UNIT-2

TRANSIENTS, SHORT DURATION AND LONG DURATION VARIATIONS

Basic terms and Definitions

Transient Impulsive transient Oscillatory transient Interruption Sag Swell Sustained Interruption	**Refer unit-1**
Under voltage	An under voltage is decrease in rms ac voltage to less than 90 percent at power frequency for a duration longer than 1 minute.
Over voltage	An under voltage is increase in rms ac voltage to less than 110 percent at power frequency for a duration longer than 1 minute.
Outage	The term outage as defined by IEEE standars refers to the state of a component in a system that has failed to function.
Voltage regulation	The degree of control or stability of the rms voltage at the load. It is specified in terms of parameters such as input voltage changes, load changes or temperature changes. (or) In electrical engineering, particularly power engineering, voltage regulation is a measure of change in the voltage magnitude between the sending and receiving end of a component, such as a transmission or distribution line. Voltage regulation describes the ability of a system to provide near constant voltage over a wide range of load conditions. In electrical power systems it is a dimensionless quantity defined at the receiving end of a transmission line as: $\%VR = \frac{Vnl - Vfl}{Vfl} \times 100$

Concepts:

Categories and Characteristics of Electromagnetic Phenomena in Power Systems:

TABLE 2.1 Principal Phenomena Causing Electromagnetic Disturbances as Classified by the IEC

- Conducted low-frequency phenomena
  - Harmonics, interharmonics
  - Signal systems (power line carrier)
  - Voltage fluctuations (flicker)
  - Voltage dips and interruptions
  - Voltage imbalance (unbalance)
  - Power frequency variations
  - Induced low-frequency voltages
  - DC in ac networks
- Radiated low-frequency phenomena
  - Magnetic fields
  - Electric fields
- Conducted high-frequency phenomena
  - Induced continuous-wave (CW) voltages or currents
  - Unidirectional transients
  - Oscillatory transients
- Radiated high-frequency phenomena
  - Magnetic fields
  - Electric fields
  - Electromagnetic fields
  - Continuous waves
  - Transients
- Electrostatic discharge phenomena (ESD)
- Nuclear electromagnetic pulse (NEMP)

TABLE 2.2 Categories and Characteristics of Power System Electromagnetic Phenomena

Categories	Typical spectral content	Typical duration	Typical voltage magnitude
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	5-ns rise	<50 ns	
1.1.2 Microsecond	1-µs rise	50 ns–1 ms	
1.1.3 Millisecond	0.1-ms rise	>1 ms	
1.2 Oscillatory			
1.2.1 Low frequency	<5 kHz	0.3–50 ms	0–4 pu
1.2.2 Medium frequency	5–500 kHz	20 µs	0–8 pu
1.2.3 High frequency	0.5–5 MHz	5 µs	0–4 pu
2.0 Short-duration variations			
2.1 Instantaneous			
2.1.1 Interruption		0.5–30 cycles	<0.1 pu
2.1.2 Sag (dip)		0.5–30 cycles	0.1–0.9 pu
2.1.3 Swell		0.5–30 cycles	1.1–1.8 pu
2.2 Momentary			
2.2.1 Interruption		30 cycles–3 s	<0.1 pu
2.2.2 Sag (dip)		30 cycles–3 s	0.1–0.9 pu
2.2.3 Swell		30 cycles–3 s	1.1–1.4 pu
2.3 Temporary			
2.3.1 Interruption		3 s–1 min	<0.1 pu
2.3.2 Sag (dip)		3 s–1 min	0.1–0.9 pu
2.3.3 Swell		3 s–1 min	1.1–1.2 pu

3.0	Long-duration variations			
3.1	Interruption, sustained		>1 min	0.0 pu
3.2	Undervoltages		>1 min	0.8–0.9 pu
3.3	Overvoltages		>1 min	1.1–1.2 pu
4.0	Voltage unbalance		Steady state	0.5–2%
5.0	Waveform distortion			
5.1	DC offset		Steady state	0–0.1%
5.2	Harmonics	0–100th harmonic	Steady state	0–20%
5.3	Interharmonics	0–6 kHz	Steady state	0–2%
5.4	Notching		Steady state	
5.5	Noise	Broadband	Steady state	0–1%
6.0	Voltage fluctuations	<25 Hz	Intermittent	0.1–7% 0.2–2 Pst
7.0	Power frequency variations		<10 s	

