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GROUP REF. : B5
PREF. SUBJECT : PS2
QUESTION N° : 2.03

1. Question

Q2.03: What are the experiences to fault identification and location and how to design the scheme to meet the practical application requirement?

2. Keywords

Fault Location, PMU, Digital Filtering, Digital Windowing, Algorithm

3. Main Contribution

The main goal of this contribution is to present the simulation results using Matlab/Simulink and ATP/Models softwares, with PMUs frame rate of 60 f/s and 480f/s and use of real PMU data with 60 fps for the Fault Location (FL) in a Transmission Line (TL) of 500 kV from the Brazilian Interconnected Power System (BIPS).

4. Synchrophasor Measurement System

3.1 PMU Class

According to IEEE and IEC standards, there are two classes of PMUs, the M class, whose main focus is the monitoring applications of an electrical system, where both the latency and the delay times of the Digital Signal Processing (DSP) are not that significant in terms of applications. Class P has its main focus on applications that require minimum delay times, where the delay time caused by the DSP digital filtering process, as well as the latency, must be minimized. The choice of PMU class becomes an important and decisive factor for the adequate fulfillment of the desired application. Class P PMU requires a minimum delay time, but low immunity in relation to the "out-of-band" interference criterion, being indicated, therefore, for applications such as high-speed control, which generally require a delay of minimum time when dynamic changes occur in the power grid. Class M PMUs require "out-of-band" filtering to avoid the phenomenon of "aliasing" in the signal, where long latencies are also acceptable. They are suitable for applications such as controlling or monitoring low-frequency electromechanical oscillation functions, which are sensitive to aliasing but can tolerate long delay times.

3.2 Digital Windowing

The main role of a digital windowing is to weight the samples for the Fourier Transform (FT). Although the FT a signal can bring a lot of information, it has limitations, making it important to know them to improve the visualization of the signal and, for these cases, the continuous-time windowing technique.

3.3 Windowing Type of a PMU

In the simulation environment, the Hamming window was used for the M class – which has a "sinusoidal" format, with a duration of 10 data cycles. For class P, a Triangular window was used, with a duration of 2 data cycles. Despite the size of these windows, there will not be a necessarily proportional delay, due to causal time compensation.

3.4 PMU Phasor Estimation

For phasor estimation, with class M and class P PMUs modeled at 60 fps, the estimation is performed cycle by cycle. At 480 fps, changing or updating the window is no longer performed cycle by cycle, but every 1/8 of the cycle. As for the recursive Discrete Fourier Transform (DFT) (Sliddding DFT), the phasor estimation is performed sample by sample, whose response to the real perturbation approached the PMU with 480 fps, and the results will be presented below.

