The Solutions Network

Rochester, New York

Dangerous Addiction: Are You Gambling on Energy Reliability?

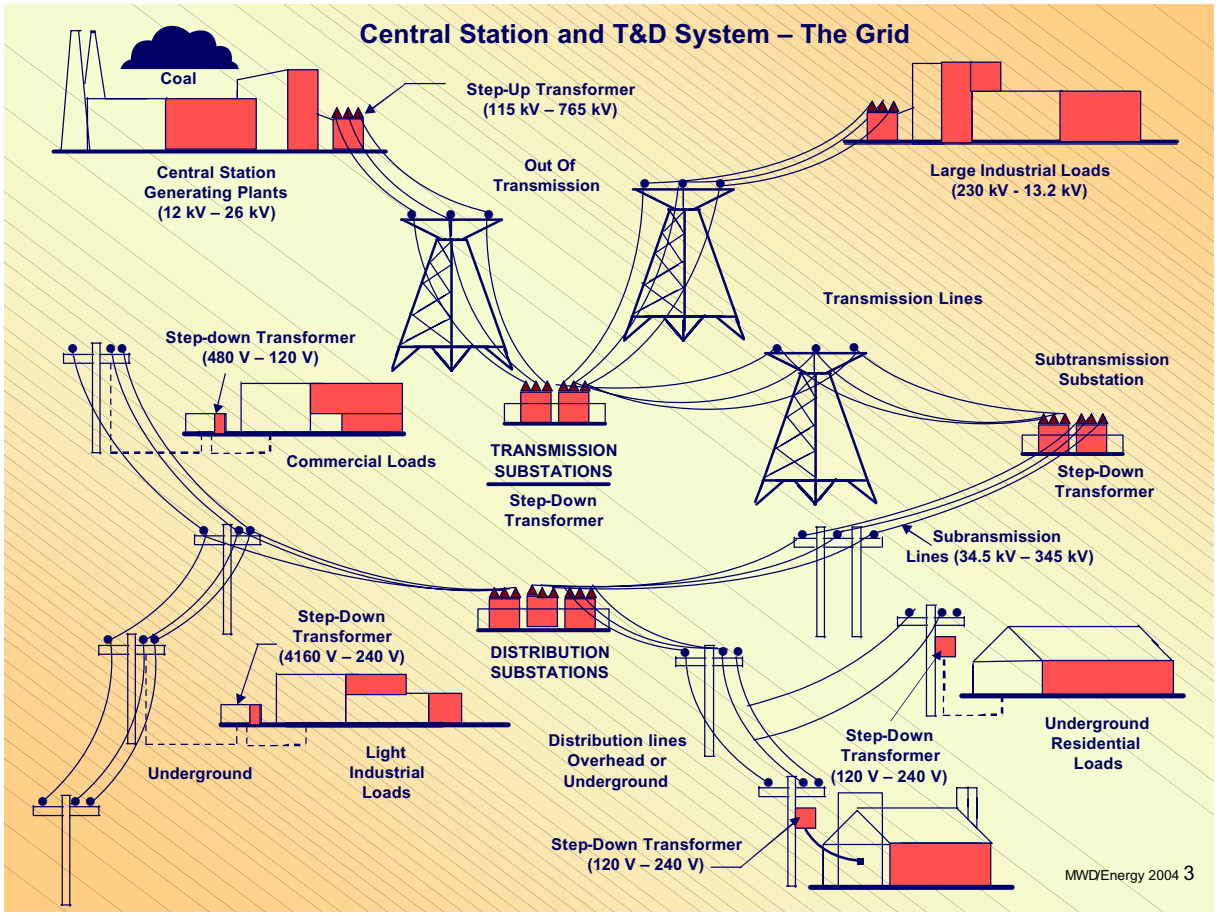
Murray W. Davis

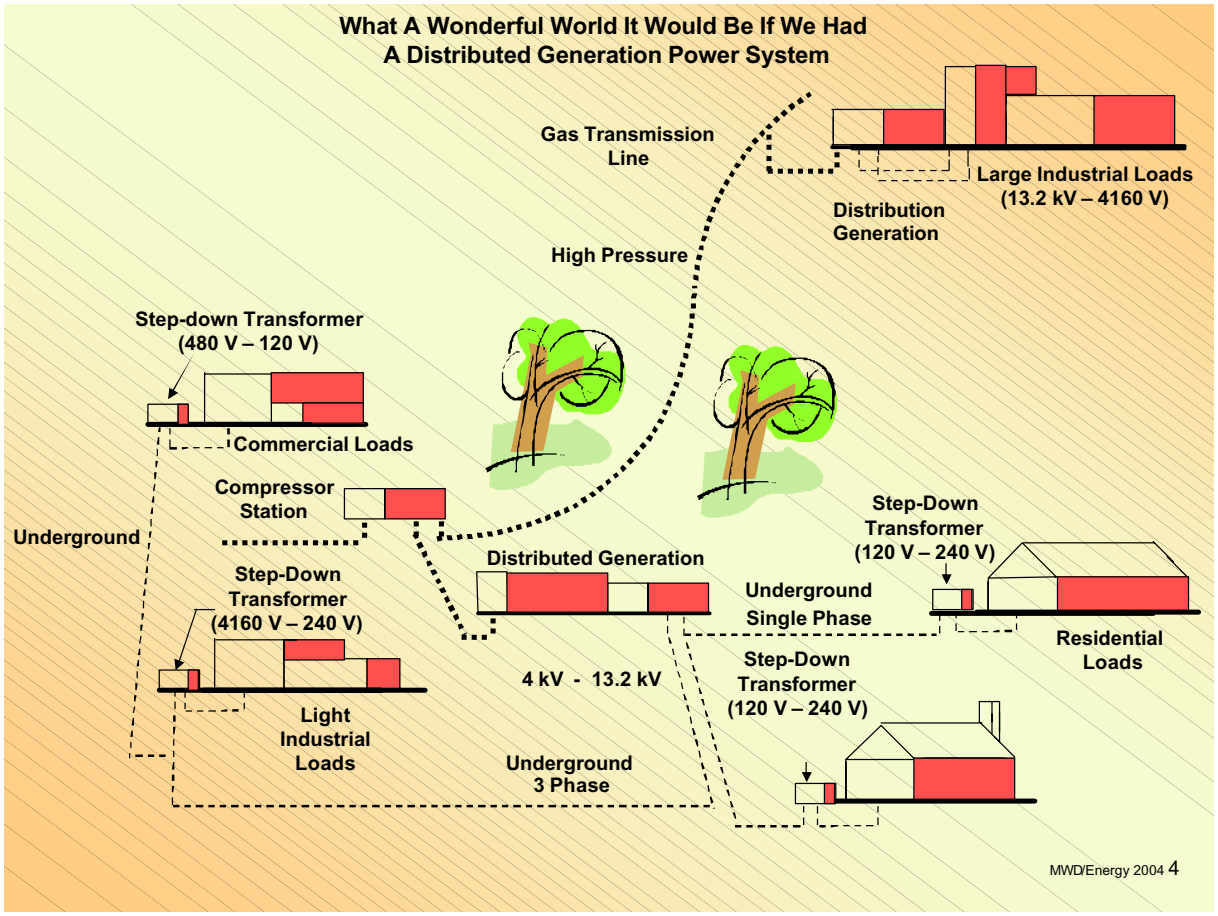
DTE Energy Technologies

The Solutions Network

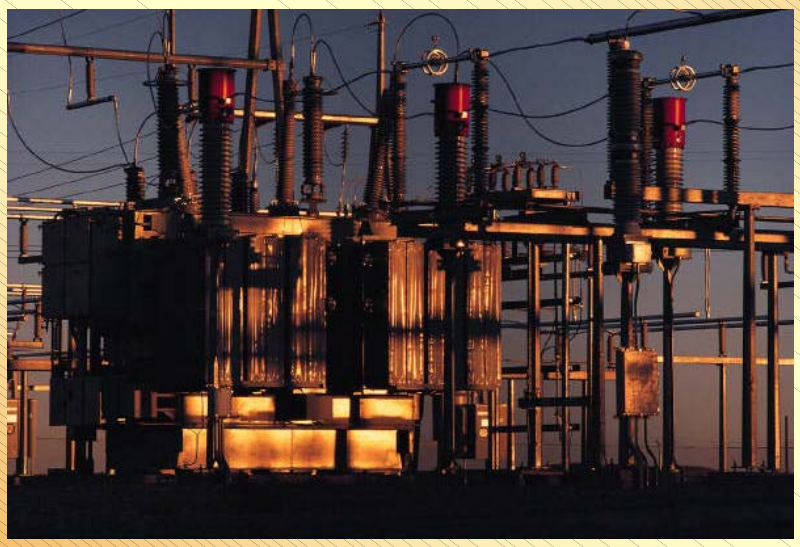
Rochester, New York

So – Why Distributed Generation ?

