NAME: Rafael Fernandes
COUNTRY : Brazil
REGISTRATION NUMBER : DLG7268

GROUP REF. : B5
PREF. SUBJECT : PS1
QUESTION N° : 1.02

1. Question

Q1.02: Are risks of distance protection maloperation or failure to trip limited to transmission lines directly connected to the wind power plant or do you see broader implications for protection further away from the wind power plant point of connection to the transmission grid?

2. Keywords

Inverter Based Source, Protection Device, Inertia, Harmonic.

3. Main Contribution

The main objective of this contribution is to address the impact of the challenges on the performance of transmission lines protection schemes. Outputs from Electromagnetic Transient (EMT) software and records from real disturbances have been included, to clarify the problematics, mainly with the distorted signals contents and the influence on the behaviour of the electrical protection relay against the digital signal processing via the application of Fourier Transform.

4. Theoretical Concepts

4.1 Classification of Inverters

The inverters can be generally classified into Voltage Source Inverter (VSI) and Current Source Inverter (CSI). The VSI converts the Direct Current (DC) voltage to three–phase Alternate Current (AC) voltage with adjustable magnitude and frequency whereas the CSI converts the DC current to an adjustable three-phase AC current. The Inverter Based Source (IBS) normally produces distorted line currents and also can cause, for example, notches in voltage waveforms.

4.2 Impact on Transmission Line Protection Schemes

The challenges posed by IBS to the transmission line protection schemes are multiple and proportional to the level of IBS penetration in the power grid, the control system settings and performance, the type of connection to the grid and the specific adopted protection scheme. As point as attention, in general:

- During the period of the fault the IBS waveform output tends to be distorted and can influence the expected behaviour of the frequency/angle on the the voltage/current phasors estimation process;
- IBS output frequency could be unstable and generate abnormal frequency with unexpected Rate of Change of Frequency (ROCOF);
- The IBS fault current magnitude contribution will be almost nominal value as limited by the thermal rating of the power electronic components;
- IBS reacts to a system fault with two distinctive period, the transient and steady state period. The transient period varies between half a cycle to 1.5 cycles;
- IBS fault current sequence components, magnitude and angle, will depend on the IBS control setting and the generating conditions before the fault;
- IBS control system tends to supply balance fault currents during balanced and unbalanced fault and might not provide adequate negative sequence components to be used by the protection and control elements that depends on the negative sequence quantities.

5. Simulation and Results
5.1 Wind Farm Simulation using EMT Tool

In Figure 1, is shown one wind fam modeled in the DigSILENT software, where it´s possible to verify the AC 230 kV network, capacitor bank in the 69 kV side (reactive power compensation P/Q and Q/V curves) and the wind farm equivalent in the 0.69 kV side. The system was modeled considering two wind farms, with 100 MW each one. In Figure 2, there is the Group 1 of the wind farm. The models used for the WTG were in accordance with benchmarcking system available from DIgSILENT software.

