Unit.2-Voltage Sag

D. Maharajan Ph.D
Assistant Professor
Department of Electrical and Electronics Engg.,
SRM University,
Chennai-203
Unit-2
-Mitigation of Voltage sag & Interruption

-Solutions at the end-user level
SOLUTIONS AT THE END-USER LEVEL

Objectives:

• Solutions to improve the reliability and performance of a process or facility can be applied at many different levels

• Available different technologies should be evaluated based on (customer requirement) the specific requirements of process.

• Finding optimum (economic) solution for improve the overall voltage sag performance
1. PROTECTION FOR SMALL LOADS [Ex: < 5 kVA]

-small individual machines and control equipments.
-Mainly, single-phase loads are protected.

2. PROTECTION FOR INDIVIDUAL EQUIPMENT (or)
GROUPS OF EQUIPMENT [upto 300 KVA]:

-protection of CRITICAL EQUIPMENT

-facility provided by power conditioning technologies (UPS)
2. PROTECTION FOR
   INDIVIDUAL EQUIPMENT (or)
   GROUPS OF EQUIPMENT [upto 300 KVA]:

   • Equipments can be grouped together conveniently.

   • Economically protected, applied only for the CRITICAL LOADS

3. PROTECTION FOR
   LARGE GROUPS OF LOADS (or)
   WHOLE FACILITIES (LV side):

   • It needs protection for large groups of loads at a convenient location (USUALLY THE SERVICE ENTRANCE)
4. PROTECTION ON THE SUPPLY SYSTEM (MV side):

- If the whole facility needs protection and improved power quality

- Solutions at the medium-voltage level can be considered
MAJOR TECHNOLOGIES AVAILABLE AND THE LEVELS WHERE THEY CAN BE APPLIED

• Ferroresonant transformers (CVTs)
• Magnetic synthesizers
• Active series compensators
• On-line UPS
• Standby UPS
• Hybrid UPS
• Motor-generator sets
• Flywheel energy storage systems
• Superconducting magnetic energy storage (SMES) devices
• Static transfer switches and fast transfer switches
1. FEROORESONANT TRANSFORMERS (CVTs)

- A voltage-regulating transformer that uses **core saturation and output capacitance** to maintain a stable output voltage even when the input voltage fluctuates.

- It provides a constant output voltage when the input voltage increases above or decreases below the nominal voltage.

- Used transformation ratio is 1 which are excited high on their saturation curves, thereby providing an output voltage which is not significantly affected by input voltage variations.

- It is the end user protection from voltage sags and transients.
Figure 3.14  Schematic of ferroresonant constant-voltage transformer.
- It uses two basic electrical principles that transformer designers usually try to avoid: **RESONANCE & CORE SATURATION**.

- **Resonance** occurs when the impedance of the capacitor equals the impedance of the inductor. In this case a capacitor is in series with the inductor of the CVT coil. This causes the current to increase to a point where it saturates the steel core of the CVT.

- **Transformer saturation** means the magnetic core (steel) cannot take any more magnetic field. Like a waterlogged sponge, it stops absorbing current and produces a constant output voltage.

- CVTs are especially attractive for constant, low-power loads. Not suitable for Variable loads, especially with high inrush currents.
General:
In a transformer, a current in the primary winding produces a magnetic flux that induces a current and voltage in the secondary winding. There is a point where increased current in the primary saturates the core with too much magnetic flux. This is the saturation point.

At this point the transformer no longer transforms the voltage or current according to the ratio of the primary and secondary turns.
2. Off Line UPS or Standby UPS

Normal line power is used to power the equipment until a disturbance is detected and a switch transfers the load to the battery backed inverter.

The transfer time from the normal source to the battery-backed inverter is important. The CBEMA curve shows that 8 ms is the lower limit on interruption through for power-conscious manufacturers.

Therefore a transfer time of 4 ms would ensure continuity of operation for the critical load.
3. On Line UPS

Figure 3.21 On-line UPS.
4. Standby UPS

Figure 3.22  Standby UPS.
Off Line UPS or Standby UPS ....contd.

-Common configuration used for protection of small computers.

**Drawback:**
-Does not provide any transient protection or voltage regulation as does an on-line UPS.

**UPS specifications:**
i.kilovolt ampere capacity,
ii.dYNAMIC and static voltage regulation,
iii.harmonic distortion of the i/p ct and o/p vt,
iv.surge protection,
v.noise attenuation.
Figure 2.15  A portion of the CBEMA curve commonly used as a design target for equipment and a format for reporting power quality variation data.
5. Hybrid UPS

Similar in design to the standby UPS, the hybrid UPS utilizes a voltage regulator on the UPS output to provide regulation to load and momentary ride-through when the transfer from normal to UPS supply is made.
6. Motor-Generator set

Motor-Generator set uses a special synchronous generator called a **written-pole motor**, produce a constant 60-Hz frequency as the machine slows.

It is able to supply a constant output by continually changing the polarity of the rotor's field poles. Thus, each revolution can have a different number of poles than the last one.

