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# Schneider Learning Series – ASCO Offer

## Generator Synchronizing and Load Control

9th February 2021

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# Learning Objectives

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|---|---|
| 1 | What is meant by “synchronization”, why is it needed, and what conditions must be met for two systems to be synchronized? |
| 2 | What is “dead bus closure arbitration”, why is it needed and how does it work? |
| 3 | What are the types of synchronization methods available and when should they be used? |
| 4 | How does an automatic synchronizer work? |
| 5 | What is meant by “load control” and why is it needed? |
| 6 | What are the methods of Active Power Load Control available and what are their advantages/disadvantages? |
| 7 | How does a “load share module” work? |
| 8 | What are the methods of Reactive Power Load Control available and what are their advantages/disadvantages? |

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# Learning Objectives

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| 9 | How does VAR control work? |
| 10 | What are some different types of engines available and how do they affect load control? |
| 11 | What is generator pitch and how does it affect load control? |

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# Please use the "Questions" feature to ask technical questions.

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# Speaker's Biography

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- 28 years with ASCO
- Bachelors degree in Electrical Engineering from Villanova University
- Licensed professional engineer in the state of New Jersey
- 7 years in Switch Power Laboratory
- 7 years as a PCS engineer
- 14 years in Engineering management

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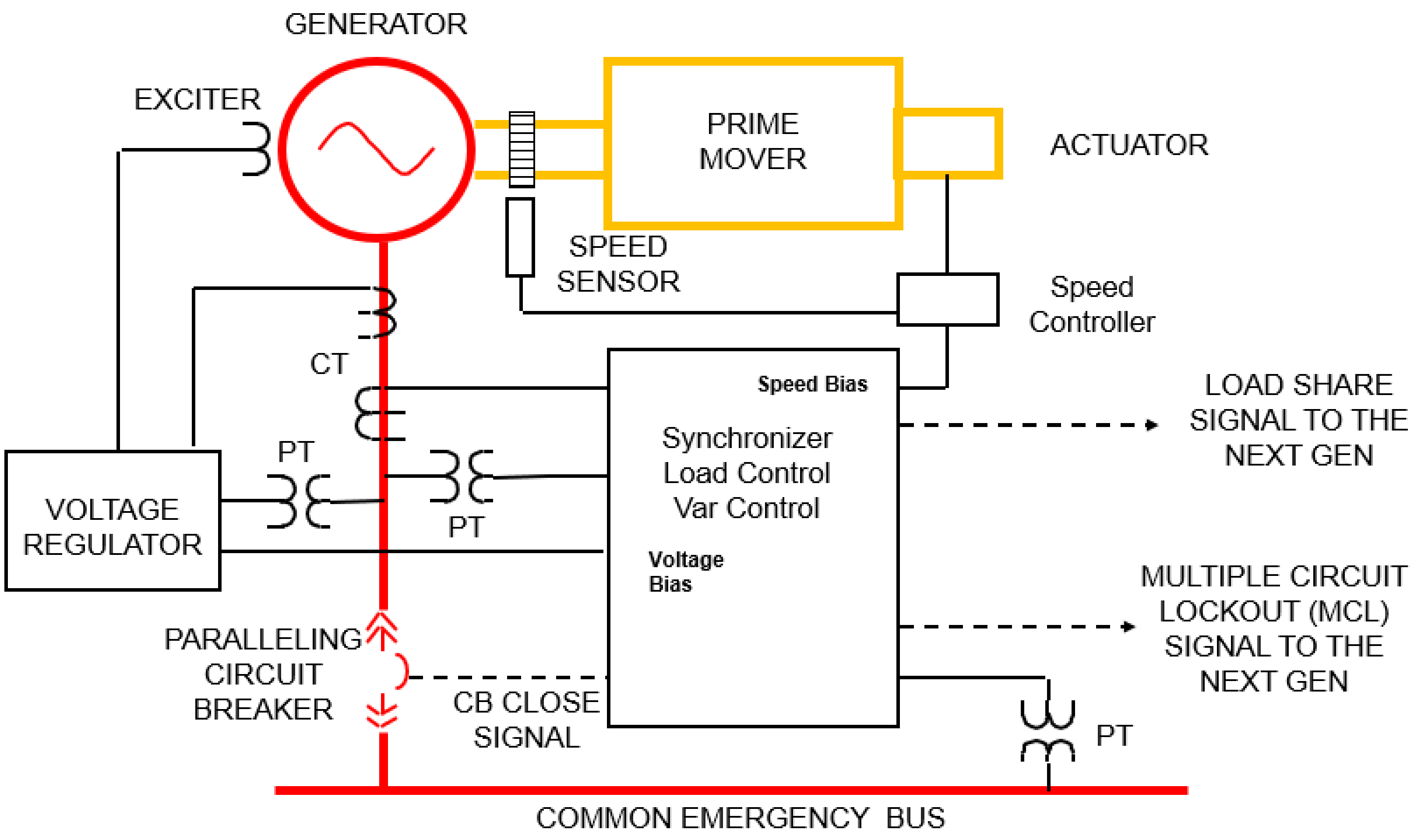
# Generator Synchronization and Load Control



