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Emergency Generator - Paralleling Switchgear Power Switching Control Methodologies for LV and MV Applications

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PSG Power Switching Control Methodologies for LV and MV Applications

OUTLINE:

- Overview/Introduction
- Basic Theory
- Design/Application
- Control Applications/System Operation

Typical Paralleling Switchgear

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PSG – Typical Applications

Auto Standby
Applications

Distributed Generation
Applications

Prime Power
Applications

PSG – Typical Application Solutions

System Applications:

- **Distributed Generation** – Utility paralleling for extended or softload closed transition transfer with Auto Standby functionality.
- **Auto Standby** – Traditional islanded operation with distributed emergency loads and/or ATS.
- **Prime Power** – Prime source of power operating 24/7 with load demand control to maximize efficiency.

Distributed Generation (DG) Switchgear Systems

- **Parallel operation of single or multiple generators to the utility grid or on an isolated bus as emergency standby power.**
- **These systems can provide auto synchronizing, soft load Closed Transition Transfer with automatic load(kW) and power factor control (kVAR).**
- **Continuous parallel operation with the utility can be utilized for, load testing, load demand management and cogeneration applications.**

Auto Standby (AS) Switchgear Systems

- To provide automatic standby power during a utility power failure.
- Single or multiple generator systems with automatic synchronizing and paralleling control.

- Designs with integral transfer switches or external distributed transfer switch schemes.
- ATS may incorporate Open Transition or Closed Transition (Momentary Operation).

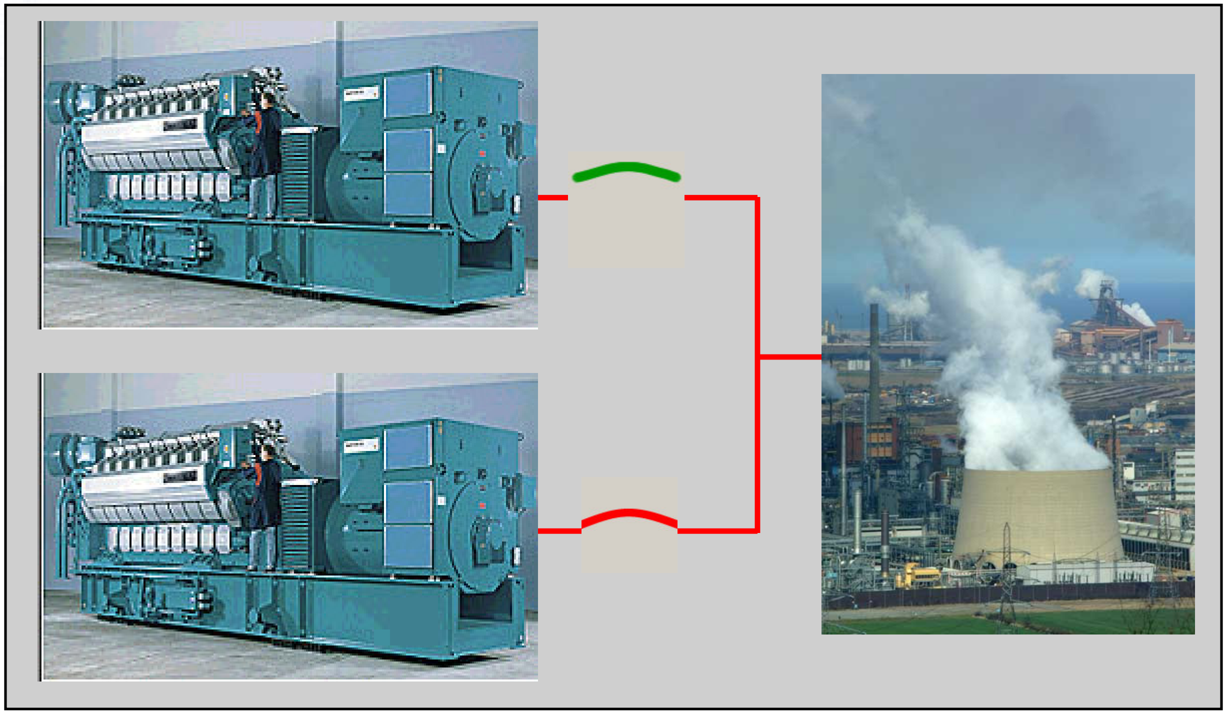
Prime Power (PP) Switchgear Systems

- To provide power & control for applications where local utility is unreliable, unavailable or uneconomical to install.
- Single or multiple generator systems with automatic synchronizing.
- Prime Power sites require unique control solutions because of their critical nature.
- These systems can incorporate automatic synchronizing, soft transfer, fuel economizing or run-time hour balancing.

BASIC THEORY:

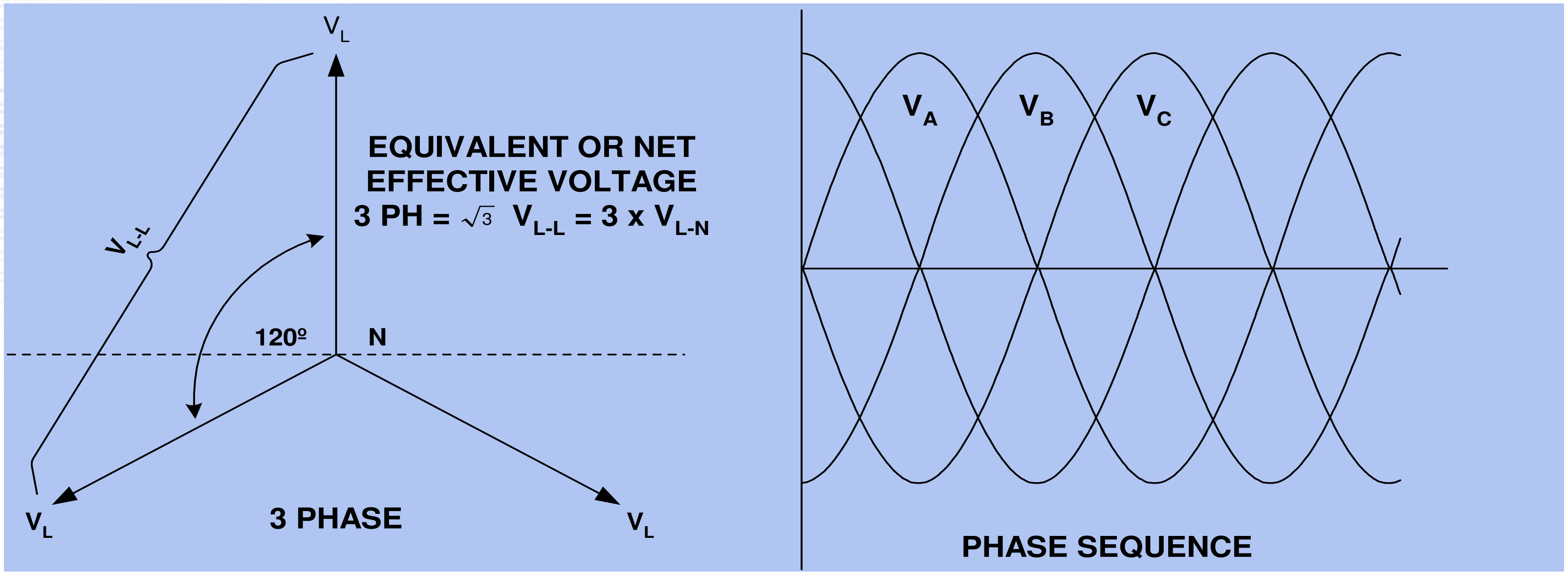
- Synchronizing
- Load Sharing
- Protective Relaying for Synchronizing

