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# Online Thevenin's Equivalent Using Local PMU Measurements

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**Abstract.** This paper presents a method for determining Thevenin's Equivalent (TE) for a node in a power system using local PMU measurements at that node. Three consecutive voltage and current measurements are used to determine the TE. The proposed method recognizes and considers the phase angle drift caused by the slip frequency between the PMU sampling frequency and the power system frequency. The accuracy of the proposed method has been verified through application to the IEEE 30 bus test system as well as to a real system data measured at the terminals of a wind farm. The proposed method is going to be used to determine an online TE, which will be used to monitor the system capability to accommodate the wind power by updating a capability chart of the system at the node where the wind farm is connected.

## Key words

Thevenin equivalent; PMU; wind power; capability chart.

## 1. Introduction

Having a Thevenin's equivalent (TE) for a system at one of its ports opens the door to many interesting possibilities. However, the quality and reliability of results obtained using TE is determined by the accuracy of the TE itself. For a linear system, the TE represents a perfect equivalent at the port it is determined for over the entire range of variations that may take place in voltage and/or current as long as the rest of the system is kept unchanged. In a real power system, the transmission network itself is linear, but node specifications, power injections and/or voltages, are not. Node specifications are either P, Q at load nodes or P, V at generation nodes. Hence, voltage/current relationships at the system nodes experience the nonlinearities of the specified injections. So, the problem lies mainly in the nonlinearity of the load/generation injections.

Using a TE several voltage stability indices have been developed [1-3]. In [1], loads and generators are replaced by equivalent static shunt admittance and the diagonal elements of the system bus impedance matrix, $Z_{bus}$, are considered the equivalent Thevenin impedances, $Z_{th}$, of the corresponding buses. $Z_{th}$ is then compared with load impedance to determine the proximity of the system to voltage collapse. The same approach has been recently used in [2] but with $Z_{th}$ calculated from local measurements. Multiple power flow solutions were used in [3] to determine a TE for the system at the weak nodes, which is then used to determine a voltage collapse proximity indicator. The TE of [3] is then used in [4] to assess the voltage stability of a system with large wind farms and in [5] to determine the system capability to accommodate wind power.

TE determined at a node will be valid as long as the rest of the system remains unchanged. This is of course not the case of monitoring a wind farm, which is the major interest of this work, as the power output from the wind farm is highly variable, power system balancing will change the output of the generators in the system to take up the power from the wind. Moreover, the power system itself is ever changing, even if no switching operations took place, loads and consequently generators are changing all the time. Therefore, the TE to be used for wind farm monitoring must be updated whenever a change takes place in the wind farm output or in the system itself.

Methods based on power flow solution [1],[3] may not suit the purpose of online TE determination as data of the whole system have to be processed each time. Moreover, the rate of updating these data is determined by the SCADA system, which is too slow to serve the purpose of wind farm monitoring. Local measurements using PMUs provide voltage and current phasors at rates as high as 1 measurement/cycle. The works of [2] tried to use one local measurement to determine a TE equivalent through making many assumptions such as neglecting the TE resistance, which cannot be justified at the voltage levels where the wind farms are usually connected.

This paper presents a new method for the determination of TE based on PMU measurements. Three consecutive voltage and current measurements are used to determine an exact TE. It is essential to have the three sets of phasor measurements be referred to the same reference. Phase drifts caused by the slip frequency between the PMU and the system are taken into consideration and can be determined accurately during the course of calculations.

The paper is organized as follows. Following this introduction, the proposed method for determining the TE is introduced followed by application to the IEEE 30