Transients:

- The term transient refers to an event that is undesirable and momentary in nature.
- Other definition of a transient is "that part of the change in a variable that disappears during transition from one steady state operating condition to another."
- Transients can be classified into two categories- impulsive and oscillatory. These terms reflect the wave shape of a current or voltage transient.

Impulsive transient:

- An impulsive transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity (primarily either positive or negative).
- Impulsive transients are normally characterized by their rise and decay times.
- For example, a 1.2 × 50-μs 2000-volt (V) impulsive transient nominally rises from zero to its peak value of 2000 V in 1.2 μs and then decays to half its peak value in 50μs.
- The most common cause of impulsive transients is lightning.

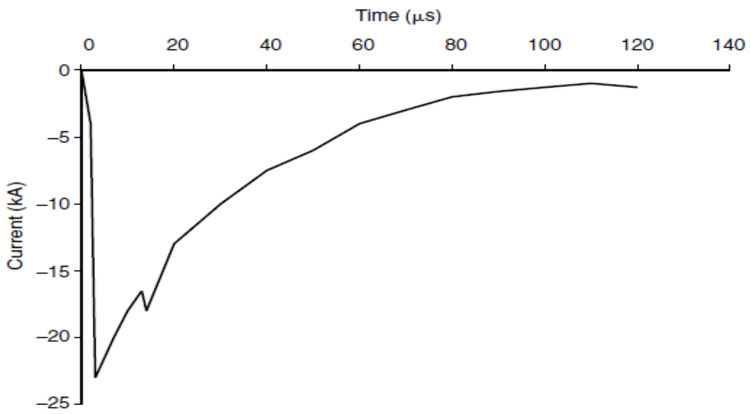


Fig 2.1 Lightning stroke due to impulsive transient

Oscillatory transient:

- An oscillatory transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values.
- An oscillatory transient consists of a voltage or current whose instantaneous value changes polarity rapidly.
- It is described by its spectral content (predominate frequency), duration, and

magnitude.

- The frequencies of spectral content are classified as high, medium and low frequencies.
- Oscillatory transients with a primary frequency component greater than 500 kHz and a typical duration measured in microseconds (or several cycles of the principal frequency) are considered high-frequency transients. These transients are often the result of a local system response to an impulsive transient.
- A transient with a primary frequency component between 5 and 500 kHz with duration measured in the tens of microseconds (or several cycles of the principal frequency) is termed a medium-frequency transient.
- Back-to-back capacitor energization results in oscillatory transient currents in the tens of kilohertz as illustrated in Figure below.

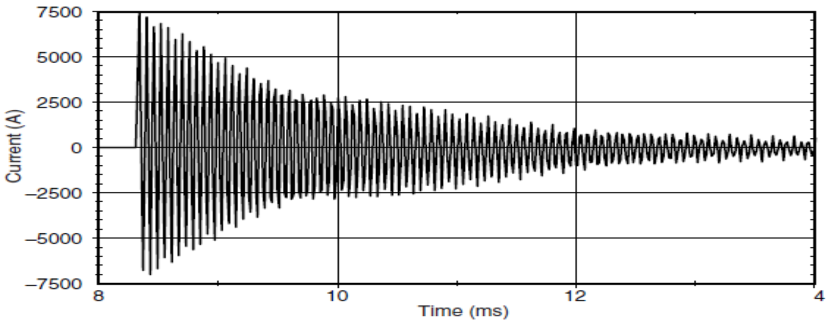


Fig 2.2 Oscillatory transient current caused by back-to-back capacitor switching.

