Power Control Systems Fundamentals – Learning Objectives

• What are Power Control systems
• What are the Applications for Power Control Systems
• What is Synchronization
• Basic Parameters
• UL/ANSI Standards
• Major Components
• Operating Modes
• Basic Load Control

“It’s just connecting a couple of generators together”

“Can you do it in series?”

Series

Parallel

If this happens....

Make sure this happens right?
PCS Fundamentals – What’s PCS? There’s a lot of names for it

- PCS stands for Power Control Systems
- Sometimes called Paralleling Switchgear
- Or Synchronizing Switchgear
- Or “P” Gear
- Or Sync/Paralleling Gear
PCS Fundamentals - What are Power Control Systems

- A Power Control System is the connection of multiple sources, usually generators to a common bus in most applications.

![Diagram of Power Control System]

Common Main Bus

To Loads

To Loads

To Loads

To Loads

Engine Generators

Paralleling Switchgear
Power Control Systems – What are the Applications?

- Standby/Emergency Power Systems
- Prime Power Systems
- Parallel with Utility Systems
- Custom Redundant Power Systems – Tier IV Data Centers
- Low Voltage Systems up to 600V
- Medium Voltage Systems up to 15kV
- Non-Paralleling Intelligent Control Switchgear
What is generator synchronization?
- Generator synchronization matches generator speed/frequency with another source (Other generators and/or utility).
- Voltage levels and phase relationships also need to be considered.

Why is synchronization needed?
- Controls power surges. Avoids reverse power, overpower and mitigates transients when bringing additional power sources online.
- Reduces electrical stress on generators and switchgear. Helps prevent high currents and breaker wear.
- Reduces mechanical stress on generators and prime movers. Helps prevent bent drive shafts and broken couplings.

What conditions must be met for two sources to be synchronized?
1. The number of phases must be the same.
2. The direction of rotation must be the same.
3. The voltage amplitudes must be closely matched.
4. The frequencies must be closely matched.
5. The phase angles must be closely matched.
Power Control Systems Fundamentals

Some Common Electrical Drawing Symbols

- Generators
- Circuit Breakers
- Current Transformers
- Zero Sequence Current Transformer
- Potential or Voltage Transformers
- Automatic Transfer Switch
- Protective Relays
- Lightening or Surge Arrestor
- Ground
- Electrically Operated
- Key Interlock
- Meter
Power Control Systems Fundamentals

- Determining generator full load current
- Determining generator circuit breaker size
- Determining main bus size
- Circuit breakers & AIC Ratings
- Main Bus Sizes & AIC Ratings
Determining Generator Full Load Current (A)

- \( KW = 1.73 \times VOLTS \times AMPS \times PF \)
- \( AMPS = \frac{KW \times 1000}{1.73 \times VOLTS \times PF} \)
- \( KVA = 1.73 \times VOLTS \times AMPS \)
- \( AMPS = \frac{KVA \times 1000}{1.73 \times VOLTS} \)

Power Factor (PF) is usually considered at 0.8

https://www.rapidtables.com/calc/electric/kW_to_Amp_Calculator.html
Determining Generator Circuit Breaker Frame Size

Gen Parameters
- kW = 1250kW
- Voltage = 480VAC
- Power Factor = .8

\[ \text{AMPS} = \frac{\text{KW} \times 1000}{1.73 \times \text{VOLTS} \times \text{PF}} \]
\[ \text{AMPS} = \frac{1250 \times 1000}{1.73 \times 480 \times .8} \]
\[ \text{AMPS} = 1879 \text{A} \]
Determining System Full Load Current (A)

1250kW 1250kW 1250kW 1250kW
G1  G2  G3  G4

To Building Loads

System Parameters
- Gen kW = 1250kW
- System Voltage = 480VAC
- Power Factor = .8

AMPS = \( \frac{KW \times 1000}{1.73 \times VOLTS \times PF} \)

AMPS = \( \frac{1250 \times 1000}{1.73 \times 480 \times .8} \)

AMPS = 1879A

4 Generators Combined Full Load Amps = 4 \times 1879A = 7516A
Determining Main Bus Size

Gen Parameters
- kW = 1250kW
- Voltage = 480VAC
- Power Factor = .8

4 X 1879A = 7516A

1250kW  1250kW  1250kW  1250kW
G1   G2   G3   G4

8000A Main Bus

To Building Loads
Determining Main Bus Size

Gen Parameters
- kW = 2500kW
- Voltage = 480VAC
- Power Factor = .8

4 x 3758A = 15,032A

To Building Loads

15,000A Main Bus???
Determining Main Bus Size – Split Bus

Gen Parameters
- kW = 2500kW
- Voltage = 480VAC
- Power Factor = 0.8

4 x 3758A = 15,032A
Power Control Systems Standards – Low Voltage

UL 891
ISBN 0-7381-1056-3

Switchboards

UL 1558
ISBN 0-7381-1039-9

Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear
Power Control Systems Standards– UL891