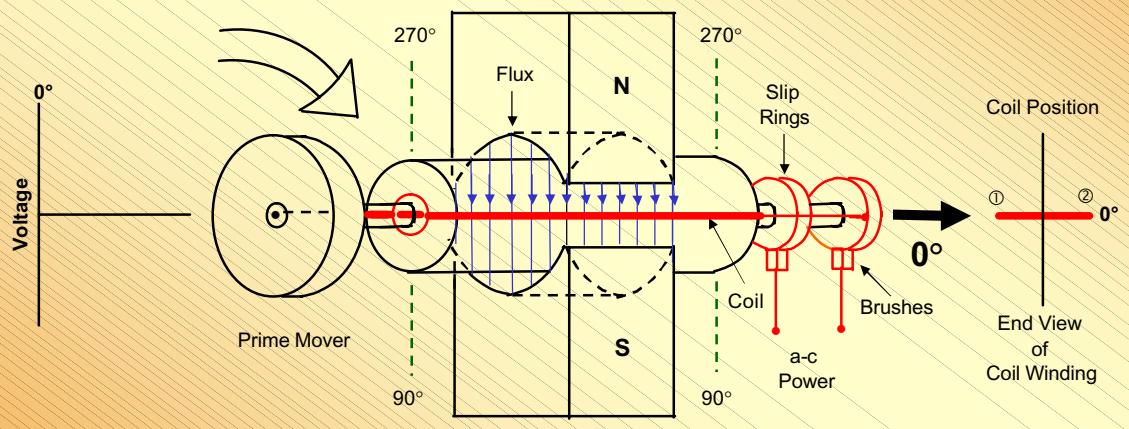

Central Station and T&D System – The Grid
Coal
Step-Up Transformer
(115 kV – 765 kV)
Central Station
Generating Plants
(12 kV – 26 kV)
Out Of
Transmission
Large Industrial Loads
(230 kV - 13.2 kV)
Transmission Lines
Step-down Transformer
(480 V – 120 V)
Commercial Loads
TRANSMISSION
SUBSTATIONS
Step-Down
Transformer
Subtransmission
Substation
Step-Down
Transformer
Subransmission
Lines (34.5 kV – 345 kV)
Step-Down
Transformer
(4160 V – 240 V)
DISTRIBUTION
SUBSTATIONS
Underground
Light
Industrial
Loads
Distribution lines
Overhead or
Underground
Step-Down
Transformer
(120 V – 240 V)
Underground
Residential
Loads
Step-Down Transformer
(120 V – 240 V)
MWD/Energy 2004 3


What A Wonderful World It Would Be If We Had
A Distributed Generation Power System
Gas Transmission
Line
Large Industrial Loads
(13.2 kV – 4160 V)
Distribution
Generation
High Pressure
Step-down Transformer
(480 V – 120 V)
Commercial Loads
Compressor
Station
Underground
Step-Down
Transformer
(120 V – 240 V)
Distributed Generation
Underground
Single Phase
Residential
Loads
Step-Down
Transformer
(4160 V – 240 V)
4 kV - 13.2 kV
Step-Down
Transformer
(120 V – 240 V)
Light
Industrial
Loads
Underground
3 Phase
MWD/Energy 2004 4

How is Power Generated?



Alternator - Single Phase



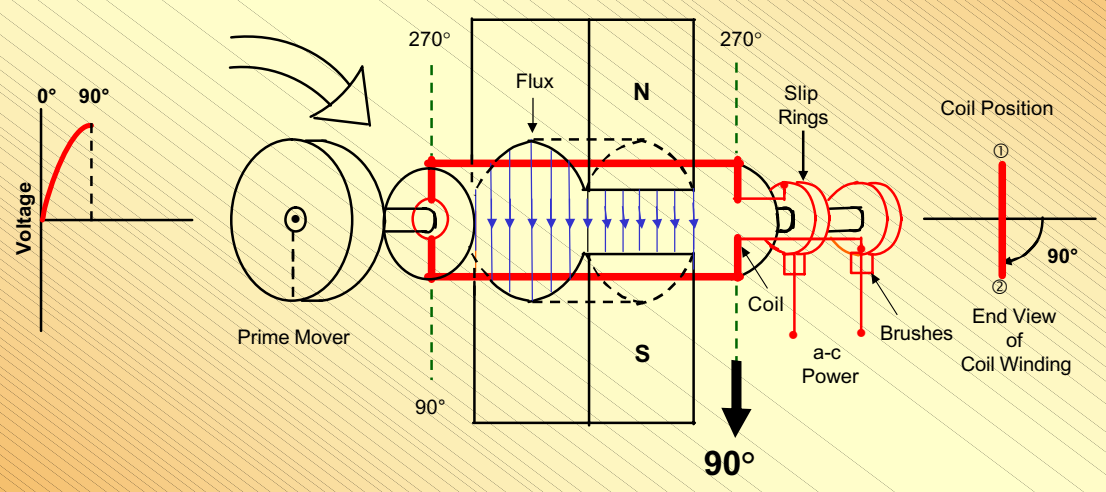
Stationary Permanent Magnet DC Field Rotating Armature Synchronous Generator – **0° Position of Coil Winding**

Voltage

- Voltage depends on the Magnitude of the Magnetic Field F , the number of turns in the coil and speed of the revolving coil.

