**ECE 4160/6160 – Smart Grid Project**

**Graph Models of Electric Power Transmission Network**

The electric power grid is a critical infrastructure, especially due to its interdependency with other complex networks like water, gas communication, and transportation. Modern power systems are complex systems, and even more so with the integration of renewable energy sources, distributed energy resources, etc. Power system operation depends on real-time system monitoring. The role of the electric power transmission network (EPTN) in modern power system operation is not limited to efficiently transmitting power over long distances, but also facilitating fair transmission access to all electricity market competitors. Thus, the energy control center (ECC) requires flexibility in transmission network connectivity and EPTN to be controlled reliably and securely. Understanding the connectivity of the large geographically distributed EPTN is crucial. Knowing the topology of an EPTN allows for optimum power transmission. State-of-the-art topology processing relies on relays conveying breaker status to the ECC through supervisory control and data acquisition (SCADA). SCADA is employed to switch the EPTN. Deploying Phasor Measurement Units (PMUs) in the EPTN has enabled fast and reliable power system monitoring and control.

The EPTN can be represented with a graph model with nodes (N) and edges (E). The graph represents the physical EPTN. Developing a graph model of the EPTN solely from measured PMU data provides an alternative approach to ECCs to operate and manage the power system efficiently and reliably.

The objective of this project is to construct a graph model of an EPTN, referred to as the transmission network graph model (TNGM) solely based on PMU measurements of voltage and current phasors from respective substations (Fig. 1). Matchmaking algorithms can be utilized to solve this graph construction problem. One such algorithm is the discrete particle swarm optimization (DPSO), specifically the integer version referred to as IPSO (integer PSO) [5]. After developing the TNGM, providing the system operators with user-friendly intelligent visualization is critical for understanding of the EPTN topology.

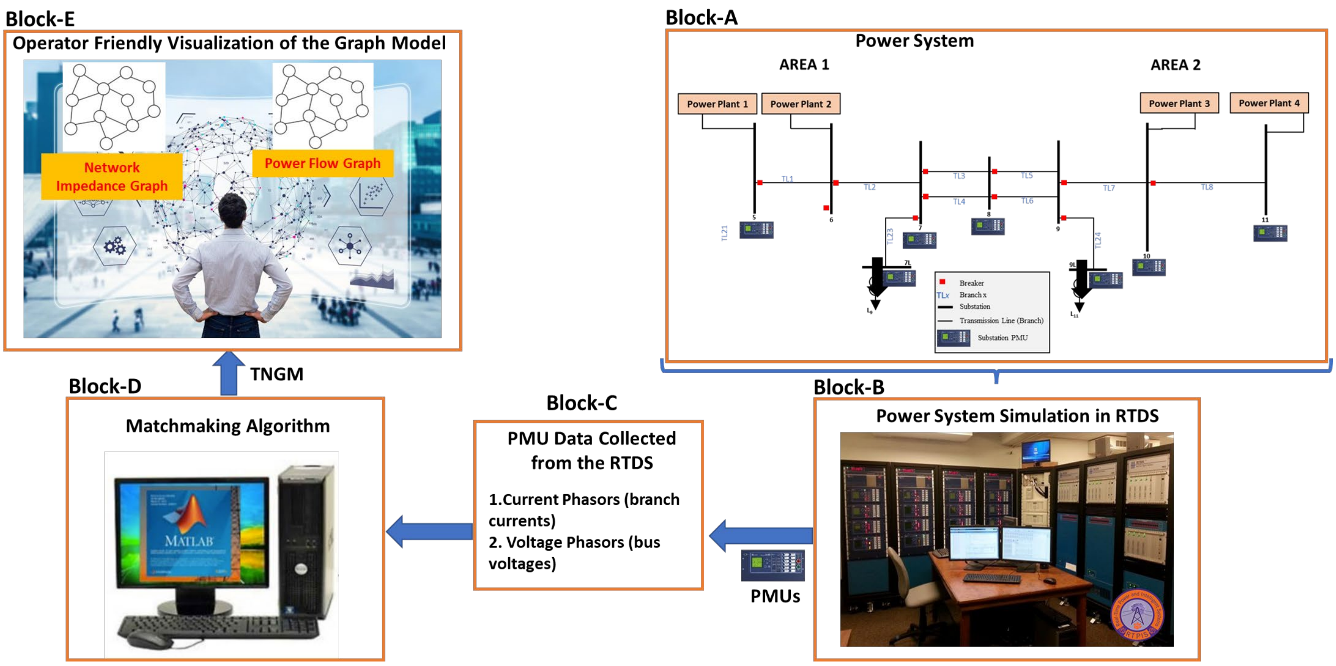



Figure 1. Flow diagram to develop TNGM for electric power transmission networks using PMU measurements.