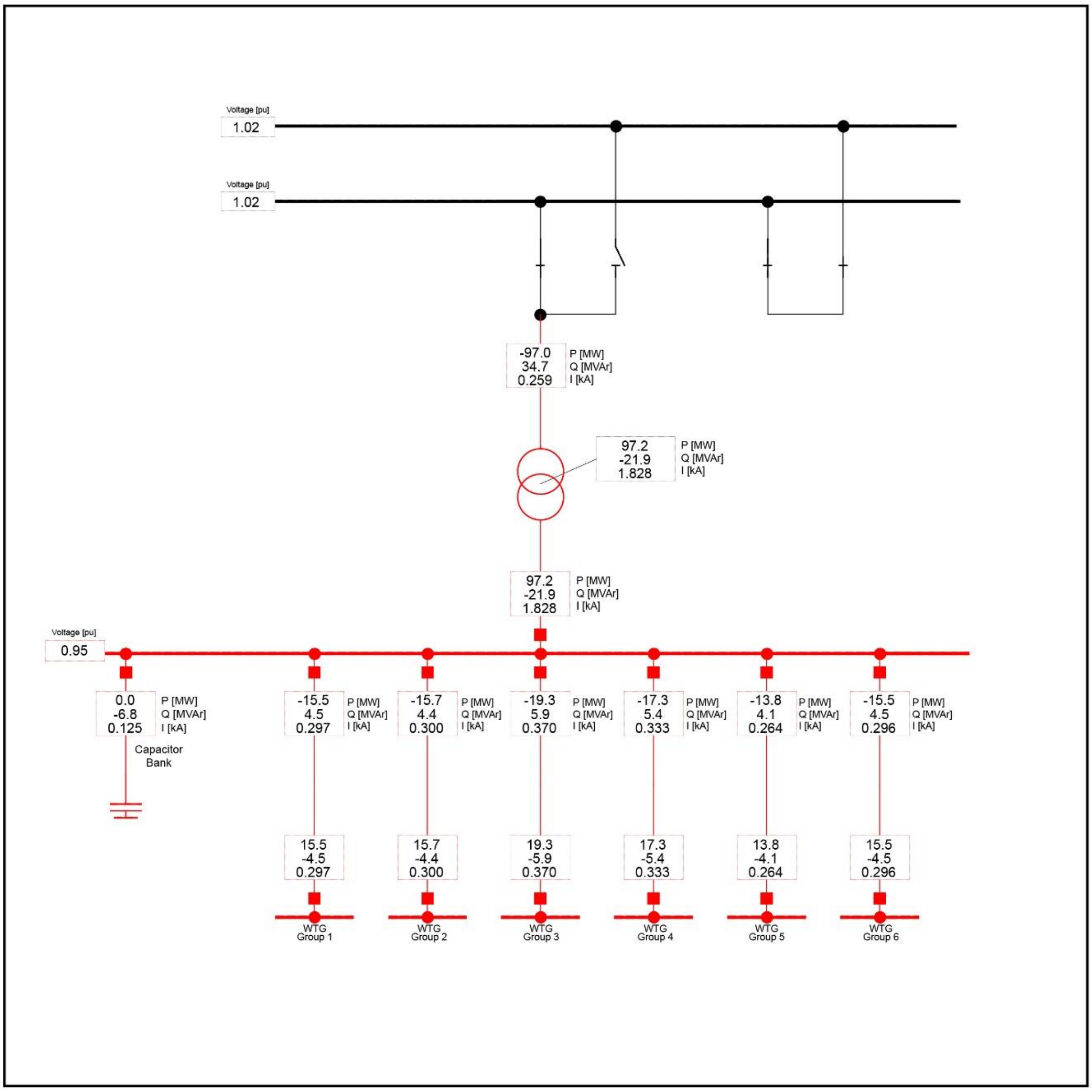

Figure 1 – Wind Farm modeled in DIgSILENT Software. Source : Author

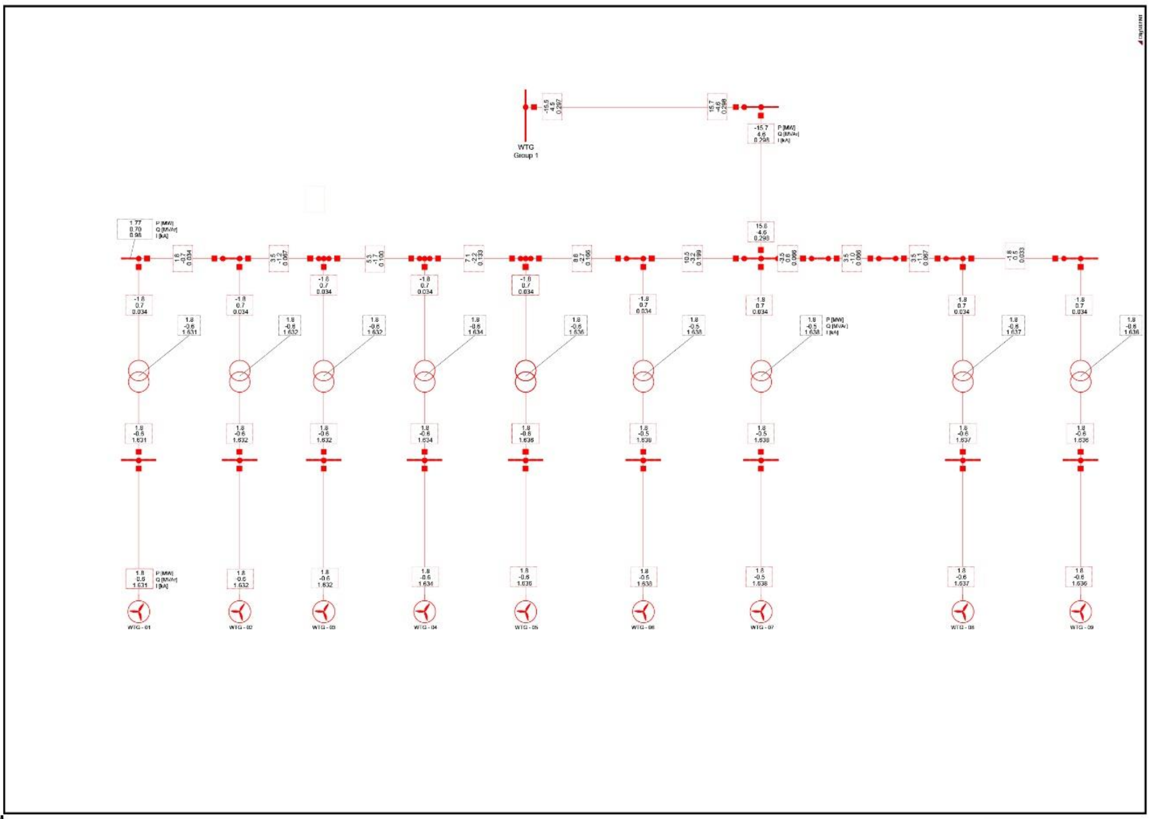

Figure 2 – Wind Farm – Group 1. Source : Author

Each WTG was modeled also considering interharmonic content in accordance with IEC 61000 standard limits. In Figure 3, there is the voltage harmonic distortion of the WTG-01, considering the fundamental frequency as 60 Hz. In Figure 4, there is the harmonic ressonance (paralell ressonance) of the WTG-01 (magnitude and angle).
Thus, it is important to model the WTG in one EMT software considering not only the interharmonics, but also the subharmonics, otherwise it will be no possible to verify the impact of these subharmonics into the network during the simulation, for example.