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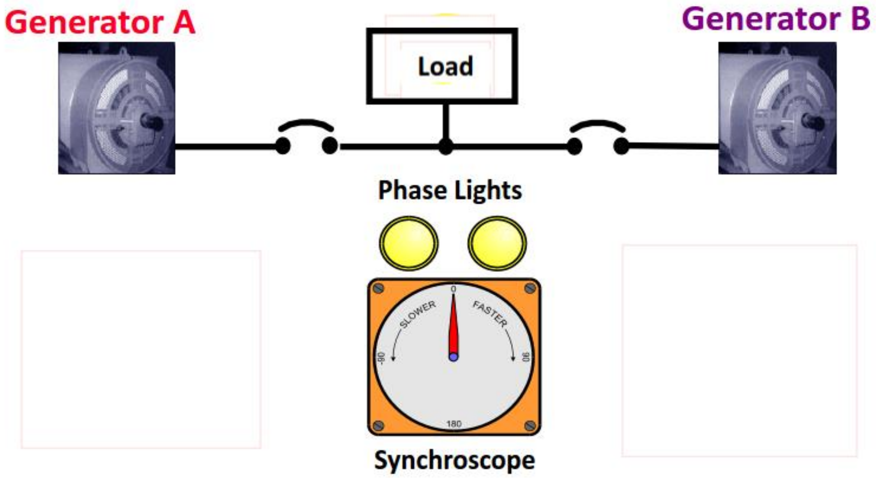
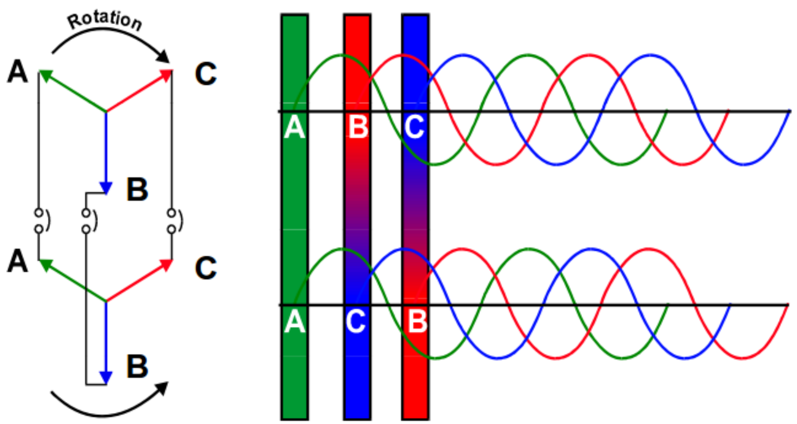
# Generator Synchronization and Load Control

- What is generator synchronization?
  - Generator synchronization is loosely referred to as matching generator speed/frequency with another source. However, 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 systems 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.

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# Generator Synchronization and Load Control

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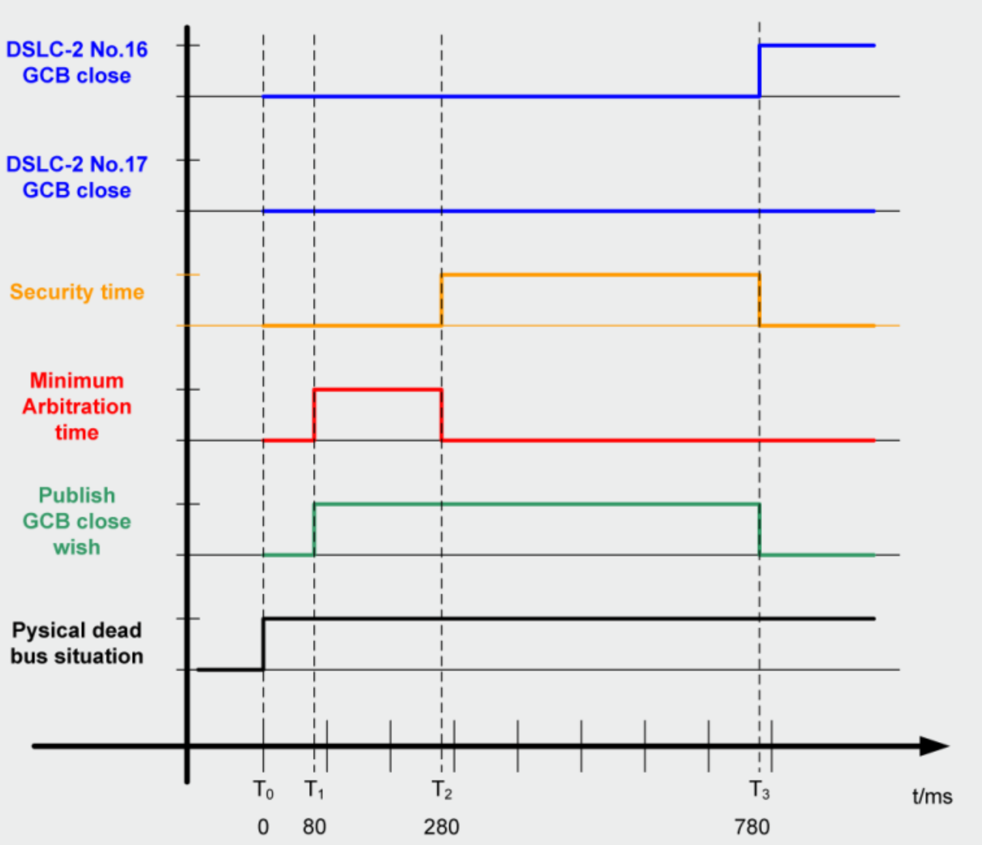
- What is “dead bus closure arbitration”?
  - In a system where multiple generators are to be paralleled to a common bus, only one generator can be permitted to close first (to a dead bus). Dead Bus Closure Arbitration is the process of selecting which generator will be allowed to connect to the dead bus. May also be referred to as “Multiple Circuit Lockout” or “First Start Sensor”.
- Why is it needed?
  - In order to ensure the bus is energized as fast as possible, all of the available generators must be started simultaneously upon sensing the emergency condition and the first generator at rated voltage and frequency must be the first generator connected to the bus.
  - All of the generators will try to reach rated voltage and frequency independently. And while more than one generator may reach these levels at the same time, they will not necessarily (in fact it is highly unlikely) be in sync with each other. As such, if the generators are closed to the dead bus at the same time, they would be out of phase and a fault current would result.
- How does it work?
  - The very first generator to reach rated speed and voltage will be closed to the de-energized bus. If more than one reaches rated V/F at the same time, the one with the lowest device ID will be closed. All other generators will be held off from closing. Once one generator has energized the bus, all other generators may then synchronize to the bus and close (their paralleling breaker) when in sync.
  - Note: the synchronizers must be able to communicate with each other for dead bus closure arbitration to work. For this reason, it is recommended that all synchronizers be of the same model.