## What is provided?

- PMU data (Block C) containing voltage and current phasors collected from an RTDS simulation of a two-area four machine (plants) – Block A (Fig. 1).
- Undergraduate student groups will be provided with data for three different operating conditions (three datasets) whereas graduate student groups will be provided with nine datasets, namely three different topologies and three different operating conditions.

## What needs to be done to complete this project?

A. Literature Survey: Importance of EPTN topology identification for power systems operations and management.
   - Resources: IEEE Xplore, ScienceDirect, etc. including references [1] to [4].

B. Graph Construction:
   - Build the power flow TNGM using IPSO (see example below – Fig. 2).
   - Compute the impedances and construct impedance graph of the EPTN (see Fig. 2).
   - Graduate Groups has to construct the TNGM using another matchmaking algorithm in addition to the integer version of PSO.

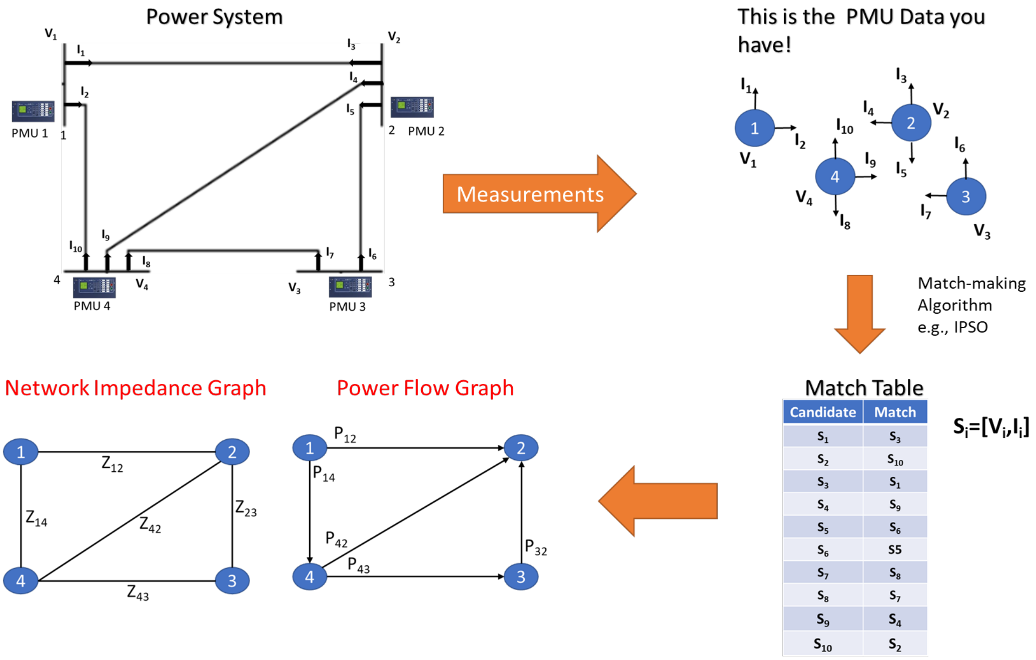



Fig. 2. TNGM Example

C. Develop an Intelligent/Smart Visualization:
   - An intelligent visualization for situational awareness at the energy control center to display the current EPTN topology (power flow graph and network impedance graph).

D. Submit project progress and final reports in IEEE paper format by **11.59pm** on following days:
   - **February 22nd** - Literature review in IEEE PES Conference paper format (Progress report 1).
   - **March 28th** - Description of the proposed method, preliminary results, and discussions.
   - **April 19th** - Final report summarizing the entire project. You may use the content of the previous reports in a coherent amalgamation.
   - **April 22nd** - Project presentation slides (format to be posted on canvas)

E. Make a Group Presentation – Class time on **Tuesday (04/23/2024) and Thursday (04/25/2024).**

## Grading:

- Interim reports – 40% (2 reports)
- Final report – 40%
- Presentation – 20%
- PEER REVIEW - Project score will be decided **50 %** based on the peer-review.