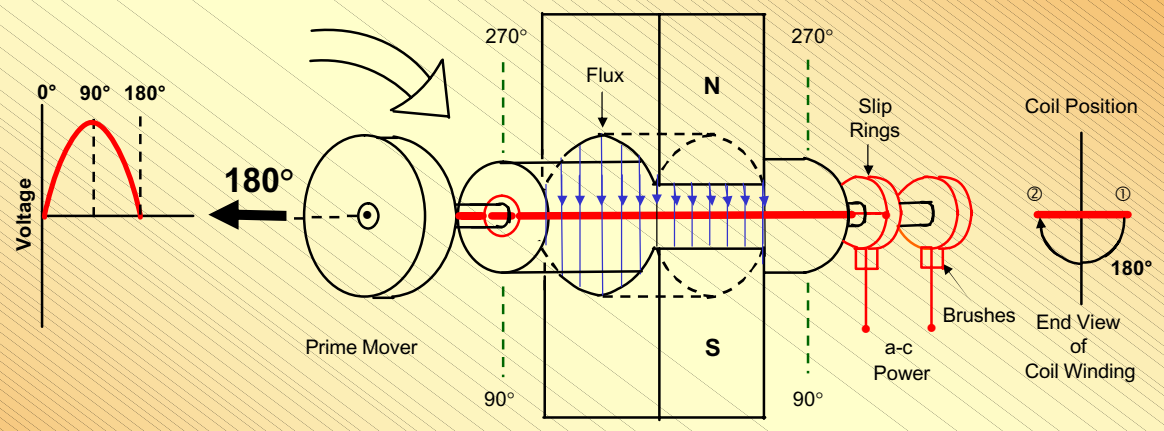
$$V = N \frac{d\Phi}{dt}$$

Alternator - Single Phase



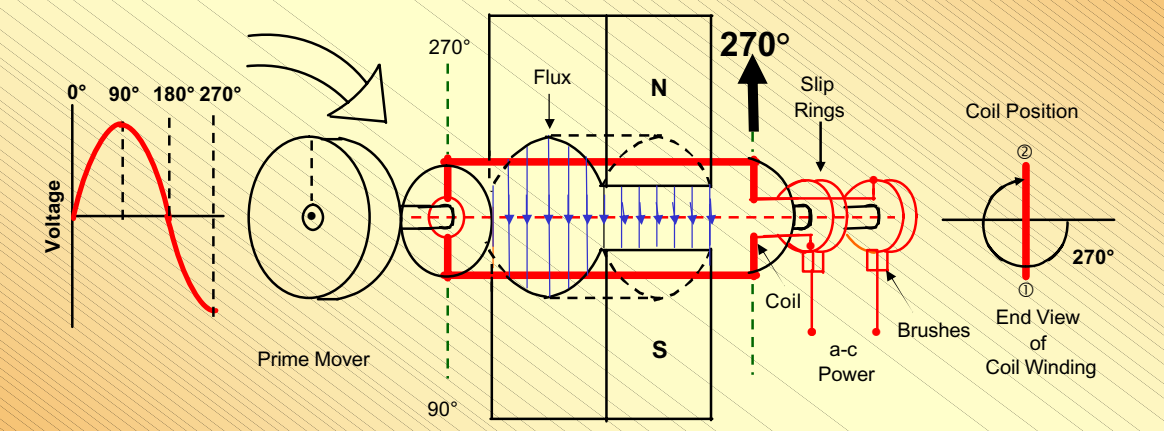
Stationary Permanent Magnet DC Field Rotating Armature Synchronous Generator - **90° Position of Coil Winding**

Alternator – Single Phase



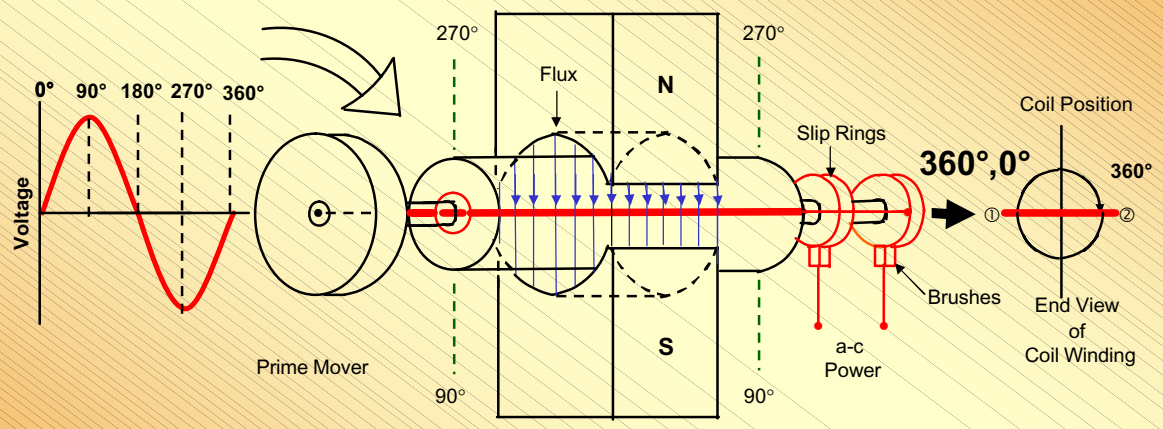
Stationary Permanent Magnet DC Field Rotating Armature Synchronous Generator - **180° Position of Coil Winding**

Alternator – Single Phase



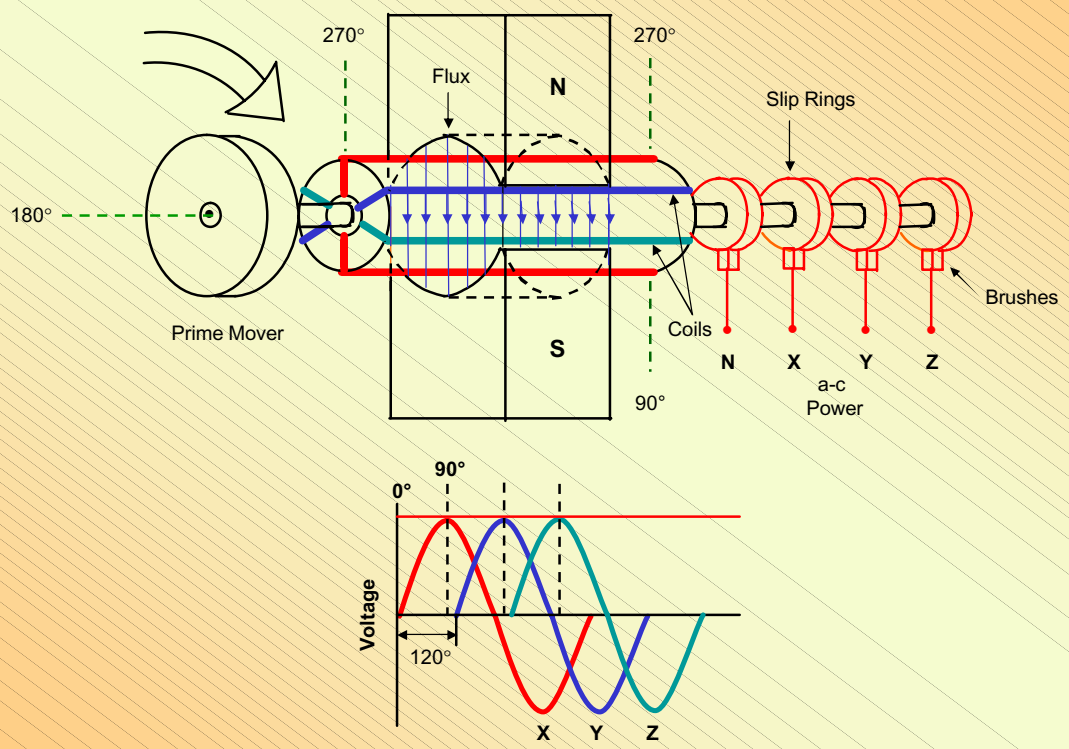
Stationary Permanent Magnet DC Field Rotating Armature Synchronous Generator - **270° Position of Coil Winding**

Alternator – Single Phase



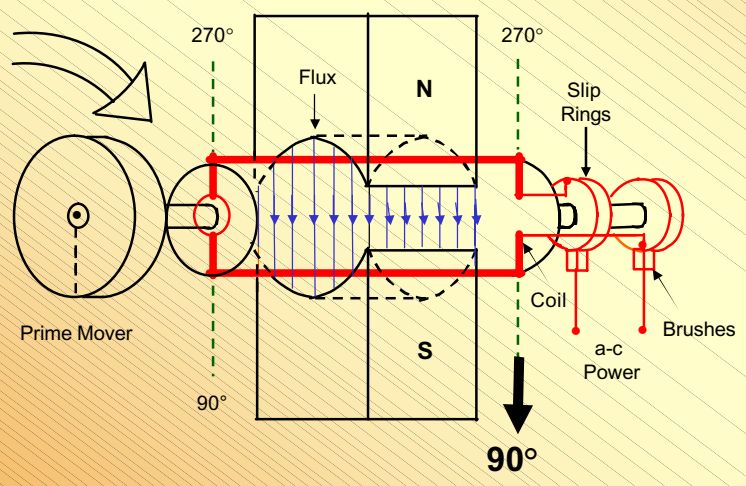
Stationary Permanent Magnet DC Field Rotating Armature Synchronous Generator- **360° Position of Coil Winding**