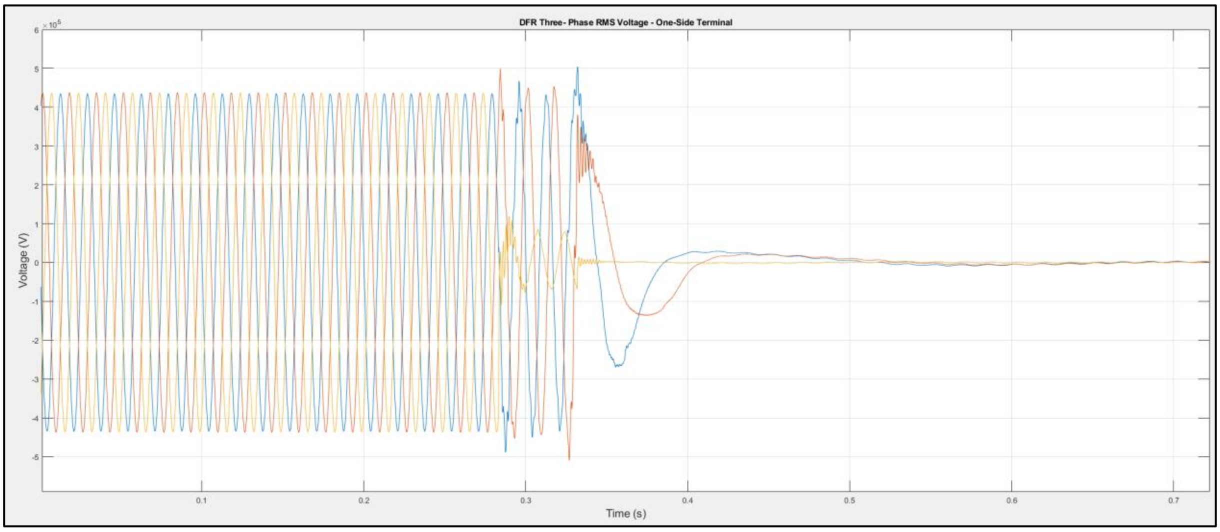

Figure 1 – Three Phase Voltage during Single-Line Ground Fault (DFR data)

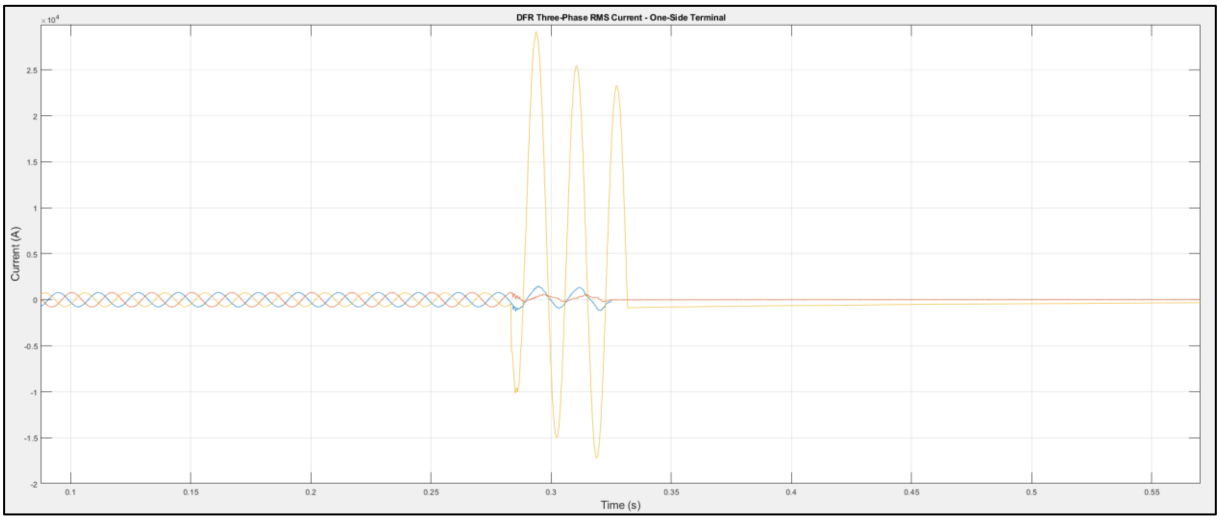

Figure 2 – Three Phase Current during Single-Line Ground Fault (DFR data)

3.5 Simulated System in the ATP Software

The input data of the models - current and voltage circuits, were obtained from the real disturbance in the BIPS, through the instantaneous data of the Disturbance Fault Recorder (DFR), with a sampling frequency rate of 15,36 kHz. In order to have the 8-character Fortran format in ATP/Models, the C++ programming language was used to format the RDP instant data and, in this way, it was possible to read the DFR data file into ATP software (models functionality).

3.6 Simulated System in the Matlab/Simulink Software

In this environment, instantaneous current and voltage data, obtained from one real disturbance in the BIPS, were used as input data. Also, in this software platform, the responses of PMUs of P and M classes, with 60 fps and 480 fps, as well as the response of the recursive DFT in ATP, were temporally aligned in order to compare the results in the same plot. Also, in the Matlab/Simulink, a phasor estimation algorithm was implemented via a protection relay, with a data acquisition frequency of 15.36 kHz (DFR data), a sampling frequency of 960 Hz, a 3rd order butterworth filter, a sliding window with 3 data cycles and DFT with 1 cycle cosine filter.

