ECE 4160/6160 – Smart Grid

Project : Graph Models of Electric Power Transmission Network

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Introduction

- The electric power grid interacts with various complex networks like water, gas, communication, and transportation, forming critical infrastructure.

- Modern power systems, incorporating renewables and distributed energy resources, rely on real-time monitoring for efficient operation.

- The electric power transmission network (EPTN) not only transmits power efficiently but also ensures fair access for all market competitors.

- Flexibility in network connectivity and reliable control are vital for energy control centers (ECC) to operate securely. Understanding the EPTN's connectivity is crucial.

- Knowing the topology of an EPTN allows for optimum power transmission.

Introduction

- The EPTN can be represented with a graph model with nodes (N) and edges (E). The graph represents the physical EPTN.

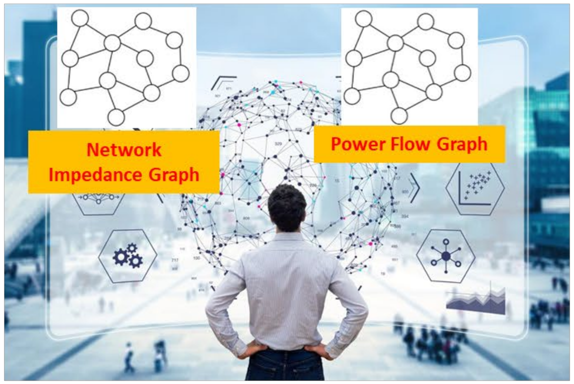
- Developing a graph model of the EPTN solely from measured PMU data provides an alternative approach to ECCs to operate and manage the power system efficiently and reliably.

- 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.

- 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).

Project Summary

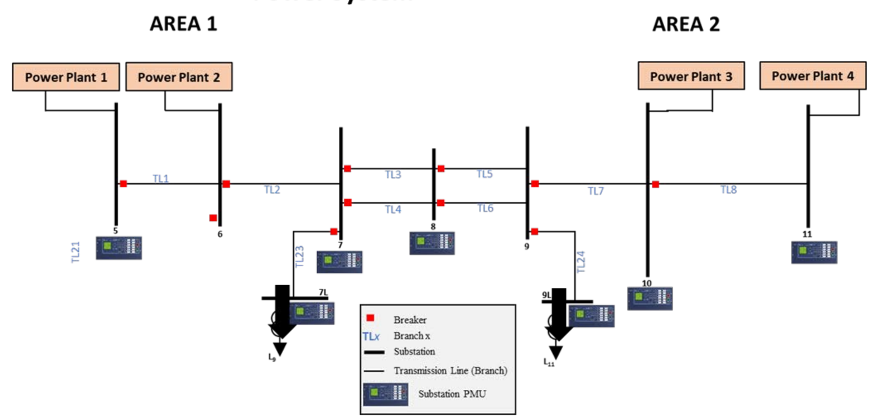
Block-E
Operator Friendly Visualization of the Graph Model



