

A Framework for Placement Assessment of Synchrophasor Measurement in Practical Power Grid: A Case Study from Borneo

AHMED M. A. Haidar¹, HENG WEI Hau²

¹Universiti Malaysia Sarawak,
Department of Electrical and Electronics, Faculty of Engineering, Malaysia
94300 Kota Samarahan, Sarawak, Malaysia, ahahmed@unimas.my

²Uni-Kenyaling Engineering SDN. BHD, Malaysia
93350, Kuching, Sarawak, Malaysia

Abstract— *Security control of electricity networks has always been a key issue in the power industry development. An important approach towards full observability of power system is by means of using the phasor measurement unit (PMU). The consideration when applying PMU in power grid is the proper selection of its location. Therefore, an optimal location has to be identified in order to minimize the number of installed units, as it is not economically viable to place PMU at each bus. Firstly, this paper reviews the methods used for PMU placement. Further, the paper proposes a framework to evaluate the optimal locations of PMUs in a practical power grid consisting of 36 buses. The power grid has been modeled by taking into account the change in system configuration. Different optimal PMU placement (OPP) methods have been utilized to determine the best location with the lowest number of installed PMUs. The implemented framework for solving a practical problem using a classical approach has proven to be ideal in terms of ensuring the complete observability of the power system under single and multiple transmission line outages.*

Keywords: *Phasor Measurement Unit, PMU placement rules, Power grid observability, Single and multiple line outages.*

I. INTRODUCTION

Phasor measurement unit (PMU) is a synchrophasor technology that is able to measure the magnitude and phase angle of voltage and current as well as frequency and the rate of its change. The use of PMU for effective measurement becomes possible due to the advancement in global positioning system (GPS) technology in addition to the development of digital signal processing. Indeed, PMU is superior as compared to supervisory control and data acquisition (SCADA) in state estimation for various aspects such as system monitoring, security control and system protection including detection of fault location, contingency analysis, model validation, stability analysis, etc. This is owing to the fact that SCADA can only perform measuring the magnitude of voltage and current whereas PMU can measure both magnitude and phase angle with much higher sampling rate as compared to SCADA.

PMU is being widely used in many countries for precise measurements of magnitude and phase angle

(voltage and current) including the frequency and its rate of change. The samples are time aligned by using GPS clock that allows accurate arrangement of data in the control center of the power grid [1]. The use of synchrophasor has been increasing since 2004 particularly, after the Northeast blackouts on 14th and 15th of August 2003 in the United States and Canada. The investigation report states that blackouts occurred due to the lack of awareness by grid operators about the power system condition as it led to cascading outage [2]. The report recommended using effective synchrophasor technologies to provide wide area monitoring in real time for minimizing the blackouts.

Traditionally, SCADA plays a significant role in planning, monitoring and control of power system. SCADA systems consist of numerous remote terminal units (RTU). These units are microprocessors controlled devices used to control and collect data from sensors situated at the remote sites and transfer the data back to the central unit. Such functions include monitoring and control of transformer tap changer as well as circuit breakers and re-closers. Since the 1960s, SCADA has been used to monitor power grids. However, the growing number of outages indicates that SCADA systems have now reached their capability limits, as they are not able to measure phase angles and can only obtain data once every 4–6 seconds. With such low data sample rate, major power utilities have now shifted their focus on deploying PMUs in power system.

The interfacing system of RTU with sensors is unable to collect voltage and current phase angles in power systems. These phasor values are important in determining the power flow, stability limits and resulting load current. Furthermore, monitoring of transient phenomena cannot be achieved using SCADA systems operated based on quasi-steady-state power flow analysis [3]. In other words, the low sample rate of SCADA with data obtained over few seconds may cause an insufficient number of measurements to be taken with respect to time, resulting in both telemetry errors and measurement bias [4]. Therefore, in modern power systems, synchrophasor technologies have become the main choice of measurement units for the power grid. The supremacy of synchrophasor technologies over

SCADA systems lies in the capability of PMU to synchronize voltage and current measurements within microseconds because of the GPS availability as well as the development of data processing techniques [5].