3.7 Results Obtained from the Simulations

According to Figures 3 and 4, there is an alignment of the PMU, class M, class P and Recursive DFT signals, as well as the protection relay and DFR. The estimate of the "steady-state" period of the fault, for this real case of disturbance, is around 1.0 cycle. With the PMU real data, it is observed that there are between one and two samples available for the FL algorithm calculation. In Figure 4, with a frame rate of 480 Hz, there is a greater amount of data available during the "steady state" period of the fault. The PMU with 480 fps, approaches the behavior of the PMU DFT Recursive.

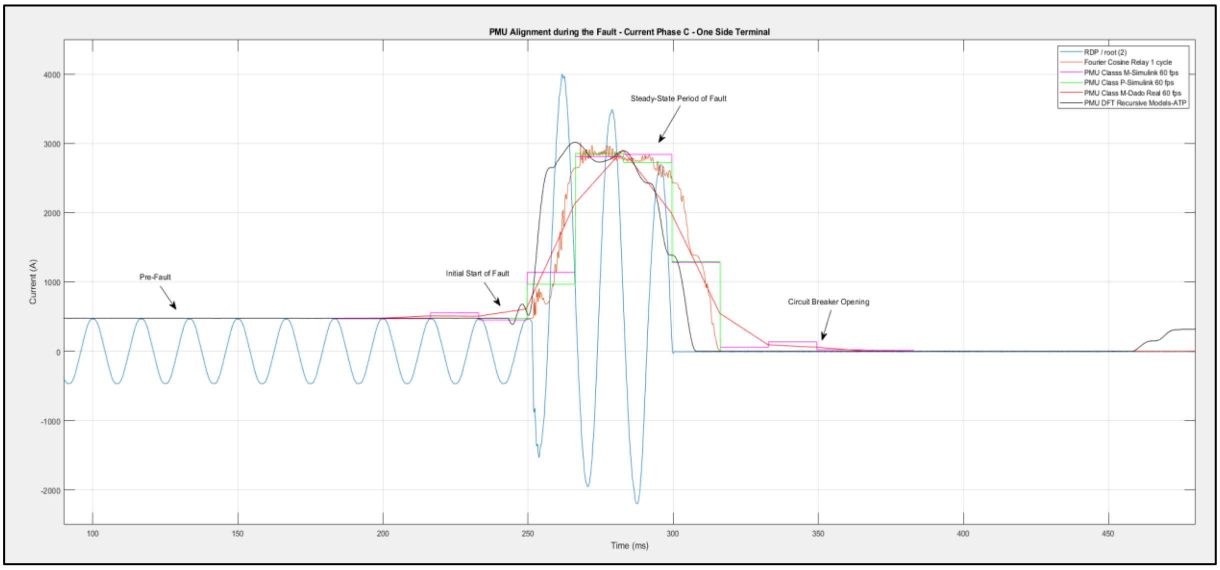

Figure 3 – PMU and DFR Alignment during the Fault – 60fps

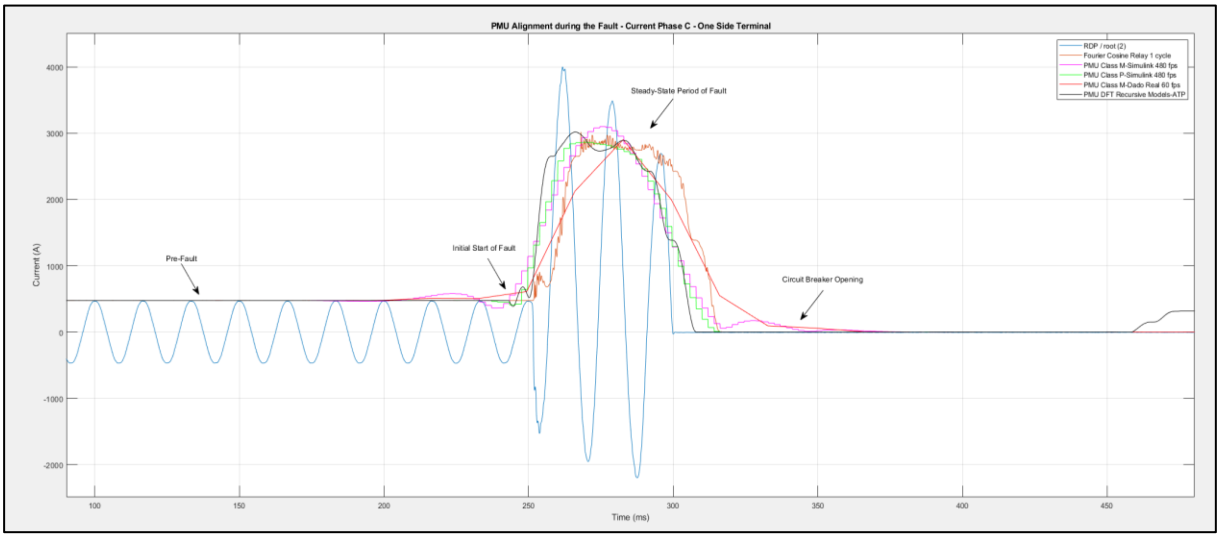

Figure 4 – PMU and DFR Alignment during the Fault – 480fps

Table 1 – Data Obtained from DFR and PMU during the Fault for FL Algorithm Calculation

Terminal 'A'	VA (kV)	θVA $(°)$	VB (kV)	θVB $(°)$	VC (kV)	θVC $(°)$	IA (A)	θIA $(°)$	IB (A)	θIB $(°)$	IC (A)	θIC $(°)$

DFR	287,0	154,0	285,0	26,3	218,0	268,2	718,0	337,0	27,9	249,0	2736,0	188,5
PMU	289,0	85,7	296,0	-40,0	220,0	-158,0	707,0	89,0	15,0	-43,0	2902,0	-58,0
Terminal 'B'	VA (kV)	θVA $(°)$	VB (kV)	θVB $(°)$	VC (kV)	θVC $(°)$	IA (A)	θIA $(°)$	IB (A)	θIB $(°)$	IC (A)	θIC $(°)$
DFR	305,0	166,0	318,0	53,3	51,8	281,6	745,0	189,6	214,0	129,7	14215,0	211,2
PMU	169,0	28,3	251,0	-45,0	10,0	-12,0	99,6	-137,0	377,0	-86,0	11177,0	-56,0