Alternator - 3 Phase

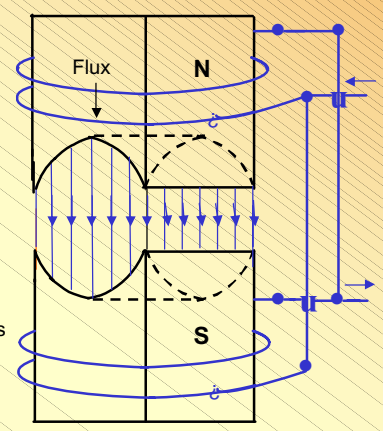


Stationary Permanent Magnet DC Field Rotating Armature Synchronous Generator

Alternator - Single Phase

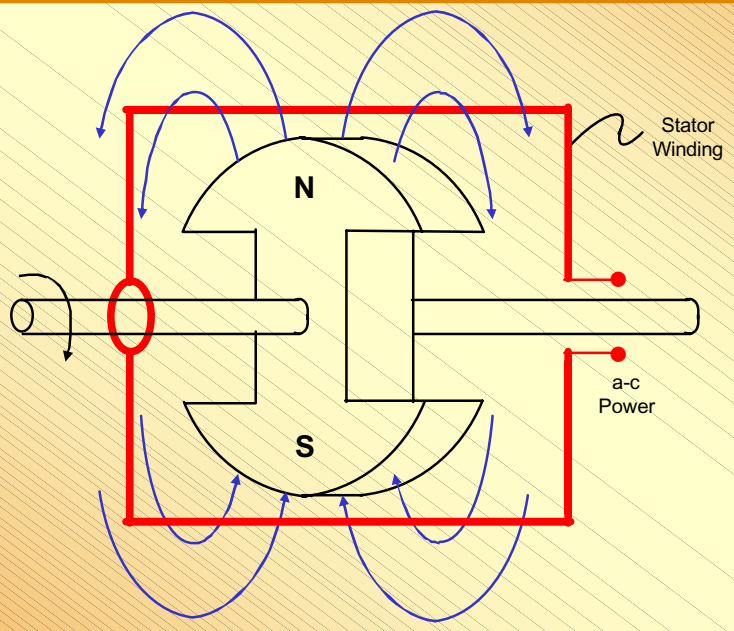


Stationary **Permanent Magnet DC Field**
Rotating Armature Synchronous Generator



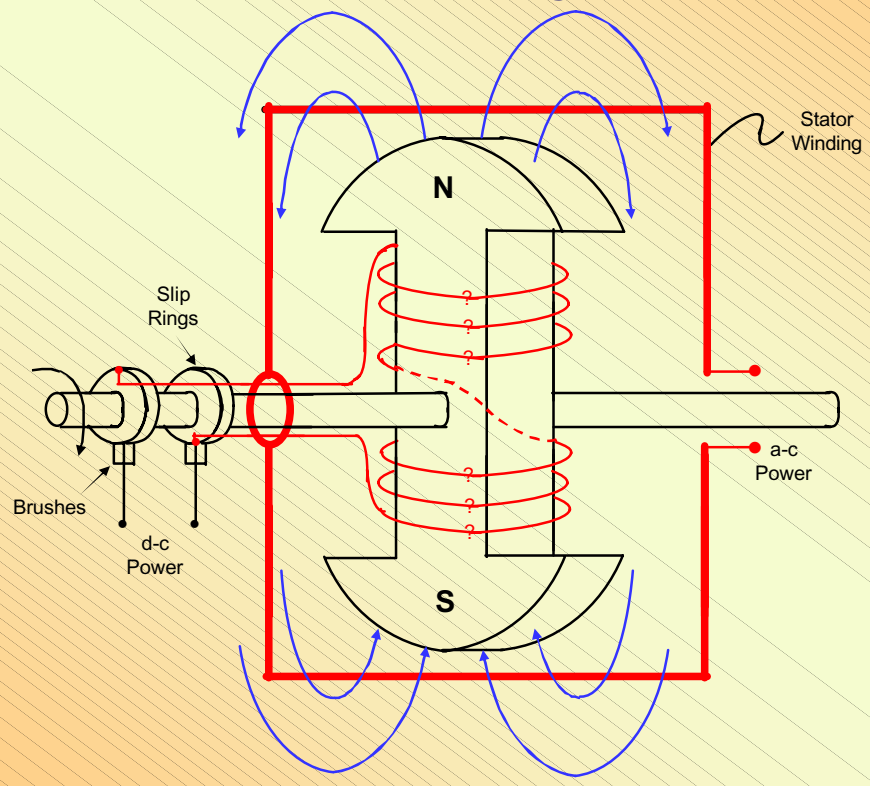
Stationary **DC Field Winding**
Rotating Armature Synchronous Generator

Alternator - Single Phase



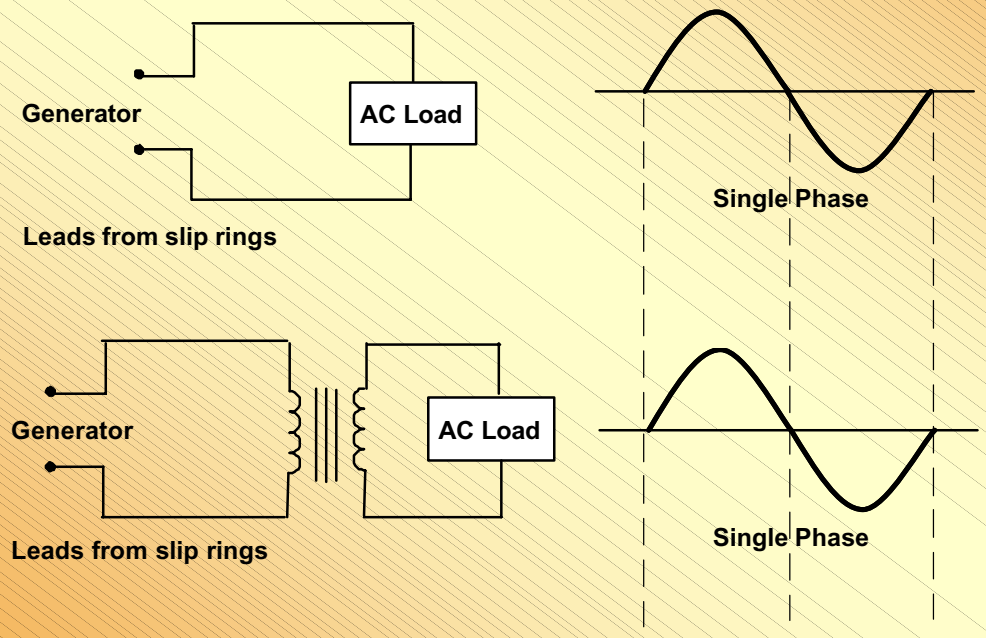
Rotating Permanent Magnet DC Field Stationary Armature (Stator) Synchronous Generator

Alternator - Single Phase



Rotating DC Field Winding Stationary Armature (Stator) Synchronous Generator

Current from the Wire Coil Flows from the Generator Slip Rings to the Load



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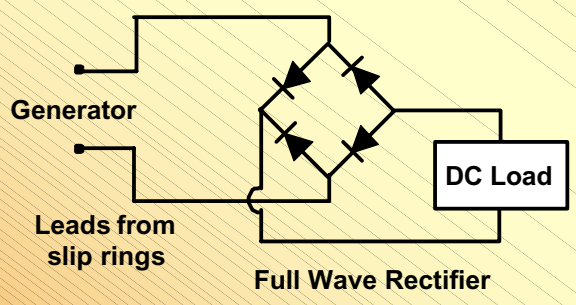
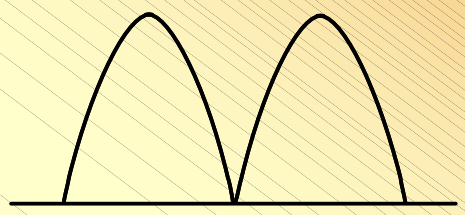
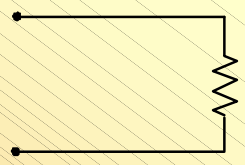
Current from the Wire Coil Flows from the Generator Slip Rings to the Load

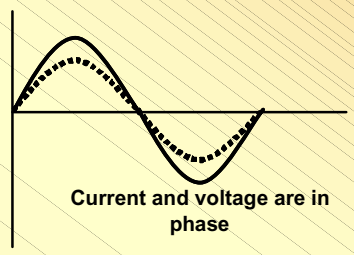


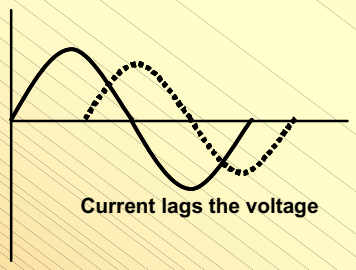


Linear Loads

Linear Loads - any load where the current increases or decreases proportionately as the voltage increases or decreases.