- A transient with a primary frequency component less than 5 kHz, and a duration from 0.3 to 50 ms, is considered a low-frequency transient. This category of phenomena is frequently encountered on utility subtransmission and distribution systems and is caused by many types of events.
- Capacitor bank energization results in low frequency oscillatory voltage transient with a primary frequency between 300 and 900 Hz.

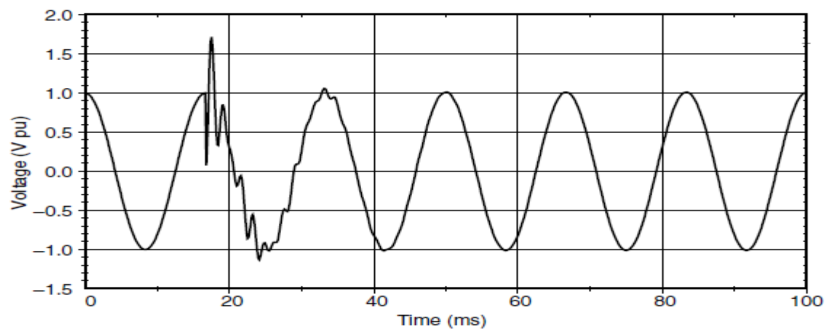


Fig 2.3 Low-frequency oscillatory transient caused by capacitor bank energization.

- Oscillatory transients with principal frequencies less than 300 Hz can also be found on the distribution system. These are generally associated with ferroresonance and transformer energization.
- Transients involving series capacitors could also fall into this category.

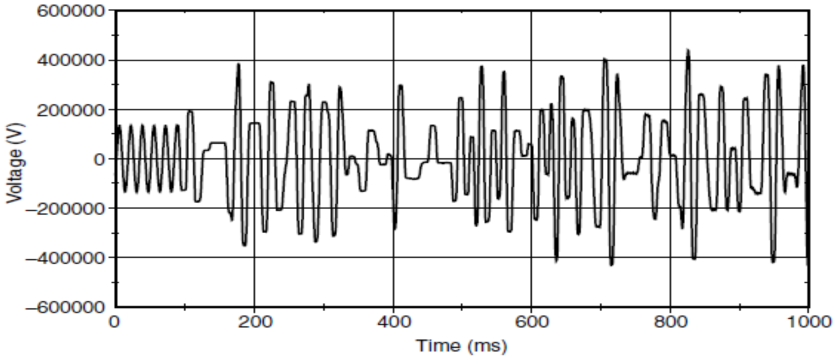


Fig 2.4 Low-frequency oscillatory transient caused by ferroresonance of an unloaded transformer.

Short Duration Voltage Variations:

- Energization of large loads which require high starting currents, or intermittent loose connections in power wiring. Depending on the fault location and the system conditions, the fault can cause either
  - ✓ Temporary voltage drops (sags),
  - ✓ voltage rises (swells),
  - ✓ a complete loss of voltage (interruptions)

Interruption:

- An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min.
- Interruptions can be the result of power system faults, equipment failures, and control malfunctions.
- The interruptions are measured by their duration since the voltage magnitude is always less than 10 percent of nominal.
- The duration of an interruption due to a fault on the utility system is determined by the operating time of utility protective devices.
- Instantaneous reclosing generally will limit the interruption caused by a non permanent fault to less than 30 cycles.
- Delayed reclosing of the protective device may cause a momentary or temporary interruption.

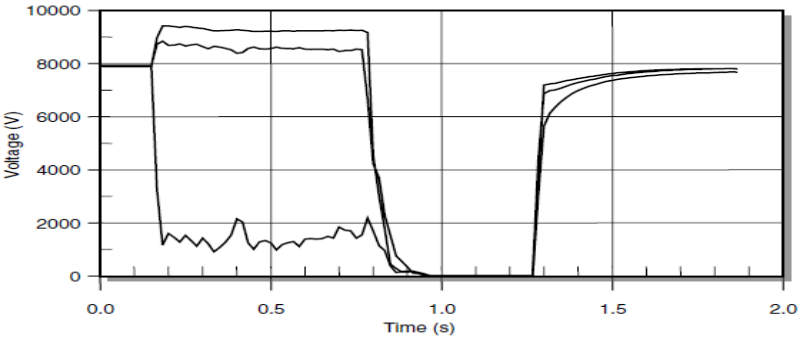


Fig 2.5 Three-phase rms voltages for a momentary interruption due to a fault and subsequent recloser operation.