Synchronizing



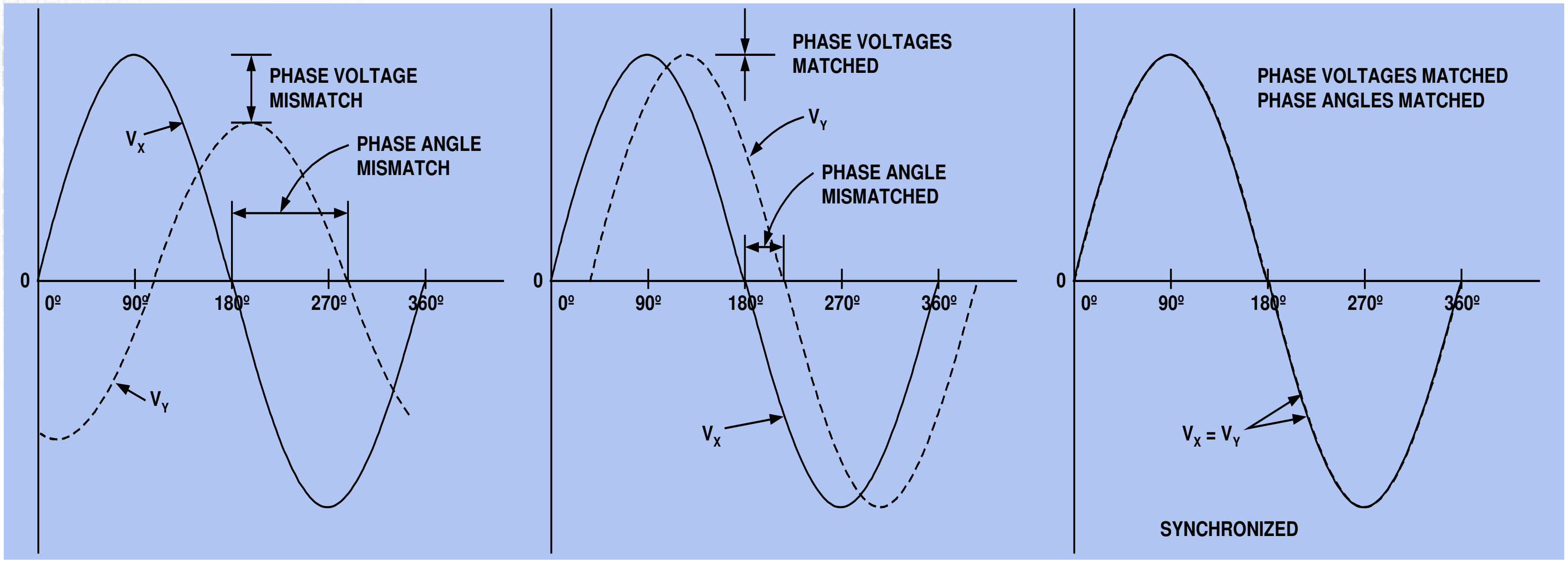
Basic Theory – Synchronizing

- Generators may only be synchronized together provided they have:
  - **Same number of phases**
  - **Same phase to phase voltage**
  - **Same phase rotation**



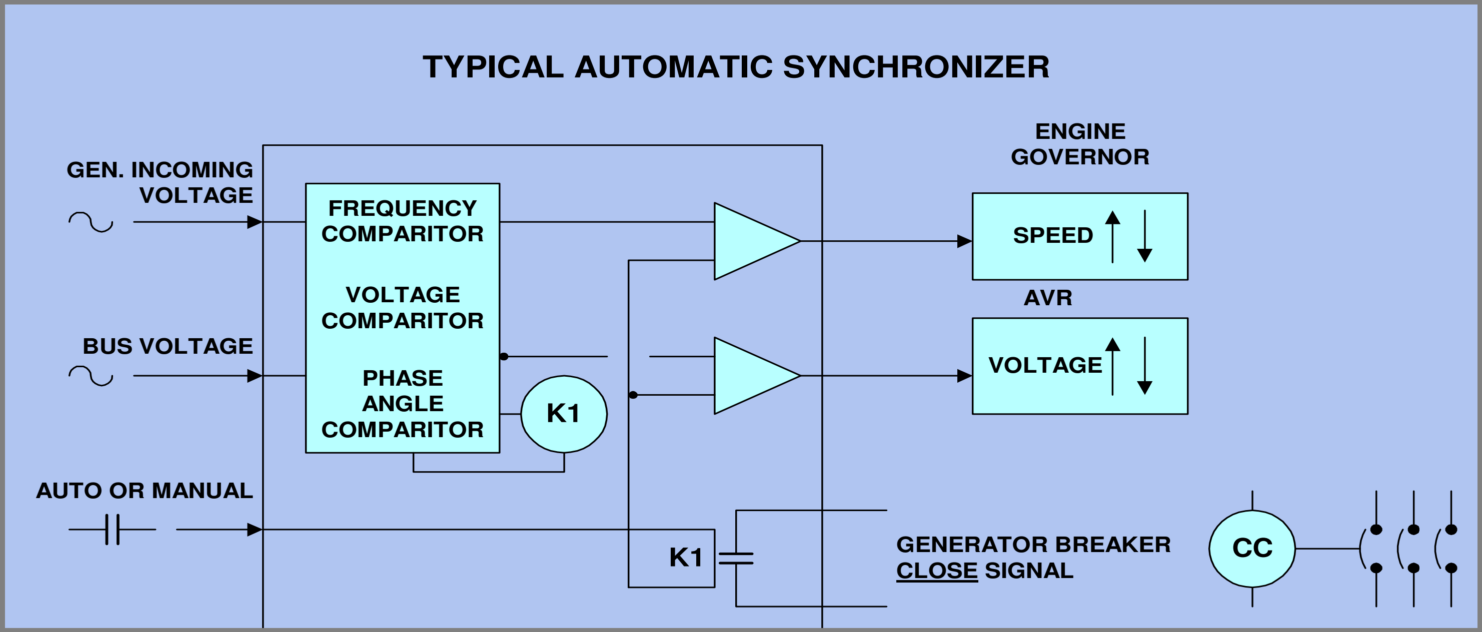
Basic Theory – Synchronizing

- Generators are "*In Synchronism*" only when:
  - **Phase voltages match**
  - **Frequencies match**
  - **Phase angles match**



