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XXXIII Cycle

Novel modeling concepts for the resilience assessment of next generation smart grids

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Research context and motivation

- Current and next generation power distribution networks are **complex systems** characterized by a large size, the interconnection of heterogeneous objects (e.g., distributed renewable sources or storages such as electric vehicles charging hubs, etc), and a **stochastic behavior due to both unknown customer demand and other external conditions** (e.g., weather, strong geo-storms, lightning storms) affecting power generation.
- All the above system features require the availability of **innovative and general modeling solutions** for the accurate prediction of the network state (e.g., via either transient or steady-state simulations).
- Emphasis on **distribution networks** modeling for steady state analyses and stochastic behavior of distributed generation (DGs).

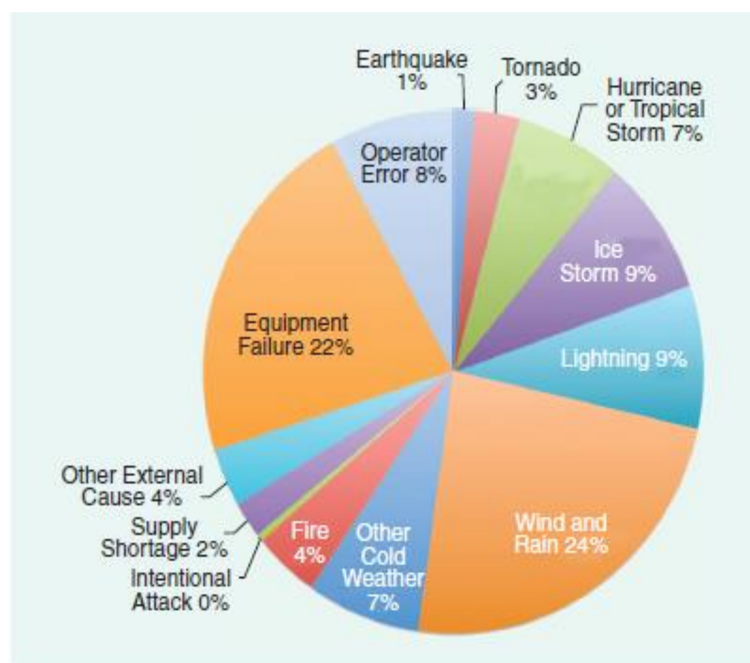


Fig. 1 Initial causes of blackouts affecting at least 50,000 customers between 1984 and 2006. Data from NERC records (www.nerc.com).

Addressed research questions/problems

- Efficient simulation of a complex (large) power distribution networks.
- Account for both the stochastic behavior of basic constitutive components (e.g., renewable sources) and disturbances (e.g., electromagnetic pulses or geomagnetic disturbances).
- Systematic assessment of the accuracy of simplified approaches and comparison with either physics-based modeling or measurements.

Novel contribution and Workplan

- **YEAR 1** (Politecnico di Torino) – attend courses, study the basic approaches for the simplified graph-based simulation of transmission (done) and distribution systems; e.g., power flow (DC type) analysis for cascade failure assessment. Custom implementation in MATLAB and comparison with available tools. Application to standard IEEE transmission. Browse published papers on electromagnetic pulses and geomagnetic disturbances (done).
- **YEAR 2** (Politecnico di Torino 3 mo, Xi'an Jiaotong Univ. 9 mo). **Circuital interpretation in the phasor domain, for the steady state solution of power flow of a generic distribution network (done).**
- Validation of the model with traditional techniques and with the tool (Power System Analysis Software Package - PSASP) used by China Electric Power Research Institute (CEPRI). *Activity in progress.*
- Account for variability effects of renewable generators spread into the network.
- **YEAR 3** (Politecnico di Torino 3 mo, Xi'an Jiaotong Univ. 9 mo). Application to real test cases. Involvement of industrial partners for data and test cases.

Submitted and published works

- Z. A. Memon, R. Trinchero, Y. Xie, F. G. Canavero, I. S. Stievano, "An Iterative scheme for the power-flow analysis of distribution networks based on decoupled circuit equivalents in the phasor domain", IEEE Trans. Power Systems. **Submitted, under review.**

Adopted methodology

Steady-state analysis of distributed networks with renewables

- Circuital interpretation of power distribution network in the phasor domain (Fig. 1(a))
- Nonlinear components in the phasor domain account for the behavior of distributed generators (Fig. 1(b))
- The net is split into a linear and a nonlinear portion at a given frequency (Fig. 1(c)).
- Equivalent circuit in fig. 1(c) is solved via the modified nodal analysis (MNA) tool using the iterative scheme (*fixed point iteration*), see Fig. 1(d), by eq. given below:

$$\begin{cases} \hat{\mathbf{M}}\hat{\mathbf{W}}^{(i)} = \hat{\mathbf{A}}_0 + \hat{\mathbf{A}}^{(i)} \\ \hat{\mathbf{A}}^{(i+1)} = \hat{\mathbf{A}}(\hat{\mathbf{W}}^{(i)}), \end{cases}$$

