# New England 250 Bus Synthetic System

The New England 250 Bus system is an entirely synthetic system created using publically available generation data, synthetic load data, and a modified version of the transmission expansion algorithm by Len Garver (1970). The synthetic system contains data on the full network characteristics and bus-level hourly load data for a representative week across the four seasons.

Table of Contents

[New England 250 Bus Synthetic System 1](#_Toc492885446)

[System Description 2](#_Toc492885447)

[Load Data 2](#_Toc492885448)

[Case Descriptions 2](#_Toc492885449)

[Bus Voltage Limits 3](#_Toc492885450)

[Generator Reactive Power Limits 4](#_Toc492885451)

[Bus Shunt Reactive Power Injections 4](#_Toc492885452)

[Master Case 5](#_Toc492885453)

[Easy Cases 5](#_Toc492885454)

[Fall 116 Generous 5](#_Toc492885455)

[Winter 12 Generous 5](#_Toc492885456)

[Winter 68 Generous 6](#_Toc492885457)

[Medium Cases 6](#_Toc492885458)

[Fall 106 Tight 6](#_Toc492885459)

[Fall 116 Tight 6](#_Toc492885460)

[Spring 4 Generous 6](#_Toc492885461)

[Summer 69 Tight 6](#_Toc492885462)

[Summer 90 Tight 7](#_Toc492885463)

[Winter 68 Tight 7](#_Toc492885464)

[Hard Cases 7](#_Toc492885465)

[Spring 13 Tight 7](#_Toc492885466)

[Summer 90 Generous 8](#_Toc492885467)

[Summer 93 Generous 8](#_Toc492885468)

# System Description

The New England 250 Bus System (NE 250) is a 250 bus system with 180 unique geographic bus locations, and 70 transformer connected buses that are at the same geographic location as the “main” 180 buses. The system has 248 transmission lines and 91 transformers at 3 voltage levels: 138 kV, 230 kV, and 345 kV. There are 42 generator buses with a total generation capacity of 29.79 GW.

# Load Data

The New England 250 Bus system (NE 250) contains hourly data for one week for each season that is based on load data from ISO New England’s state load profiles. This load data contains active and reactive power demands at each of the 250 buses, with notable differences between weekdays and weekends and between each season. The load data also reflects the influence from seasonal and weather changes, as well as the underlying load characteristics from the 3 main load categories: residential, commercial, and industrial.

This hourly time-varying load data is included in 2 Excel spreadsheets: “ReactivePowerLoadSeasons” and “RealPowerLoadSeasons.” Each row represents one of the 250 buses in the NE 250 bus system, and each column represents an hour in a 168-hour week.

# Case Descriptions

The initial release of the system contains 12 cases with different load and generation levels, and contain the data necessary to run power flow, economic dispatch, and optimal power flow. It also contains one “Master Case” with all of the time-varying load data as well as the full range of switched shunt values. The cases were chosen from representative data points from the hourly load data across all four seasons, and are created to represent a wide range of loading conditions: from the system base load of 9.4 GW to the peak of 24 GW. The cases are also placed one of three categories: easy, medium, or hard, based on the stringency of the generator reactive power limits and the bus voltage limits. The bus voltage limits are divided into two categories: generous and tight, as explained later in the document. The case files are named appropriately to indicate which set of bus voltage limits was used for that particular case. The file name also includes the hour from the week-long load profile that was used to create the particular case.

Table 1 below shows the recommend algorithms for each of the 12 cases.

**Table 1: Recommended Algorithms for the NE 250 System Cases**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Case Name** | **MVAR Limits** | **Load (GW)** | **OPF** | **Security constrained OPF** | **Unit Commitment OPF** |
| Spring 4 Generous | Generous | 9.4 | Yes | Yes | Yes |
| Spring 13 Tight | Tight | 12.9 | Yes |  | Yes |
| Winter 12 Generous | Generous | 14.3 | Yes | Yes | Yes |
| Fall 106 Tight | Tight | 14.8 | Yes | Yes | Yes |
| Fall 116 Generous | Generous | 16.1 | Yes | Yes | Yes |
| Fall 116 Tight | Tight | 16.1 | Yes | Yes | Yes |
| Winter 68 Generous | Generous | 17.5 | Yes | Yes | Yes |
| Winter 68 Tight | Generous\* | 17.5 | Yes |  | Yes |
| Summer 69 Tight | Generous | 20.0 | Yes |  |  |
| Summer 93 Generous | Generous | 22.8 | Yes |  |  |
| Summer 90 Generous | Generous | 24.0 | Yes | Yes |  |
| Summer 90 Tight | Generous | 24.0 | Yes |  |  |