Sags (dips):

- A sag is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.
- A short-duration voltage decrease is called as "sag".

- The IEC definition for this phenomenon is “dip”.
- Voltage sags are usually associated with system faults but can also be caused by energization of heavy loads or starting of large motors.
- Figure below shows a voltage sag waveform.

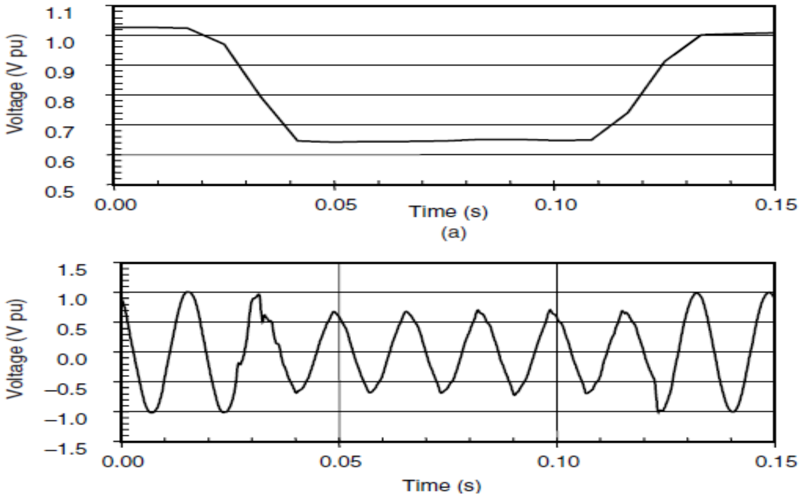


Fig 2.6 Voltage sag caused by an SLG fault. (a) RMS waveform for voltage sag event. (b) Voltage sag waveform.

- As shown in the Fig 2.6(b) An 80 percent sag exists for about 3 cycles until the substation breaker is able to interrupt the fault current. Typical fault clearing times range from 3 to 30 cycles, depending on the fault current magnitude and the type of overcurrent protection.

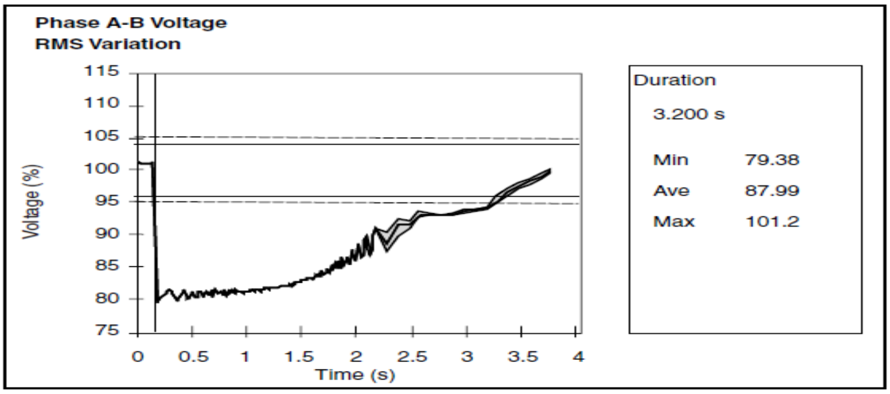


Fig 2.7 Temporary voltage sag caused by motor starting.

- The above Fig illustrates the effect of a large motor starting. An induction motor will draw 6 to 10 times its full load current during start-up.
- If the current magnitude is large relative to the available fault current in the system at that point, the resulting voltage sag can be significant.
- In this case, the voltage sags immediately to 80 percent and then gradually returns to normal in about 3 s.