$T_0$ : Logical situation for dead busbar closure
$T_1$ : The unit recognizes and publishes close wish
$T_2$ : In this moment a dead busbar negotiation is theoretically made
$T_3$ : The security time after dead busbar negotiation is proceed - > The device with the smallest Device-ID gets the allowness and switches.

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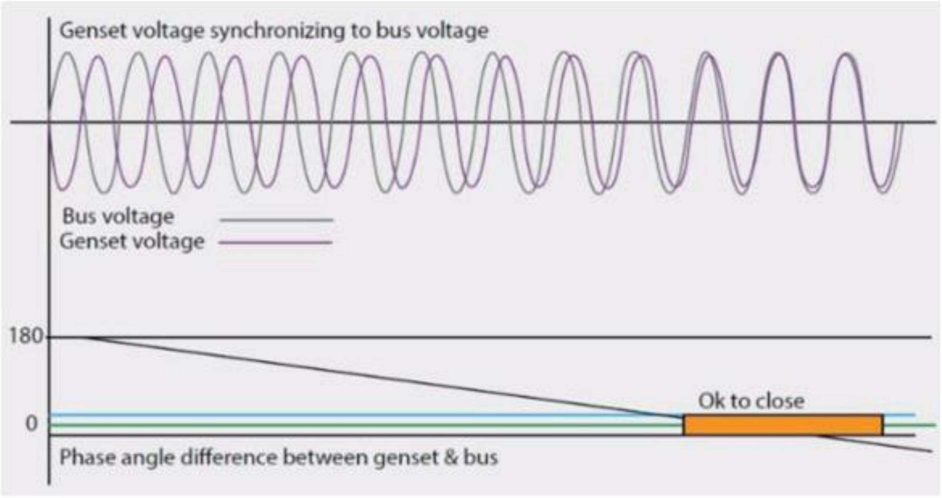
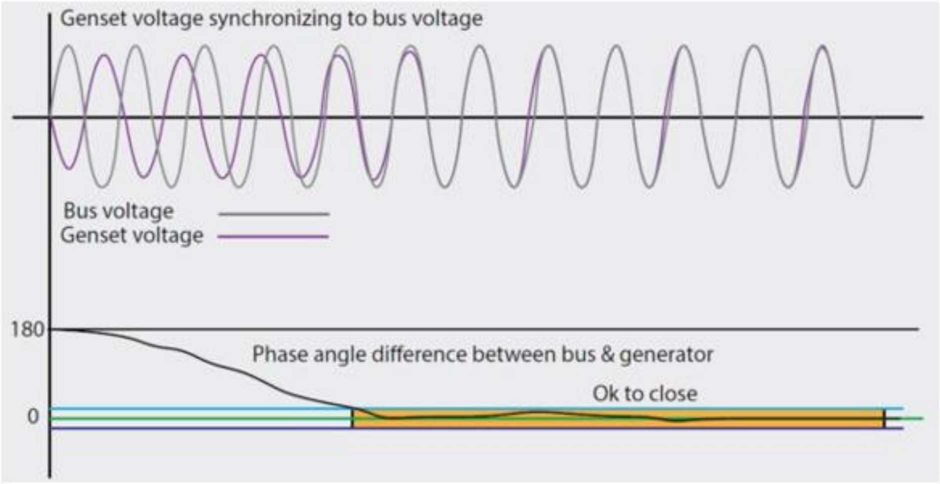
# Generator Synchronization and Load Control

- What are the types of synchronization methods available?
  - SLIP FREQUENCY - The oncoming generator has a frequency slightly higher or lower than the bus. Breaker closure is timed to occur at the moment the measured voltage sine waves align.
  - PHASE MATCH – The oncoming generator frequency is matched to the bus. Subtle speed changes are made to align the measured voltage sign waves. Breaker closure is initiated after a dwell time to assure both frequency and phase matching.

- When should they be used?
  - SLIP FREQUENCY - Useful when direction of power flow needs to be controlled at the moment of paralleling. This can be particularly important in parallel with Utility applications that have tight reverse power trip settings. The frequency setpoint change requires only a simple ramped adjustment to the speed, and this method is generally considered smoother and more stable when trying to synchronize a loaded generator plant to the utility. The slip frequency method is typically used when synchronizing to utility, so as to have maximum control and stability during the transfer.
  - PHASE MATCH – Generally speaking, the phase match method of synchronizing is faster. The adjustments to speed will be proportional to the phase difference and the phase angle will be held within the window for a longer period of time. The phase match method is generally used when synchronizing generators to an emergency bus, so as to get the generators online as fast as possible.