TNGM

Block-A

Power System



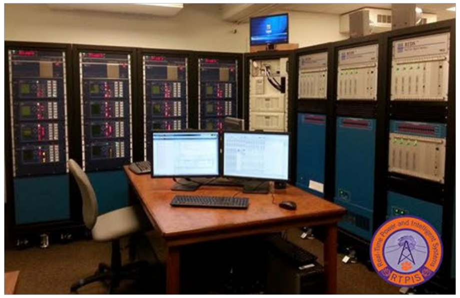
Block-D
Matchmaking Algorithm

Block-C
PMU Data Collected from the RTDS

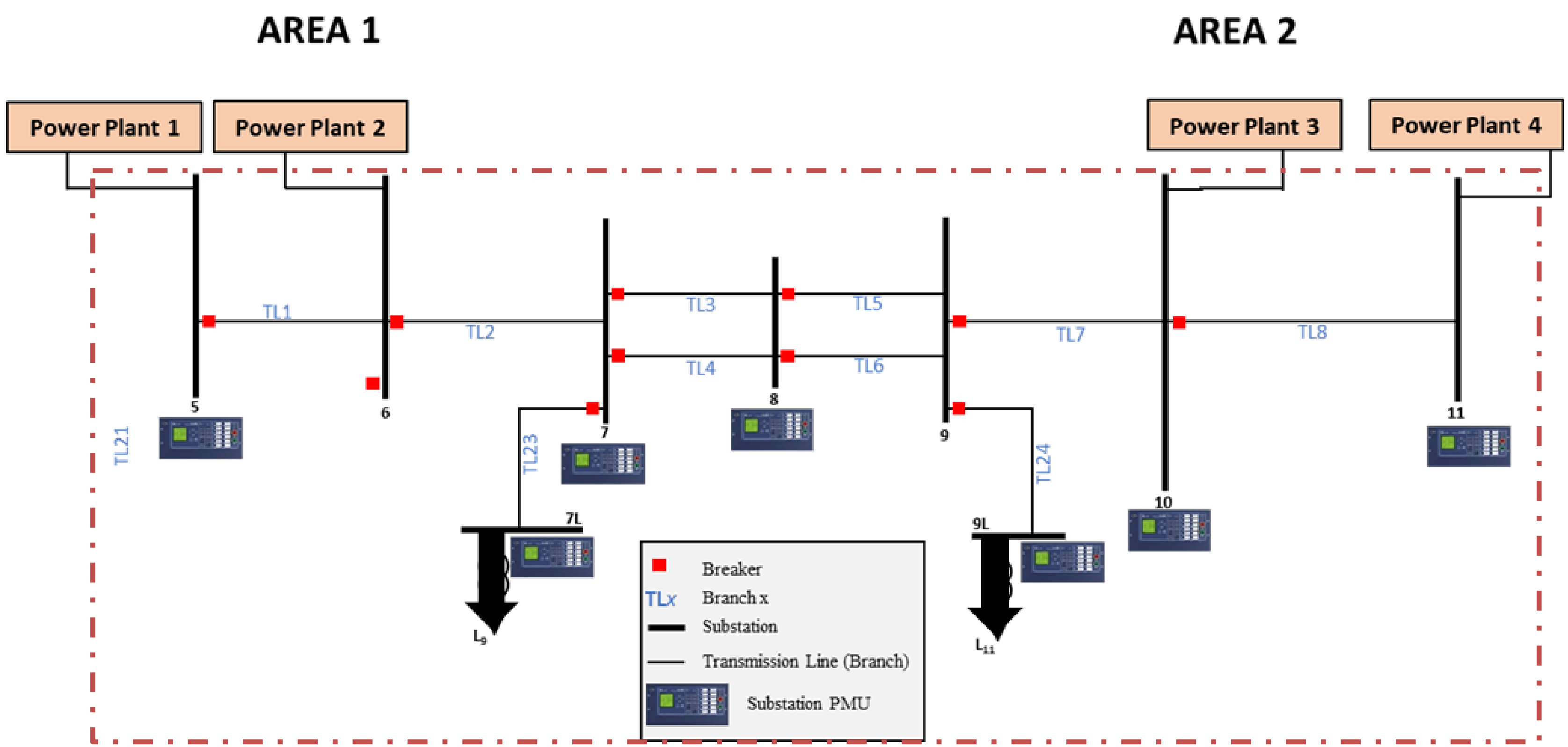
1. Current Phasors (branch currents)
2. Voltage Phasors (bus voltages)