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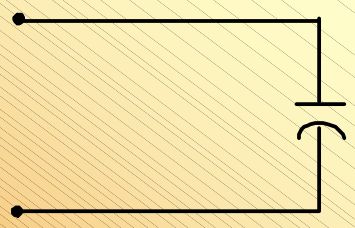
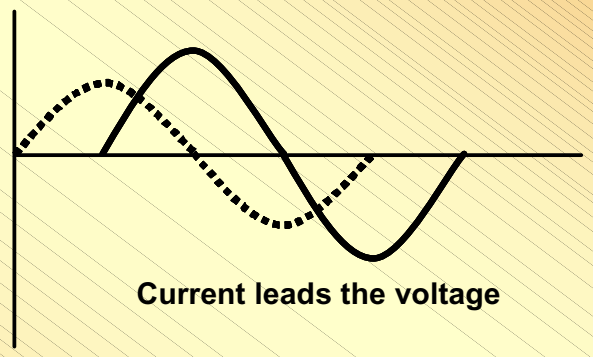


Capacitor

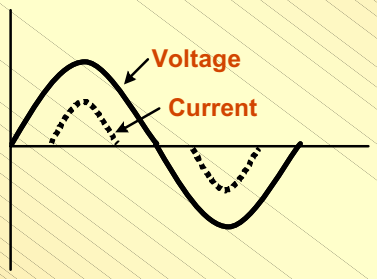


Current leads the voltage

Voltage and current are sinusoidal even if they are out of phase.

Non Linear Loads

Non Linear Loads - any load where the instantaneous current is not proportional to the instantaneous voltage.



Voltage is a pure sinusoid but current is not.

Single Phase Loads
Computers
Copiers
Printers
Electronic Lighting Ballasts
VCR's
TV's

Three Phase Loads
Variable Speed Drives
UPS (uninterruptible power supplies)

What is Reliability

- Reliability is defined as <u>how often</u> and <u>how long</u> the electric power service is interrupted.

What is Reliability

- The <u>how often</u> is described in terms of interruption frequency:
- <u>Load Interruption Frequency</u> – is the expected number of power interruptions to the load per year.

What is Reliability

- The <u>how long</u> is described in terms of repair time (restoration):
- <u>Duration of Load Interruption</u> – is the time of the failure (outage) to when the service is restored or the duration of the interruption.
- (Repair time and forced outage duration are used synonymously.)

What is Reliability

- Often you hear reliability described in terms of the number of 9's.

THIS IS INCORRECT!

- 9's define the <u>availability</u> not the <u>reliability</u> (measures how often and how long the service is interrupted).
- <u>Availability</u> is the time the system is in service, or 9's.

What is Reliability

Examples

Two 9's: 0.99 x 8760 hrs/yr = 8672.4 hrs, or 87.6 hours of outage/yr.

Three 9's: 0.999 x 8760 hrs/yr = 8751.2 hrs, or 8.8 hours of outage/yr.

Typical Electric Utility Service

Four 9's: 0.9999 x 8760 hr/yr = 8759 hrs, or 1.0 hour of outage/yr.

Six 9's: 0.999999 x 8760 hrs/yr = 8759.99 hours, or 31.5 seconds of outage/yr.

What is Unavailability

Unavailability = 1 - Availability

It is the time the system is not available to serve load.

Two 9's:	87.6 hrs/yr
Three 9's:	8.8 hrs/yr
Four 9's:	1.0 hrs/yr
Six 9's:	31.5 seconds/yr

Types of Interruptions

Momentary Interruptions –
Interruptions lasting less than 2 to 5 minutes (time for automatic switching devices to operate and attempt to restore service to the load).

Sustained Interruptions –
Interruptions lasting more than 2 to 5 minutes.

Another Measure of Reliability for Power Generation

LOLE – or Loss of Load Expectation

This is the amount of time between load interruptions caused by generation outages; typically every ten years load is expected to be interrupted due to loss of generation.

Another Measure of Reliability for Power Generation

- Why is it then, residential loads are lost about once to twice per year when the generation is planned to lose load only once in 10 years?
- **REASON** – Reliability degrades due to the exposure of the T&D System to failures.
- 97% of the reliability is lost in the Subtransmission and Distribution system.

Where Do Outages Occur ?
λ - Average Data And, Best In Class Utility Data

	λ_{BIC} Frequency	Percent Contribution
Transmission	.015	2.91%
Subtransmisson	.10	19.42%
Primary	.40	77.67%
Total	.515	100.00%
Subtransmission		
OHL	.055	55%
UL	.017	17%
STA	.028	28%
	.10	100%
Primary		
OHL	.35	87.5%
UL	.03	7.5%
STA	.02	5.0%
	.40	100%

Microgrid λ of interruption

λ_{BIC} = 12.5% x .40(1) = .050(3)

λ_{AVG} = 12.5% x 1.05(2) = .131(3)

Note (1): "Best in Class" λ
Note (2): Average λ
Note (3): w/o generation λ's

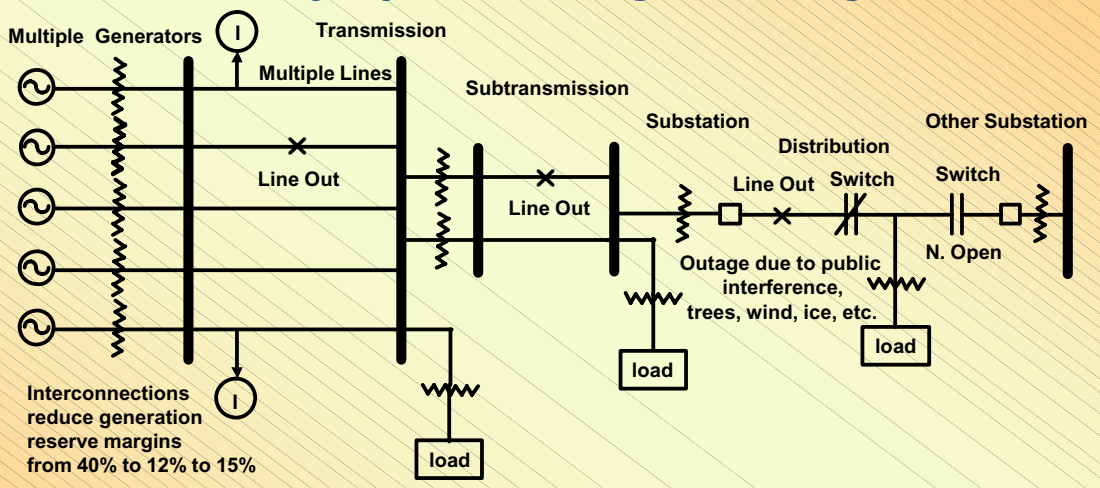
Two Questions Could Be Asked

Q1. Why is the transmission system so reliable and the distribution system is not?

Q2. How is reliability improved?

Answer Q1. Transmission has a network of lines – distribution is radial (single line)

Why is the Central Station Generation and T & D Power Delivery System being Challenged?



Transmission

(1) High Reliability - due to multiple lines, multiple generators and multiple interconnections.
(2) Although multiple lines provide improved reliability, the increase in exposure due to the high density of lines and equipment causes many momentary outages and voltage sags.
(3) Also, parallel lines have lower impedance which results in more customers seeing faults on the system.

Distribution

(1) Low Reliability - due to single radial lines
(2) Environmental conditions such as wind, ice trees, etc. cause a few (2-3) sustained outages, and a large number (> 30) of momentary outages.
(3) Distribution automation has reduced the number of sustained outages by providing alternative substation feeds via switches.

