PARIS 2022

Study Committee B5

Protection and Automation

Paper ID 10147

Federal University of Paraíba (UFPB)

FROM HERTZ TO MEGAHERTZ: LESSONS LEARNED ABOUT THE IMPACT OF INVERTER-BASED WIND TURBINE GENERATORS ON THE PROTECTION OF INTERCONNECTING LINES

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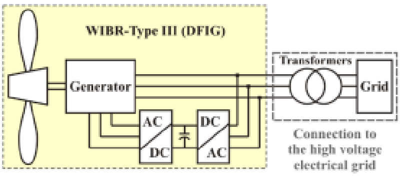
Motivation

- Massive integration of Inverter-Based Resources (IBRs) have resulted in great changes in electrical power grids
- Wind IBRs (WIBRs) already accounts for about 12.5% (2022) of the total Brazilian generation capacity
- Traditional protection schemes have been challenged!
  - Various solutions have been developed
  - Several researches → **LESSONS LEARNED TO SHARE!**

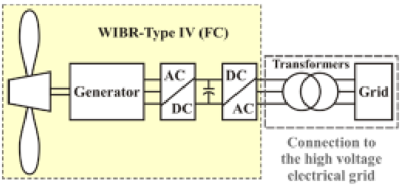
Evaluated Topologies

- This work is focused on two types of WIBRs
  - **Doubly-Fed Induction Generator (DFIG/Type III)**



✓ Two connection paths:
  - 1) Stator to the grid;
  - 2) Rotor windings via an AC-DC-AC converter

  - **Full Converter Generators (FC/Type IV)**



✓ Only one path → Completely decoupled (≈ PV plants)
  - 1) Connected via an AC-DC-AC converter

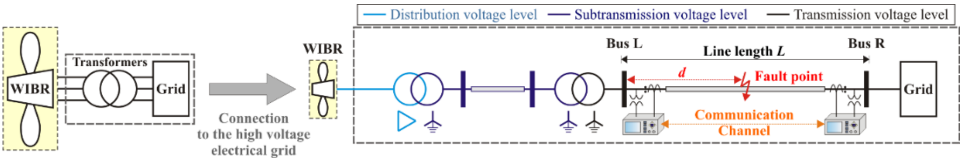
Atypical Fault Contributions of IBRs

- Conventional synchronous generators have high inertia
  - During short-circuits, energy continues to be delivered to the fault → **Design of classical protection**
    - Relevant fault current contributions
    - Well-defined voltage angles
- IBRs are governed by converters
  - Control strategies define how DFIG and FC units ride through faults → **Atypical fault contributions**
- Fault response often verified in systems with WIBRs
  - DFIG → Fault currents up to 2 pu
  - FC → Often limited to 1.2 pu
  - Crowbar operation and control strategies can result in relevant frequency deviations
    - Low fault current contributions
    - Voltage angles difficult to predict
    - Uncertainties on the presence of certain sequence components, etc

Grid Codes

- Grid codes have been proposed to avoid multiple control strategies in the same power system
- A variety of grid codes can be found and they are under development in several countries
- In this work, two grid codes are evaluated:
  - An European Grid Code (EGC) (see paper references)
    - Reactive current emulation
  - An American Grid Code (AGC) (see paper references)
    - No reactive current emulation

Topology of Typical WIBRs Interconnection to the Power Transmission Grid



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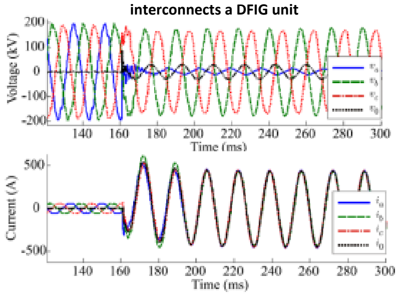
Lesson 1: "Not everything is 'control'. The interconnection circuit topology matters!"