PMUs

Block-B
Power System Simulation in RTDS



Test Cases – 2 Area 4 Machine System



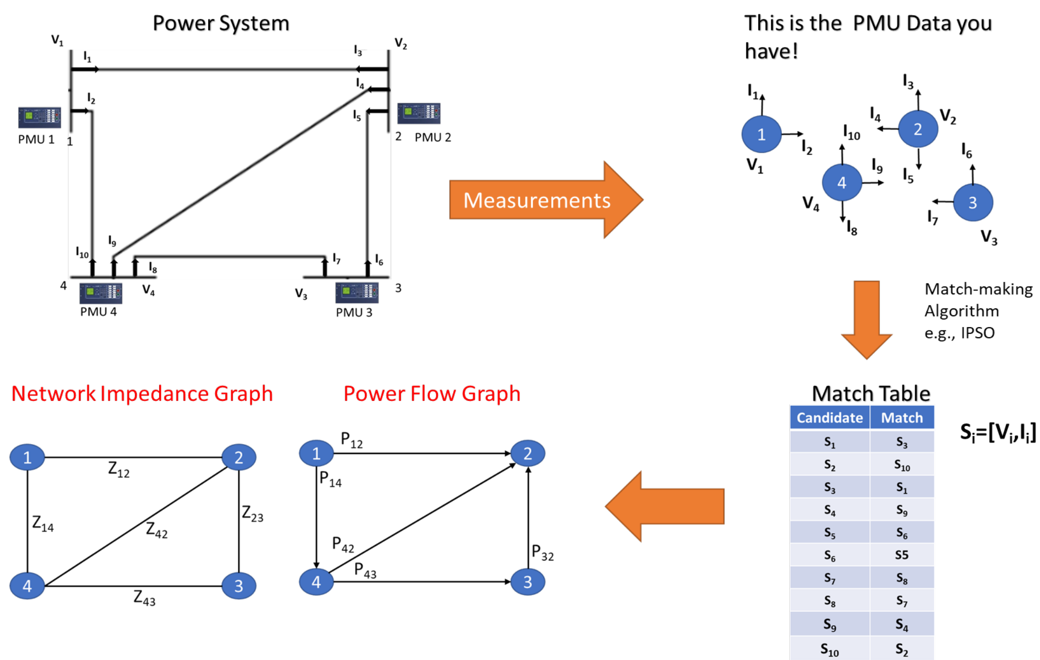
What is Provided?

- PMU data (Block C) containing voltage and current phasors collected from an RTDS simulation of a two-area four machine (plants) – Block A .
- 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?

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.
   - Compute the impedances and construct impedance graph of the EPTN.
   - Graduate Groups has to construct the TNGM using **another matchmaking algorithm** in addition to the integer version of PSO.



Candidate	Match
S_1	S_3
S_2	S_{10}
S_3	S_1
S_4	S_9
S_5	S_6
S_6	S5
S_7	S_8
S_8	S_7
S_9	S_4
S_{10}	S_2

What you need to do

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).

Progress and final reports need to be prepared in IEEE PES paper format (https://www.ieee-pes.org/templates-and-sample-of-pes-technical-papers).

Estimated Timeline & Grading

	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											

Grading:

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

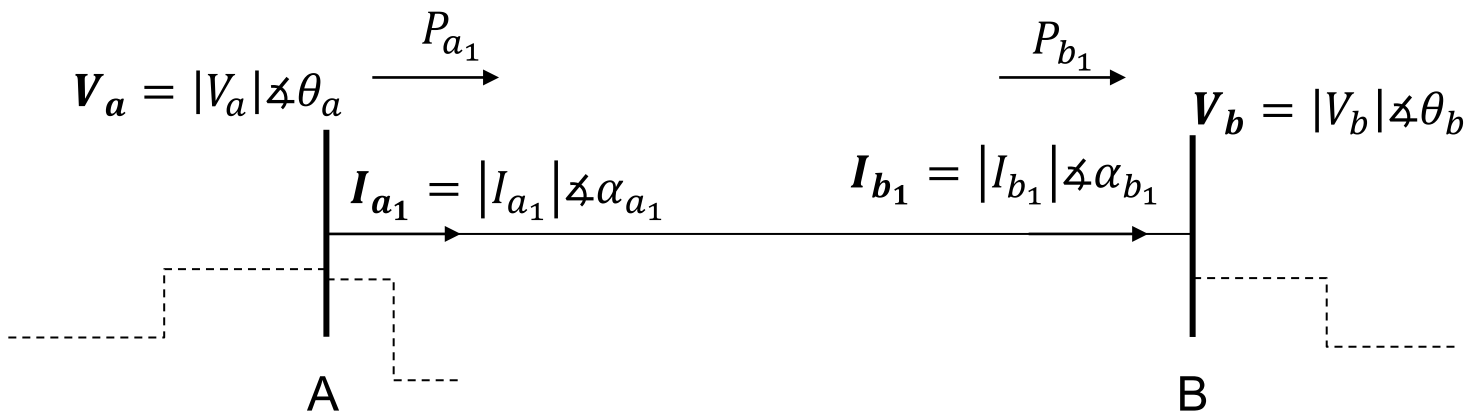
EXAMPLE:

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%

Equations



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.**

Equations

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 Calculation

Line Impedance

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

References

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.

Thank You!

Questions?