Hardware-In-the-Loop Testing of Phasor Measurement Unit using Mini-Full Spectrum Simulator

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I. Introduction

DAy by day power system is becoming more nad more complex, which makes it impossible to operate it without automation for higher reliability. Due to wider geographical distribution of the grid, timely detection of faults and taking preventive/corrective counter measure has become a complex task, which requires a reliable, fast-acting and absolute techniqe to deal with the challenge. This is where the Phasor Measurements Unit (PMU) comes in to the picture. Phasor is a complex number which represents both magnitude and angle of an AC quantity. And the synchronized sampling/ measurement of this phasor at a precise reference (time) is called **synchrophasors** [1]. Using these synchrophasor measurements, different quantities are derived like phase angle, frequency, rate of change of frequency (ROCOF) etc. Frequency is computed as the first derivative of the synchrophasor phase angle, and ROCOF is computed as the second derivative of the same phase angle.

A. Background Theory

Phasor representation of sinusoidal signals is commonly used in AC power system analysis. The sinusoidal waveform defined in Equation (1):

$$x(t) = X_m cos(\omega t + \varphi) \tag{1}$$

is commonly represented as the phasor as shown in Equation (2):

$$\mathbf{X} = \frac{Xm}{\sqrt{2}} \exp^{j\phi} \, or \, \mathbf{X} = X_r + jX_i \tag{2}$$

The *synchrophasor* representation of the signal $x(t)$ in Equation (1) is the value X in Equation (2) where φ is the instantaneous phase angle relative to a cosine function at the nominal system frequency synchronized to UTC.

II. Standard Compliance

EVery PMU should be able to caluculate the value of phasor estimate accurately. The estimate will include positive sequence or single phase values, phase difference, freqnency and ROCOF. So it is importnat to keep in mind that the measurements are actually estimates of certain values.

Now, for a given input wave the computation for estimating the desired quantity are given below: For estimating frequency:

$$f(t) = \frac{1}{2\pi}\frac{d\psi(t)}{dt} \tag{3}$$

The ROCOF is defined as:

$$ROCOF(t) = \frac{df(t)}{dt} \tag{4}$$

important thing to note here is that phasors are always computed in relation to the system nominal frequency (f_0). Here $\psi(t) = \omega_0 t + \varphi(t)$

A. Measurement Evaluation

To validate the estimation coming from PMUs they are compared with the theoretical results. As results consists of amplitude and phase difference both they are considered combinedly and this quantity is called *total vector error* (TVE). TVE is an expression of difference between "perfect" sample of a theoretical synchrophasor and the estimate given by the unite at the same instant of time [1]. The value is normalized and expressed in PU of the theoretical phasor:

$$PVE(n) = \sqrt{\frac{\hat{X}_r(n) - \hat{X}_r(n)}{den}} \tag{5}$$

to be complient with standard,PMU shall provide synchrophasor, frequency, and ROCOF measurements that meet the requirements as per the standards.

References

[1] C37.118 - IEEE Standard for Synchrophasor Measurements for Power Systems
[2] K. R. Padiyar, *Power System Dynamics Stability and Control*, B.S. Publications, Hyderabad, India, 2002.
[3] T. Smed, "Feasible eigenvalue sensitivity for large power systems", *IEEE Trans. on Power Systems*, vol. 8, no. 2, pp. 555-561, May 1993.
[4] C. Y. Chung, L. Wang, F. Howell, and P. Kundur, "Generation Rescheduling Methods to Improve Power Transfer Capability Constrained by Small Signal Stability", *IEEE Trans. on Power Systems*, vol. 19, no. 1, pp. 524-530, Feb. 2004.
[5] K. Scharnhorst, "Angles in complex vector spaces," *Acta Appl. Math.*, vol. 69, no. 1, pp. 95-103, Oct. 2001.