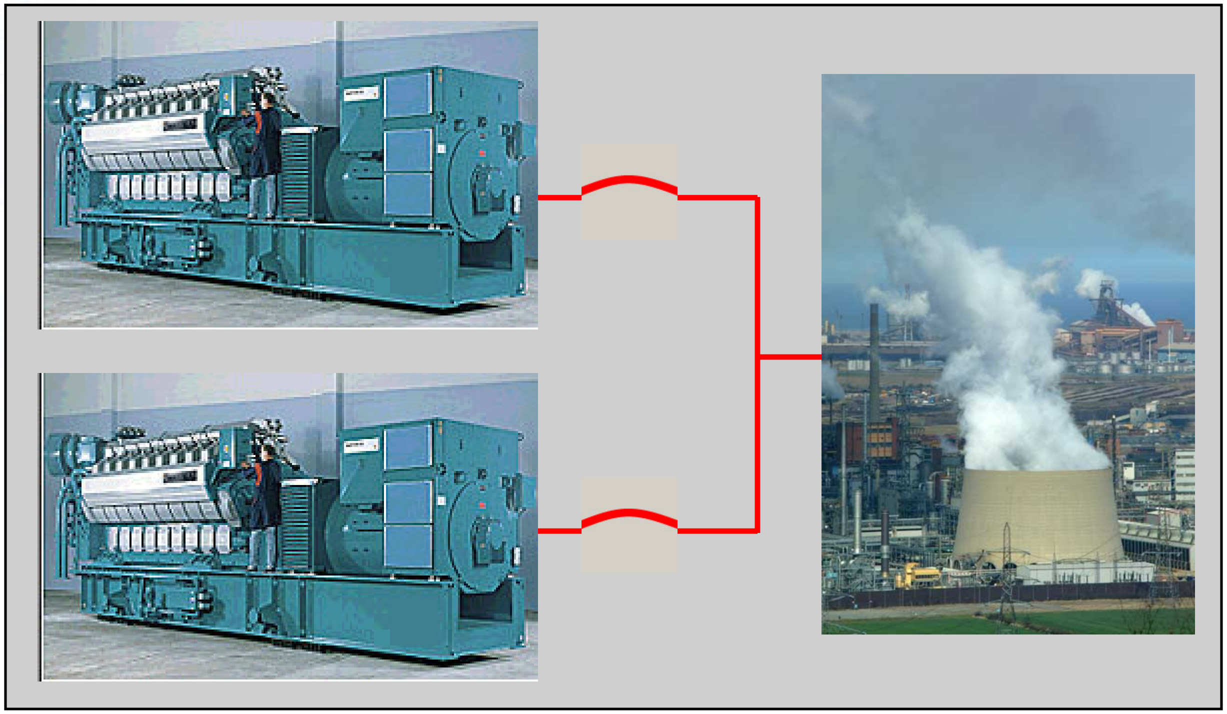
Basic Theory – Synchronizing

- Typical automatic synchronizers provide the following functions:
  - **Control speed (frequency) of incoming generator set.**
  - **Match incoming & bus frequencies & phase angles.**
  - **Provide breaker close signal when “in synchronism”.**
  - **Optional voltage matching control.**



Emergency Generator – Paralleling Switchgear

Load Sharing



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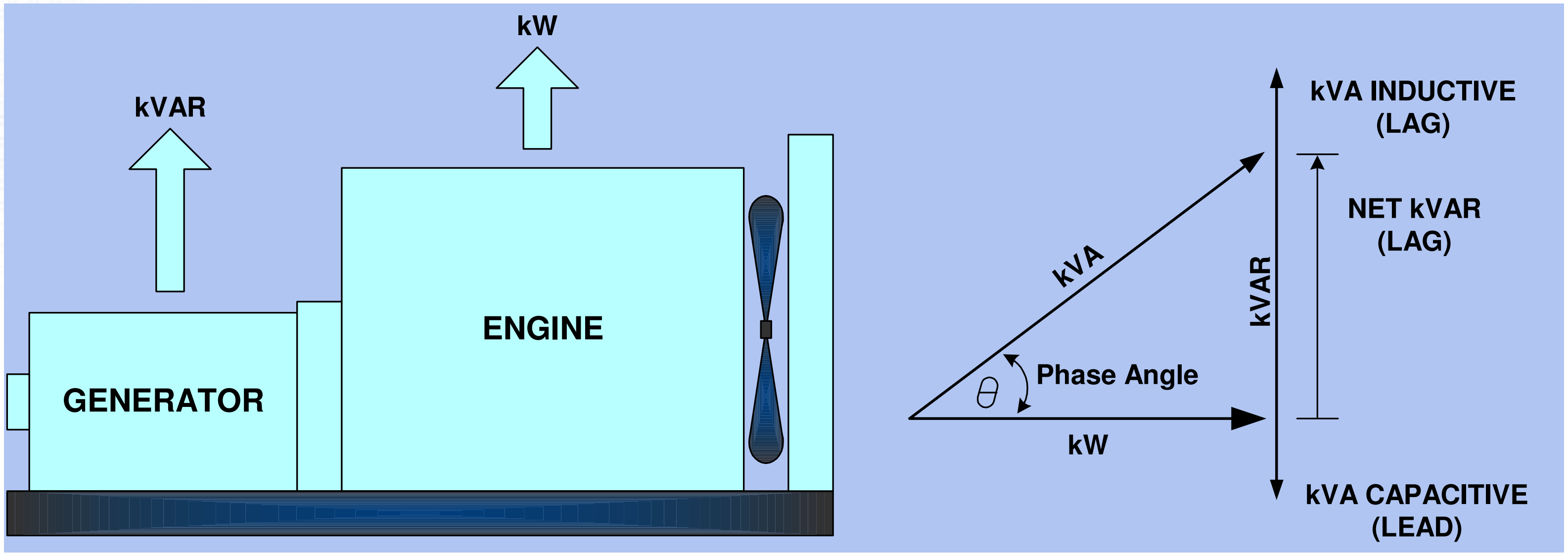
Basic Theory – Automatic Load Sharing

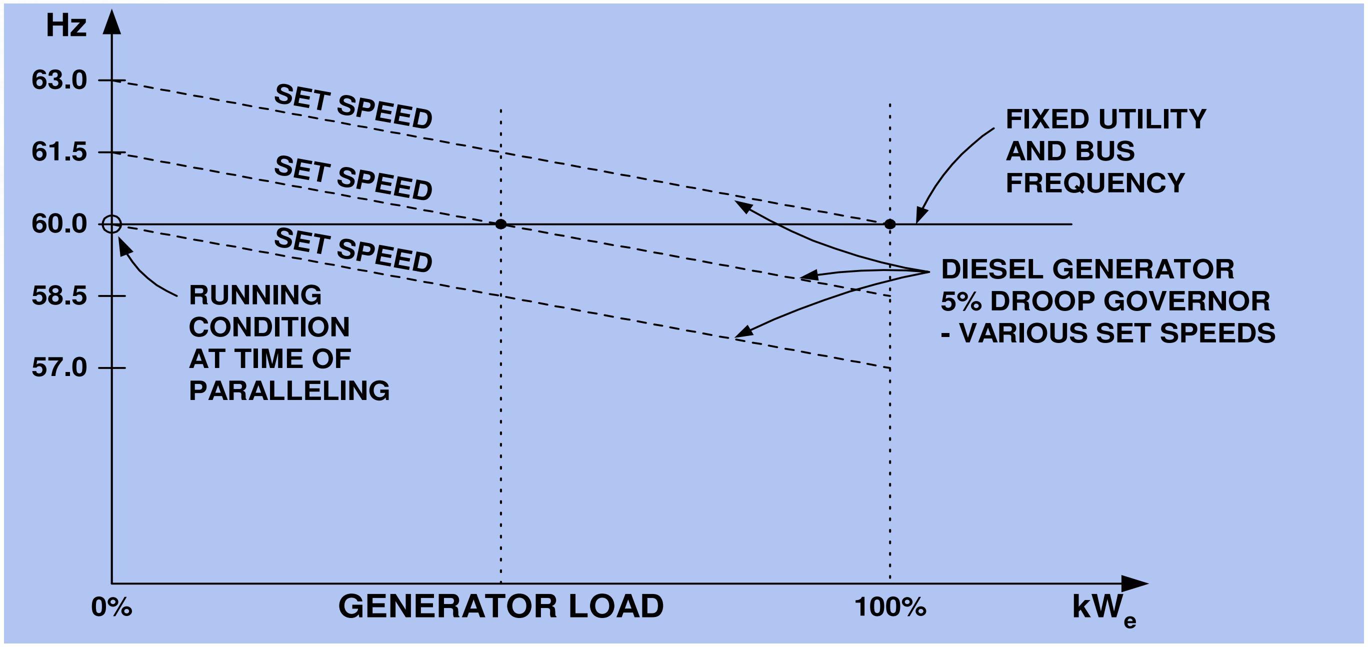
- **Automatic load sharing is required between generators to maintain maximum capacity of the system.**
- **Generator capacity is divided into two basic types:**
  - **<u>Kilowatt (kW) Load</u> - Power is provided only by the primer mover (engine) i.e. horsepower**
  - **<u>Kilovar (kVAR) Load</u> - Power is provided only by the alternator (i.e. generator)**



Basic Theory – Kilowatt (kw) Load Sharing

- Once engines are synchronized together they must share real power (kW) to balance capacity.