**Slip Frequency Synchronization**




**Phase Match Synchronization**

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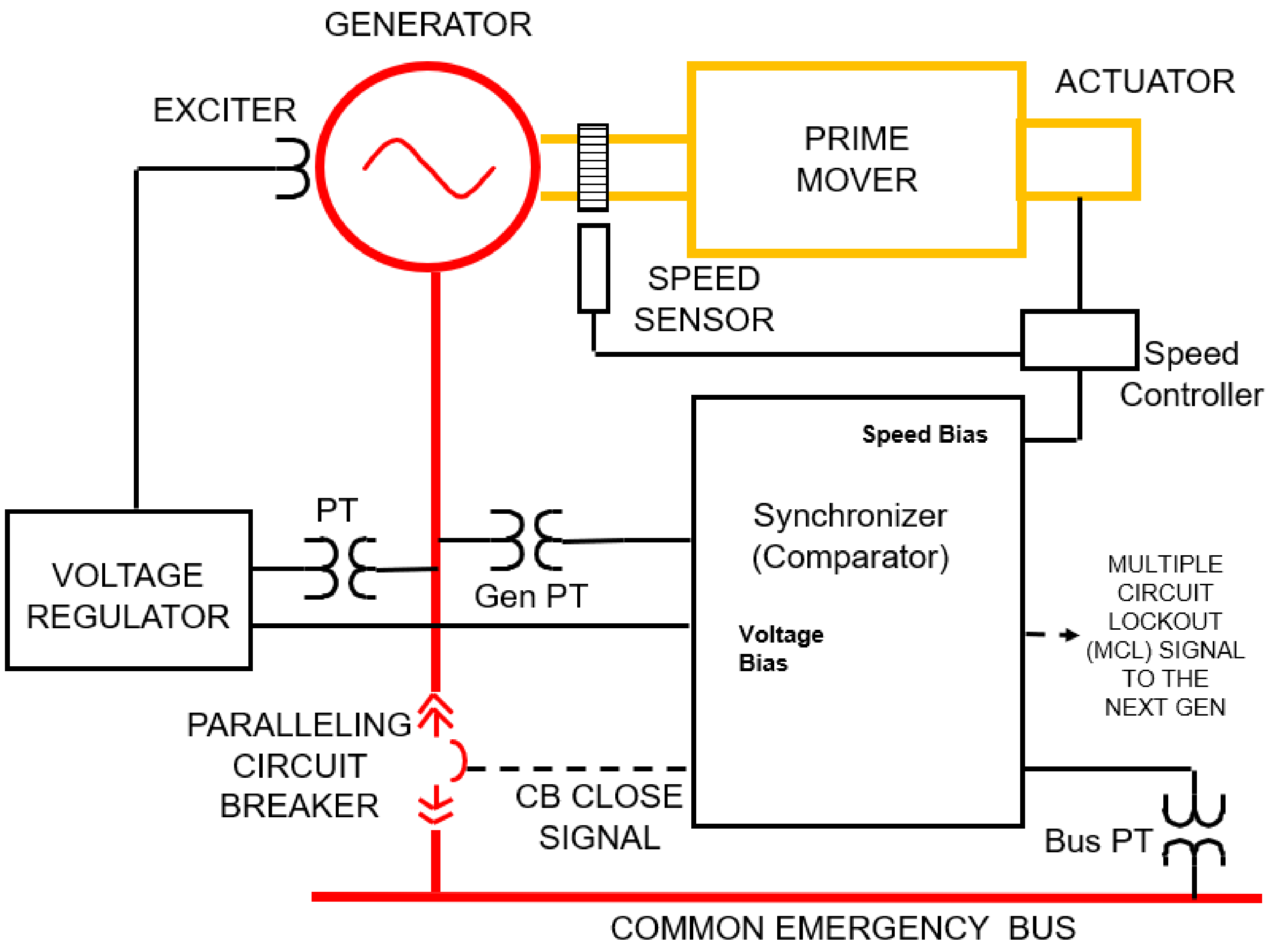
# Generator Synchronization and Load Control

- How does an automatic synchronizer work?
  - Voltage from both sides of the generator breaker is brought into a comparator.
  - This comparator looks at the frequency, phase, and voltage differences across the breaker and makes appropriate corrections to the speed control and voltage regulator.
  - Circuit Breaker closure is determined by either Phase Matching or Slip Frequency criteria.

Note: Voltage matching is typically enabled for MV and/or parallel with utility applications. For LV Emergency power applications, disabling voltage matching can speed up the connection of the generators and, provided the voltage regulators have the same setpoint, the error between the voltage levels should be small enough for the generators to recover once paralleled.

Reminder: for dead bus closure there must be a multiple circuit interlock to prevent more than one generator trying to close to the dead bus at a time. This may be part of the synchronizer or external.

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# Generator Synchronization and Load Control

- What is meant by "Load Control"?
  - This terminology is used for both system controllers (where it refers to load add/shed control) and genset controllers. For this discussion we will focus on what "Load Control" refers to regarding genset controllers.
  - Load control refers to both active (or real) and reactive (or imaginary) load control. The load can be adjusted to either a setpoint (as in baseload or VAR/PF control) or can be tuned such that the units online share the load (both kW and kVAR) proportionally.
- Why is Load Control Needed?
  - Load control is essential to avoid overloading and stability problems on the systems' generator sets.
  - When gensets are in parallel, they will be running at the same frequency and voltage (established via the common bus). However, any perceived differences due to the sensing error of the genset controllers can result in one or more controllers making small adjustments to their speed and voltage bias signals.
  - These adjustments will typically be small enough that it does not noticeably affect the overall bus voltage or frequency, but over time they can cause the load to become imbalanced between the units. Eventually one or more units may either become overloaded or trip offline on reverse power or reverse kVAR (loss of excitation).


