Substation Engineering

Compensation Equipment (Part 2 of 2)

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Compensation Equipment (Part 2)

- Reactive Power Compensation
- Reactors, Synchronous Condensers & FACTS

Lecture Agenda

- The Ferranti Effect on lightly loaded lines
- Shunt Reactors: Function and Construction
- The need for Dynamic Compensation
- Synchronous Condensers
- Introduction to FACTS technology
- Static Var Compensator (SVC)
- Static Synchronous Compensator (STATCOM)
- Comparison of SVC and STATCOM

The Ferranti Effect

- Occurs on long, lightly loaded or open-circuited EHV transmission lines.
- The line capacitance generates huge amounts of reactive power (charging current).
- This capacitive current flows through the line inductance, causing a voltage rise.
- Result: The receiving end voltage (Vr) becomes significantly higher than the sending end voltage (Vs).
- Can lead to insulation failure of substation equipment.

Diagram/Visual: Phasor diagram showing the capacitive charging current leading the voltage, resulting in Vr ¿ Vs.

Shunt Reactors: Function

- To counter the Ferranti effect, we use Shunt Reactors.
- A reactor is essentially a giant inductor connected in parallel (shunt) with the line.
- It absorbs the excess capacitive reactive power generated by the long line.
- Keeps the receiving end voltage within safe operational limits during light load conditions.

Shunt Reactors: Construction

- They look very similar to power transformers (oil-filled, radiators, bushings).
- However, they only have one winding per phase.
- The magnetic core is heavily gapped (air gaps) to prevent magnetic saturation from the continuous high reactive current.
- Can be connected directly to the EHV line or to the tertiary winding of a transformer.

The Need for Dynamic Compensation

- Fixed capacitors and reactors are 'passive'. They are either ON or OFF.
- Mechanical switching via circuit breakers is slow and causes voltage transients.
- Modern grids with renewable energy and fluctuating industrial loads (like arc furnaces) require instantaneous, continuous, step-less reactive power control.
- Solution: Dynamic Compensation devices.

Synchronous Condensers

- A synchronous motor running without a mechanical load.
- By varying the DC excitation field, it can either generate or absorb reactive power smoothly.
- Over-excited: Acts like a capacitor (supplies Q, boosts voltage).
- Under-excited: Acts like a reactor (absorbs Q, lowers voltage).
- Provides crucial mechanical inertia to the grid.

Pros and Cons of Synchronous Condensers

Advantages	Disadvantages
Provides smooth, stepless Q control	High maintenance (rotating parts)
Adds short-circuit strength to the grid	Slower response than static devices
Provides physical inertia for frequency stability	Significant active power losses to keep spinning
Can survive severe voltage dips without tripping	Very expensive foundation and installation

Introduction to FACTS

- FACTS: Flexible AC Transmission Systems.
- Uses high-power electronics (Thyristors, IGBTs) to control power flow and improve stability.
- Offers millisecond response times.
- Two main shunt FACTS devices for reactive compensation:
- 1. SVC (Static Var Compensator)
- 2. STATCOM (Static Synchronous Compensator)

Static Var Compensator (SVC)

- An SVC uses Thyristors to rapidly switch capacitors or control reactors.
- Components:
- - TCR: Thyristor Controlled Reactor (allows continuous absorption of Q).
- - TSC: Thyristor Switched Capacitor (steps of Q generation).
- - Harmonic Filters.
- The control system adjusts the thyristor firing angles to maintain exact bus voltage.

Diagram/Visual: Schematic of an SVC showing a TCR (inductor with anti-parallel thyristors) and TSC (capacitor with thyristors) connected to a bus via a step-down transformer.

SVC Operation Characteristics

- Provides smooth control from lagging (inductive) to leading (capacitive).
- Disadvantage: The reactive power generated by a capacitor is proportional to the square of the voltage ($Q = V^2/Xc$).
- If grid voltage drops severely (e.g., during a fault), the SVC's ability to inject Q drops drastically exactly when it is needed most.
- Creates harmonic distortion (due to TCR switching), requiring bulky filter banks.

STATCOM (Static Synchronous Compensator)

- The most advanced shunt compensator.
- Uses a Voltage Source Converter (VSC) with IGBTs and a DC capacitor.
- It electronically synthesizes a 3-phase AC voltage waveform.
- If synthesized voltage ¿ Grid voltage: Injects Q (Acts capacitive).
- If synthesized voltage ¡ Grid voltage: Absorbs Q (Acts inductive).

Diagram/Visual: Block diagram of a STATCOM: DC Capacitor -¿ VSC (IG-BTs) -¿ Coupling Transformer -¿ Grid.

Advantages of STATCOM over SVC

- Constant Current Capability: STATCOM can provide full rated capacitive current even if the grid voltage drops to near zero.
- Faster Response: Uses IGBTs which switch at high frequencies, offering sub-cycle response times.
- Smaller Footprint: Does not require bulky passive reactors and large capacitor banks. Takes up much less land in the substation.
- Less Harmonic Filtration needed.

Comparison: SVC vs STATCOM

Feature	SVC	STATCOM
Technology	Thyristors (LCC)	IGBTs (VSC)
Space Required	Large (Capacitor/Filter yards)	Small (Compact indoor valves)
Low Voltage Performance	Poor (Q drops with V^2)	Excellent (Constant current)
Response Time	Fast (1-2 cycles)	Very Fast (¡1 cycle)
Cost	Lower	Higher

Summary of Compensation Equipment

- Shunt Reactors control the Ferranti effect by absorbing Q.
- Synchronous Condensers offer dynamic Q and mechanical inertia.
- FACTS devices (SVC/STATCOM) provide sub-second electronic voltage control.
- SVC uses switched passive components.
- STATCOM synthesizes waveforms electronically for superior low-voltage performance.

End of Unit 6 / Preview

- This concludes Unit 6 on Reactive Power Compensation.
- In the next series of lectures, we will move to Unit 7:
- Substation Automation and SCADA Systems.
- Introduction to IEC 61850.