- Developed from NEMA Standards – Dead Front Switchboard Construction in accordance with NEC
- Molded Case, Panelboards, Insulated case breakers as defined in UL 489 allowed
- Fusible Switches allowed
- ANSI Rated Breakers as defined by ANSI 37.16, ANSI 37.13 and UL1066
- 3 cycle short circuit rating on the bus
- No barriers or compartmentalization required
- Typical AIC ratings 50KAIC, 65KAIC, 100KAIC & 150KAIC. Can go up to 200KAIC
- Defines an interrupting current rating for the breaker
Power Control Systems Standards– UL 1558

- Based on ANSI Standard C37.20.1 for Metal Enclosed Low Voltage Circuit Breaker switchgear
- Drawout Power circuit breakers as defined in UL 1066 and ANSI are the only type allowed
- 4 cycle short circuit rating on the bus
- Panelboards, UL489 listed circuit breakers and fusible switches can NOT be mounted in the line up
- Complete breaker compartmentalization required
- Typical AIC ratings (65KAIC, 85KAIC, 100KAIC & 200KAIC)
- Defines an interrupting current rating and short time rating (30 cycle rating) for circuit breakers
- ASCO UL1558 listing is for up to 200KAIC for 4 cycles and 85KAIC for 60 cycles
Low Voltage Standards FAQ’s

■ FAQ: When I buy UL 1558 labeled switchgear I get full depth barriers between sections right?
■ Answer – No, UL 1558 does not require full depth barriers between sections, it requires compartmentalization.

■ FAQ: What’s the difference between UL891 design and 1558 design?
■ Answer – UL 891 is switchboard construction (Fixed group mounting) & UL 1558 is Switchgear Construction (Individually compartmentalized draw-out type breakers).

■ FAQ: Aren’t UL 891 designs less expensive than UL 1558?
■ Answer – Not necessarily, it depends on several variables including breaker type and AIC rating.

■ FAQ: UL 1558 requires insulated bus right?
■ Answer – UL 1558 does not require insulated bus
IEEE Standard for Metal-Clad Switchgear

Sponsor
Switchgear Committee
of the
IEEE Power Engineering Society

Approved 1 October 1999
IEEE-SA Standards Board

Abstract: Metal-clad (MC) medium-voltage switchgear that contains drawout electrically operated circuit breakers is covered. MC switchgear is compartmentalized to isolate all components such as instrumentation, main bus, and both incoming and outgoing connections with grounded metal barriers. Rated maximum voltage levels for metal-clad switchgear range from 6.6 kV to 38 kV with main bus continuous current ratings of 1250 A, 2000 A, and 3000 A. MC switchgear also contains associated control, instruments, metering, relaying, protective, and regulating devices, as necessary. Service conditions, ratings, temperature limitations and classification of insulating materials, insulation (electric) withstand voltage requirements, test procedures, and applications are discussed.

Keywords: control, cumulative loading, current transformers, disconnector, indoor, instrumentation, load current-carrying, metal-clad (MC) switchgear, metal-enclosed (ME) power switchgear, outdoor, protection, qualifying term, switchgear assemblies, transformer accuracy, voltage transformers.

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA.
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ISBN 0-7381-6226-1
Printed in the United States of America.
Power Control Systems – ANSI 37.20.2 Requirements

- Removable circuit breaker
- Fully compartmentalized construction
- Grounded metal barriers
- Automatic shutters
- Insulated bus
- Mechanical interlocks
- Disconnect type voltage transformers
  - Control power transformers (CPT) and voltage transformers (VT)
- Grounded breaker truck in and between test/disconnected and connected positions
- Instrument/control compartment isolated from primary voltage
Power Control Systems – ANSI 37.20.2

- Cable Compartment
- Compartment Barriers
- Insulated Main Bus
- Automatic Shutters
- Circuit Breaker Compartment
- Control Compartment
- Main Bus Barriers
Low Voltage Circuit Breakers and AIC Ratings