Constant output is maintained as long as the rotor is spinning at speeds between 3150 and 3600 revolutions per minute (rpm).
6. Motor-Generator set & Fly wheel energy storage

Figure 3.24  Block diagram of typical M-G set with flywheel.
6. Motor-Generator set & Flywheel energy storage

Flywheel inertia allows the generator rotor to keep rotating at speeds above 3150 rpm once power shuts off.

The rotor weight typically generates enough inertia to keep it spinning fast enough to produce 60 Hz for 15 s under full load.

Another means of compensating for the frequency and voltage drop while energy is being extracted is to rectify the output of the generator and feed it back into an inverter.

This allows more energy to be extracted, but also introduces losses and cost.
6. View of Motor-Generator set with Flywheel energy storage

Figure 3.25 Cutaway view of an integrated motor, generator, and flywheel used for energy storage systems. (Courtesy of Active Power, Inc.)
6. Motor-Generator set & Flywheel energy storage

- Motor-generator sets are exploiting the energy stored in flywheels.

- A modern flywheel energy system uses high-speed flywheels and power electronics to achieve sag and interruption ride-through from 10 s to 2 min.

- M-G sets operated in the open and are subject to aerodynamic friction losses, these flywheels operate in a vacuum and employ magnetic bearings to substantially reduce standby losses.
8. Superconducting magnetic energy storage (SMES) devices

An SMES device can be used to mitigate voltage sags and brief interruptions.

The electric energy stored in the current flowing in a superconducting magnet.

The coil is lossless, the energy can be released almost instantaneously.

Using voltage regulator and inverter banks, this energy can be injected into the protected electrical system in less than 1 cycle to compensate for the missing voltage during a voltage sag event.
8. Superconducting magnetic energy storage (SMES) devices

The superconducting magnet is constructed of a Niobium Titanium (NbTi) conductor.

Since the coil is lossless, the energy can be released almost instantaneously.

Using voltage regulator and inverter banks, this energy can be injected into the protected electrical system in less than 1 cycle to compensate for the missing voltage during a voltage sag event.
System with SMES for mitigation of Voltage Sag:

Figure 3.26 Typical power quality–voltage regulator (PQ-VR) functional block diagram. (Courtesy of American Superconductor, Inc.)
Comparison of Grid voltage and Load voltage without sag (mitigated by SMES):

Figure 3.27 SMES-based system providing ride-through during voltage sag event.
10. Static transfer switches and fast transfer switches

- Conventional transfer switches will switch from the primary supply to a backup supply in seconds.

- Fast transfer switches that use vacuum breaker technology are available that can transfer in about 2 electrical cycles.

- This can be fast enough to protect many sensitive loads.

- Static switches use power electronic switches to accomplish the transfer within about a quarter of an electrical cycle.
10. Static transfer switches and fast transfer switches

Figure 3.28  Configuration of a static transfer switch used to switch between a primary supply and a backup supply in the event of a disturbance. The controls would switch back to the primary supply after normal power is restored.
Sag performance Evaluation

• Ref to sensitive point
  – Mag & duration obtained

• Data required for Estimation
  – **System parameter**
    • System topology
    • Line imp & component imp
    • Trans connection
    • Relay protection (all are fixed parameter)
  – **Fault event related parameter**
    • Fault type, location & fault imp (difficult to analyze)
Voltage sag magnitude determination

fault analysis-program
Voltage divider model

\[ V_{\text{sag}} = \frac{Z_2 + Z_f}{Z_1 + Z_2 + Z_f} \cdot V_0 \]

\[ V_{\text{sag}} = f(l) = \frac{z \cdot l}{Z_1 + z \cdot l} \cdot V_0 \]

Where,

- \( Z_f \) = Source impedance at the PCC;
- \( Z_2 \) = Impedance of the feeder between the fault point and the PCC;
- \( Z_f \) = Fault impedance; \( V_0 \) = Prefault voltage at the PCC.
Duration determination

• Sag lasts till fault cleared
  – Type
  – Location
  – Settings of relay
Block diagram of Sag Performance Estimation

System configuration: line impedance; source short circuit level; fault type

Fault analysis

Exposed Areas

Primary protection reliability & setting

Duration

Sag Density Table

Component failure rate; Fault type distribution

Back up protection reliability & setting
Procedure for voltage sag indices
Steps...

1. Obtain sampled voltages with a certain sampling rate and resolution.
2. Calculate event characteristics as a function of time from the sampled voltages.
3. Calculate single-event indices from the event characteristics.
4. Calculate site indices from the single-event indices of all events measured during a certain period of time.
5. Calculate system indices from the site indices for all sites within the system.
Single Event Indices

- The basic measurement of a voltage dip and swell shall be $V_{\text{rms}}$ on each measurement channel.