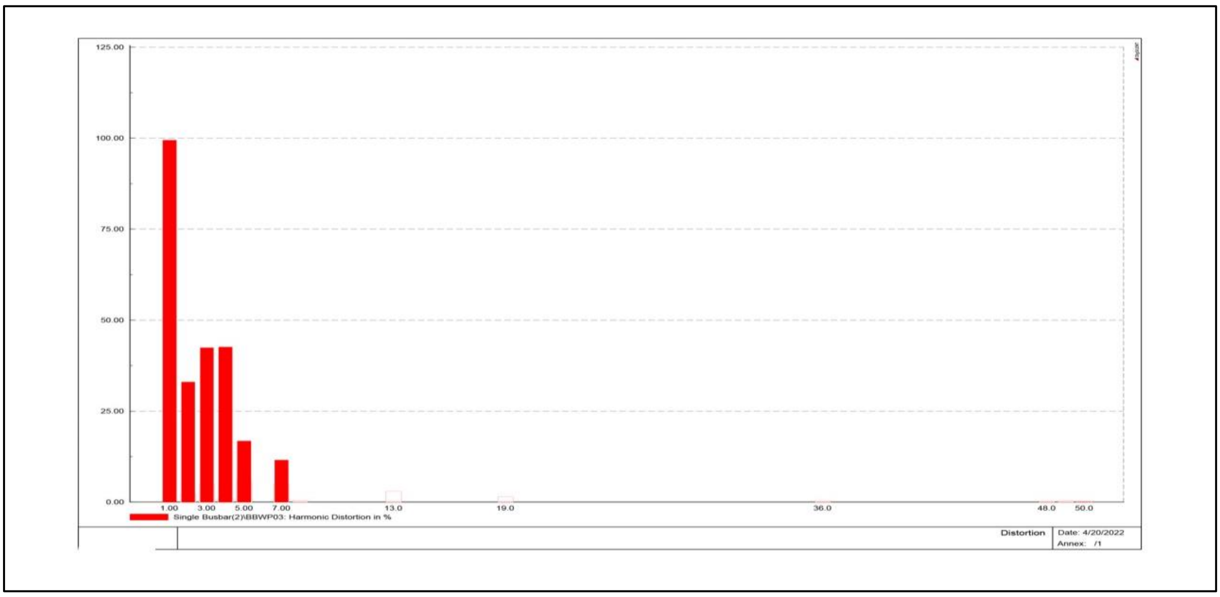

Figure 3 – WTG-01 Wind Farm Distortion. Source : Author

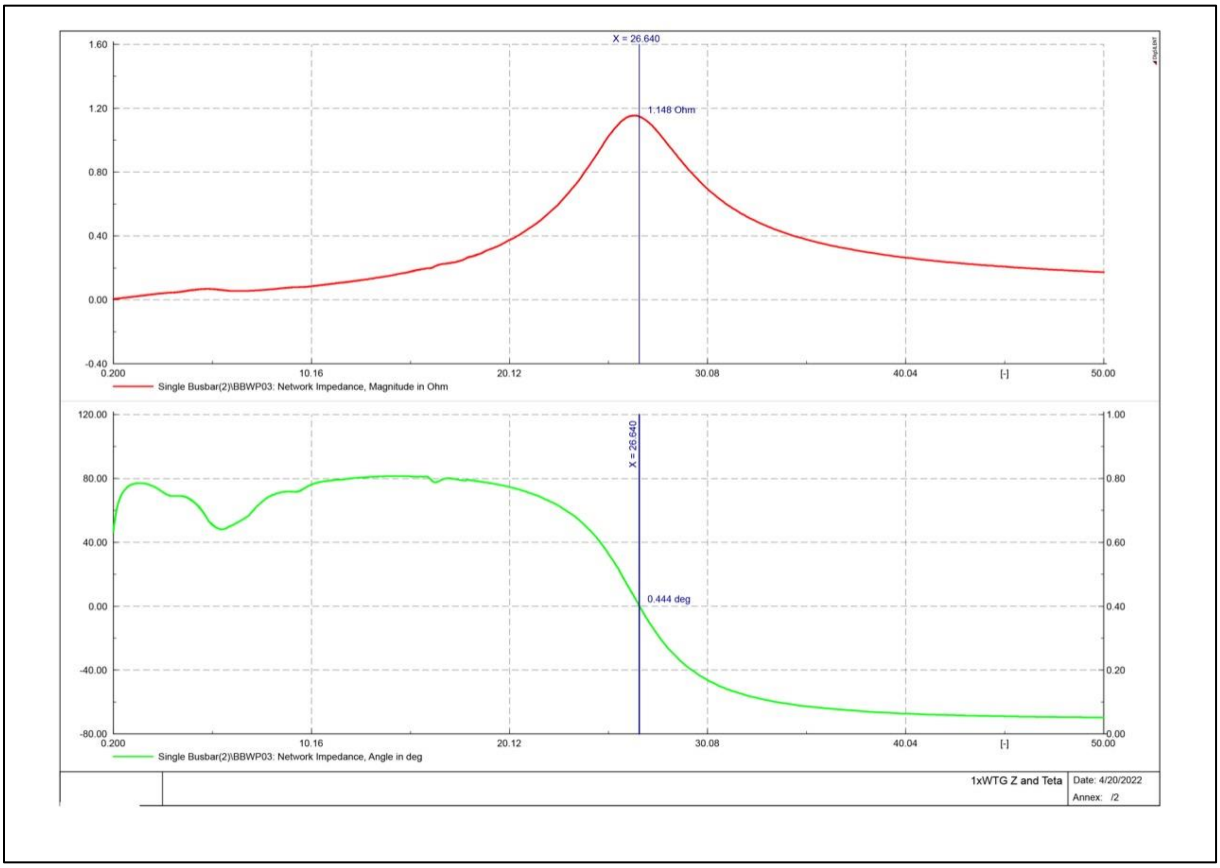

Figure 4 – WTG-01 Frequency Sweep. Source: Author

5.2 Real Disturbance Event in the BIPS

Figure 5 corresponds to the single-line diagram of a 138kV transmission line close to a wind farm with an installed capacity of 164 MW, where the single-phase short-circuit at point P stands out. This event occurred in the Brazilian Interconnected Power System (BIPS). Figures 6 and 7 show the behaviour of voltages and currents during the short-circuit event, with the total pre-fault current being lower than the rated current of inverters. In the Figure 8, there is 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 6 Hz, 20 Hz and 30 Hz, respectively, and magnitudes around 10% of fundamental frequency of 60 Hz