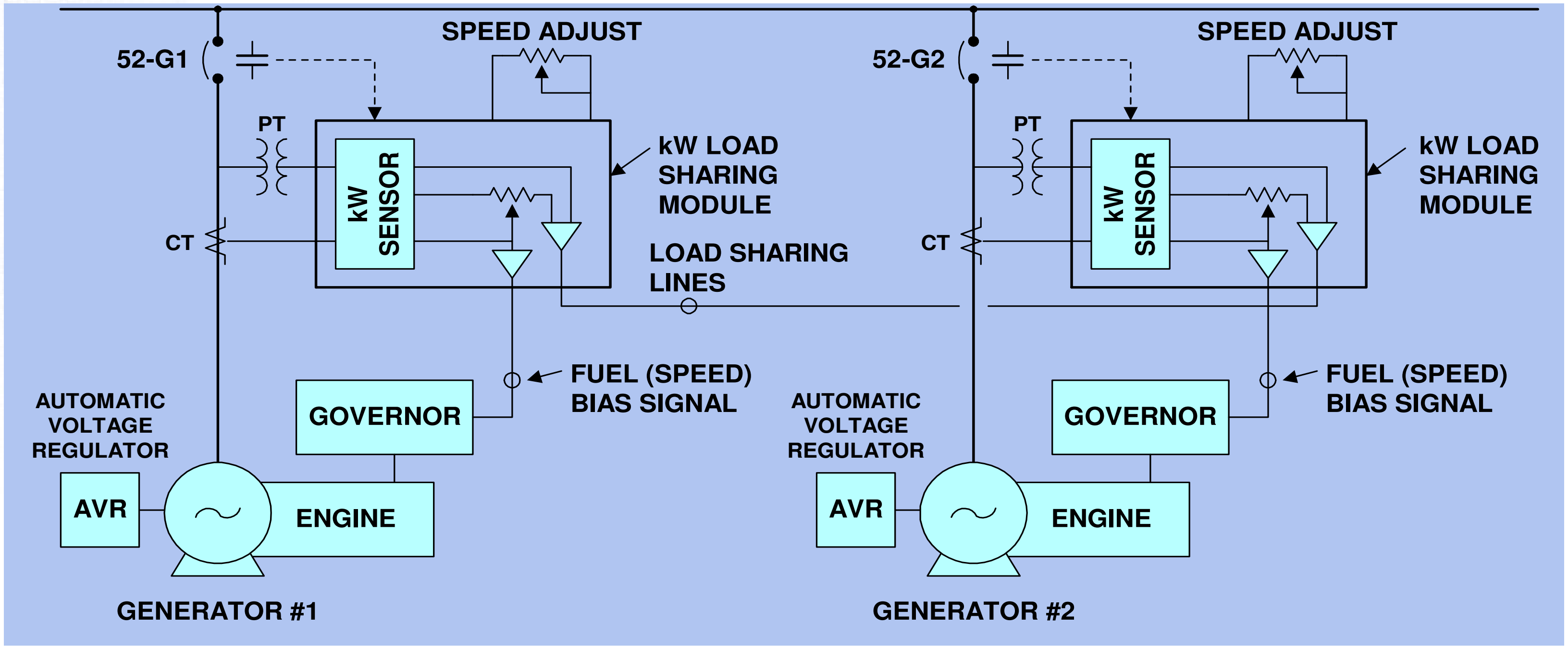
- Two types of kW load sharing systems may be used.
  - Droop (varying frequency)
  - Isochronous (constant frequency)



Basic Theory - Kilowatt (kW) Load Sharing

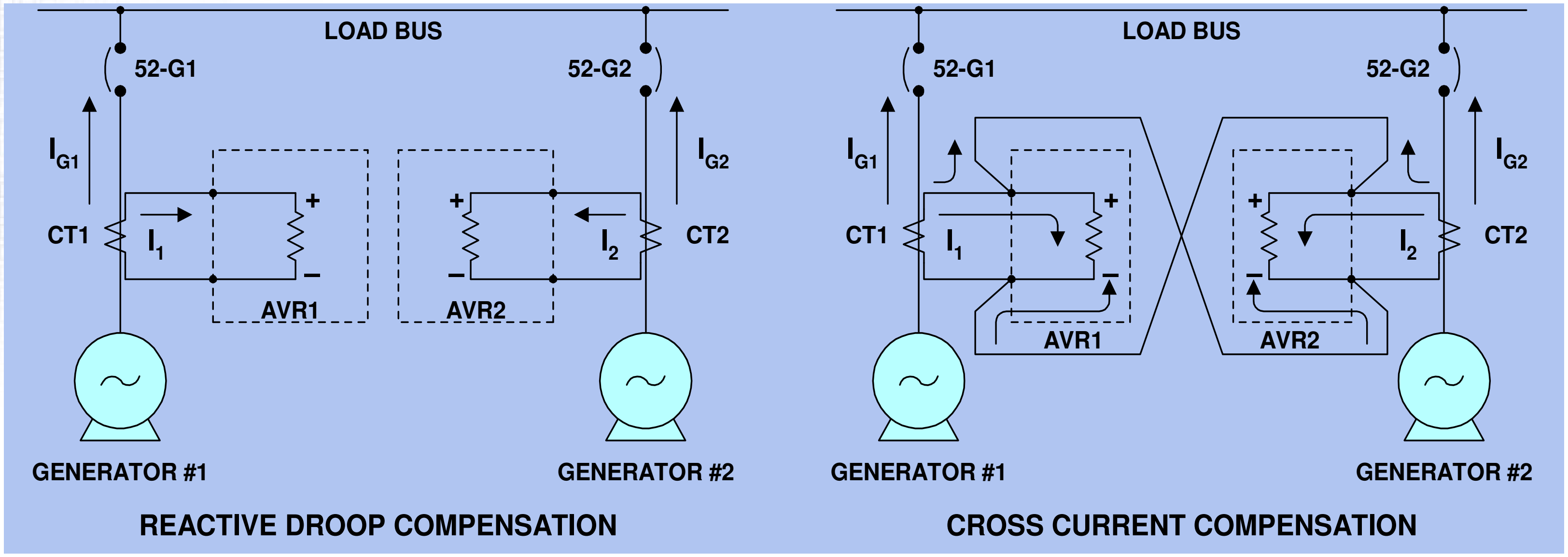
Typical Isochronous Load Sharing:

- Control kW by adjusting engine governor (fuel)
- Increase or decrease in fuel changes kW (speed frequency is held constant)
- Load balance between generators is set as a <u>percentage</u> load



Basic Theory - kVAR (Reactive) Load Sharing

- **Once generators are synchronized together, they must share reactive load (kVAR or power factor) to balance capacity.**
- **Two types of reactive load sharing systems may be used.**
  - **Reactive droop compensation (varying voltage)**
  - **Cross current compensation (constant voltage)**



Design/Application - Switchgear

Typical Engine/Gen Set Control Configurations

Typical Genset Manufacturer	Engine Control	Speed Control	Loadsharing	Synchronizing
MTU Onsite Energy	Integral	Integral		
Cummins	Integral	Integral	Integral	Integral
Caterpillar	Integral	Integral		
Waukesha	Optional	Integral		
Fairbanks Morse	Integral	Integral		
GE/Jenbacher	Integral	Integral	Integral	Integral
Deutz	Integral	Integral	Integral/droop	
Indepedent OEMs	Optional	Integral	Optional	Optional
Turbines	Integral	Integral	Optional	Optional

