
**Ain Shams University**
**Faculty of Engineering**

# Optimal Phasor Measurement Unit (PMU) Placement for Full Power System Observability

By

**Eng. Reham Hosny Salem Mansour**

A Thesis Submitted for the Requirement of the Degree of Master of Sciences in Electrical Power Engineering

Supervised by

**Prof. Dr. Almoataz Youssef Abdelaziz**

**Dr. Amr Mohamed Ibrahim**

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# Supervisors Committee

Name, Title and Affiliation — Signature

1. Prof. Dr. A. Y. Abdelaziz
   Electrical Power and Machines Dept.
   Faculty of Engineering,
   Ain Shams University

2. Dr. A. M. Ibrahim
   Electrical Power and Machines Dept.
   Faculty of Engineering,
   Ain Shams University

# Examiners Committee

Name, Title and Affiliation Signature

1. Prof. Dr. Nabil Hasan Abbasy
   Electrical Engineering Dept.
   Faculty of Engineering,
   Alexandria University

2. Prof. Dr. Abla Soliman Attia
   Electrical Power and Machines Dept.
   Faculty of Engineering,
   Ain Shams University

3. Prof. Dr. A. Y. Abdelaziz
   Electrical Power and Machines Dept.
   Faculty of Engineering
   Ain Shams University

# Statement

This dissertation is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Master of Sciences in Electrical Engineering.

The work included in the thesis was carried out by the author at the department of Electrical Power and Machines, Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

Name: Reham Hosny Salem Mansour
Signature:
Date:

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# List of Abbreviations

| | |
|---|---|
| PMU | Phasor Measurement Unit |
| GPS | Global Positioning System |
| OPP | Optimal PMU Placement |
| AI | Artificial Intelligence |
| DFS | Depth First Search |
| SA | Simulated Annealing |
| MST | Minimum Spanning Tree |
| RTU | Remote Terminal Unit |
| WDN | West Delta Network |
| MIWO | Modified Invasive Weed Optimization |
| PPA | PageRank Placement Algorithm |
| DE | Distributed Evolution |
| ILS | Iterated Local Search |
| ES | Expert systems |
| GA | Genetic Algorithms |
| ITS | Improved Tabu Search |
| KCL | Kirchhoff`s Current Law |
| KVL | Kirchhoff`s Voltage Law |
| MPSO | Modified Particle Swarm Optimization |
| MTS | Modified Tabu Search |

| | |
|---|---|
| IP | Integer Programming |
| PSO | Particle Swarm Optimization |
| SA | Simulated Annealing |
| SCADA | Supervisory Control and Data Acquisition |
| TS | Tabu Search |

# Abstract

In recent years, Phasor Measurement Units (PMUs) have been widely acknowledged as one of the most promising developments in the field of real-time monitoring of electric power systems.
An essential tool for power system monitoring is state estimation. Phasor Measurement Units (PMUs) can greatly improve the state estimation process. However, for state estimation, the PMUs should be placed appropriately in the network. The problem of optimal PMU placement for full observability is adressed in this thesis.

The thesis adopts minimization the size of the PMU configuration while allowing full observability of the network. At first, three algorithms; Depth First Search (DFS), Simulated Annealing (SA) and Minimum Spanning Tree (MST) Algorithms are introduced as well as their differences and relations are discussed in detail. The applied optimal PMU placement methodologies included the system observablility during normal operating conditions, as well as during single branch forced outages in order to obtain a reliable measurement system.

To verify the effectiveness of the introduced algorithms, comparative studies are conducted on three test systems with encouraging results. A 14-bus, 39-bus and 118-bus electrical distribution systems are selected for optimizing the configuration to minimize the number of PMUs. The effect of zero injection buses is taken into consideration as well.
The thesis also adopts two new efficient heuristic techniques for optimal PMU placement.
Greedy algorithm and Single Vertex Algorithm are used as an optimization tool to obtain the minimal number of PMUs and their corresponding locations while satisfying associated constraints.

Applications of the proposed optimization algorithms are applied to the IEEE 14-bus test system as a standard system and to two real systems customized from the British and Egyptian networks with different scales,

topologies and voltage levels, to demonstrate the effectiveness of the proposed approaches.

The obtained results, using the presented approaches, are compared with the results of other approaches from literature to examine the performance. However, the two algorithms require shorter simulation time but more practice of the iterative process than the other methods. The difference in time is more significant as the system size increases. In comparison with previously applied algorithms, the introduced algorithms outperform purely heuristic as well as various AI-based algorithms such as Tabu Search (TS) and Simulated Annealing (SA) in finding the optimal PMU placement to guarantee the complete power system observability.

**Keywords:** Phasor Measurement Unit (PMU); Observability; Greedy algorithm; Single Vertex Algorithm; Depth First Search; Simulated Annealing Method; Minimum Spanning Tree; Optimal PMU Placement (OPP).