EXAMPLE:
Interim Report 1 - **18**, Interim Report 2 - **20**, Final Report - **35**, Presentation – **17, Total - 90**
PEER Review - **80%**
**Final project score - (45+45 x 0.8) = 81%**

## Estimated Timeline:

| | Week | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task** | **February** | | | **March** | | | | **April** | | | |
| | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| A. Literature review | | | | | | | | | | | |
| 1st Project progress report Feb 22nd | | | | | | | | | | | |
| B. Graph Construction | | | | | | | | | | | |
| 2nd Project Progress report March 28th | | | | | | | | | | | |
| C. Visualization | | | | | | | | | | | |
| Final Report April 19th | | | | | | | | | | | |
| Project presentation slides April 22nd | | | | | | | | | | | |
| Presentation April 23rd &25th | | | | | | | | | | | |

**Reference:**


[1] J. De La Ree, V. Centeno, J. Thorp, and A. Phadke, "Synchronized phasor measurement applications in power systems," in *IEEE Transactions on Smart Grid*, vol. 1, no. 1, pp. 20-27, June 2010.

[2] D. Madurasinghe and G. K. Venayagamoorthy, "An efficient and reliable electric power transmission network topology processing," *IEEE Access*, vol. 11, pp. 127 956–127 973, 2023.

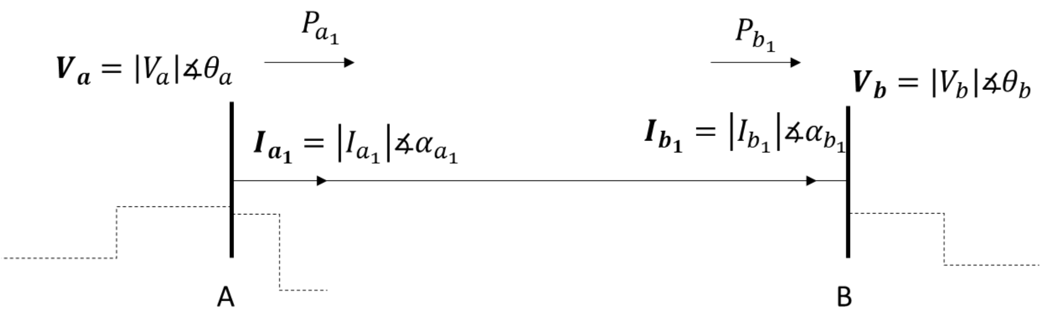
[3] D. Singh, J. Pandey, and D. Chauhan, "Topology identification, bad data processing, and state estimation using fuzzy pattern matching," *IEEE Transactions on Power Systems*, vol. 20, no. 3, pp. 1570–1579, 2005.

[4] M. Kezunovic, "Monitoring of power system topology in real-time," *in Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS'06)*, Kauia, HI, USA, 2006, pp. 1–10.

[5] P. W. Moore,and G. K. Venayagamoorthy. "Evolving digital circuits using hybrid particle swarm optimization and differential evolution." *International Journal of neural systems 16*, no. 03 (2006): 163-177.

# Appendix

## Useful Equations and Fitness/cost function




*Power Flow*

$$P_{a_1} = 3 \times |V_a||I_{a_1}|\cos(\theta_{a_1} - \alpha_{a_1})$$

*Absolute Power Flow Difference*

$$DF_{P_{a_1,b_1}} = |P_{a_1}| - |P_{b_1}|$$

*Mean Power Loss*

$$I_{mean_{a_1,b_1}} = \frac{I_{a_1} + I_{b_1}}{2}$$

$$\Delta V_{a,b} = V_a - V_b$$

$$MPL_{a_1,b_1} = \left|3 * real\left(\Delta V_{a,b} \times \left(I_{mean_{a_1,b_1}}\right)^*\right)\right|$$

*Edge Score*

$$ES_{a_1,b_1} = \frac{1}{\left|DF_{P_{a_1,b_1}} - MPL_{a_1,b_1}\right|}$$

- The greater value of ES, the higher the better level of match.

*Fitness Function of TNGM*

$$J = \sum_{i=1}^{n} \frac{1}{ES_i}$$

$n$- Total number of matches
$ES_i$ Edge Score for $i^{th}$ match

- The objective will be minimizing *J* throughout the process of the algorithm.
- This is an example of setting the fitness function. The team is welcome to improve the fitness function.
- Penalties can be incorporated with the fitness function when constraints are present.

*Line Impedance*

$$Z_{a_1,b_1} = \frac{V_a - V_b}{I_{mean_{a_1,b_1}}}$$