

Synchronized Phasor and Frequency Measurements in Power Systems

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The synchronized measurement of voltage phasors is becoming widespread in electric power systems worldwide. These phasors, which are also called synchrophasors, are measured by Phasor Measurement Units (PMUs) which measure voltages and calculate the corresponding phasors with respect to a global timing reference, typically provided by the Global Positioning System (GPS). These phasor calculations are time stamped and sent to receiving equipment using a standardized communication protocol. Time-stamped synchrophasor measurements over a wide-area power network have several uses. These uses include protection, power system state estimation, model validation, and post-fault analysis. In addition, the synchronization methods used in synchrophasor measurement are now being investigated for use in microgrid control. Synchronized phasor measurements are covered by two IEEE standards: C37.118.1-2011, "IEEE Standard for Synchrophasor Measurements for Power Systems", and C37.118.2-2011, "IEEE Standard for Synchrophasor Data Transfer for Power Systems". The first deals with the definition and calculation of synchrophasors, time-synchronization requirements, error compliance and performance under steady-state and transient conditions. The second standard essentially defines the communication protocol that the PMU should use to communicate with external equipment. We shall discuss both standards in this tutorial. In addition to synchronized phasor measurement, we shall also present synchronized frequency measurement in a wide-area power network. The rate of change of frequency in a power system is typically low, so that it is possible to time-stamp frequency measurements using the Network Time Protocol (NTP), widely available on the Internet.

In this tutorial, we shall cover the following points:

- An overview of phasors and synchrophasors.
- Synchrophasor standards: IEEE Std. C37.118.1-2011 and C37.118.2-2011.
- Algorithms for synchrophasor calculations.
- Time-synchronization methods.
- Overview of PMU design.
- Synchronized frequency measurements.
- Hardware overview for synchronized frequency measurements.
- Use of synchrophasor concepts in microgrids:
 - Primary control
 - Decentralized controller testing