Swells:

- A swell is defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.
- Swells can occur due to temporary voltage rise on the unfaulted phases during an SLG fault.
- Swells can also be caused by switching off a large load or energizing a large capacitor

bank.

- Fig 2.8 illustrates a voltage swell caused by an SLG fault.

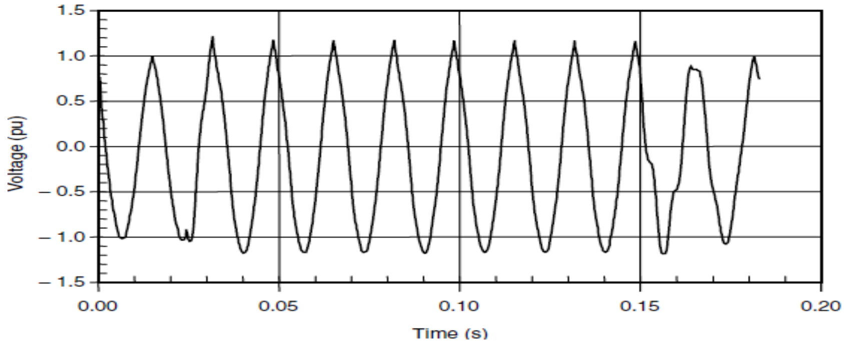


Fig 2.8 Instantaneous voltage swell caused by an SLG fault.

- Swells are characterized by their magnitude (rms value) and duration.
- The severity of a voltage swell during a fault condition is a function of the fault location, system impedance, and grounding.
- A swell is commonly defined as "momentary over voltage".

Long Duration Voltage Variations:

- Long-duration variations encompass root-mean-square (rms) deviations at power frequencies for longer than 1 min.
- The voltage variation is considered to be long duration when the ANSI limits are exceeded for greater than 1 min.
- Long-duration variations can be either over voltages or under voltages.
- Over voltages and under voltages generally is not the result of system faults, but are caused by load variations on the system and system switching operations.
- Such variations are typically displayed as plots of rms voltage versus time.

Over voltage:

- An overvoltage is an increase in the rms ac voltage greater than 110 percent at the power frequency for duration longer than 1 min.
- Over voltage is usually the result of load switching (e.g., switching off a large load or energizing a capacitor bank). The over voltages result because either the system is too weak for the desired voltage regulation or voltage controls are inadequate.
- Incorrect tap settings on transformers can also result in system over voltages.

Under voltage:

- An under voltage is a decrease in the rms ac voltage to less than 90 percent at the power frequency for a duration longer than 1 min.
- Under voltages are the result of switching events that are the opposite of the events that cause over voltages.
- A load switching on or a capacitor bank switching off can cause an under voltage until voltage regulation equipment on the system can bring the voltage back to within tolerances.
- Overloaded circuits can result in under voltages also.

Sustained Interruptions:

- When the supply voltage has been zero for a period of time in excess of 1 min, the long-duration voltage variation is considered a sustained interruption.
- Voltage interruptions longer than 1 min are often permanent and require human intervention to repair the system for restoration.

- The term sustained interruption refers to specific power system phenomena and, in general, has no relation to the usage of the term outage.
- Outage, as defined in IEEE Standard 100, does not refer to a specific phenomenon, but rather to the state of a component in a system that has failed to function.
- In power quality monitoring, the term interruption has no relation to reliability or service continuity.
- Thus interruption is only referred to the absence of voltage for long periods.

