cigre PARIS 2022

Study Committee B5

Protection and Automation

Paper PS1_10145_2022

Influence of Inverters Based Sources on Protection Devices

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Motivation

- Inverter Based Sources (IBS) continue to be added to power grids and shift away from traditional generation based on high-inertia Synchronous Generator (SG), towards smaller and dispersed renewable sources based on SG and/or IBS, will continue being implemented. Under fault conditions in the power system, the IBS do not behave in the same way as large SG.
- The unique response of these sources to fault conditions considerably challenges traditional protection principles developed decades ago for grids with SG driving fault currents.
- With the increased penetration of these IBS, traditional grid protection principles will be stressed to the point of potentially losing dependability of voltage and/or current quantities.
- Nowadays, there is only slow progress in devising new protection principles more suitable for grids with the presence of IBS.

Method/Approach

- The paper demonstrates the harmonic analysis considering one real disturbance case in the Brazilian Interconnected Power System (BIPS), in the presence of one Wind Park (WP), and also one simulation using Electromagnetic Transient Software (EMT). Also, the paper highlights recommendations regarding complex generation interconnection model, protection settings and power quality.

Objects of Investigation

- Due to several improper operations of electrical protection functions, particularly those of distance and current and power directional protection in the Brazilian electrical system, in the presence of IBS, many studies and analyzes have been conducted in order to understand this new behavior, as well as able to characterize and mitigate it.
- Recommendations from some manufacturers have been made to avoid the maloperation of relay protection functions.
- Harmonic analyzes have demonstrated the influence of subharmonics on the performance of digital processing of protection relays, together with problems involving the Phase-Locked Loop (PLL), causing instability in the angle and/or frequency phasors, causing problems such as over/underreaching distance protection elements as well estimation of voltage polarization for directional protection elements.

Objects of Investigation

Real Disturbance Event in the BIPS

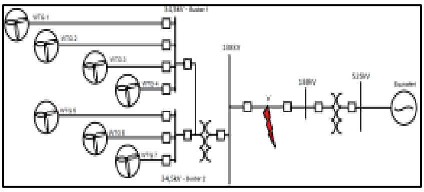

Figure 1 – Wind Park and Single-Line Ground Fault at Point 'P'

- Figure 1 corresponds to the single-line diagram of a 138 kV Transmission Line (TL) close to a WP with an installed capacity of 164 MW, where a single-phase short-circuit at point P stands out. This event occurred in the BIPS. Figures 2 and 3 show the behaviour of voltages and currents during the event. Figure 4 shows the spectral analysis using Fourier Transform (FT) of voltage phase A during the whole period of the signal. It is possible to verify the presence of subharmonic orders around 6Hz, 20 Hz and 30 Hz, and magnitudes around 10% of fundamental frequency of 60 Hz.

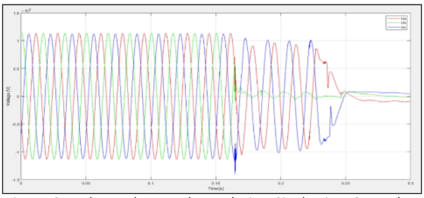

Figure 2 – Three Phase Voltage during Single-Line Ground Fault at Point ´P'

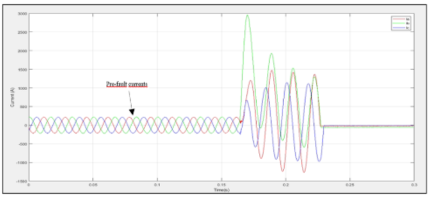

Figure 3 – Three Phase Current during Single-Line Ground Fault at Point ´P'

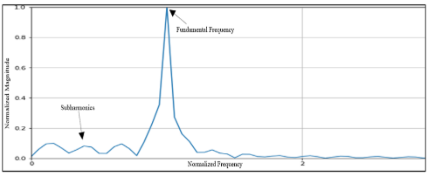

Figure 4 – Voltage Phase A – Normalized Frequency and Magnitude

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Objects of Investigation

- As the relay will work with one sliding FT window, it will be able to capture these 3 fault cycles, however, to perform the harmonic content, for example, the subharmonic of order 5 Hz, it will be necessary to have one sliding window size of 60Hz / 5 Hz = 12 data cycles, and the protection relays, normally, working with one sliding window, considering 1 or 3 data cycles, for example, depending on the digital processing strategies of each manufacture.
- The unique response of these sources to fault conditions considerably challenges traditional protection principles developed decades ago for grids with SG driving fault currents.
- If the relay works with one sliding window of 12 data cycles, for example, in the first fault cycle, it would have 11 pre-fault cycles plus 1 fault cycle, and then it would discriminate the subharmonic.
- In the second estimation it would "slide" the samples discarding the oldest one and updating the newest one from the second fault cycle, then estimating the subharmonics until the circuit breaker opens.
- In case the protection relay is not able to discriminate the subharmonics, working with only the 3 data cycles, for example, these subharmonics will appear in the signal as DC shift and this will influence, depending on the magnitude of the subharmonic, the algorithms of fault location, infeed/outfeed, under/overreach, and loop selection of the relay.

