Substation Engineering
Future of Substations (Part 2 of 3)

Milav Dabgar

Future of Substations (Part 2 of 3)

- Course: Substation Engineering (DI04009011)
- Unit 6: Future Trends in Substation Engineering
- Focus: Renewable Integration & Microgrids

Agenda

- The Traditional Power Grid Model
- The Shift to Distributed Generation (DG)
- Challenges of Renewable Integration
- Bi-directional Power Flow & Protection Issues
- Inverter-Based Resources (IBR)
- Introduction to Microgrids
- Battery Energy Storage Systems (BESS)
- Substations as Energy Hubs

The Traditional Grid Model

Generation → Transmission → Distribution → Consu

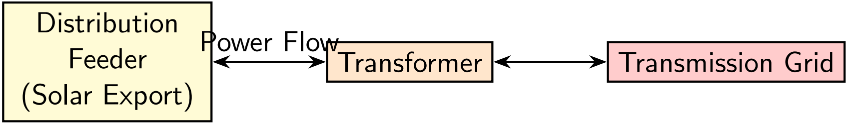
The Shift to Distributed Generation (DG)

- Power generation is moving closer to the load.
- Rooftop solar, local wind farms, biomass.
- Consumers become 'Prosumers' (producing and consuming power).
- Results in a highly decentralized and complex power network.

Challenges of Renewable Integration

- Intermittency: Solar and wind output fluctuates rapidly with weather.
- Voltage Regulation: Rapid power fluctuations cause voltage sags and swells.
- Reduced Inertia: Solar panels don't have heavy spinning rotors; the grid loses its natural kinetic stability.
- Fault Current Issues: Inverters cannot supply the massive fault currents that traditional generators can.

Bi-directional Power Flow



Impact on Protection Schemes

- Loss of Sensitivity: High fault contribution from DG can 'blind' relays at the main substation.
- Sympathetic Tripping: A fault on one feeder causes DG on a healthy feeder to contribute to the fault, tripping the healthy feeder.
- Requirement: Modern substations require adaptive protection relays (IEDs) that can change settings based on grid conditions.

Inverter-Based Resources (IBR)

Characteristic	Synchronous Generator	Inverter (Solar/Wind)
Inertia	High (Kinetic energy)	Zero (Electronic)
Fault Current	5x to 10x rated current	Limited to $\sim$1.2x rated current
Control Speed	Slow (Mechanical governors)	Extremely Fast (Power electronics)

What is a Microgrid?

- A localized group of electricity sources and loads.
- Normally operates connected to the traditional wide-area synchronous grid.
- Can disconnect to 'island mode' and function autonomously.
- Used for critical facilities (hospitals, military) or remote communities.

Substations in Microgrids

- The Point of Common Coupling (PCC) is usually a substation.
- The substation must manage the transition between grid-connected and islanded modes.
- Requires advanced synchrophasor measurements (PMUs) to ensure safe reconnection to the main grid.
- Must balance local generation and load precisely.

Battery Energy Storage Systems (BESS)

- Large-scale batteries installed directly at substations.
- Mitigates the intermittency of renewables (store solar during day, use at night).
- Provides 'synthetic inertia' by injecting power instantly to stabilize grid frequency.
- Enables Peak Shaving: Discharging during high demand to avoid overloading transformers.

BESS Applications in Substations

Application	Description	Benefit
Frequency Regulation	Absorbs/injects active power rapidly.	Maintains grid frequency at 50Hz/60Hz.
Voltage Support	Injects/absorbs reactive power via smart inverters.	Maintains stable local voltage.
Black Start	Provides initial power to restart the grid after a total blackout.	Faster system recovery.

Substations as Energy Hubs

- Future substations will not just be passive switching nodes.
- They become active Energy Hubs.
- Managing local generation, massive EV charging stations, and grid-scale storage.
- Rely heavily on AI and advanced SAS to optimize power flows in real-time.

Summary

- Distributed generation causes bi-directional power flow and alters fault currents.
- Traditional protection schemes must be upgraded to adaptive, intelligent relays.
- Microgrids provide local resilience and require precise synchronization at the substation PCC.
- BESS mitigates renewable intermittency and provides critical grid stability services.

Next Lecture Preview

- The digital era brings new threats: Cybersecurity in Substations.
- Understanding vulnerabilities in IEC 61850 networks.
- AI and Machine Learning for Predictive Maintenance.
- Concluding thoughts on the future of the power grid.