Nowadays, reliability has become more important especially in the modern bulk transmission system. By analyzing synchrophasor data, an early indication of power system problems can be detected. This allows the power grid operators to take preventive steps and mitigation measures to minimize the duration and severity of outages. In this case, the system restoration can be achieved in a shorter time. With advanced software applications, the full potential of synchrophasor technologies can be realized in both online and offline applications. PMU is also widely used for state estimation, wide area monitoring, islanding and control as well as for fault classification. State estimation is important for various power system analysis such as optimal power flow, contingency analysis, stability analysis, load forecasting [6], [7], [8]. The solvers of state estimation in control centers of power grids provide optimal estimates of real time operating state by using sets of conventional measurements. These measurements are traditionally obtained through SCADA system. As the reliability of power system requires fast and accurate estimation of the system condition, the measurements can also be performed using PMU, as it is able to provide synchronized data at high speed that definitely improves the state estimation performance [9].

Certainly, the power system network can be said observable if the condition of each part in the system is recognizable either directly or indirectly. It is possible to make the system fully detectable by placing PMU in each bus. However, installing the PMUs in all buses is not economically viable, since the PMU is the most expensive part in the protection system. On the same note, PMU installation in some substations may not be possible due to the lack of communication devices, security and control facilities [10]. Therefore, it is critical to identify the best location of PMU that mainly depends on the configuration of the power system.

Numerous OPP methods have been developed since the introduction of PMU. The notion of spanning tree was extended in [3] to find through a dual search algorithm the minimal PMU set. The concept of depth-of-unobservability was applied in [11] to reduce the required number of PMUs for achieving complete observability. An integer quadratic programming method was proposed in [12] to maximize the redundancy of measurement at the power grid bus. Authors in [13] introduced stochastic simulated annealing for solving optimal PMU placement. Unlike [13], the authors in [14] proposed a two-stage PMU placement method. In this approach, the first stage finds the minimum number of units while the second stage checks if the identified placement leads to a full ranked measurement Jacobian. In recent years, several research studies have been carried out to develop methods for minimizing the number of installed PMUs in the power system. For instance, an adaptive scheme for wide area backup

protection has been proposed in [15] to limit the number of synchronized phasor measurements. The scheme can be realized if the grid is equipped with advanced communication infrastructure. Authors in [16] used binary particle swarm optimization for the installations of PMUs in a large-scale network. In this approach, a practical solution has been implemented by minimizing the number of substations in which the PMUs have to be installed. To reduce the omission of optimization in a large system, a hybrid integer linear programming-based method was proposed in [17]. In this method, the system is categorized into three groups by considering three constraints in the optimization problem such as the number of PMUs, system observability and measurement redundancy. An optimal PMU placement approach was formulated in [18] for power system dynamic state estimation using the empirical observability Gramian. Authors in [19] proposed selection rules to determine the best candidate bus that involves a merging procedure of zero-injection bus with its neighbors. A modified choice of the greedy algorithm was proposed in [20] to solve the OPP problem. This study also considered the realistic aspects affecting the optimal location of PMU such as zero injection bus, the presence of PMU channel limitation and conventional measurements. The authors in [21] utilized intelligent optimization techniques based on a genetic algorithm to search the optimal set of PMUs. A formulation of mixed-integer programming for dynamic state estimation was proposed in [22]. This technique is based on PMU measurements and can accelerate the estimation execution. In practice, it is neither economically feasible nor technically necessary to equip all buses with PMUs. An imperialist competitive algorithm was modified in [23] for solving the OPP problem during normal and abnormal conditions.

The literature review indicates that most of the aforementioned studies have focused on the development of intelligent methods for PMU placement, while others have used the topological approaches based on assumptions and simple rules. The obtained outcomes from these studies are found to be satisfied; however, the validation of these proposed methods on practical power systems was not applied, and therefore, the methods may have drawbacks when implemented on a dynamic system. Furthermore, ensuring the complete power system observability under various operating conditions was not investigated. Note that the conducted study in this paper only involves the location assessment of PMUs for practical power grid using different classical placement methods (depth first, graph theoretic, dual search and recursive N-1 security algorithm). The SCADA measurements and fault location algorithm using PMU-based wide area backup protection are out of study scope. Motivated by the above review and discussion, this paper aims to evaluate the current states of the practical power system in Sarawak [24] in terms of PMUs locations. The rest of the paper is organized as follows, the basic concept of phasor estimation is explained in Section II. The approaches implemented for