Sources of Power Quality Disturbances:

Category	**Causes**
Voltage Dips	Local and remote faults, Inductive loading, Switching on large loads
Voltage Surges	Capacitor switching, switching off large loads, phase faults
Over voltage	Load switching, capacitor switching, system voltage regulation
Harmonics	Industrial furnaces, non-linear loads, transformers/ generators, rectifier equipment
Power Frequency variations	Loss of generation, extreme loading conditions
Voltage Fluctuations	AC motor drives, Inter harmonic current components, welding and arc furnaces
Rapid voltage change	Motor Starting, Transformer Tap changing
Voltage imbalance	Unbalanced loads, Unbalanced impedances
Short and long duration voltage interruptions	Power system faults, Equipment failures, Control malfunctions, Circuit breaker tripping
Under voltage	Heavy network loading, Loss of generation, poor power factor, lack of var support
Transients	Lightning, Capacitive switching, non-linear switching loads, system voltage regulation

Principles of Regulating Voltage:

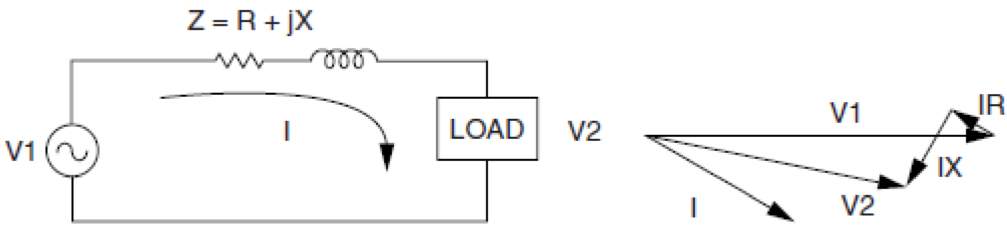


Fig 2.9 Voltage drop across the system impedance is the root cause of voltage Regulation problems.

Some common options for improving power system voltage regulation

- ✓ Add shunt capacitors to reduce the current I and shift it to be more in phase with the voltage.
- ✓ Add voltage regulators, which boost the apparent V1.
- ✓ Reconductor lines to a larger size to reduce the impedance Z.
- ✓ Change substation or service transformers to larger sizes to reduce impedance Z.
- ✓ Add some kind of dynamic reactive power (var) compensation, which serves the

same purpose as capacitors for rapidly changing loads.
- ✓ Add series capacitors to cancel the inductive impedance drop IX.

Conventional Devices for Voltage Regulation:
There are a variety of voltage regulation devices in use on utility and industrial power systems. These are divided into three major classes:
1. Tap-changing transformers
2. Isolation devices with separate voltage regulators
3. Impedance compensation devices, such as capacitors

- There are both mechanical and electronic tap-changing transformers.
- The mechanical devices are for the slower-changing loads, while the electronic ones can respond very quickly to voltage changes.
- Isolation devices include UPS systems, ferroresonant (constant-voltage)transformers, and motor-generator sets. These are devices that essentially isolate the load from the power source by performing some sort of energy conversion. Therefore, the load side of the device can be separately regulated and can maintain constant voltage regardless of what is occurring at the power supply.
- Impedance compensation devices include series and shunt capacitors.
- Shunt capacitors help to maintain the voltage by reducing the current in the lines.
- Series capacitors compensate for the inductance in the system. This will significantly reduce the impedance in the system.

Other device s for voltage regulation include:
Utility step voltage regulator:

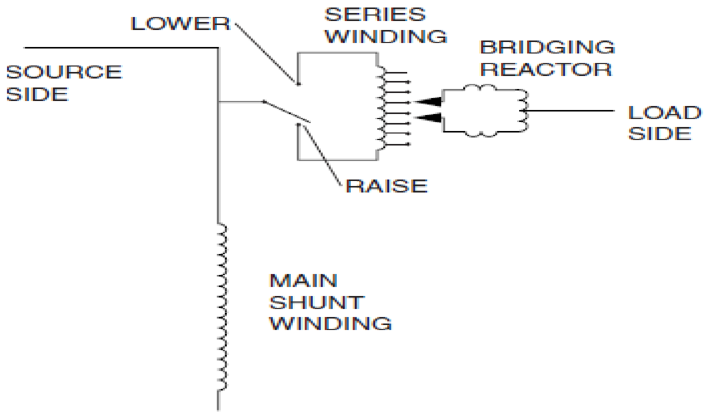


Fig 2.10 Schematic diagram of one type of utility voltage regulator commonly applied on distribution lines.