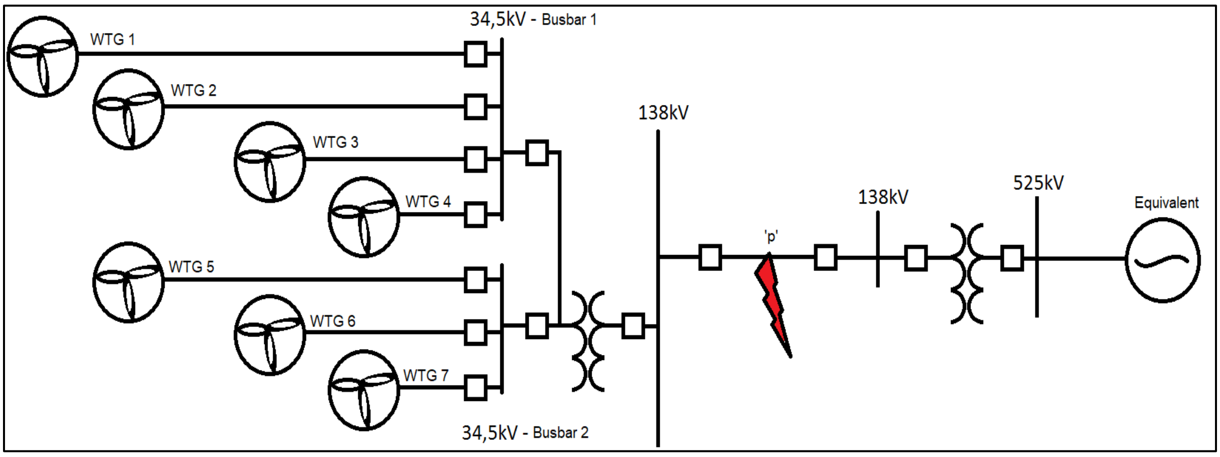

Figure 5 – Wind Farm and Single-Line Ground Fault at TL 138kV. Source: Author

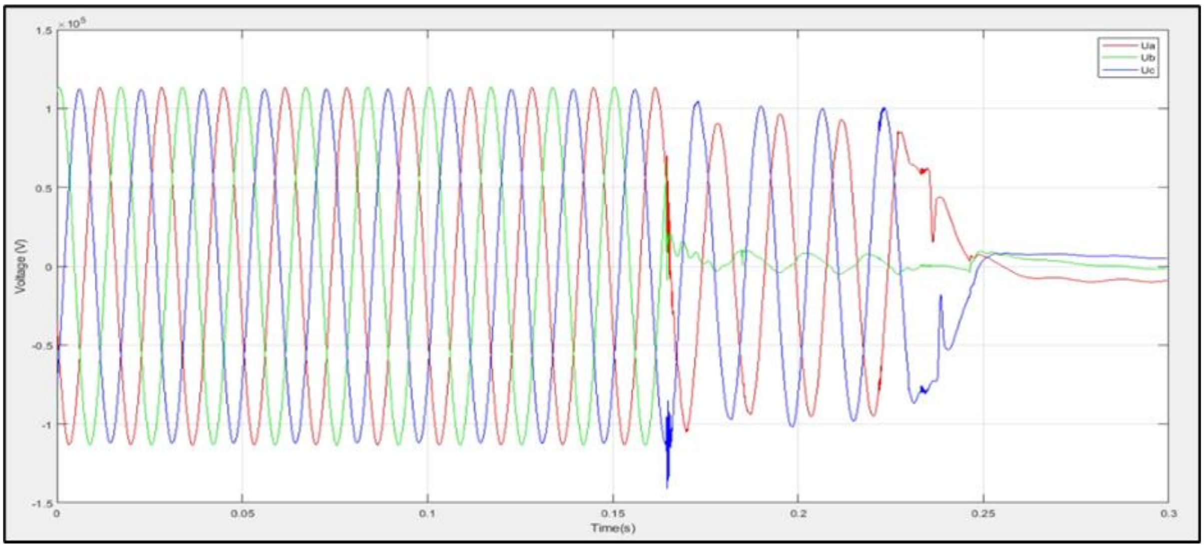

Figure 6 – Three Phase Voltage during Single-Line Ground Fault at Point

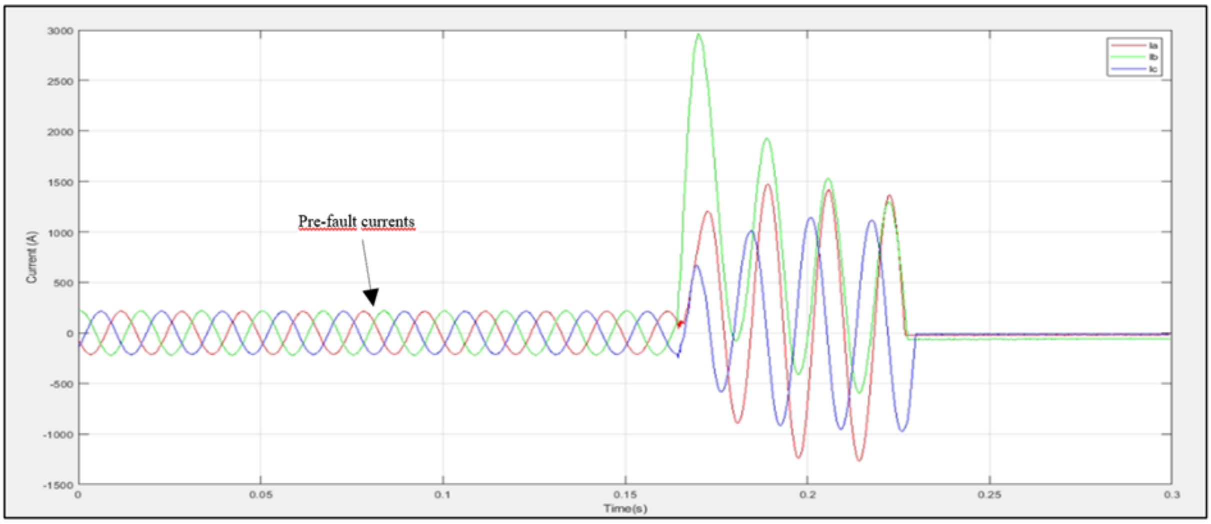

Figure 7 – Three Phase Current during Single-Line Ground Fault at Point

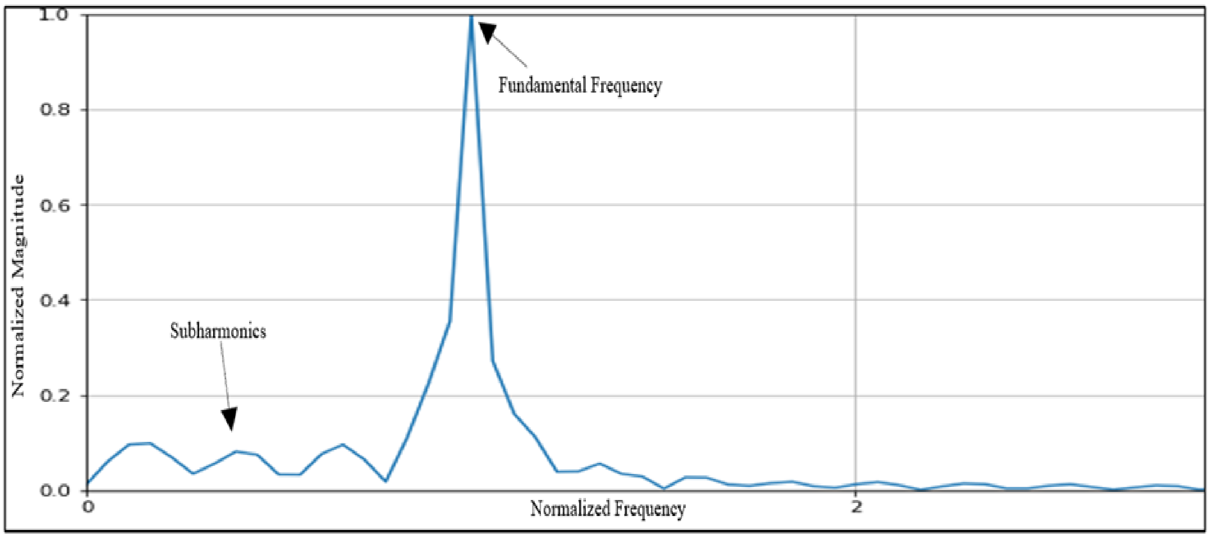

Figure 8 – Voltage Phase A – Normalized Frequency and Magnitude

As the relay will work with one sliding FT window, it will be able to capture 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. 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. The problem is that if the protection relay delay does this, i.e., it works with a window size of 12 data cycles, their processing will include delay. Thus, nowadays, protection manufacture relays via FT with only 3 data cycles cannot precisely discriminate the subharmonic contents. 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. Concluding this approach, the window size needed to discriminate the subharmonic is a 3-cycle window, which is commonly used by most relay manufacturers, and impacts on the errors of the protection algorithms.

6. Conclusion

This contribution shows the impact on electrical protection systems against non-conventional energy sources, particularly wind and solar sources, also addressing, in an informative way, the challenges to be faced in the operation in view of the increasing presence of converters in the power grid. As a highlight, certain phenomena in the power grid, 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. Thus, some electrical protection functions, such as distance and/or current/voltage directional functions, may operate incorrectly in the presence of solar and/or wind sources. It is also recommended that the performance of electrical protection functions for up to 2 adjacent busbars (local protection relay overreaching zone) be evaluated, because the coordination problem between protection functions may occur considering adjacent remote busbars.

7. Bibliography

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