Two Questions Could Be Asked

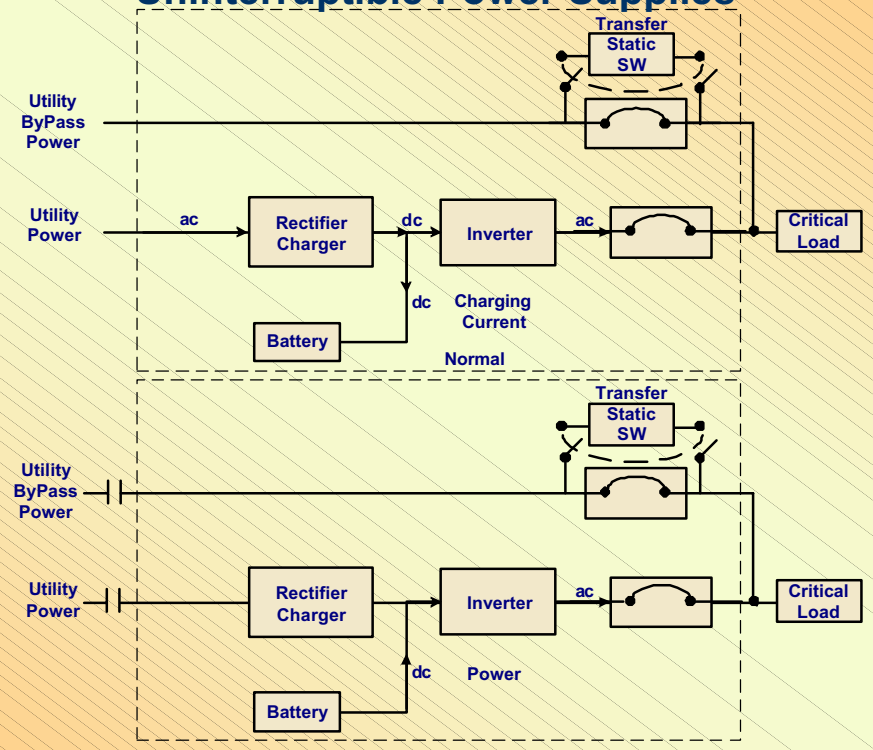
Q2. How is reliability improved?

1. Add more redundancy – more lines
2. Add more reserve generation
3. Add more manual and automatic sectionalizing devices in the systems
4. Convert overhead lines to underground lines (more expensive)
5. Move the generator closer to the load and eliminate the overhead T&D
6. Add UPS Systems

So Why Consider Distributed Generation?

- One answer to improve reliability is multiple generation (more reserve margin) and very little T&D
- Power Quality is also improved due to less load being served (creating contamination – interference may still exist)

Uninterruptible Power Supplies



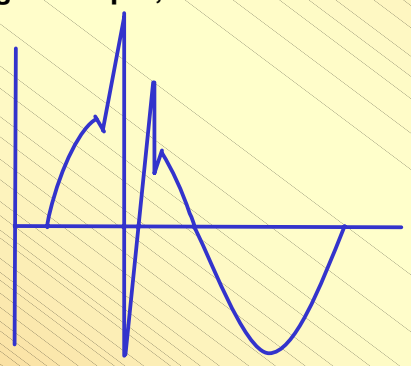
Emergency (Loss of Utility Power)

What is Power Quality?

It is electrical contamination and interference

Spikes or Impulses - causes may be lightning, switching operations (breakers, semi-conductor switches), electrostatic discharges from walking on carpet, electric traction systems, and contact bounce.

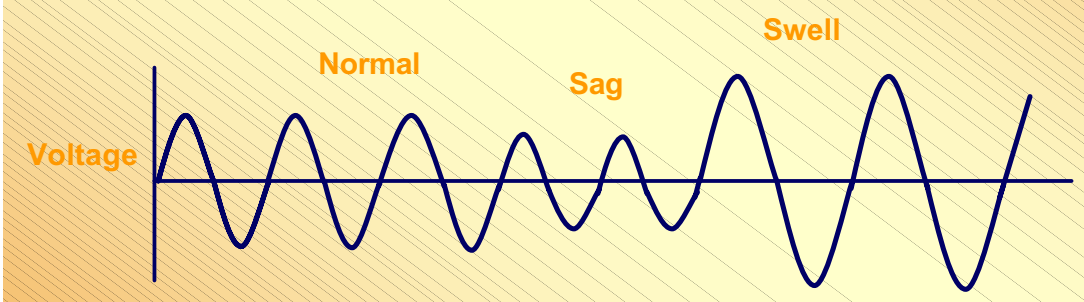
Voltage



Characteristics:
Short rise time of about 1 μs and short duration of some 100 μs

Power Quality

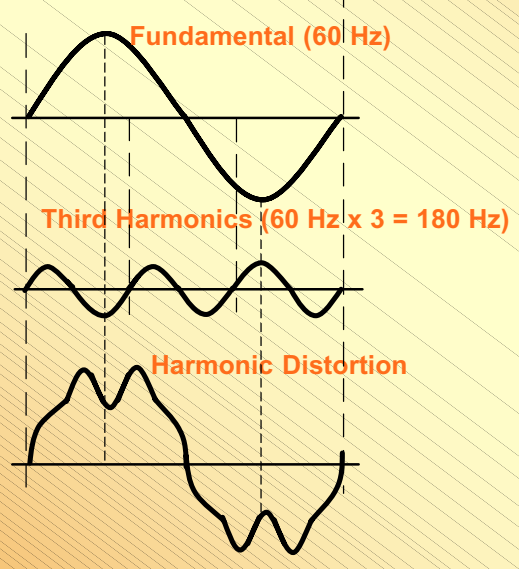
Swells (surges) and **Sags** (dips) - causes are primarily due to switching off and switching on large loads, electric system faults, arc furnaces, and reversing mill motor drives.



Characteristics: Rise or depression of voltage of about 6% to 10% lasting from .5 cycles to several cycles.

Non Linear Loads

Non Linear Loads Cause Harmonics - a harmonic is a frequency that is an integer (whole number) multiple (2nd, 3rd, 4th, 5th, etc.) of the fundamental 60 Hz sinusoidal waveform.

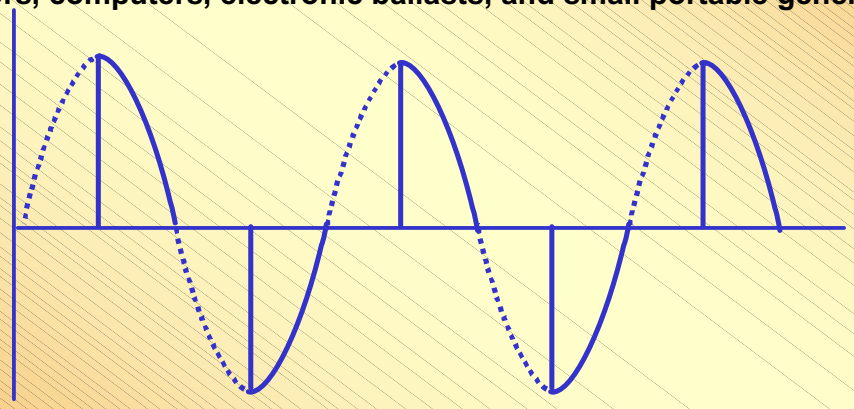


Why is Harmonic Distortion Not Desirable?

- Neutral conductors overheat
- Transformers overheat which reduces load carrying capability
- Equipment malfunctions

Power Quality

Harmonics: Causes may be variable speed drives, induction motors, computers, electronic ballasts, and small portable generators.



Characteristic: 1. Crest Factor - The higher or lower the crest factor the more distorted the wave form becomes. A pure sinusoidal waveform has a 1.414 crest factor. The above has a crest factor of 2.40.

$$CF = \frac{Vpeak}{Vrms} = \frac{1}{.707} = 1.414$$ **, for pure sinusoidal waveform**

Power Quality

Harmonics (cont'd)

2. **Total Harmonic Distortion** - an index used to measure distortion.

$$THD = \sqrt{\frac{?\,[(h_2)^2 + (h_3)^2 + \ldots}{(\text{Fundamental})^2}}$$

$$THD = < 5\%$$

3. - **Positive Sequence Harmonics**

(1st, 4th, 7th, etc. have the same phase sequence as the fundamental and cause additional heating in conductors, circuit breakers, etc.

Power Quality

- **Negative Sequence Harmonics**

(2nd, 5th, 8th, etc. have a phase sequence opposite to the sequence of the fundamental and cause a rotating field in the opposite direction. This reverse rotation causes a reduction in the forward torque of motors and overheating.

- **Zero Sequence Harmonics**

(3rd, 6th, 9th, etc.) do not produce a rotating field in either direction but cause overheating. Since zero sequence harmonics do not cancel, they add together in the neutral conductor which is a major problem, because there are no breakers or fuses that would trip or blow for an overloaded condition.