Protective Relaying Considerations

for

Paralleling Equipment

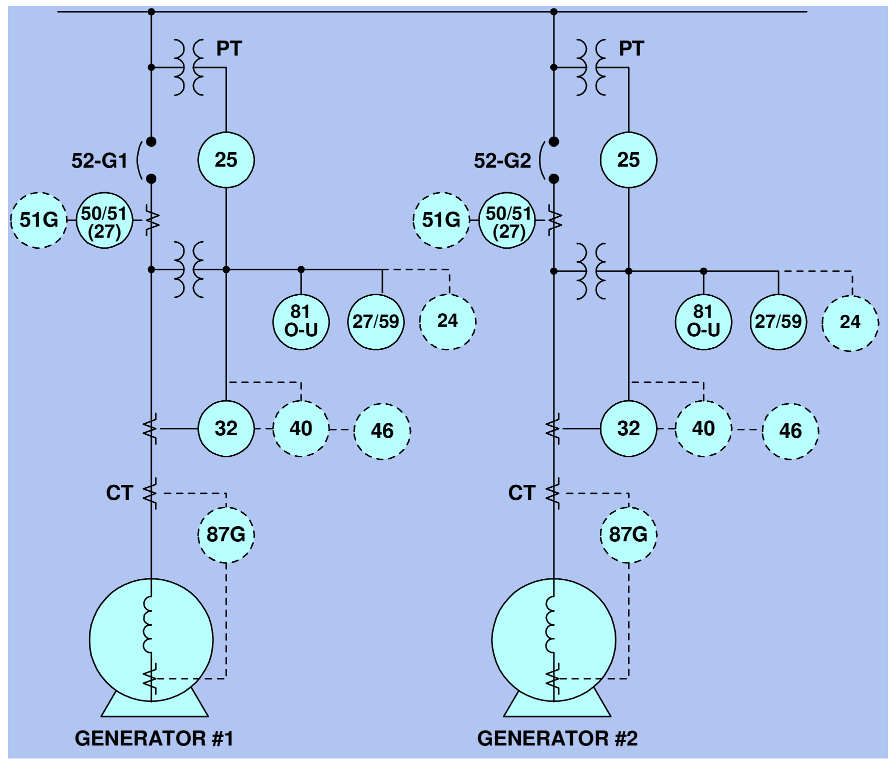
Basic Theory - Protective Relaying for Paralleling-Generators

A LV synchronizing system requires more protection than a non-synchronizing system.

- **Sync Check Relay (25)**
- **Under/Overvoltage Relay (27/59)**
- **Reverse Power Relay (32)**
- **Overcurrent (50/51)**
- **Under/Overfrequency Relay (81 O/U)**

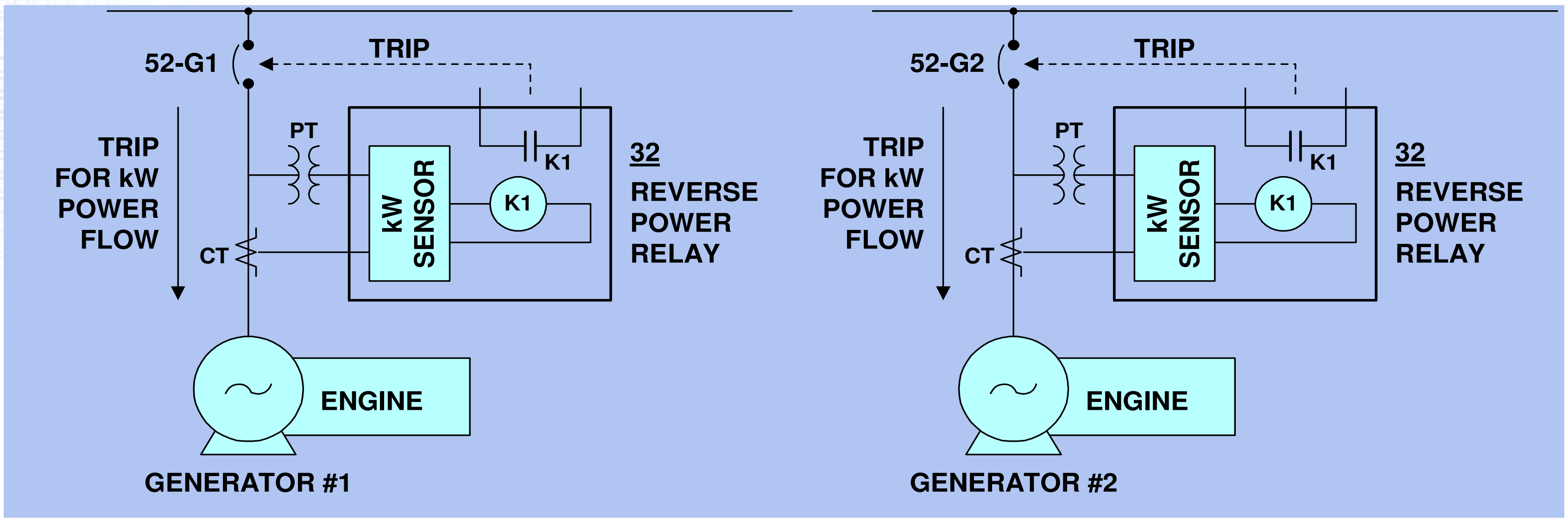
OPTIONAL

- **Volts/Hertz Over excitation (24)**
- **Loss of Excitation Relay (40)**
- **Negative Sequence Overcurrent (46)**
- **Voltage Restrained Overcurrent (51/27R)**
- **Ground Fault Relay (51G)**
- **Differential Overcurrent Relay (87G)**



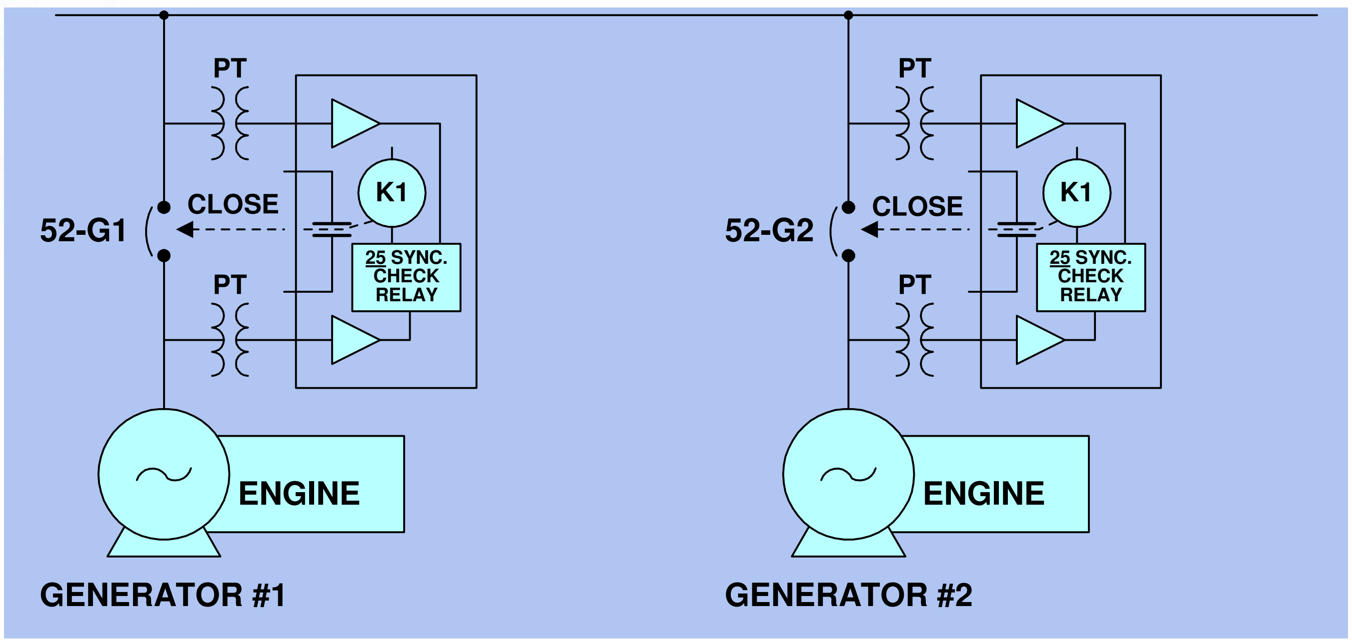
Basic Theory - Protective Relaying for Paralleling-Generators