- **UL 1066** Circuit Breakers - 800AF, 1600AF, 2000AF, 3200AF, 4000AF, 5000AF, 6000AF
- **UL 489** Circuit Breakers - 800AF, 1600AF, 2000AF, 2500AF, 3000AF, 4000AF, 5000AF, 6000AF
- **Circuit Breaker AIC Ratings** - 50KAIC, 65KAIC, 85KAIC, 100KAIC, 150KAIC, 200KAIC (fused and non fused)
- AIC ratings vary by manufacturer, UL standard and frame size. Ex: a 4000A UL 1066 circuit breaker may only have rating of 100K and 200K
Medium Voltage Circuit Breakers and AIC Ratings

- **Circuit Breaker Sizes** - 1200AF, 2000AF, 3000AF, 4000AF
- **Circuit Breaker AIC** - 25KAIC (15kV), 40KAIC, 50KAIC, 63KAIC
- **ANSI rated** per 37.06, 37.09, 37.54
- **AIC ratings sometimes shown as MVA or AIC. Current Industry ratings are based on AIC**

<table>
<thead>
<tr>
<th>MVA Rating</th>
<th>AIC Rating</th>
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<tbody>
<tr>
<td>250 (5KV)</td>
<td>40KA</td>
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<tr>
<td>350 (5KV)</td>
<td>50KA</td>
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<tr>
<td>500 (5KV)</td>
<td>63KA</td>
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<tr>
<td>500 (15KV)</td>
<td>25KA</td>
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<td>50KA</td>
</tr>
<tr>
<td>1500 (15KV)</td>
<td>63KA</td>
</tr>
</tbody>
</table>
Main Bus Continuous Current and Bracing Ratings

Low Voltage

- Bus Bracing Level – 100KAIC & 200KAIC

Medium Voltage

- Main Bus Size - 1200A, 2000A, 3000A for 5 or 15KV
- Bus Bracing Level – 50KAIC, 63 KAIC
Power Control Systems – Major Components

- **Building Blocks**

  - **Generator Control Section**
    - Typically 1/Gen or Dual Gen
  
  - **Master Control Section**
    - Typically 1 per system
  
  - **Distribution Section**
    - As needed
Power Control Systems – Major Components

- Low Voltage Generator Control Section

  ▪ Programmable Logic Controller
    - Generator Start Signal
    - Cooldown Timer
    - Generator Paralleling Breaker Control and status
    - Generator Status (Alarm and Shutdown) annunciation
  
  ▪ Synchronizing Control
    - Matches generator speed/frequency with another source
    - Controls Generator speed and voltage
    - Sends “Breaker Close” command to close generator paralleling circuit breaker

  ▪ Generator Circuit Breaker
    - Provides Short Circuit and Overcurrent Protection via trip unit
    - Closes to connect Generator to the bus
    - PLC or Synchronizing Control issues close command
    - Always Electrically Operated and Drawout type
Power Control Systems – Major Components

▪ Master Control Section

Programmable Logic Controller
- Provides Auto Start to Generator Control Sections when an outage occurs - Generator Section sends start signal to it’s associated Generator
- Provides system control and sequence of operation functions
- Priority Load Control, Load Add/Load Shed via ATS, Load Circuit Breakers or both
- Load Demand Control
- Interfaces with ATS for engine start and load add/shed
- Interfaces with distribution circuit breakers for load control

Redundant Programmable Logic Controller
- Runs same program as Primary Master PLC
- Provides synchronized backup to Primary Master PLC
- If the Primary Master PLC is not available the Secondary Master PLC takes control without interruption to the program
Power Control Systems – Major Components

- **Master Control Section**

- **Operator Interface Terminal**
  - Allows Operator to adjust some parameters – Ex: Load Priorities
  - Allows Operator to perform some control operations – Ex: System Test
  - Includes Power Control System Dynamic One Line
  - Generator and Total System Metering, Status, Alarms & Shutdowns
  - Historical Trending
  - Joint Commission Reporting if required
  - BMS/EPMS Interface/Gateway
  - Includes several levels of Password Protection
  - System Operation should not be dependent on Touchscreen
Power Control Systems – Major Components

- **Distribution Sections**
  - Distribution Circuit Breakers
    - Provides Short Circuit and Overcurrent Protection for loads via trip unit
    - Can be operated for load control
    - Manually or Electrically Operated
    - Drawout or Fixed Mount depending on UL Standard Required
  - Circuit Breaker Control Switch
    - Allow operator to open or close electrically operated circuit breakers
    - LEDs indicate breaker position – Open/Closed/tripped
    - Manually or Electrically Operated
Generator Paralleling Modes of Operation

- **Open transition** is the transfer of load from one power source to another power source by interrupting one power source before the other power source can feed the load (Break before Make).

- **Closed Transition** is the transfer of load between two power sources without interruption of power (Make before Break). Typically closed transition is 100ms or less. Closed transition is typically used on retransfers to utility power or during transfer tests of emergency equipment so that load is not interrupted.

