Cyber Infrastructure for the Smart Grid

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**Smart Grid Compute and Control**

[Image of buildings and trees]
Compute: Forecasting

- Weather Forecasting
- Load forecasting
- Price Forecasting
- Renewable energy forecasting
- Fuel Forecasting (price, quantity)
State Estimation:
- Filter measurements and build a good real time model
- Measurements can be corrupted/ missing
- Goal is to obtain a reliable snapshot/ remove BAD data
- Given the 8 measurements, estimate $V_1$ and $v_2$ with angle
Power flow is basically finding all four variables (Two known, two unknown) on each bus of the power system.

<table>
<thead>
<tr>
<th>BUS TYPES</th>
<th>KNOWN</th>
<th>UNKNOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>PQ</td>
<td>$P_{\text{inj}}, Q_{\text{inj}}$</td>
<td>$</td>
</tr>
<tr>
<td>PV</td>
<td>$P_{\text{inj}},</td>
<td>V_k</td>
</tr>
<tr>
<td>Swing/Slack</td>
<td>$</td>
<td>V_k</td>
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\[
P_k = \sum_{j=1}^{N} |V_k||V_j|(G_{kj} \cos(\theta_k - \theta_j) + B_{kj} \sin(\theta_k - \theta_j))
\]

\[
Q_k = \sum_{j=1}^{N} |V_k||V_j|(G_{kj} \sin(\theta_k - \theta_j) - B_{kj} \cos(\theta_k - \theta_j))
\]

Three bus power system
1. Several power flow tools are available:
   a) Siemens PSS/E
   b) GE PSLF
   c) ABB NEPLAN
   d) ETAP
   e) PowerWorld
   f) DIgSILENT

2. Power flows helps in determining voltage magnitude, angle, P, Q

3. Gauss-Siedel is one of the simplest method to solve using iterative approach
Minimize the cost of supplying particular set of loads with constraint of generation equals load is economic dispatch.

OPF is solving power flow equation, while optimizing generation cost, or emissions, or losses etc.

Economic dispatch is reduced form of OPF.
What is Optimal Power Flow?

Definition of OPF:

“Solving power flow with additional objective of optimization.”

Objective function could be:

1. Minimum generation cost
2. Minimum transmission losses
3. Maximum profit of Generation Company
4. Minimum shift of generation and control from operating point
5. Minimum load shedding schedule under emergency condition
Power system stability is the ability of an electric power system, to remain in a state of operating equilibrium under normal operating condition for a given initial operating condition, and to regain a state of operating equilibrium after being subjected to a physical disturbance.

- Slow: several minutes
  - involving devices such as transformer
  - mechanical taps and boiler dynamics

- Fast: several cycles (60 cycles per second)
  - Involving devices such as induction motors
  - dynamics, SVC, HVDC devices
Small signal angle stability can be non-oscillatory instability or oscillatory stability. Oscillatory instability can be local plant modes, interarea modes, control modes and torsional modes.
Compute and Control: Frequency Stability
Electric grid could be target:

- Critical support to economy,
- National security
- Public well being

Vulnerability types:
- Physical vulnerability
- Cyber Vulnerability

There is need to identify:

- Critical facilities or combination of critical facilities
- Loss impact due to these.
Objective: Investigate the influence of potential faults on power system in advance to come up with preventive action

Compute and Control: Power system security analysis

Steps: Security analysis includes following steps:
- Selection of critical contingencies
- Performing a detailed analysis for critical contingencies
- Analysis and checking of results for violations
- Come out with strategies for secure case
Contingencies are the unexpected loss of a significant device, such as a transmission line or a generator.

No power system can survive a large number of contingencies.
First contingency refers to loss of any one device.

How much power can be transferred from point A to point B without causing any overloads in base case and with first contingencies (n-1).