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# Generator Synchronization and Load Control

- What are the methods of Active Power Load Control available?
  - (Speed) Droop – In this application, any change in load will result in a frequency (speed) change. In applications with two or more droop governors, the individual "speed references" will change by the same amount to maintain an even percentage of load. If the same percent of droop is set on all governors, load will stay balanced under all load conditions. Frequency (speed) will not stay constant with load variances.
  - Isochronous – In this application, frequency (speed) remains constant regardless what the load is on the generator (within the capability of the unit). Isochronous Load Sharing requires an electronic load controller for load signal communications. Multiple generator sets can be connected together for proportional load sharing between each generator set. Each generator set will carry a proportional amount of the system load while maintaining constant bus frequency.

- What are their advantages/disadvantages?
  - (Speed) Droop – since the controllers can make droop adjustments independent of each other, there is no need for compatible communication between the units. This allows the use of different model controllers, but the variability of the bus frequency is considered undesirable in many applications.
  - Isochronous – the constant frequency is a significant advantage of this method and it is the most common method of load control in emergency paralleling systems. However, the ability to communicate between controllers requires all of the controllers to be compatible (same make and model). That can be a disadvantage, especially with brownfield applications.


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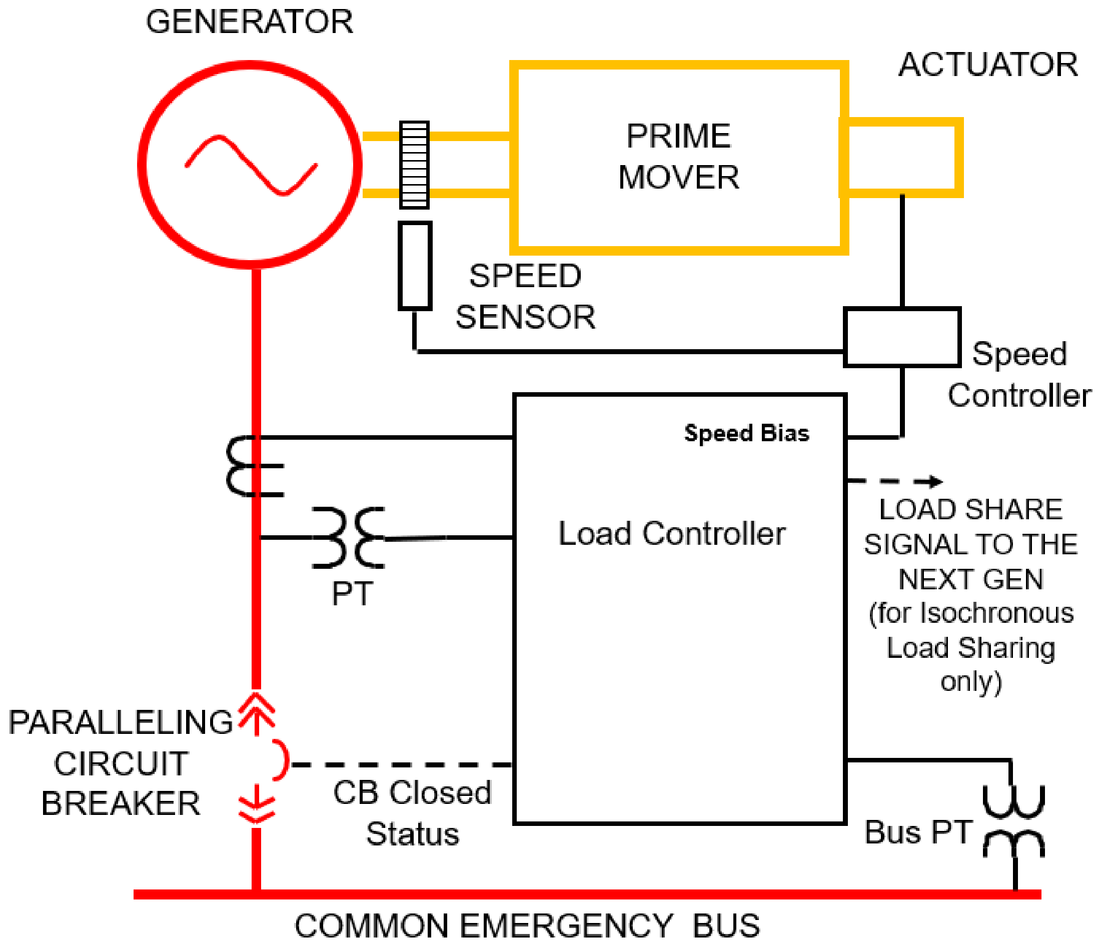
# Generator Synchronization and Load Control

- How does a "load share module" work?
  - The Load Controller must monitor the paralleling breaker status, power output of the generator, and the frequency of the bus.
  - Once the load controller confirms the paralleling breaker is closed it can then adjust speed up or down depending on the method of load control.
  - For (speed) droop, as the load increases the frequency will be decreased by biasing the speed down. And if the load decreases, the frequency will be increased by biasing the speed up.
  - For Isochronous load sharing, the load controller will first make any necessary adjustments to maintain the setpoint frequency level (for ex. 60Hz). Once the 60Hz setpoint is verified, it can then adjust speed up or down, depending on its relative load level, until it is sharing load proportionally with the other gensets it sees online (via network interconnection).