- $V_{\text{rms}}$ defined as the RMS voltage measured over one cycle and refreshed over one half cycle.

$$V_{\text{RMS}(1/2)}(k) = \sqrt{\frac{1}{N} \sum_{i = 1 + k \frac{N}{2}}^{(k+1) \frac{N}{2}} v(i)}$$

Where $N$ is the number of samples per cycle, $v(i)$ is the recorded (sampled) voltage waveform, and $k=1, 2, 3$, etc. The resulting $\text{RMS}$ voltage versus time, for the sag event is shown in Fig.2.9.
Fig. 2.9. RMS voltage as a function of time for voltage sag
Factors Affecting Sag due to fault

Factors affecting the sag magnitude due to faults at a certain point in the system are:

(i) Distance to the fault
(ii) Fault impedance
(iii) Type of fault
(iv) Pre-sag voltage level
(v) System configuration
(vi) System impedance
(vii) Transformer connections
(viii) The type of protective device used determines sag duration.
In general, voltage sags can causes:

(i) Motor load to start/stop
(ii) Digital devices to reset causing loss of data
(iii) Equipment damage and/or failure
(iv) Materials Spoilage
(v) Lost production due to downtime
(vi) Additional costs
Sag due to motor starting

- Magnitude depends on
  - Characteristics of I.M
  - Strength of the system where motor is connected
Fig. 2.11. Voltage sag due to motor starting
Induction Motor starting methods

• Autotransformer starters

• Resistance and reactance starters

• Star delta starters
Estimating sag severity during full voltage starting

\[ V_{\text{Min(\text{pu})}} = \frac{V(\text{pu}) \cdot kVA_S}{kVA_L + kVA_S} \]

Where,
- \( V(\text{pu}) \) = per unit system voltage
- \( kVA_L \) = motor locked rotor kVA
- \( kVA_S \) = system short-circuit kVA at motor
Data required for simulation

• Transient analysis computer program

✓ Equivalent circuits Parameters such as resistances and reactances.
✓ Number of motor poles and rated rpm
✓ Inertia constant values for the motor and load
✓ Speed versus Torque characteristic for the motor load
Sag due to Transformer Energizing

The causes for voltage sags due to transformer energizing are:

(i) Normal system operation, which includes manual energizing of a transformer.

(ii) Reclosing actions.
Fig. 2.12. Voltage sag due to transformer energizing.
Voltage Sag and Mitigation Technique

• Power system design
  – Faults main cause
    • UG Cables
    • trimming trees
    • surge arrestors

• Equipment Design
  – Manufacturing less sensitive to sags

• Power conditioning Equipment
  – Using PC device at loads
Possible mitigation methods

• Four locations
  – 1,2 cheap not available in market
  – 4 costly
  – 3 widely used
Dynamic voltage Restorer (DVR) static series compensator with transformer injection

- Series compensation devices
  - Protects against
    - Sags
    - Swells
    - unbalance and
    - Distortion

Generates or absorbs Reactive power
Response time less
Dynamic voltage Restorer (DVR)
DVR- switching arrangement:
Active series compensators
(Transformer less series injection)
DISTRIBUTION STATIC COMPENSATOR DSTATCOM
• VSC
• DC Energy storage device
• coupling transformer

• Voltage regulation and compensation of Q
• Pf correction
• Elimination of harmonics
Building blocks

Three modes of operation

Vi=Vs , Vi>Vs , Vi<Vs

Note: 

Vs = System voltage
Vi = Inverter output voltage
Solid State (static) Transfer Switch (SSTS)
## OPEN TRANSITION

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Synchronizing gear may not be required, but the two sources must be</td>
<td>1. Loads will de-energize resulting in a large in-rush current when transition is complete.</td>
</tr>
<tr>
<td>within certain tolerance windows with regards to voltage, frequency,</td>
<td>2. New source will be required to handle a large step load increase due to in-rush current.</td>
</tr>
<tr>
<td>and phase angle.</td>
<td></td>
</tr>
<tr>
<td>2. No paralleling of sources, problems on one source will not be transferred to the other source</td>
<td></td>
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</tbody>
</table>
## CLOSED TRANSITION

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The transition is seamless to the load, the voltages and currents are</td>
<td>1. Synchronizing and paralleling equipment required.</td>
</tr>
<tr>
<td>never interrupted,</td>
<td>2. Problems on one source may be transferred to the other source.</td>
</tr>
<tr>
<td>2. The alternate source will see less of a step change in load,</td>
<td>3. Paralleling will allow both sources to supply a downstream fault increasing the available fault current. Equipment will need to be</td>
</tr>
<tr>
<td>3. There will be no in-rush currents as loads magnetize.</td>
<td>rated to handle this condition. May not be allowed by local utility.</td>
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</table>
Schematic representation of SSTS as a custom power device
Thyristor of SSTs conducting in $^\text{+ve}$ & $^\text{-ve}$ half cycle
Static UPS with minimal Energy storage
Backup storage Energy supply

![Diagram of backup storage system]

- Utility supply
- Isolation switch
- Protected load
- Isolation transformer
- Voltage source converter
- Energy storage system
- Charger
Flywheel with UPS System
References

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