Congestion Effects on LMPs Modeled in PowerWorld

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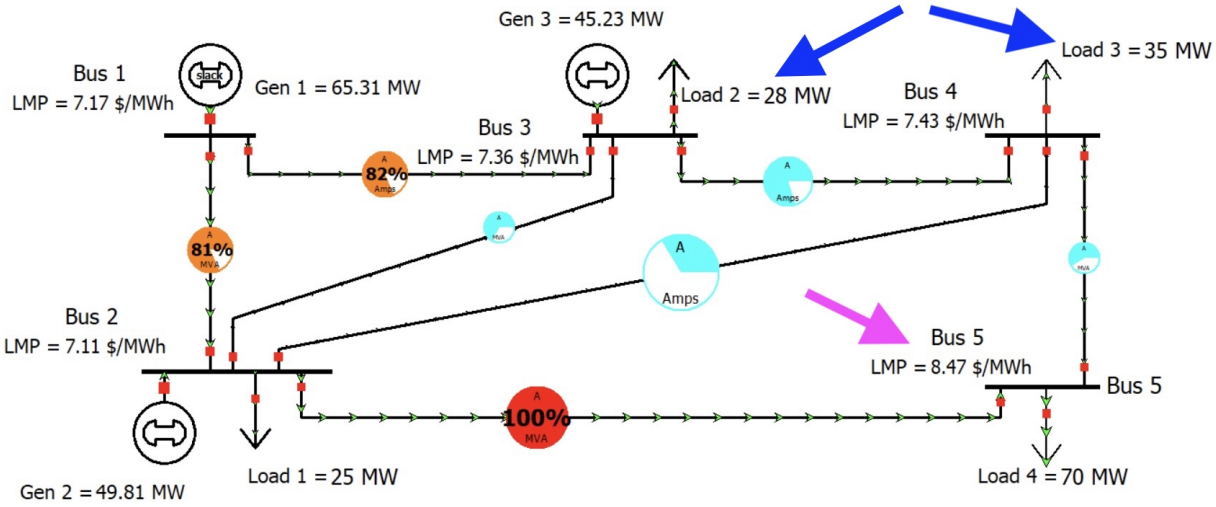
Overview

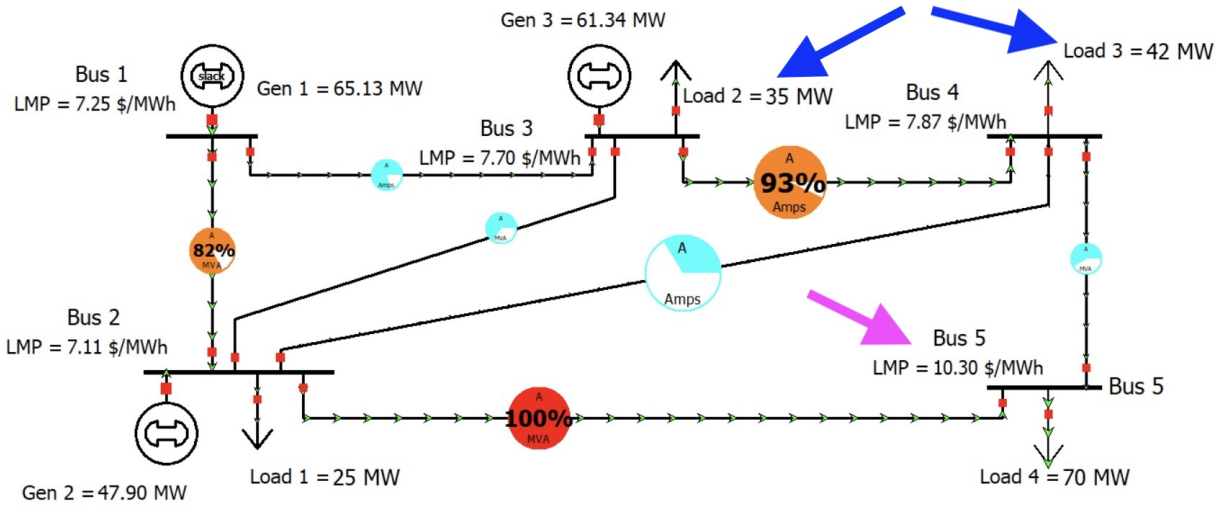
This project explores how changes in load affect transmission congestion and Locational Marginal Prices (LMPs) in a small power system. Using PowerWorld Simulator, I analyzed a 5 bus network under different operating conditions to observe how physical constraints in the grid translate into nodal price differences. Insights from these manual Optimal Power Flow (OPF) studies also motivated the development of a tool for automating LMP sweeps and congestion analysis at scale.