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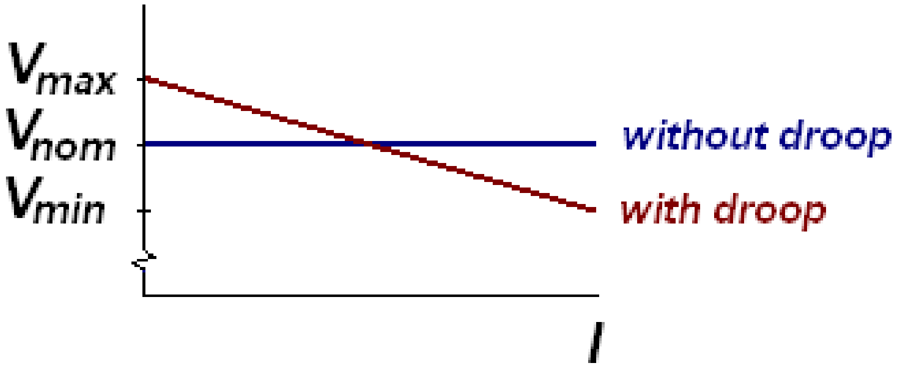
# Generator Synchronization and Load Control

- What are the methods of Reactive Power Load Control available?
  - (Voltage) Droop – In this application, any change in current will result in a voltage change. In applications with two or more voltage regulators, the individual "voltage references" will change by the same amount to maintain an even percentage of VARs. If the same percent of droop is set on all Voltage Regulators, VARs will stay balanced under all load conditions. Voltage will not stay constant with load variances.
  - Cross Current (also known as Reactive Differential Compensation) – In this application the cross current CT is wired into the regulator same as a droop CT, but the CT is also wired out to the other voltage regulators such that an increase on the primary current of the local CT will subtract from the totalized current at the other units. If the primary currents are all balanced, the resultant input to the VR's will be zero and the system will stabilize at rated voltage even with load variances.
  - VAR Sharing – In this application voltage remains constant regardless what the load is on the generator (within the capability of the unit). VAR Sharing requires electronic voltage control for voltage signal communications. Multiple generator sets can be connected together for proportional VAR sharing between each generator set. Each generator set will carry a proportional amount of the system VARs while maintaining constant bus voltage. When provided, VAR sharing is usually integrated into the genset controller (DSLC for example).

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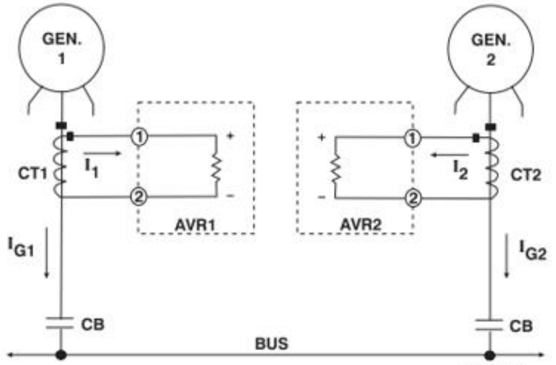
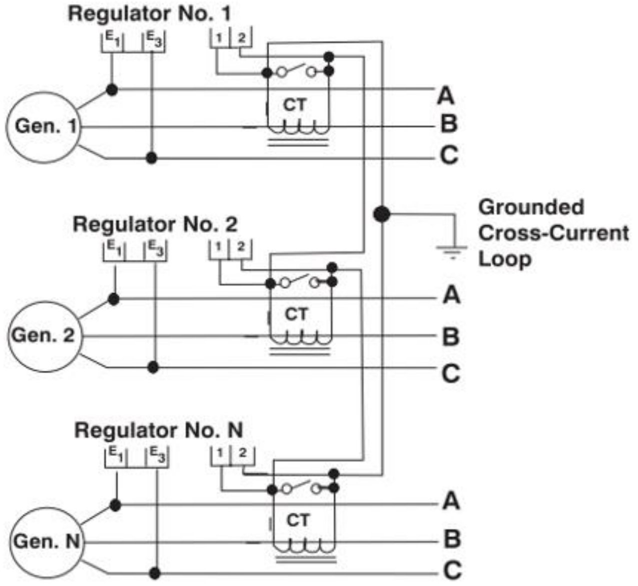
# Generator Synchronization and Load Control

- What are the advantages/disadvantages of the different methods of VAR control?
    - (Voltage) Droop – this is the simplest form of VAR control.  Since the voltage regulators can make droop adjustments independent of each other, there is no need for any interconnection between the units.  This allows the use of different model voltage regulators.  However, the system voltage will change as the system load changes, and this may not always be desirable.
    - Cross Current – this method allows for (analog) VAR sharing at a constant (nominal) voltage level regardless of the system load. While cross current circuits are effective, they are relatively complicated and the wiring involved is often considered a drawback. Additionally, Cross Current is incompatible with Parallel with Utility Applications and is therefore limited in it’s use.
    - Note: in cross current applications it is crucial that the voltage regulators have compatible input impedances as the circuit it is essentially a current divider and any mismatch will almost certainly result in voltage control errors.  It is also required that the cross current CT loop be grounded in one location; this may require isolation transformers if the CT’s are individually grounded.
    - VAR sharing – this is a digital solution that provides the benefits of cross-current, without the complex wiring.  On the downside, tuning is more complicated and, not only must the controllers be compatible with each other, they must be compatible with the voltage regulator.