- **Closed Transition/Soft-load**, like closed transition, soft-load transition parallels two power sources. In this mode, however, the sources can be paralleled for extended periods. This method is used to decrease loading on the original source while increasing loading on the alternate source.
Open Transition Mode of Operation

Typical Emergency Standby System

- Most Power Control Systems are intended to provide power in the absence of a Utility supply. In Emergency Standby systems, a signal must be received that Utility power has been lost.
  - The Emergency Power system starts the generators, connects them to a distribution bus, and controls downstream loads to allow loading based on the capacity of emergency power available.
- An Emergency Standby System needs both Generator Controls and Master Control including Load Control via ATS or distribution breakers.
- Typical Applications include Healthcare.

Open Transition occurs at each ATS.
Closed Transition Mode Using Automatic Transfer Switches

Typical Standby System

- 100ms or less overlap time at each Closed Transition ATS
- No additional Switchgear controls required
- Typically does not require additional protection

Closed Transition Occurs at each Closed Transition ATS - Less than 100ms overlap
Closed Transition Mode Using Breaker Pairs

- Typically 100ms or less overlap time
- Requires additional controls to synchronize with Utility
- Typically requires protection on circuit breaker per utility requirements – Protective relay
- Requires utility company approval

Closed Transition Occurs between breakers
Closed Transition Mode on Common Bus

Utility & Emergency Sources on one common bus

- Transition Occurs between breakers
- Generator/Utility Paralleling Switchgear
- Requires additional controls to synchronize with Utility
- Requires utility company approval
- Benefits include no interruption to loads on return to utility or in test mode
- Typically requires protection on circuit breaker per utility requirements – Protective relay
Soft Load/Closed Transition Mode on Common Bus

- Applications include Mission Critical Facilities, Water Treatment and sites where Utilities offer Peak Shaving credits.
- Requires additional controls to synchronize with Utility
- Extended Parallel/Connection to Utility Source
- Requires protection on utility circuit breaker per utility requirements – Protective relay
- Requires utility company approval
- Some benefits of a Soft load Parallel with Utility design:
  - No interruption of load when retransferring to Utility from Generator.
  - Saves wear and tear on circuit breakers and UPS’s.
  - No interruption of load when transferring from good utility to generator for maintenance or peak shave.
  - Provides opportunity for revenue via Utility Import/Export control.
Power Control Systems  Automatic Priority Load Control

What happens when the lights go out?

Master Section “Brains of the System” tells Generator Sections to start all engines.

Effected ATS(s) send start signal to Master Section.

Utility Power

Power Control System

Automatic Transfer Switches
Power Control Systems - Automatic Priority Load Control

■ What happens next?
■ All loads can’t be connected immediately
■ Loads are connected to the emergency bus as the system connects generators
■ The Master Controls signal loads (ATS or CB) to connect to the emergency bus in priority order – User adjustable in Master OIT
■ Load can be added in priority blocks
■ Or in steps

Block Load Control

Step Load Control
Power Control Systems - Automatic Priority Load Control Features

- What happens if an engine fails?
- It depends
- Traditional systems will shed the lowest priority load block
- Current Systems do nothing unless they have to
- Systems can provide a "load latch" function that compares remaining capacity to real time kW demand of online loads
- If sufficient capacity remains, load latch ensures that the loads will remain online preventing unnecessary disconnection and re-connection of loads
Power Control Systems - Automatic Priority Load Control Features

Master Controls account for changes or failures in System configuration

**Load Demand**
- Maximizes the efficient use of standby generator capacity by adding or removing generators according to demand
- Calculates kW Demand On The Emergency Bus
- Disconnects Unnecessary Generators And Allows A Cooldown Period
- Highly specified feature but not always necessary

**Bus Optimization Feature**
- Controls the number of load blocks to connected to the Emergency Bus
- Maximizes the Load Blocks on the Emergency Bus
- Calculates if the next Load Block can be connected
- Should be specified more

Operating Examples:
- **Load Demand**: Operates When Excess Capacity is Available
- **Bus Optimization Feature**: Operates When A Generator Fails
Power Control Systems – Bus Optimization Feature

- Bus Optimization Operates if an engine fails or fails to start
- Individual Loads within Priority blocks are pre-assigned Subpriorities and kW Values via the Master HMI
- The lowest priority load block is shed if the remaining capacity can’t support it
- After a time delay Loads within a priority block are reconnected to the emergency bus in order up to 90% of capacity
- Dynamic Bus Optimization Measures real time load kW and reconnects loads
- Bus Optimization features are typically under specified