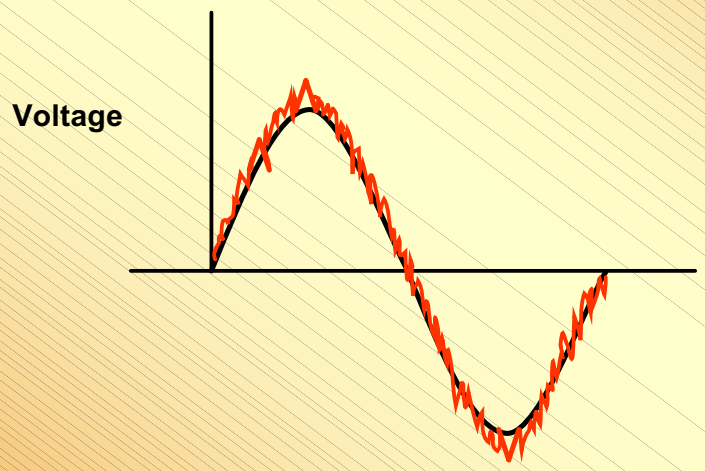
Power Quality

Noise: There are two types. **Common Mode Noise** is produced between the ground and the phase conductors, or ground and neutral conductors. **Traverse Mode Noise** is produced between the phase conductors and the neutral conductors.

Common Mode Noise causes may be arcing motor brushes, ground faults, radio transmitters, ignition systems, and arcing from opening contacts.

Traverse Mode Noise causes may be welders, switching power supplies, and the firing of SCR's.

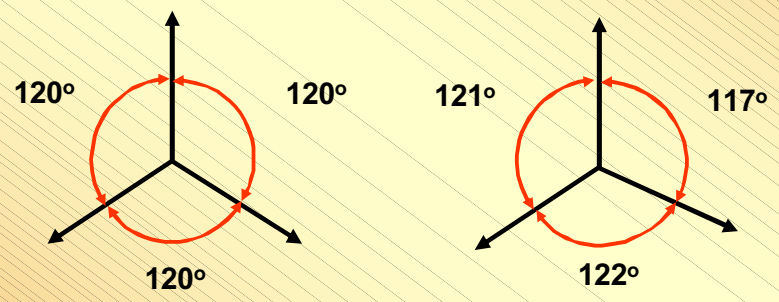
Power Quality



Characteristic: Noise problems can cause processing and data transfer errors in electronic equipment and microprocessor based relays to incorrectly operate.

Power Quality

Phase Unbalance – causes may include applying 1F loads to 3F power systems which results in more current being carried in one or two of the phases.



Characteristics: The phases are no longer 120° apart which causes 3F motors to operate at higher temperatures, and insulation breakdown or loss of dielectric strength. A phase unbalance of 3% may cause a motor to deliver only 90% of rated torque.

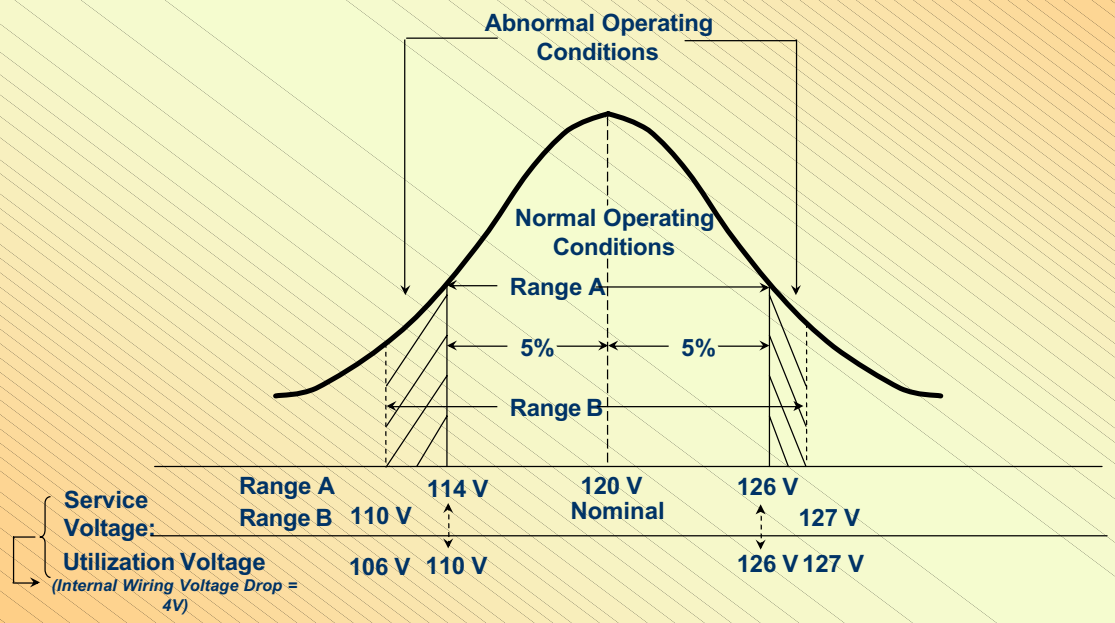
Power Quality

Voltage Regulation

Overvoltage and Undervoltage - causes may include connecting and disconnecting large loads, and malfunctioning voltage regulation equipment and capacitors.

Power Quality

Voltage Regulation



Single Phase Systems - Nominal system voltage and voltage range.

Power Quality

Voltage Regulation

Characteristics: Operating above or below the ANSi Standard C-84.1

	Service Voltage
Normal	114 - 126V
Emergency	110 - 127V

	Utilization Voltage
at Terminals	106 - 127V

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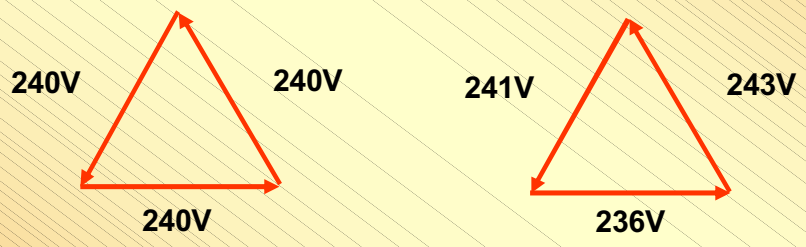
Power Quality

Voltage Unbalance – causes motors to overheat due to unbalanced current.



Characteristics: Voltage unbalance should not exceed 1%. The primary reason for voltage unbalance is open delta transformer connections, single phase loads, and blown fuses on 3F capacitor banks. An open phase creates the maximum condition of voltage imbalance.

Power Quality

Current Unbalance – causes motors to overheat.

Characteristic: A small voltage unbalance causes a much higher current unbalance and insulation breakdown. The typical ratio is 1:8 or a 3% voltage unbalance causes a 24% current unbalance. Current unbalance should not exceed 10%.