$$\|\hat{\mathbf{W}}^{(i+1)} - \hat{\mathbf{W}}^{(i)}\|_{L2} \leq \varepsilon.$$

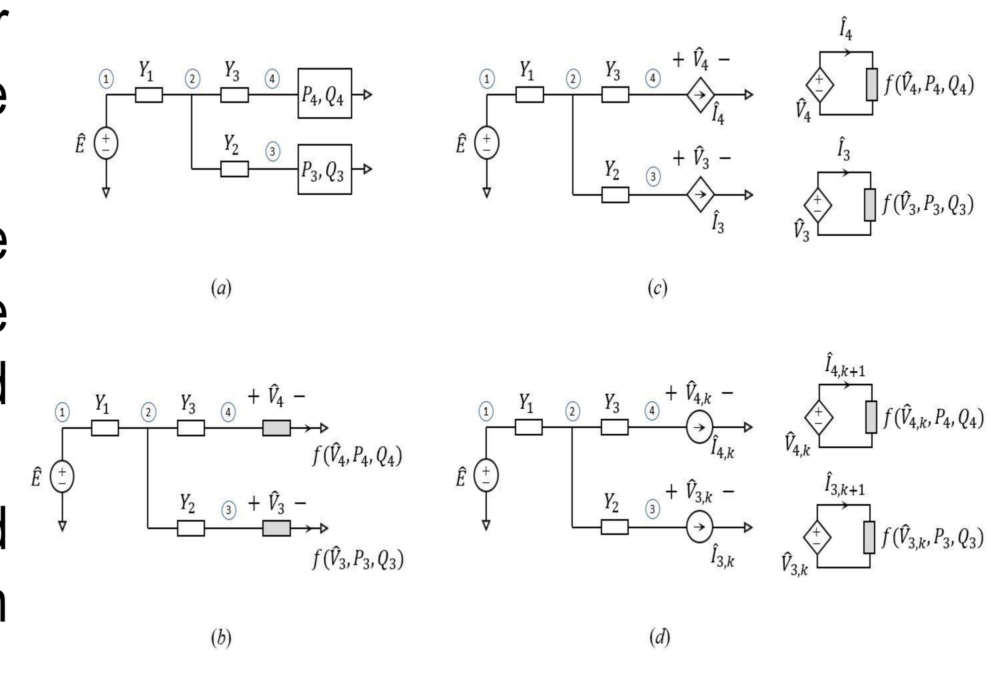
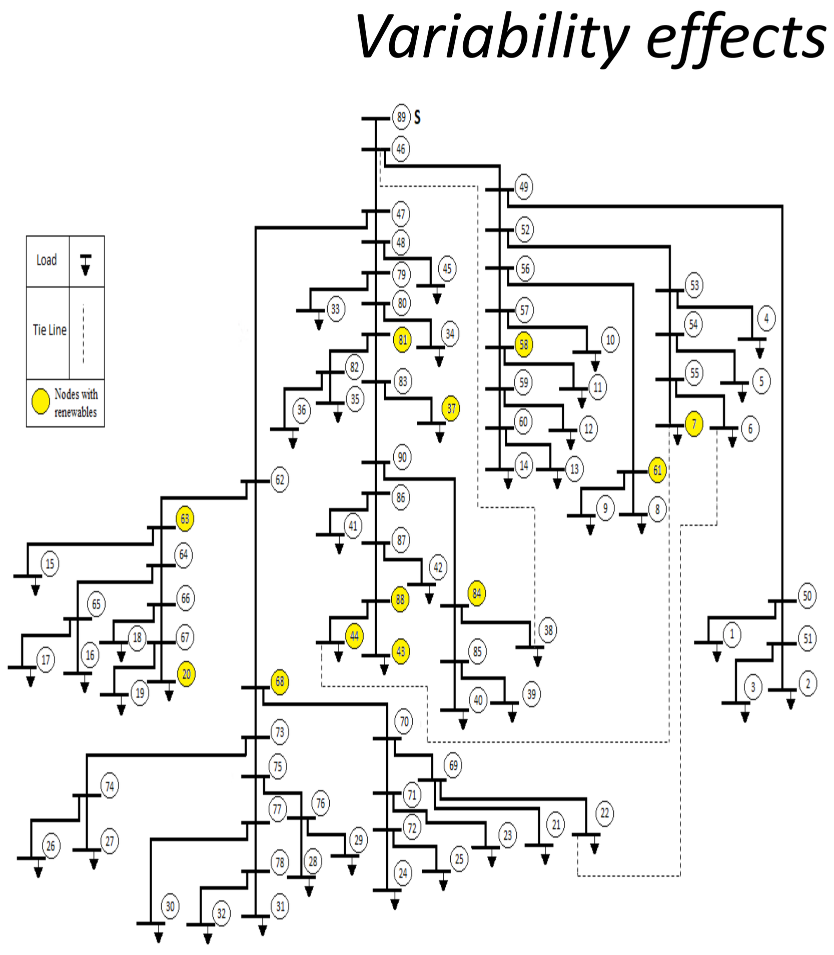


Fig. 1: Arbitrary power distribution network with two renewables connected at nodes 3 and 4. Panel (a): original power network; panel (b): interpretation of the network as a nonlinear circuit in the phasor domain. The gray boxes represent two-terminal elements defined by nonlinear current-voltage relations in the phasor domain which are equivalent to the renewables defined by the information on power; panel (c): circuit equivalent with controlled circuits, splitting the original network into two parts, a large linear portion and a nonlinear section defined by the nonlinear elements only; panel (d): circuital interpretation of the proposed iterative solution scheme.

