ECE 325 – Electric Energy System Components
9- Selected Real Problems in Power Engineering

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1. **Wide-area power grid stability monitoring**
   - Power-Angle Curve of a transmission line

2. **Fault-induced delayed voltage recovery issues**
   - Induction motors has high current (high reactive power consumption) in locked-rotor conditions
   - Reactive power control using shunt capacitors/reactors

3. **Wind turbines**
   - Induction generators and power electronics convertors

4. **Prevention of voltage collapse**
   - Power-Voltage Curve of a transmission line
Requirements for a reliable electric power service

• Voltage and frequency must be maintained within close tolerances

• Synchronous generators must be kept running in parallel with adequate capacity to meet the load demand

• Maintain the “integrity” of the bulk power network (avoid cascading outages)
1 - Wide-Area Power Grid Stability Monitoring

From Terry Bilke’s presentation at NASPI working group meeting in 2009
Inductive line connecting two systems

\[ P = \frac{|E_s \parallel E_r|}{X} \sin \delta \leq P_{\text{max}} = \frac{|E_s \parallel E_r|}{X} \approx \frac{|E|^2}{X} \]

\[ P \approx \frac{|E_s \parallel E_r|}{X} \delta \text{(in rad), if } \delta \text{ is small} \]

**Figure 25.30a**

Power versus angle characteristic.
Angle Sensitivity Monitoring Display

Mapping ‘Angular Separation’ to ‘MW Flows’ (Example: 0.6 °/100 MW)

From Terry Bilke’s presentation at NASPI working group meeting in 2009
2 – Fault-Induced Delayed Voltage Recovery (FIDVR)

- FIDVR issues are increasingly reported with the growth of induction motor loads, e.g. air conditioners.
- For example, a power utility company Southern California Edison has experienced delayed voltage recovery problems due to its high percentage of air conditioner loads. The high load currents and VAR demands caused up to 30s delays for the voltage to recover following the fault clearing operation.
• Following a single contingency, voltage dip should not exceed 25% and should not exceed 20% for more than 20 cycles at load buses
When the motor is stalled, i.e. locked-rotor condition, the current is 5-6 times the full-load current, making $P^2R$ losses 25-36 times higher than normal, so the rotor must never remain locked for more than a few seconds.

Small motors (15 hp and less) develop their breakdown torque at about 80% of $n_s$.

The rated power of 5 hp is developed at $s = 0.026$.
Use of Static Var Compensators (SVC)

- Typically, a SVC installed at a bus is composed of
  - shunt reactors (reactive loads) and capacitors (reactive sources) connected via high-speed thyristor switches
- a control system adjusts the amount of reactors or capacitors in-service to maintain the bus voltage at a target level

TCR - Thyristor-controlled reactor
TSC - Thyristor-switched capacitor
HP filer - High-pass filter to absorb high frequency harmonics caused by thyristor switches
Use of STATCOM

- Unlike a passive SVC, a STATCOM (static synchronous compensator) provides constant output current even at very low voltages.
- STATCOM is a dc-to-ac converter with an internal voltage source.

3 – Wind Turbines

**Type 1 – Conventional Induction Generator**

**Type 2 – Variable Rotor-Resistance Induction Generator**

**Type 3 – Doubly-Fed Asynchronous Generator**

**Type 4 – Full-Converter Unit**

From EPRI report “Proposed Changes to the WECC WT4 Generic Model for Type 4 Wind Turbine Generators”, 12, 2011
DFIG Wind Turbine

• A Doubly-Fed Induction Generator (DFIG) wind turbine can deliver energy to the power grid from both the stator and rotor windings through power electronics converters.

• By means of the converters, it can be a reactive power source of the grid like a STATCOM.
4 - Voltage Collapse - July 2\textsuperscript{nd}, 1996 Western Cascading Event
Inductive line

\[ P = |I|^2 (kX) = \left| \frac{E_S}{jX + kX} \right|^2 kX \]

\[ = \frac{|E_S|^2}{X |k-1/k + 2j|} \leq \frac{|E_S|^2}{2X} \]

When \( k=1 \), i.e. \( R_R=X \)

\[ P = P_{\text{max}} = |E_S|^2/2X \]

where \( |E_R| = |E_S|/\sqrt{2} = 0.707|E_S| \)

and voltage collapse happens

\[ \text{Figure 25.22} \]

Characteristics of an inductive line.
Prevention of Voltage Collapse

- Load
- SVC
- Thermal Plant
- Wind Turbine
- PMU

Voltage Collapse after a Generator Trip

With Under-Voltage Load Shedding (Today’s control)

With Centralized Control of SVCs

Dispatch more VAR from Wind Turbines