- The typical utility tap-changing regulator can regulate from -10 to +10 percent of the incoming line voltage in 32 steps of 5/8 percent.
- Distribution substation transformers commonly have three-phase load tap changers (LTCs).
- The concept of a tap-changing autotransformer is simple, but a utility voltage regulator has a complicated operation.
- Utility line voltage regulators and substation LTCs are relatively slow.
- The time delay when the voltage goes out of band is at least 15 sec and is commonly 30 or 45 sec.
- Their main application is boosting voltage on long feeders where the load is changing slowly over several minutes or hours. The voltage band typically ranges from 1.5 to

- 3.0 V on a 120-V base system.
- The control can be set to maintain voltage at some point on the feeder by using the line drop compensator.
- This results in a more level average voltage response and helps prevent overvoltages on customers near the regulator.

Ferro Resonant Transformer:

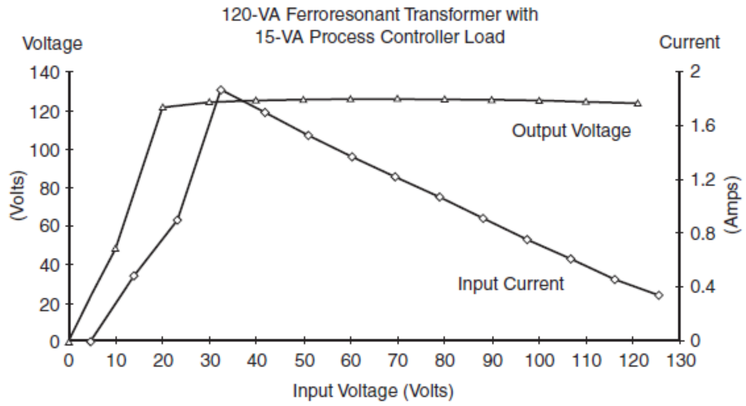


Fig 2.11 Ferro resonant transformer steady-state characteristics.

- On the end-user side, ferro resonant transformers are not only useful in protecting equipment from voltage sags but they can also be used to attain very good voltage regulation (±1 percent output).
- As shown in Fig 2.11 as the input voltage is reduced down to 30 V, the output voltage stays constant.
- If the input voltage is reduced further, the output voltage begins to collapse.
- In addition, as the input voltage is reduced, the current drawn by the ferroresonant transformer increases substantially from 0.4 to 2 A.
- Thus, ferroresonant transformers tend to be lossy and inefficient.

Electronic tap-switching regulators:

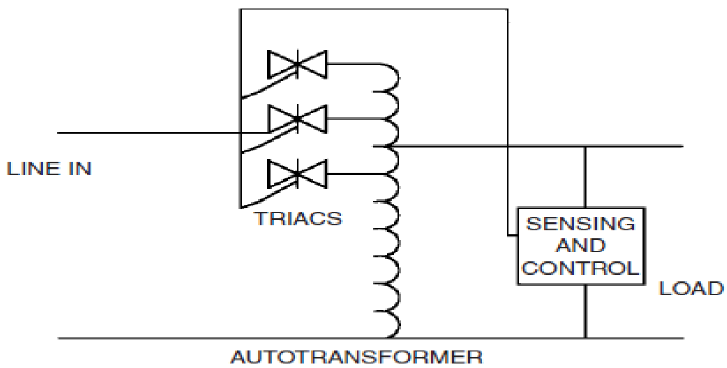


Fig 2.12 Electronic tap-switching regulator.

- Electronic tap-switching regulators can also be used to regulate voltage.
- They are more efficient than ferroresonant transformers and use SCRs or triacs to quickly change taps, and hence voltage.
- Tap switching regulators have a very fast response time of a half cycle and are popular for medium-power applications.

Magnetic synthesizers:

- Magnetic synthesizers, although intended for short-duration voltage sags, can also be used for steady-state voltage regulation.
- One manufacturer, for example, states that for input voltages of ±40 percent, the output voltage will remain within ±5 percent at full load.