System Response to Load Changes

A base case was constructed using a standard IEEE 5 bus power system to establish a reference operating point for analyzing LMPs. In this base case, Load 2 and Load 3 are set to 28 MW and 35 MW, respectively, as indicated by the blue arrows in Figure 1, and the LMP at Bus 5, highlighted by the pink arrow, is \$8.47/MWh.



To examine the effects of increased demand, loads at Bus 2 and Bus 3 were increased from 28 MW to 35 MW and from 35 MW to 42 MW, respectively. These changes represent a realistic increase in regional electricity demand, such as elevated cooling load during periods of high temperatures.



Under these conditions, LMPs increase across the system, with the largest impact observed at Bus 5. The LMP at Bus 5 rises from \$8.47/MWh in the base case to \$10.30/MWh in the increased load scenario, reflecting the presence of transmission congestion. This behavior illustrates how physical grid constraints translate directly into economic price signals, as captured through an OPF solution in PowerWorld.

LMP Toolkit

While PowerWorld is well suited for detailed, interactive analysis of individual operating conditions, performing large numbers of sensitivity studies manually is time consuming and difficult to scale. Exploring how LMPs respond to incremental changes in load, congestion patterns, or system parameters often requires dozens or hundreds of OPF runs, making manual workflows impractical. To address this limitation, the LMP Toolkit was developed. Once a system is solved in PowerWorld, it can be exported as a `.m` file containing all essential system information, including bus data, generator parameters, transmission line characteristics, and cost curves, which serves as the primary input to the toolkit. The LMPs Toolkit is a Python based tool for automating OPF studies and extracting LMPs across many operating scenarios. By programmatically modifying system inputs, executing repeated OPF simulations, and recording the resulting LMPs in a structured format, the toolkit enables efficient congestion and price sensitivity analysis that would be impractical to perform manually, which may be used in applications such as congestion forecasting and machine learning workflows. The manual PowerWorld cases shown earlier serve as validation examples, illustrating the same congestion driven LMP behavior that the toolkit captures at scale. The code for the LMP Toolkit is available at `https://github.com/wcolglazier/LMP_Toolkit`.

Example LMP Toolkit Output

```
Base Load Values:
----------------------------------------
Bus 2: 25.00 MW
Bus 3: 28.00 MW
Bus 4: 35.00 MW
Bus 5: 70.00 MW
----------------------------------------

Loads: Bus 4 = 30.00 MW, Bus 5 = 70.00 MW
Bus 1: $7.01/MWh
Bus 2: $7.19/MWh
Bus 3: $7.37/MWh
Bus 4: $7.48/MWh
Bus 5: $8.16/MWh

Loads: Bus 4 = 32.00 MW, Bus 5 = 71.00 MW
Bus 1: $6.97/MWh
Bus 2: $7.14/MWh
Bus 3: $7.45/MWh
Bus 4: $7.60/MWh
Bus 5: $8.82/MWh

Loads: Bus 4 = 34.00 MW, Bus 5 = 72.00 MW
Bus 1: $6.91/MWh
Bus 2: $7.08/MWh
Bus 3: $7.54/MWh
Bus 4: $7.75/MWh
Bus 5: $9.66/MWh

Loads: Bus 4 = 36.00 MW, Bus 5 = 73.00 MW
Bus 1: $6.86/MWh
Bus 2: $7.00/MWh
Bus 3: $7.64/MWh
Bus 4: $7.87/MWh
Bus 5: $10.58/MWh

Loads: Bus 4 = 38.00 MW, Bus 5 = 74.00 MW
Bus 1: $6.98/MWh
Bus 2: $7.00/MWh
Bus 3: $7.69/MWh
Bus 4: $8.02/MWh
Bus 5: $11.06/MWh
```