- **Reverse Power (32)**
  - **Protects generators from being driven as a motor when its prime mover (engine) looses power. Generator windings will be damaged due to overheating caused by motoring.**
  - **Reverse Power function senses kW power flow in the reverse or opposite direction, and signals a breaker trip condition.**
  - **Reverse power setting has adjustable kW level trip point and time delay. Typical relay setting is 5% of generator kW rating with a 2 second transient delay.**



Basic Theory - Protective Relaying for Paralleling-Generators

- **Sync Check Relay (25)**
  - Protects generators from being connected together out of sync or not "In phase".
  - Sync Check Relay senses voltages & phase angles between two sources. Relay energizes output contact only when voltage, frequency and phase angle are within acceptable limits.
  - Sync Check Relay is typically adjustable from 1% to 30% nominal voltage. Typical setting is 5%.
  - Sync Check Relay is typically adjustable from 0 to 20 electrical degrees. Typical setting is 10 degrees.



Basic Theory - Protective Relaying for Paralleling-Generators

- Directional Overcurrent Relay (67)(Optional)
  - Protect utility from being fed from an alternative power source, or a transformer being backfed higher than rated capacity.
  - Directional overcurrent relay senses current flow in both directions and has two set points enabling different settings in either direction.
  - Directional overcurrents settings are based on site conditions, loads and transformers and therefore have no typical settings.

- Timed/Instantaneous Overcurrent Relay (50/51)
  - Protects the generator from external overcurrent faults in the system. A typical 50/51 relay has 3 protective elements: - instantaneous (for extremely high fault current of short duration), short time (for high short circuit fault conditions), and long time (for overload conditions). The 50/51 relay should be set using the generators short circuit decrement and overload curves to obtain a coordinated protective system.

Basic Theory - Protective Relaying for Paralleling-Generators

- **Volts/Hertz Over Excitation Relay (24) (Optional)**
  - Provides protection for the generator during slow speed operation. The excitation system is inhibited until a preset voltage and frequency level has been reached. Typical applications are for large generators directly connected to a step up transformer.
- **Loss of Excitation Relay (40) (Optional)**
  - Protects generators from loss of excitation during parallel operation. Relay provides additional generator protection. Primary protection is provided by 27/59 relay and overcurrent relays.
  - Low cost methods – industrial grade protection using reverse kVAR
  - Higher cost utility grade relay providing mho/distance function for loss of excitation detection - typically used on larger and MV generators.
- **Negative Sequence Current Relay (46) (Optional)**
  - Provides generator protection from unbalanced loading conditions which in turn causes damaging negative sequence current to flow. Negative sequence current causes excessive heating in the generator windings.

Basic Theory – Protective Relaying for Paralleling-Generators

- **Under/Overvoltage Relay (27/59)**
  - Protects system load & generators from abnormal voltage conditions due to overload or generator excitation system fault.
  - One relay required per generator.

- **Over/Underfrequency Relay (81 O/U)**
  - Protects system load and generators from abnormal frequency conditions due to overload or engine governor system fault.
  - One relay required per generator.

Basic Theory -
Protective Relaying for Paralleling-Generators

- **Voltage Restraint Overcurrent Relay (51/27R) (Optional)**
  - **Protects the generator from external overcurrent faults in the system which may occur at reduced levels of voltage. The overcurrent setpoint is variable dependent upon generator output voltage. Should a fault occur which reduces the generators output voltage, the fault current will also be reduced. The 51/27R relay will detect this condition and provide a lower trip setting to disconnect the generator from the fault.**
- **Differential Overcurrent Relay (87G) (Optional)**
  - **Protects generators from internal phase to phase or phase to ground faults.**
  - **Typically utilized in LV distributed/cogeneration and prime power applications and standard for most MV applications.**

Basic Theory -
Protective Relaying for Paralleling-Generators

<u>Ground Fault Protection (Optional)</u>

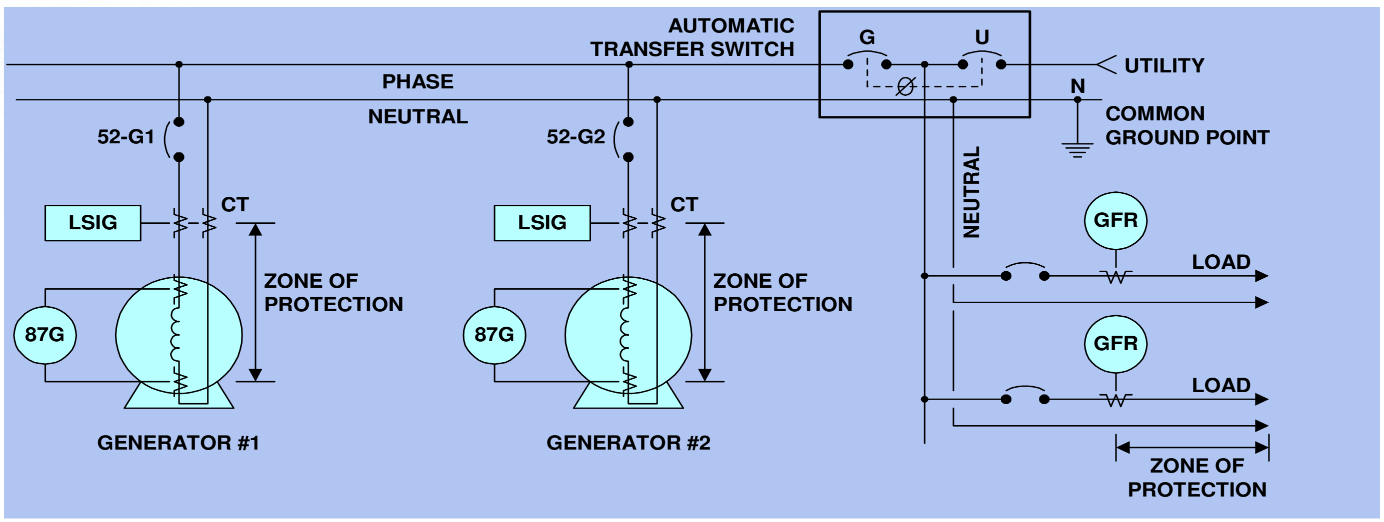
Many methods of ground fault protection are dependent on grounding systems used and zones of protection required.