The real TL data used in the implemented algorithm (two-terminals) were: $L = 147\ km,\ R^+ = 3{,}35\ \Omega\ and\ \ X^+ = 50{,}58\ \Omega$.

Using the two-terminal fault location algorithm (DFR and PMU data), according to the methodology described by (Tziouvaras, et al., 2004), the results presented in Table 2 were obtained, having the FL estimation from Relay as reference.

Table 2 – FL Estimation

Terminal	PMU (km)	RDP (km)	R_{falta} $Estimation$ (Ω)	FL $Protection\ Relay$ (km)	$PMU\ Error$ $(\%)$	$DFR\ Error$ $(\%)$
From A to B	139,94	139,46	0,38	140,17	**- 0,16**	**-0,51**

4. Conclusion

The use of synchrophasor information for FL in power systems is still little explored, especially with class M PMUs. The result obtained with the real PMU data, referring to a real disturbance in BIPS, presented an excellent result, with an estimated error of only 235 meters (less than 1 tower for this 500 kV voltage level), when compared to the FL estimated by the algorithm of protection relay. The work showed that although the M-class PMU had a larger data window than the P-class PMU, there were samples in the "steady state" window of the transient event available to the algorithm calculation. A PMU with 480 fps and a PMU with Recursive DFT showed a larger amount of data during the period under analysis, however, having a PMU with 480 fps may impose a very significant data load on the communication channel, so the need and application of the project should be evaluated.

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