Wind Park Simulation using EMT Tool

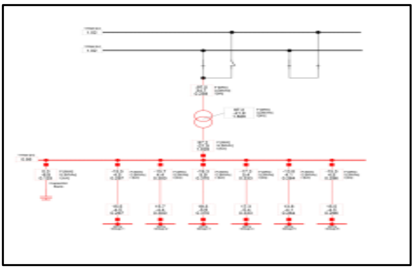

Figure 5 – Wind Park modeled in EMT Software

- Figure 5 shows one WP modeled in one EMT software, where it´s possible to verify the AC 230 kV network, one capacitor bank in the 69 kV side (reactive power compensation P/Q and Q/V curves at PCC), and the WP equivalent in the 0.69 kV side. The system was modeled considered ont WP with 100 MW.
- In Figure 6, there is the Group 1 of the WP. The models used for the WTG were in accordance with benchmarching system available from DIgSILENT library software.

Objects of Investigation

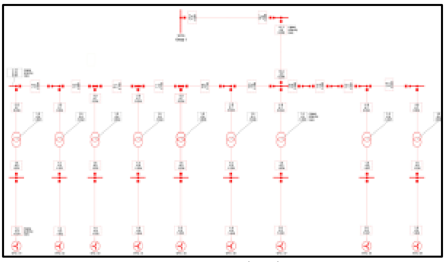

Figure 6 – Wind Park Group 1

- Each WTG was modeled also considering interharmonic content in accordance with IEC 61000 standard limits. In Figure 7, there is the voltage harmonic distortion of the WTG-01, considering the fundamental frequency as 60 Hz.
- In Figure 8, there is the harmonic resonance (parallel resonance) of the WTG-01 (magnitude and angle).

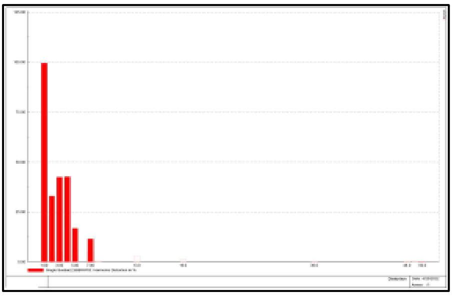

Figure 7 – WTG-01 Harmonic Distortion

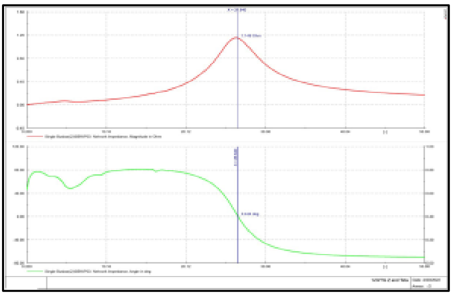

Figure 8 – WTWTG-01 Frequency Sweep

- Thus, it is importante to model the WTG in one EMT software considering not only the interharmonics, but also the subharmonics contents, otherwise it will be not possible to verify the impact of these subharmonics into the network during the simulation.

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General Recomendations

Complex Generator Interconnection Process and Modeling and Studies:

- Inconsistent modeling and study requirements, lack of clarity at time of request and changes in equipment and settings throughout process;
- Lack of transparency and "sign-off" on critical decisions;
- Lack of mutual agreement and understanding about equipment settings and detailed models;
- Process improvements needed and difficult for both Generation and transmission sides.

Growing List of Modeling Issues:

- Transmission entities taking models at face value with no analysis of model quality;
- Unintentionally incorrect models (parametrization) used and never questioned. Intentionally incorrect models used to get through interconnection process easily;
- There is a lack of technical expertise in companies to detail EMT models and analyze vast number of models for interconnection requests;
- Interconnection studies not picking-up reliability issues with positive sequence studies mostly, will not identify transients problems;
- Furthermore, detailed EMT studies without accurate models of protection and inappropriate use of EMT models, or overestimation of model quality, will bring wrong results;
- Studies disabling protection and modifying controls without systemic modeling errors during interconnection and in planning studies with defaults models used in interconnection studies, never get updated or restudied during interconnection process;
- Generator owners making changes to equipment without seeking prior approval (models not getting updated).

Protection Settings:

- The IBS protection system must be defined based on the limitations of the power electronic equipment and must meet the minimum technical requirements;
- Frequency related tripping should use accurately measured frequency over time window;
- Inverter sub-cycle overvoltage protection should be set as high as possible within equipment limitations. Specify performance during successive fault events;

General Recommendation

Protection Settings:

- The ROCOF protection should be disabled unless equipment limitation exists;
- Distance relays with instantaneous device, installed close to the IBS, must have their settings checked, evaluated and tested using properly specific software programs;
- It is observed that the frequency, at the time of the fault, being different from the pre-fault, can lead to wrong behaviour in protection based on voltage memory polarization over time.

Power Quality:

- Specify outage scenarios for IBS to assess power quality impacts and request grid harmonic impedance characteristics from utilities;
- Request reactive data from utilities and measure background power quality prior to interconnection for design reference and later power quality matrix of responsibility (injection of harmonics into network);
- Steady-State power quality monitoring recommended for commercial operations and to characterize current harmonic distortion;
- Any issues must be addressed based on the requirements established by utilities.

Conclusion

- This work made a contribution on the impact on the electrical grid and on electrical protection systems against non-conventional energy sources such as wind sources;
- The work also addressed, in an informative way, the challenges to be faced in the operation in view of the increasing presence of converters in the power grid;
- It becomes very important to perform the correct modeling of the harmonic sources in the EMT software, as well as the adequate modeling of the WTG control loop, such as the PLL loop control, for example;
- As a highlight, certain phenomena in the electrical network, such as the presence of subharmonics, should be monitored in real time and new digital signal processing techniques, in addition to the Fourier transform - commonly used in electrical protection relays, should be studied, tested, implemented and validated, in order to bring more reliability of the phasor protection functions.