- **Two basic grounding systems are used:**
  - Solidly grounded neutral (low voltage only)
  - High resistance grounded neutral
- **Two basic zones of protection are provided:**
  - System loads
  - Generators

Basic Theory -
Protective Relaying for Paralleling-Generators

Ground Fault Protection - Solidly Grounded Systems

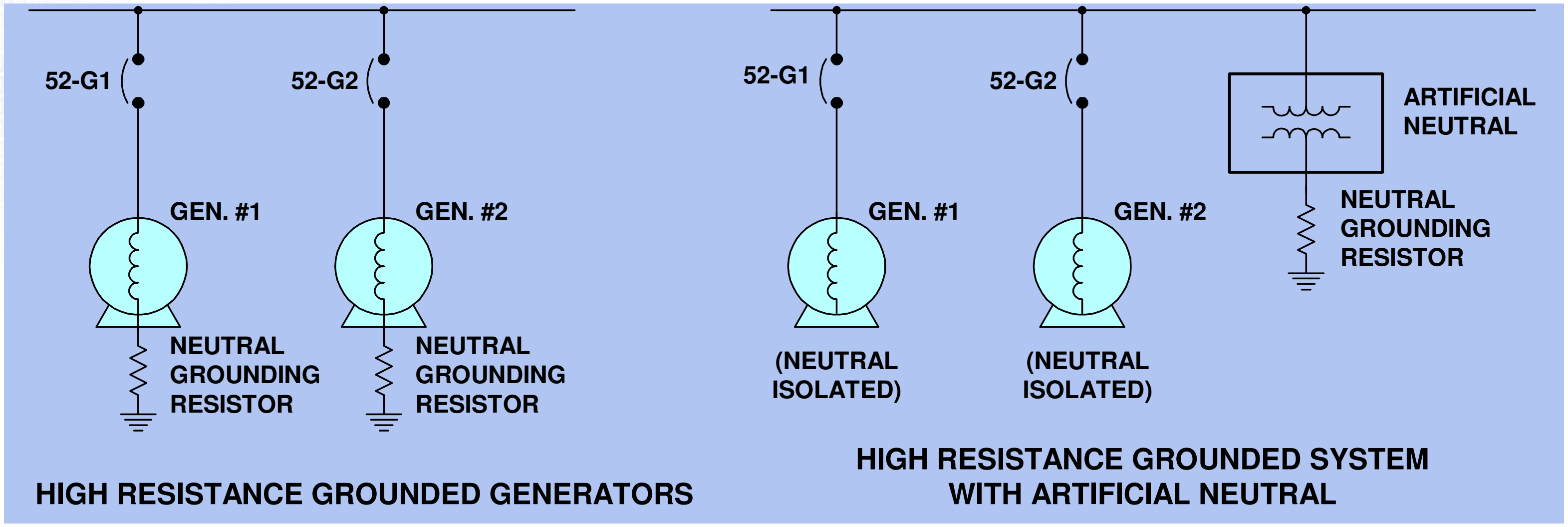
- **Generator Zone Protection**
  Two typical methods:
  - Breaker overcurrent trip unit with built-in ground fault element (neutral grounded at one point only).
  - Differential overcurrent relaying.
- **Load Protection**
  - Ground fault relays required on load feeder breakers.



Basic Theory - Protective Relaying for Paralleling-Generators

Ground Fault Protection - High Resistance Grounded Systems

- High Resistance Grounded System Applications
  - Typically used for high voltage systems > 480V.
  - Avoids interconnecting generator neutrals.
  - Reduces high levels of ground fault current (very damaging).
  - System can still operate normally with a single ground fault condition.
  - Ground fault current is typically limited to 1Amp per 1000kVA system loading for LV systems and vary for MV applications.



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PSG - Methods for Power Switching Control

Review of the common power switching control techniques used in industry today:

- **Open Transition**
- **Momentary Closed Transition**
- **Soft-Load Closed Transition**
- **Continuous Parallel Generation for load testing and/or distributed generation applications.**

PSG Power Switching Control – Open Transition

Open Transition Transfer with integral or external distributed ATS:

- Provide both mechanical and electrical interlocks to prevent paralleling of utility and generator sources. This is typically done with UL1008 ATS but may also include transfer pairs in both LV and MV applications.
- Simple operation with no additional protective relaying or control requirements.
- Load management is controlled via adding and/or dumping of the transfer pairs.

PSG Power Switching Control – Momentary Closed Transition

Momentary Closed Transition Transfer with integral or external distributed ATS:

- Provide momentary paralleling (less than 100ms) of utility and generator sources.
- This is typically done with UL1008 ATS but may also include transfer pairs in both LV and MV applications.
- Prevents all Power Interruptions due to Testing and Utility Power Restoration.
- Generator may be utilized for utility interruptible rate programs for load displacement without affecting facility loads.

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PSG Power Switching Control – Momentary Closed Transition

Control and generator interface considerations:

- Synchronizing is passive, utilizing “drift sync” between the two sources). When in sync and the voltage/frequency of the two sources are within acceptable parameters the transfer is initiated. Drift sync can attribute to extended transfer times or failure to transfer (should be alarmed & monitored).
- Standard ATS interface with new or existing engine generator.
- Block loading of generator and utility in less than 100 milliseconds if a single ATS is utilized.
- Voltage and frequency transients to the load during transfer operations.

PSG Power Switching Control – Momentary Closed Transition

Protection Considerations:

- All ATS vendors must provide electrical interlocks to monitor the closed transition window and provide contacts to signal if the Close Transition period were to exceed 100ms to trip utility or generator source breaker feeding the ATS.
- Some ATS vendors also provide additional protection enabling isolation within the ATS by disconnection of the source being transferred to and remaining on the original source and alarming the condition.
- As both of the operations and isolation result in the disconnection of the two sources in no more than 200ms the majority of Utility companies do not require any additional protection.
- Some Utility companies may (varies from region to region) include 32 protection etc., this will provide a tertiary level of protection to satisfy the utility.

PSG Power Switching Control – Soft Loading Closed Transition

Soft Load Transition Transfer with integral or external distributed ATS:

- Provide paralleling control logic for utility and generator sources for a short period of time, typically no more than 30 seconds.
- Provide kW & kVAR control during the transition time.
- This can be done with UL1008 ATS or PSG but due to the enhanced control and interface requirement with the engine/generators is more commonly seen as integral to the PSG.
- Prevents all Power Interruptions due to Testing and Utility Power Restoration.
- Minimizes voltage and frequency transients to the load during transfer operations.

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PSG Power Switching Control – Soft Loading Closed Transition

"Zero" Power Transferring

- Increases life of breaker contacts by transferring power near zero levels.
- Reduces power system transients during transferring (i.e. no large load blocks applied on generator or utility) .
- Generator may be utilized for utility interruptible rate programs for load displacement without affecting facility loads.

PSG Power Switching Control – Soft Loading Closed Transition

Control and generator interface considerations:

- Synchronizing is active, as a minimum only the generator frequency is controlled (governor), however quite often both voltage & frequency are controlled. The system will actively synchronize the the two sources and only initiates breaker closure/transfer when; Voltage, Frequency & Phase angle differential of the sources are within acceptable limits.
- Soft loading and unloading is managed by the kW ramp rates of the generator(s) of the ATS or PSG control system.
- Detailed interface requirements between the ATS and/or PSG vendor and the generator supplier for coordination of AVR and governor interface are required.
- On site startup/commissioning will be required by both the ATS/PSG vendor and generator supplier.

PSG Power Switching Control – Soft Loading Closed Transition

Digital Auto Synchronizer / Load Sharing Module

- Auto Synchronizer
  - Must be designed for use with supplied electronic engine governor
  - Adjustable gain/stability
  - Analog speed matching signal
  - Auto breaker close contact (voltage, slip freq, & phase angle)
  - Voltage matching is required for utility paralleling applications.
  - Voltage matching is not required for isolated generator systems and will enable faster response than if voltage matching feature is applied.
  - One synchronizer per generator
- kW Load Sharing
  - Must be designed for use with supplied electronic engine governor
  - Must provide isochronous load sharing (non-droop)
  - One load sharing module required per generator
  - Phase sensitive
  - (Note: May be integral with speed control or synchronizer.)
- kVAR (Reactive) Load Sharing
  - Automatic voltage regulator must have load sharing capability (I.e. accept cross current or droop CT input)
  - One cross current CT required per generator
  - Cross current CT can be in generator or switchgear
  - Phase sensitive

PSG Power Switching Control – Soft Loading Closed Transition

Protection Considerations:

- Most Utility companies will require separate control and protection devices for this operation regardless of inherent protection offered in the integrated transfer/synchronizing and loading control devices provided by many ATS/PSG vendors.