On-line UPS systems:

- On-line UPS systems intended for protection against sags and brief interruptions can also be used for voltage regulation provided the source voltage stays sufficiently high to keep the batteries charged.
- This is a common solution for small, critical computer or electronic control loads in an industrial environment that has large, fluctuating loads causing the voltage to vary.

Motor-generator sets:

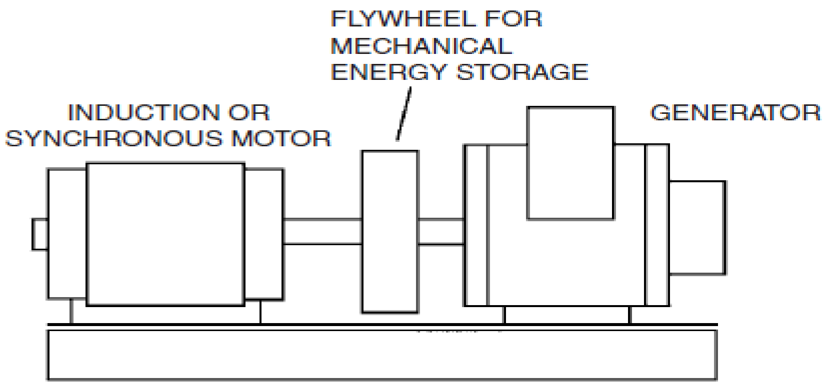
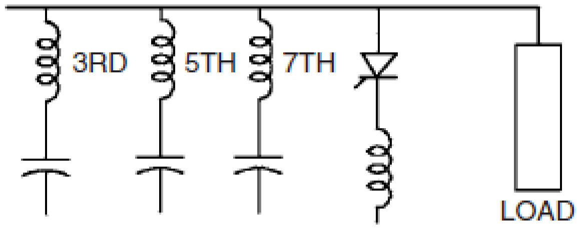


Fig 2.13 Motor-generator set.

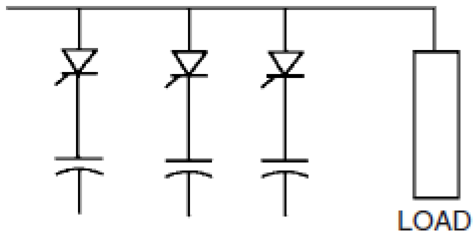
- Motor-generator sets (as shown in Fig above) are also used for voltage regulation.
- They completely decouple the load from the electric power system, shielding the load from electrical transients. Voltage regulation is provided by the generator control.
- The major drawback of motor-generator sets is their response time to large load changes.
- Motor-generator sets can take several seconds to bring the voltage back up to the required level, making this device too slow for voltage regulation of certain loads, especially rapidly varying loads.
- Motor-generator sets can also be used to provide "ride through" from input voltage variations, especially voltage sags, by storing energy in a flywheel.

Static var compensators:

- There are two main types of static var compensators in common usage, as shown in Fig above.
- The thyristor-controlled reactor (TCR) scheme is probably the most common.
- It employs a fixed capacitor bank to provide leading reactive power and a thyristor-controlled inductance that is gated on in various amounts to cancel all or part of the capacitance.
- The capacitors are frequently configured as filters to clean up the harmonic distortion caused by the thyristors.



THYRISTOR-CONTROLLED REACTOR



THYRISTOR-SWITCHED CAPACITOR

Fig 2.14 Common static var compensator configurations.

- The thyristor-switched capacitor operates by switching multiple steps of capacitors quickly to match the load requirements as closely as possible.
- This is a more coarse regulation than a TCR but is often adequate.
- The capacitors are generally gated fully on so there are no harmonics in the currents. The switching point is controlled so that there are no switching transients.

Important Questions:

1. Define transient. Write short notes on impulsive and oscillatory transients with the help of figures.
2. Define the term "Long Duration voltage variation" and explain its various types with examples.
3. Define the term "Short Duration voltage variation" and explain its various types with examples.
4. List out the different sources of power quality disturbances.
5. State the principles of voltage regulation and explain about any five devices that are used for improving voltage regulation.