- It is common to hear: "converter controls cause the problem of WIBR' fault response"
  - Control strategies limit positive and negative current sequence contributions
  - Grounded neutrals lead the fault to be dominated by zero sequence quantities in grounded faults
  - Being dominated by zero sequence currents usually minimizes protection issues → **It is a system contribution rather than a WIBR contribution**

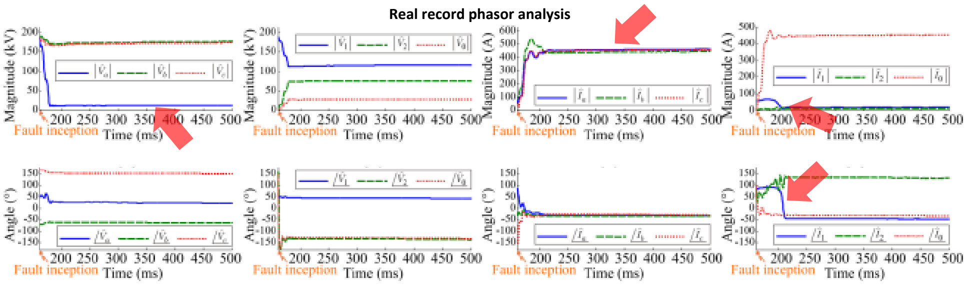
Real record taken from a transmission line that interconnects a DFIG unit



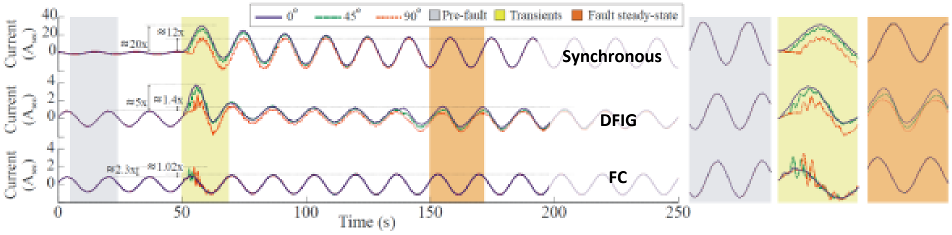
Lesson 2: "Atypical WIBR fault contributions are not limited to fault current levels"

- Study on fault current contributions based on EMTP simulations and real record studies
- Low fault current contributions consist in only one of the possible impacts → **Synchronous generator >> DFIG > FC**
- Angles of electrical quantities may vary during the fault period → **Quite challenging for protection functions!**

Real record phasor analysis

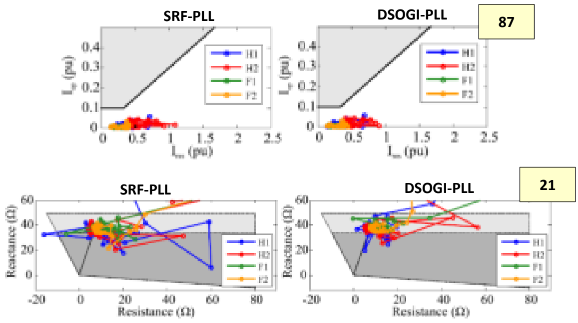


- Fault-induced high frequency components follow the classical theory of electromagnetic transients
- DC decaying component varies with the fault inception angle (here, sinusoidal ref.) → **Synchronous generator > DFIG > FC**



Lesson 3: "Pay attention to digital phasor estimation filters"

- Phase-locked-loop (PLL) schemes are used to estimate system voltage frequency and amplitude → **It drives the inverters!**
- Errors in estimated frequencies can occur
- Spurious frequency components can take place
- Synchronous Reference Frame (SRF-PLL) [19] and Dual Second Order Generalized Integrator (DSOGI-PLL) are evaluated
- Full-cycle (F1, F2) and half-cycle (H1, H2) phasor estimation filters are assessed



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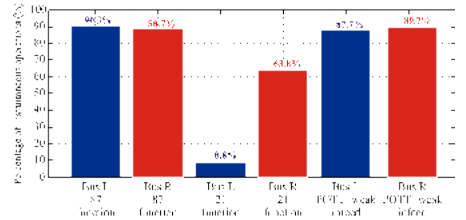
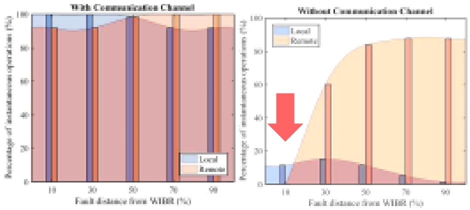
Lesson 4: ''Blind zones on the interconnecting line may exist if communication is lost''