Voltage Droop




Cross Current

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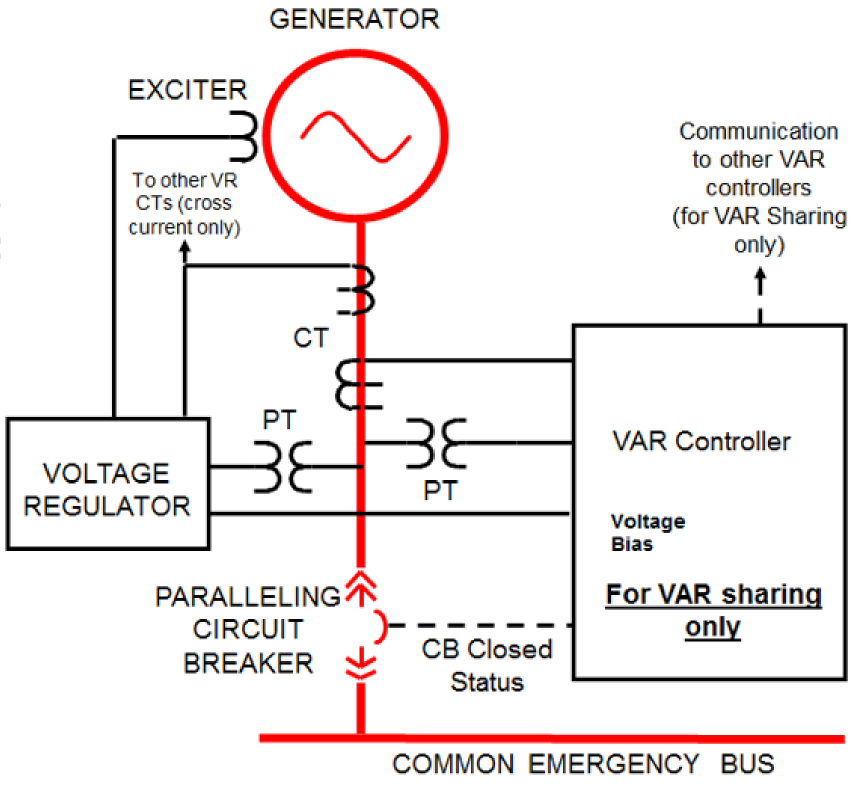
# Generator Synchronization and Load Control

- How does VAR control work?
  - The Voltage regulator must monitor the Voltage and Current of the generator.
  - For (voltage) droop, the voltage regulator will adjust the voltage up or down depending on the voltage and current of the generator. As current increases, voltage will be decreased.
  - For cross current, the summation of the differential ckt between the CT's will be zero when primary currents are balanced. As a result, the voltage regulator will remain at rated voltage even as the system load changes.
  - For VAR sharing, the VAR share module will need to know what the VARs are on the other generators in the system. Once it confirms the paralleling breaker is closed, it can then bias voltage up or down depending on its relative VAR level.

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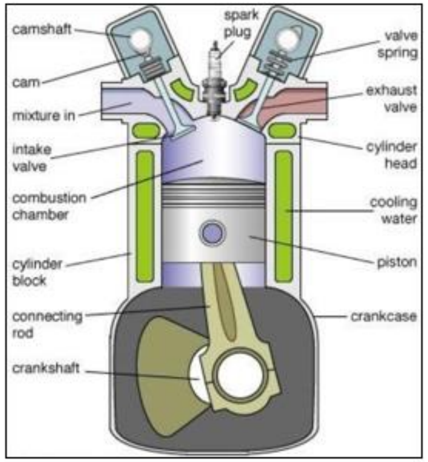
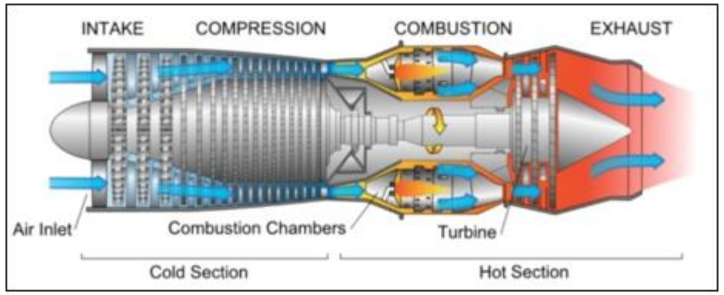
# Generator Synchronization and Load Control

- What are some different types of engines available and how do they affect load control?
  - The generator (alternator) and genset controller are only part of the equation when paralleling multiple generators. Even if all the controllers are compatible and can communicate effectively, if the mechanical response to the speed bias signal is different between the different engines, it will impact the effectiveness of the load controller.
  - Reciprocating Internal Combustion Engine – most emergency systems use diesel fueled internal combustion engines. This is because of their black start capability and ability to reach rated voltage and frequency in under 10 seconds. Additionally, they are very good at handling large blocks of load (add or shed).
  - Turbine Engines – turbines are more efficient (CHP) and typically of much larger capacity than internal combustion engines. They take considerably longer to reach rated speed and voltage, do not have black start capability on their own, and are slow to respond to changes in loading.
  - When trying to parallel a diesel reciprocating engine with a gas or steam turbine, the turbine's mechanical response will be slower than the diesel engine's response. Load sharing can become greatly imbalanced during block loading/unloading of paralleled devices. As a result, the diesel can be overloaded during a block load add or the turbine may trip on reverse power during a block load shed,
  - Note: this is true (on a somewhat smaller scale) when paralleling diesel and gas engines even if both are reciprocating (piston driven) engines.




**Reciprocating Engine**




**Turbine**

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# Generator Synchronization and Load Control

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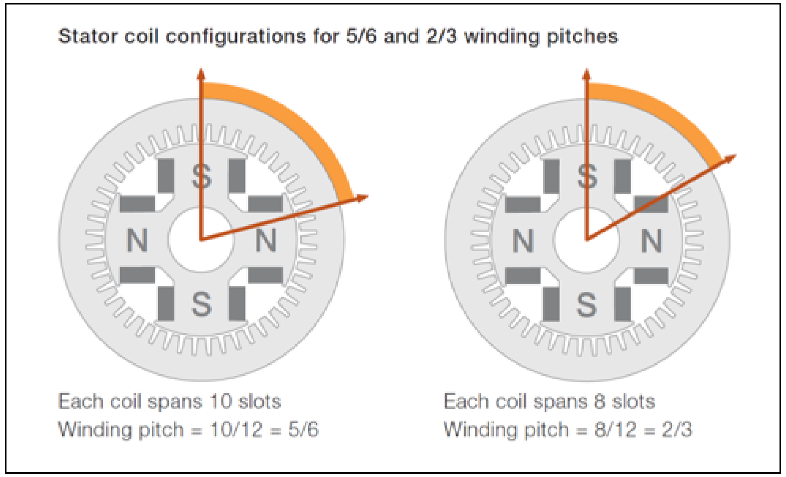
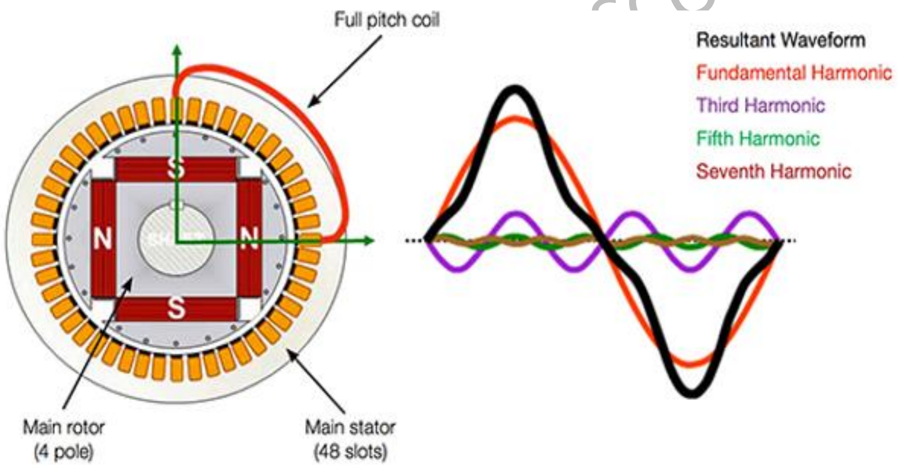
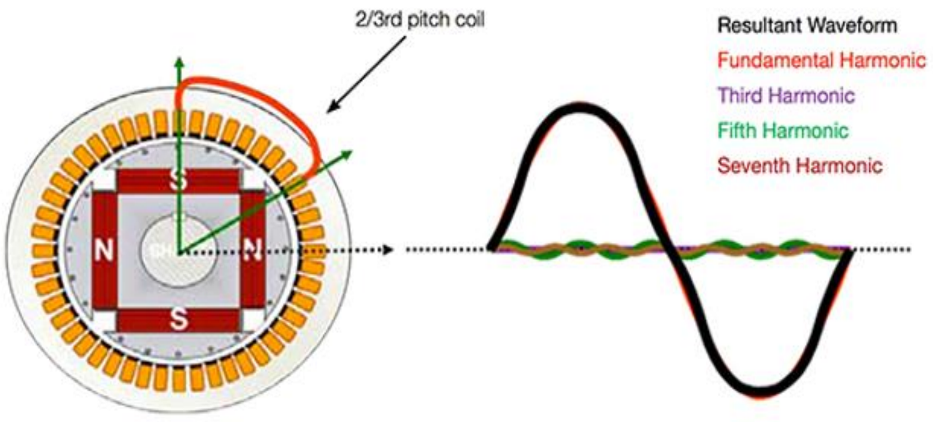
- What is generator pitch and how does it affect load control?
  - All generators are wound to some fractional pitch to provide control over harmonics. It is important, when paralleling different generators in a 3P4W system, to make sure the pitch is matched.
  - While some harmonic control is possible, it is impossible to eliminate all harmonics. The most common configuration is 2/3 pitch. The 2/3 pitch eliminates 3rd level harmonics, but increases 5th level harmonics. Another common pitch is 5/6 which reduces 5th and 7th level harmonics but increases 3rd level harmonics. Therefore if the pitch is mismatched, instead of reducing harmonics, you end up increasing them as the neutral voltage differences at the 3rd and 5th level harmonics will increase waveform distortion. You will likely have to de-rate your system and may experience power quality issues due to waveform distortion.




Generator Pitch




Generator full Pitch w/ harmonics




Generator 2/3 Pitch w/ harmonics

# For further information

- PDH Certificates
  - All attendees will receive an email an hour after the webinar with instructions regarding the link to download your PDH certificate.

- **Speaker's contact**
  Feel free to reach out to the speaker by email should you have any questions

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# Thank You!

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