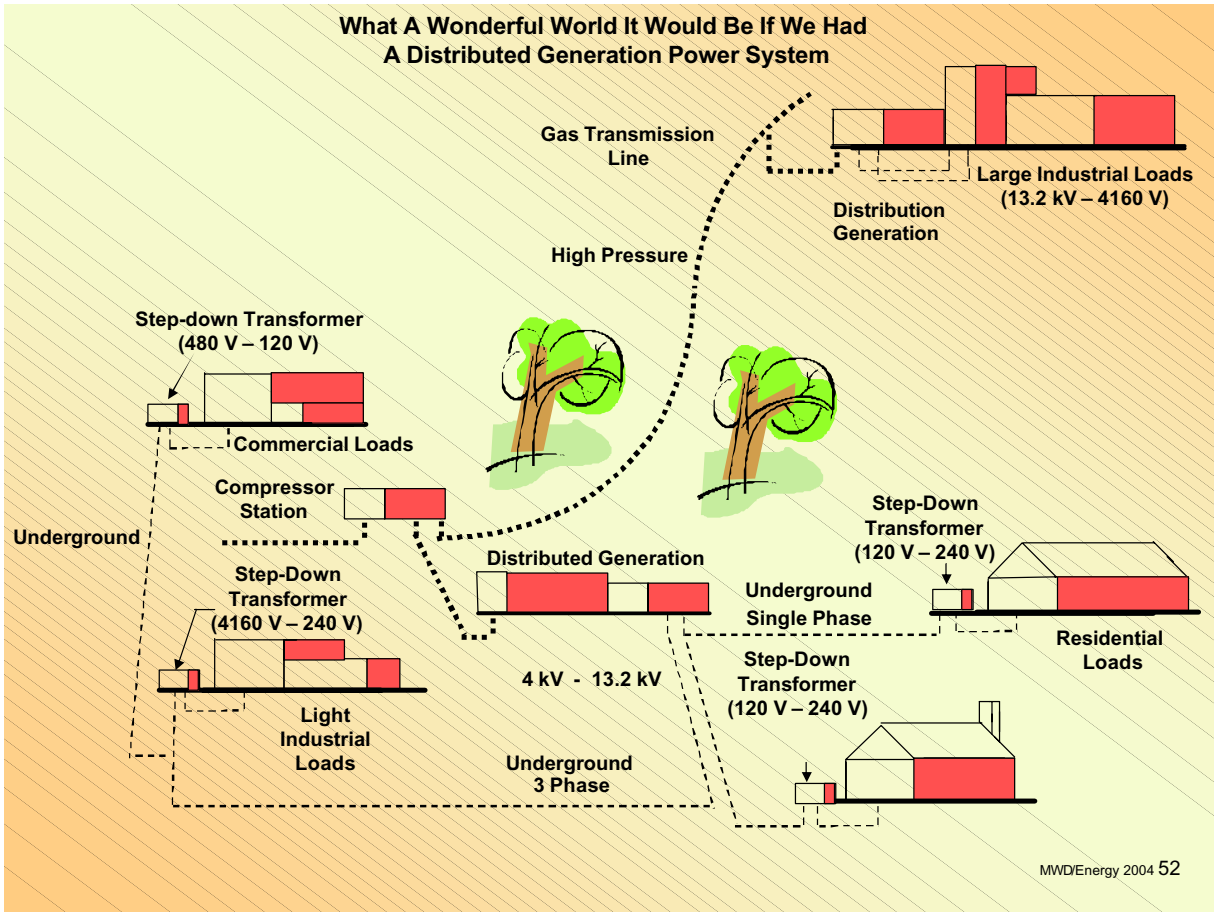
Power Quality

Frequency Stability

Overfrequency and Underfrequency – causes are overgeneration (too high MW output) and undergeneration (too low MW output)

< 30 kW generation	> 30 kW generation
>60.5 <59.3	>60.5 < 57.0

Characteristic: On heavy load days the frequency may decline and on light load days the frequency may increase. The normal utility frequency stability is ± .03 Hz.



Performance Comparison Summary

Performance Comparison Round Number's		Winner: Central Station, & T&D	Winner: Self Generation
(1) Efficiency & Losses	w/o CCHP	✓	
	w/ CCHP		✓
(2) Investment, Fuel and O & M Costs	w/o CCHP	✓	
	w/ CCHP		✓
(3) Reliability & Power Quality			✓
(4) Emissions			✓
(5) Infrastructure Requirements			✓

Final Winner is Self Generation With CCHP

Performance Comparison Summary

Performance Comparison Round Number's		Winner: Central Station, & T&D	Winner: Self Generation
(6) Electrical Environmental Effects			✓
(7) Installation Time			✓
(8) Electrical Safety	Primary	✓	✓
	Secondary		✓
(9) Combined Cooling, Heating, & Power Opportunities			✓
(10) Financial Risk & Security Risk			✓

Final Winner is Self Generation With CCHP

Why Hasn't Distributed Generation Prospered?

High Investment Cost (in some cases), High O&M Cost, High Fuel Cost, and Unavailability of Fuel

Central Station			**DG**
Investment: $1500/kw → $350/kw			$1500/kw → $700/kw
(¢/kWh)			**(¢/kWh)**
Investment:	3.58 →	.84	3.58 → 2.33
Fuel Cost:	1.55	1.55	4.87 → 4.27
O&M:	0.68	0.68	1.6 → 1.0
T&D:	3.12	3.12	0.84 → negligible
	8.93 →	6.19	10.89 → 7.60

Solution is DG With Combined Heat and Power

Because electricity is generated and the waste heat is also used for both heating and cooling

Total Cost of Electric and Thermal =

5.93¢ → 5.56¢

NOW, DG has a lower cost than Central Station & T&D

Distributed Generation Products are Divided into Three Major Categories:

1.

Continuous or Prime Power – High Availability High Efficiency

2.

Standby or Emergency – Low Cost Low Efficiency

3.

Peaking or Load Leveling – Low Cost Low Efficiency

What are Some Examples of Successful DG Installations?

FC Series – Fuel Cells

7.5 kW

IC Series – Internal Combustion Engines

75 and 150 kW

IC Series – Mid-Range

280 to 830 kW

T-Series Mini Gas Turbines 400 kW

Side View Package

DG Connection Trailer Voltage, OH/UG Connection, Protection & Communication

DG Technologies at DTE

Solar

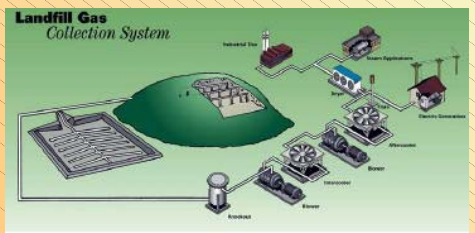
Natural Gas IC Engine

Natural Gas and Hydrogen Fuel Cell

Battery Storage

1 MW Natural Gas

External Combustion

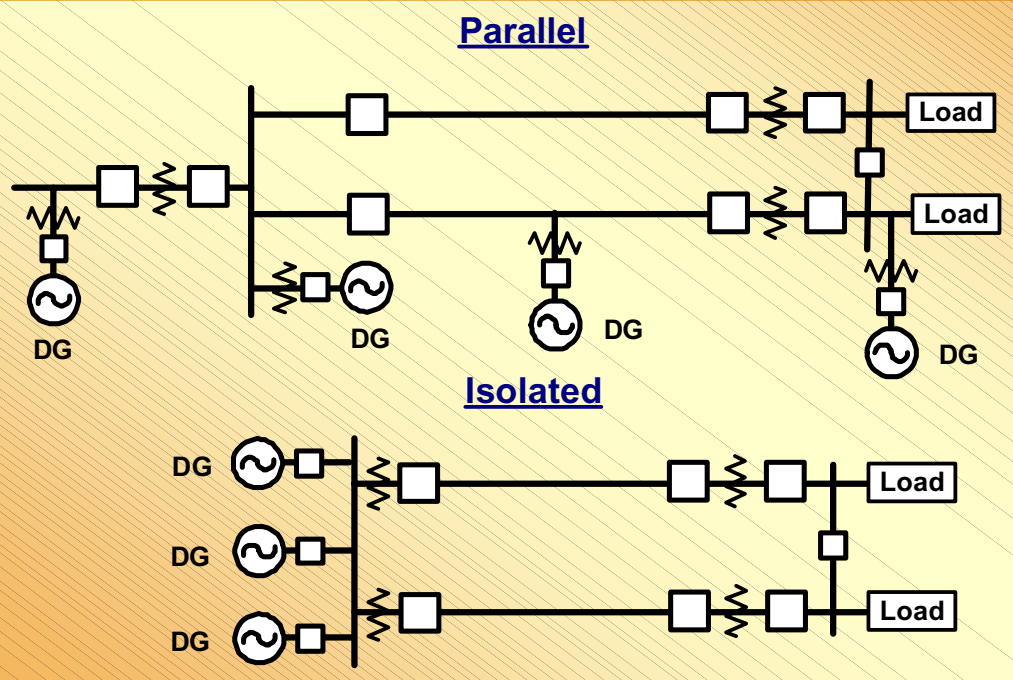


Biomass

2 MW Diesel

Mini Turbine

Applications



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So - Why Distributed Generation?

- Transmission Lines are Difficult to Site
- Transmission Interconnections are Operating Near Transfer Limits on Peak Load Days
- Underground Natural Gas Pipelines are Easier to Site
- Distributed Generation Coupled with CHP Possess Higher Efficiencies and lower cost.
- High Cost Power and Coal Fired Plant Emissions Will Drive Installation of Lower Cost and Higher Reliability DG Systems
- Faster Installation Time than Central Station Generation