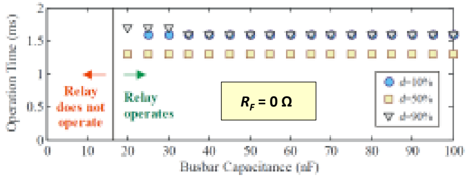
- Differential protection and pilot protection schemes have shown to be promising → **The need for a communication channel is a drawback** → **Is the non-unit protection reliable?**
- PS Simul EMTP massive simulations and playback tests using the CE-7012 test box + real microprocessed relays from 4 different manufacturers (firmware versions from 2018) → **Evaluation of instantaneous operation percentage of: 87, 21 and POTT+Weak Infeed schemes**

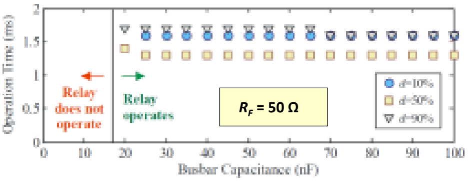




Lesson 5: ''EMTP models must include stray capaci ''

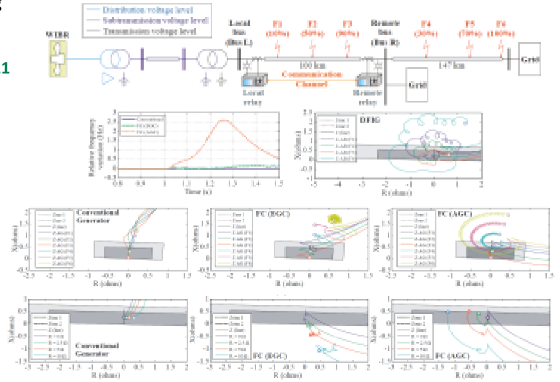
- Results on the busbar stray capacitances are presented in this work. Transformer stray capacitances must be also considered
- Evaluation of a traveling wave-based differential element, varying the busbar stray capacitance, for different fault resistance R_F → **Conclusions are different!**
- Realistic modeling is mandatory to avoid misinterpretation on the performance of transient-based protection functions





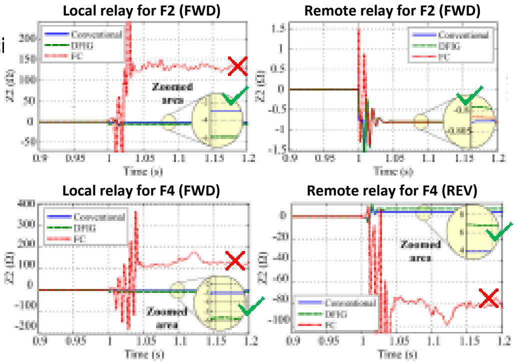
Lesson 6: ''For each system, a particular study. Uncertainties are inevitable!''

- Sources of uncertainty: Diversity of grid codes, control strategies, interconnection topologies, IBR features, use of BESS, increasing IBR insertion at remote terminals, crowbar operation, protection particularities, and so on



Lesson 7: ''Directional elements will not always fail. It depends on the fault location''

- Many people thinks that directional elements will always fail in systems with IBRs, but it depends on the fault location
- Negative sequence element: FWD: Z2 < thr+ and REV: Z2 > thr+



Conclusion

- Innovative solutions have been developed, specially to improve non-unit protection
- Alternative operating characteristics, enhanced phasor estimation solutions, use of voltages rather than currents for phase selection, analysis of fault-induced transients, reduced decision-making time, communication redundancy, and so on
- Uncertainties are inevitable and more challenging scenarios are coming soon
- Reliable open-source EMTP models are of paramount importance for future developments

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