Autonomous Paralleling Design

- No paralleling master
  - No single point of failure
- Consistent design
- Reduce wiring
- Reduce footprint
- Easy to learn and operate
- Low or medium voltage
Paralleling Control (Energized Bus)

- Match Frequency, Phase and Voltage

Closed feedback loop:

Freq Hz, Ø & V

Load Side

Offset

Line Side

Generator Set Control

Fuel

Offset

Voltage Field

Close Signal

Feedback 'A'

CB Green: Breaker Open

CB Red: Breaker Closed

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

Synchronized

Line Side Wave

Load Side Wave

Energized Bus 480 VAC, 60 Hz, 3Ø
Paralleling Control (De-Energized Bus)

1. All generators start
2. First Start Arbitration
   a) One genset closes
3. The remaining genset sets synchronize and close breakers simultaneously
4. Load Share
Paralleling Sequence of Operation

Gen Bus

Remote Start

Engine Cranks & Builds Up To Rated Speed & Voltage

Ready to Load

First Start Arbiteration

First Start Permission Won

De-energized

Energized

Gen Bus Status

Synchronize

Sync Check Conditions Met

Close Generator Breaker & Load Share

G1

CB

G2

CB

Paralleling Sequence of Operation
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
  - Isochronous: frequency & voltage are fixed regardless of the load. Requires communication wiring
  - Droop: frequency & voltage vary as the load varies. Communication wiring between generators not needed

- e.g. 2.8MW Load

```
<table>
<thead>
<tr>
<th>kW</th>
<th>kVAR</th>
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</thead>
<tbody>
<tr>
<td>2 MW</td>
<td>1.4 MW</td>
</tr>
<tr>
<td>1 MW</td>
<td>0.7 MW</td>
</tr>
<tr>
<td>1 MW</td>
<td>0.7 MW</td>
</tr>
</tbody>
</table>
```

All generator set are 70% Loaded

e.g. 2.8MW Load
Seamless Paralleling Operation

- Paralleling is a function of the generator set control

- Distributed logic architecture (control redundancy):
  - The paralleling logic (synchronizing, load sharing, governing, protection,…) is repeated on each generator set
  - If a generator set fails
    - Open paralleling breaker
    - Shutdown generator set
    - The paralleling system continues running

- No paralleling master control
  - Single point of failure eliminated
Capacity to Load Consumption Optimization

- Prolong generator sets life expectancy
- Save fuel

Capacity: 5MW

Load: 8.55MWV
Generator Protection Elements

- 15 – Synchronizer
- 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

The numbers represent ANSI device numbers
Energy Reducing Maintenance Switching

- Energy Reduction Maintenance Setting (ERMS)

- Some generator set manufacturers have built into their controls:
  - Overcurrent protection
  - Maintenance mode
    - Bypasses all time delays

Local ERMS Switch

ERMS Switch “OFF” and “ON” Mode
Comprehensive Remote Monitoring

- Single point visibility to assets and site performance anytime anywhere
- Immediate notification of any critical or non-critical issues through automated emails and push notifications
- Access to historical performance data to any asset through reports and trending
Concept Check

Which of the following is true when isochronous load sharing is utilized:

a) Output voltage is constant but not frequency
b) Frequency and phase angle are constant
c) Output voltage and frequency stay constant as the load varies
d) Output voltage and frequency vary as the load varies
Parallelizing Hardware

- What is needed to parallel generators:
  - Two or more generator sets
  - Electrically operated breakers: one per generator (in switchgear or generator set mounted)
    - Open coil
    - Close coil
    - Breaker position status
    - Breaker charging motor
    - Power supply to operate coils
      - (CPT's, batteries)
  - Point of common connection
    - Switchgear
    - Collector bus
  - Paralleling functions for each generator set
    - For example: Integrated in generator control
Generator Sets Manual Paralleling

- How to manually parallel generator sets with integrated control?
  - Start/Stop generator sets
  - Synchronize generator sets and close paralleling circuit breaker

- Some Generator set manufacturers are able to incorporate manual operation into their integrated control
  - CB Close: initiates synchronizing and breaker closes when synchronized (phase, voltage and frequency)

- What to avoid?
  - Additional components to perform manual operation
    - Still communicating to the generator set control
    - More components that can fail
    - False sense of reliability

**Spec Note:** The control shall include manual open and close provisions for the paralleling breaker, and LED status lamps indicating whether the breaker is open or closed.
Extended Paralleling Example

- Obtain approval from the utility
  - Hard-closed transition (100msec)
  - Soft-Closed transition (>100msec, load ramp)
  - Extended closed transition
- Minimum import set point
- Power export back to the utility?
  - Reverse power protection
- Extended closed-transition control algorithm expectations:
  - Keep the lights on!
  - Follow the utility
  - Output power regulation
  - Fast response as load changes
### Extended Parallelizing Example

- **Extended parallel with UMA:**
  - Close GMA and GMB
  - Open UMB
  - Start all generator sets and ramp load

- **Utility import set points:**
  - Start at 600 kW
  - @ Approx. 7:24:37 import set point changed to 400kW

- Frequency of four generator sets and utility during operation locked at 60Hz
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Specify:
- Write specifications based on functions and performance
- Integrated paralleling and protection control
- Seamless paralleling operation if a generator set fails
- Paralleling control architecture redundancy
- Capacity to load consumption optimization to reduce fuel and wear/tear on generator sets
- Request a paralleling demonstration/witness testing for future projects

Avoid specifying:
- Specific hardware and components
- External hardware to perform generator set manual paralleling
Q&A

Type your questions, comments, feedback in the WebEx Q&A box. We will get to as many questions as we can. We will publish consolidated FAQ along with presentation and webinar recording on powersuite.cummins.com

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