PSG Power Switching Control – Soft Loading Closed Transition

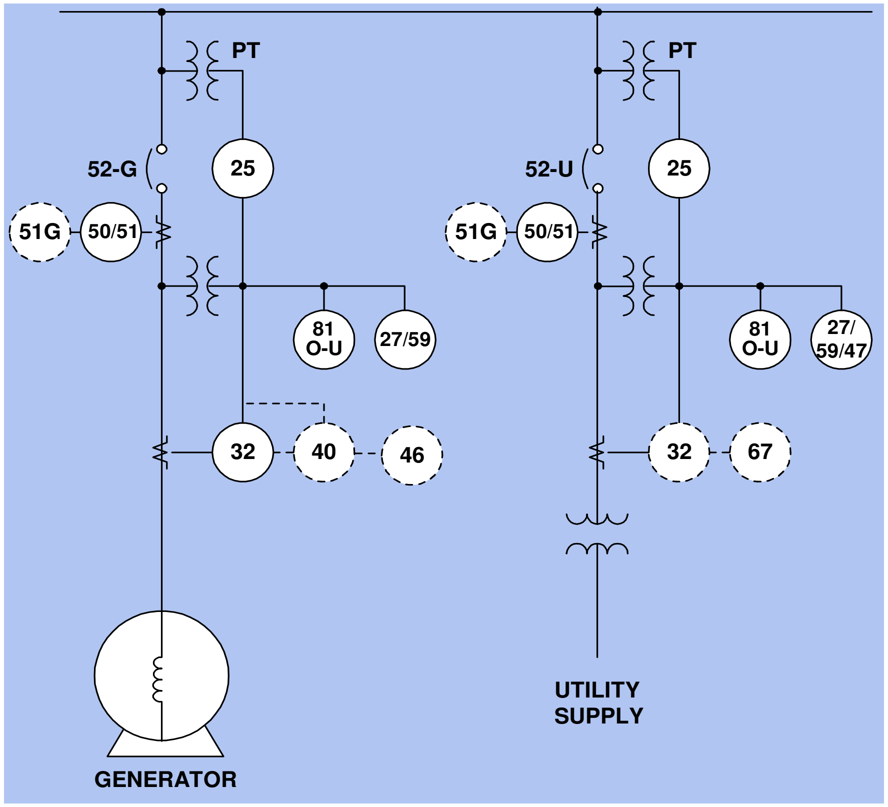
Typical Utility intertie protective relays:

- Sync Check Relay (25)
- Under/Overvoltage Negative-Sequence Voltage Relay (27/59/47)
- Overcurrent (50/51)
- Under/Overfrequency Relay (81 O/U)

<u>OPTIONAL</u>

- Reverse Power Relay (32)
- Loss of Excitation Relay (40)
- Negative Sequence Overcurrent Relay (46)
- Directional Overcurrent Relay (67)

Note: Optional relays may be mandatory dependent on the utility requirements and/or equipment sizes and site application requirements



PSG Power Switching Control – Soft Loading Closed Transition

- **Anti-Islanding Protection:**
  - Must correctly sense the loss of the utility supply during parallel operation and immediately isolate the two supplies to prevent back-feeding the utility supply. Primary protective relays used are 27/47/59, 32 and 81 O/U.
- **Equipment Protection:**
  - Generators, and utility transformers must be adequately protected in cases of abnormal operation (i.e. equipment failure).
  - Primary generator protection relays required are 50/51, 32, 27/59, and 81 O/U.
  - Primary utility protection relays are 50/51 and 27/59/47.

PSG Power Switching Control – Soft Loading Closed Transition

- **Sync Check Relay (25)**
  - A sync check relay must be connected across each circuit breaker to be synchronized.
  - Protects utility and generator from being interconnected out of sync or without power sources.
  - Relay senses phase voltages, system frequency and phase angles to determine an “in-sync” condition.
  - Breaker closure signal will only be issued when all conditions of voltage, frequency and phase angle have been satisfied.
  - Typical relay settings are; max 0.1 Hz slip frequency, +/- 5 electrical degrees phase angle and +/- 3% voltage difference.
- **Reverse Power Relay (32)**
  - One reverse power relay is required for each generator and utility feeder (If generator power is not to be exported into the utility grid).
  - Reverse power relays used on generator(s) prevent power (kW) flow into the generator for anti-motoring protection, which can damage the synchronous alternator or the prime mover.
  - Reverse power relays used on the utility supply prevent power (kW) flow into the utility grid (typically undesirable-subject to utility company regulations).
  - Typical relay settings for generator applications are 5% of nominal generator kW rating and 5% of nominal utility feeder size or equivalent kW level but usually not less than 100kW to allow the generator(s) to respond to load fluctuations.

PSG Power Switching Control – Soft Loading Closed Transition

- **Over/Under/Negative Sequence Voltage Relay (27/59/47)**
  - **One voltage relay is typically required for each generator and utility feeder.**
  - **Protects system load, generator and utility transformers from abnormal voltage conditions (e.g. over, under and phase balance).**
  - **Negative Sequence Voltage function detects a voltage phase unbalance condition typically caused by single phasing of a 3 phase device (i.e. blown fuse on a motor or transformer).**
  - **Typical relay settings for generators will be +- 10% with 1-2 second time delay. These settings must allow correct operation on isolated loading conditions (i.e. block loading).**
  - **Utility feeder voltage relays setting will vary dependent upon typical site conditions. The utility voltage relay settings will generally be set to smaller tolerances than the generator relays to ensure immediate Anti-Islanding protection. Typical settings are +- 5% with 0.2 second time delay.**

PSG Power Switching Control – Soft Loading Closed Transition

- **Over/Under Frequency Relay (81-O/U)**
  - **One frequency relay is typically required for each generator and utility feeder.**
  - **Frequency relays used on generators detect abnormal frequency conditions and disconnect the generator from service.**
  - **Frequency relays used on the utility supply are for Anti-Islanding protection. When an abnormal frequency is detected, the relay operates immediately to trip off the utility supply.**
  - **Typical relay settings for utility supply must be set very tight-typically +- 0.05 Hz with 0.1 second time delay.**
  - **Typical relay settings for generators will be +- 10% with 1-2 second time delay. These settings must allow correct operation on isolated loading conditions (i.e. block loading).**

PSG Power Switching Control – Continuous Parallel Operation

- **Provides Soft Loading Closed Transition Transfer with available continuous parallel operation with the utility and is a function of the PSG.**

- **Provide paralleling of utility and generator sources for extended periods of time:**
  - Load testing at 100% rated with facility load
  - Minimum risk to facility if there is problems with engine/generators during testing
  - Utility load demand management programs
  - Distributed or Cogeneration

PSG Power Switching Control – Continuous Parallel Operation

Control and generator interface considerations:

- Synchronizing is active and controls interface to the generator voltage/frequency will actively synchronize the two sources and initiates connection when voltage/frequency of the two sources are within acceptable parameters.
- Soft loading and unloading is managed by the kW and kVAR ramp rates of the generator(s) PSG control system.
- Minimum utility import/export load levels are monitored and controlled.
- Base load of generator or utility sources are maintained during parallel operation.

PSG Power Switching Control – Continuous Parallel Operation

Protection Considerations:

- Identical to Soft Load Closed Transition application with the following additional considerations.
- Allowable utility import/export load levels at the point of common coupling.

Questions?