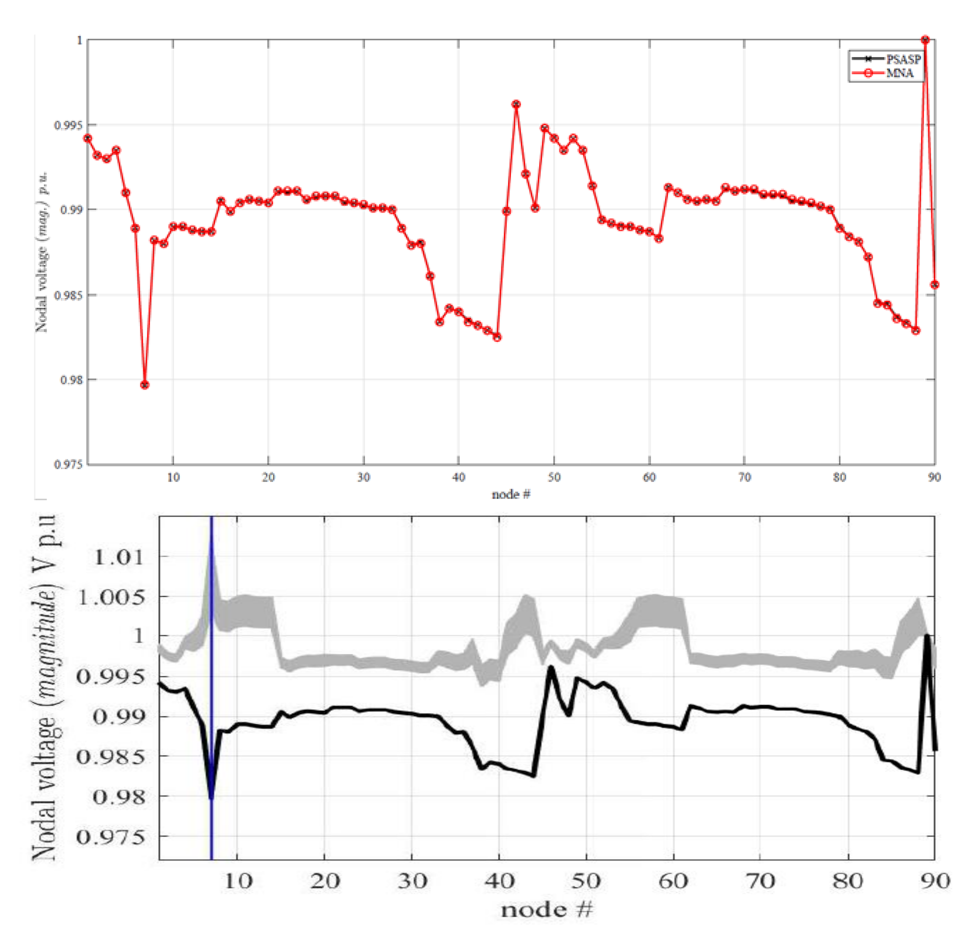
Where, $W \in C^5$ is a complex vector collecting the nodal voltages and currents flowing through current controlled elements,
$A \in C^5$ is a complex vector collecting the independent sources of the circuit, and M is a complex circuit readily derived from the topology of the circuit (fig.1(b))
$A(W)$ accounts for the nonlinear I-V characteristics of the network load and renewable elements.

Results (YEAR 2)

Variability effects of renewables (±20%)



IEEE90 Test Case Topology



Future work (short/medium term)

- Analyses of larger distribution networks (e.g. 8500 Node feeder) for efficiency analysis of the model.
- Application of real test cases. Involvement of industrial partners for data and test cases.

List of attended classes

01SWJRV – Control and optimization in Smart Grids (Jun. 2018, 20h), 01QTEIU – Data mining concepts and algorithms (Mar. 2018, 20h), 02ITTRV – Photo voltaic generators and systems (Apr. 2018, 25h), 01QSAIU – Heuristics and metaheuristics for problem solving: new trends and software tools (July 2018, 20h), 02PJWRV – Energy Efficient Networks (July 2018, 40h), 02LWHRV – Communication (Mar. 2018, 5h), 01RISRV – Public speaking (Mar. 2018, 5h), 01SAYRV – Self Management: techniques for work environment (Apr. 2018, 10h), 01PJMRV – Etica informatica (Mar. 2018, 20h), 01LYXRV – Electrical load management, forecasting and control (Sept. 2018, 25h), 01NDLRV – Italian Language Level 1 – (Jun. 2018)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering