Research Overview:
Power System Operations in the Context of Smart Grids

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Outline

• Motivations and background:
  – Smart grid definition.
  – Smart grid history.
  – Smart grid components.

• Research Track A Objectives: Smart Grid Operations and Control
  – Theme 1: Smart Grid Systems Modeling, Analysis & Operation.
  – Theme 2: Smart Loads in Smart Grids.
  – Theme 3: Distributed Energy Supply, Storage & Integration.

• Projects:
  – Mathematical modeling of residential loads (J. M. Gonzalez, PDF).
  – Impact of renewable source uncertainties on power system stability (J. C. Munoz, PhD student)
  – Distribution system operation with smart loads and controllable EVs (I. Sharma, PhD student)
  – Operation and planning of distribution and transmission systems with EVs (N. Mehboob, PhD student).
Smart Grid Definition

- There are a variety of definitions, with no generally accepted one.
- Smart grid main characteristics:
  - Power grids with significant distributed and green energy resources.
  - Loads and distribution networks are active rather than passive participants.
  - Information and communication technologies (ICT) play a significant role.
Smart Grid Definition

• Generally accepted view of a smart grid:

Source: European Technology Platform SmartGrids
Smart Grid History

• Electricity supply started as a private business in the late 1800’s with Westinghouse’s/Tesla’s ac and General Electric’s/Edison’s dc local grids.
• Started as isolated local grids, i.e. microgrids.
• Electricity generation, transmission and distribution got larger during the 20th century, with grid interconnections based on reliability and macroeconomic imperatives, leading to:
  – “Smart”, integrated and multi-directional generation and transmission systems, with ICT being widely applied for grid management and control (e.g. dispatch, generator control, HVDC, FACTS, Secondary Voltage Regulation).
  – “Dumb”, passive and unidirectional distribution systems and loads.
Smart Grid History

• From the economic and political points of view, the grid has been seeing as a “natural monopoly”, leading to government regulation and/or ownership, and “vertical integrated” utilities:
  – Government owned, especially at the generation and transmission level (e.g. ENEL, EDF, BPA, Ontario Hydro).
  – US mostly locally owned utilities (e.g. private or municipal).
  – At the distribution level the ownership has been more dispersed, in many cases owned by municipalities.
Smart Grid History

• Vertically integrated utilities:
  – Own and control generation and transmission and parts of the distribution network.
  – Centrally operate the system at “minimum” costs with “maximum” reliability.

• In the 1980’s and 1990’s the concept of competitive electricity markets evolved.

• Main concerns that led to deregulation/privatization:
  – Large utilities “inefficiencies”.
  – “High” costs of electricity.
  – Crossed subsidies in developing countries.
  – “Political” issues.
Smart Grid History

• Competitive markets, limited resources, environmental concerns and politics led to:
  – Limited new large generation.
  – Limited new transmission lines.
  – More share of renewable technologies, particularly wind and solar power generation.
  – Development of renewable generation at low voltage levels, especially solar PV (since wind power is mostly through large farms), i.e. distributed generation.
  – Need for “elastic” loads to help reduce electricity prices and peak demand.
Smart Grid History

- The smart grid “concept” appears around 2005.
- The main driver has been the need for more “intelligent”, flexible and bidirectional distribution networks and loads, i.e. “smartening” the last mile.
Smart Grid Components

• Generation and transmission system management and control improvements (e.g. optimal dispatch considering non-dispatchable sources, centralized monitoring and control such as WAMS and WACS).

• Advanced Metering Infrastructure or AMI:
  – “Smart” meters.
  – ICT associated with smart meters to address communications and data management needs (e.g. LANs and WANs, data services).

• Energy Management Systems (EMS):
  – For distribution networks (e.g. optimal feeder control).
  – For customers (e.g. “intelligent” thermostats).
Smart Grid Components

• Distributed generation (DG):
  – Integration of non-dispatchable renewable resources (e.g. forecasting, voltage and frequency control).
  – Bidirectional flows in distribution networks.

• Microgrids:
  – Isolated (e.g. remote) and grid-connected.
  – Optimal planning, management and control considering DGs and demand-responsive loads.
Smart Grid Components

• Energy storage:
  – Integration with renewable resources.
  – Local voltage and frequency control.

• Electric vehicles:
  – Optimal grid utilization and planning.
  – Grid impact.
  – Smart charging (Grid-to-Vehicle or G2V)
  – Energy storage (V2G).
Objectives

• Theme 1: Smart Grid Systems Modeling, Analysis & Operation
  – Develop appropriate Smart Grid systems models:
    • Models need to include customer load dynamics vis-à-vis real-time price dependencies and their role in reverse feeder power flows.
    • Model the distribution feeders, and the associated three-phase component representations to properly represent unbalancing.
    • Development of appropriate power flow models for smart distribution systems that incorporate adequate models of different DG technologies, smart loads responding to real-time prices, EVs, energy storage devices, etc.
  – Consider various operational objectives due to different players, i.e. the customers (loads), the DERs, and the external grid:
    • Minimizing deviations from unity power factor along the feeder.
    • Minimizing the power drawn from substation.
    • Maximizing the revenue for systems with DERs.
    • Minimizing costs and/or energy consumption for the loads.
Objectives

– Consider critical regulatory issues in Smart Grids:
  • The ownership structure of DG units and DERs will influence energy scheduling and optimization.
  • Study the impact of incentives such as the Feed-in Tariffs (FITs) to examine their effect and validity.
– Apply internet design techniques based on analytical models and detailed simulations and emulations to the study of smart grids.
– Study stochastic sources to understand and manage the behavior of DGs and DERs.
– Examine the basic communication requirements associated with the various proposed methodologies/algorithms and the associated possible communication infrastructure needed to realize the proposed solutions.
Objectives

• Theme 2: Smart Loads in Smart Grids
  – Study the impact of demand response programs on the Smart Grids.
  – Consider load elasticity on grid operation and planning studies, including DERs and EVs in both G2V and V2G mode.
  – Develop models of elastic loads considering the communication and information technologies available in smart loads, particularly for real-time applications.
  – Study communication and information technologies and protocols needed in smart loads to properly manage large amounts of data flows among customers and LDCs.
Objetives

• Theme3: Distributed Energy Supply, Storage & Integration
  – Apply ideas from internet content distribution networks to the grid to determine energy storage needs and technologies to properly manage DERs:
    • “Caching” (excess storage)
    • “Peer-to-peer” matching (matched storage).
    • “Data mules” (EVs) to provide delay-tolerant demand.
  – Study the application of pricing regimes, akin to internet pricing schemes used to manage network overloads, and other incentives to manage demand.
Mathematical Models of Residential Loads

• The primary objective is to develop a Matlab-based simulator of residential loads (like a power systems’ simulator).
• This will allow to study demand side management techniques and their impact on the grid.
• This work addresses issues under Themes 1 and, especially, 2.
• PDF Juan Miguel M. Gonzalez is carrying out this work.
Impact of DER Uncertainty on Power System Stability

• The main aim of this work is to develop techniques and tools for power system voltage and transient stability studies.
• This will allow to analyze the impact of DER uncertainty on power system operation.
• This work addresses issues under Theme 1.
• This research is being carried out by PhD student Juan Carlos Munoz.
Distribution System Operation with Smart Loads and EVs

• The primary aim of this work is to develop techniques and tools to optimally control the distribution feeder assets in coordination with demand-responsive loads and EVs.

• This work will allow to determine optimal control of feeder tap changers and capacitors as well as elastic loads and EVs that address both LTC and customer needs.

• This work primarily belong to Theme 1, but does cover some aspects identified in Theme 2.

• This work is being carried out by PhD student Isha Sharma.
Operation and Planning of Distribution and Transmission Systems with EVs

• The main objective of this work is to develop technique and tools based on internet content distribution network ideas to study the impact and control of EVs, in G2V and V2G mode, at both the transmission and distribution system levels.

• This will allow optimal operation and planning of distribution and transmission system assets properly considering EVs.

• This work belongs to Themes 2, primarily, and 3.

• PhD student Nafeesaa Mehboob is carrying out this work.