Generous\* = 3 generators modified to be at limits

**Table 2: Summary of the Cases at uniformly scaled generator MW outputs**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Case Name** | **MVAR Limits** | **Load (GW)** | **Buses < Vmin** | **Buses > Vmax** | **Bus Vmin** | **Bus Vmax** | **Gen at Qmin** | **Gen at Qmax** | **Buses w/ Shunt B** | **Total Shunt B** |
| Spring 4 Generous | Generous | 9.4 | 0 | 2 | 0.974 | 1.078 | 2 | 0 | 0 | 0 |
| Spring 13 Tight | Tight | 12.9 | 1 | 7 | 0.959 | 1.121 | 5 | 4 | 0 | 0 |
| Winter 12 Generous | Generous | 14.3 | 0 | 0 | 0.943 | 1.049 | 1 | 1 | 0 | 0 |
| Fall 106 Tight | Tight | 14.8 | 1 | 3 | 0.946 | 1.117 | 5 | 5 | 0 | 0 |
| Fall 116 Generous | Generous | 16.1 | 0 | 0 | 0.931 | 1.043 | 1 | 1 | 0 | 0 |
| Fall 116 Tight | Tight | 16.1 | 8 | 3 | 0.926 | 1.106 | 3 | 11 | 0 | 0 |
| Winter 68 Generous | Generous | 17.5 | 1 | 0 | 0.900 | 1.042 | 1 | 2 | 0 | 0 |
| Winter 68 Tight | Generous\* | 17.5 | 9 | 1 | 0.931 | 1.043 | 0 | 3 | 1 | 20 |
| Summer 69 Tight | Generous | 20.0 | 29 | 0 | 0.933 | 1.037 | 0 | 6 | 4 | 150 |
| Summer 93 Generous | Generous | 22.8 | 13 | 0 | 0.875 | 1.033 | 0 | 10 | 0 | 0 |
| Summer 90 Generous | Generous | 24.0 | 1 | 0 | 0.964 | 1.030 | 0 | 3 | 94 | 3040 |
| Summer 90 Tight | Generous | 24.0 | 47 | 1 | 0.934 | 1.040 | 0 | 12 | 17 | 750 |

## Bus Voltage Limits

The bus voltage limits for the 12 cases are set to create a variety of scenarios for the power flow and optimal flow algorithms to be tested. The “generous” voltage limits are set to allow for an “easier” convergence of the power flow and a wider range of load and generation variations in the optimal power flow, and are shown below in Table 3. The “tighter” voltage limits are set to create are more conservative set of constraints and create cases that are more realistic to actual operating conditions. These limits are shown in Table 4.

**Table 3: Generous Bus Voltage Limits**

|  |  |  |
| --- | --- | --- |
| **Bus Type** | **Minimum Voltage (per unit)** | **Maximum Voltage (per unit)** |
| Load | 0.92 | 1.06 |
| Generator | 0.98 | 1.10 |

**Table 4: Tight Bus Voltage Limits**

|  |  |  |
| --- | --- | --- |
| **Bus Type** | **Minimum Voltage (per unit)** | **Maximum Voltage (per unit)** |
| Load | 0.95 | 1.04 |
| Generator | 1.00 | 1.06 |

## Generator Reactive Power Limits

The generator reactive power limits are also created to allow for a variety of scenarios with varying “difficulty” for power flow and optimal power flow algorithms. The PV buses in the NE 250 system are given a rectangular generator capability curve that is dictated by the real (MW) and reactive (MVar) limits in the excel spreadsheet titled “Generator Reactive Power Limits”. In order to create varying “difficulty” but still allow for optimal power flow feasibility, two different levels of generator reactive power limits were created: generous and tight. The generous reactive power limits were set using the typical power factor values listed in Table 5 below. Generators connected to combustion or steam turbines are considered “conventional” generators.

**Table 5: Power Factor Values used to determine generous generator reactive power limits**

|  |  |  |
| --- | --- | --- |
| **Generator Type** | **Power Factor for Qmin** | **Power Factor for Qmax** |
| Wind | 0.95 | 0.95 |
| Conventional | 0.95 | 0.85 |

## Bus Shunt Reactive Power Injections

To match current electric utility practice, shunt capacitors totaling approximately 3000 MVar are installed at approximately 50% of the unique geographic locations in the NE 250 system, as described in the excel spreadsheet titled “Switched Shunt Capacitor Values”. These shunt capacitors are then switched in or out in discrete steps as needed. To create “easier” cases, more of the shunt capacitors are switched in (connected to the buses) to create scenarios where only a few buses and generators violate their voltage and MVar limits, respectively. Whereas to create “harder” cases, fewer to no shunt capacitors are connected. The user is also able to vary the value of the shunt capacitors that are switched on to control the “difficulty” of the cases as well. However, in keeping with industry practice and to ensure optimal power flow feasibility, 4 of the 12 cases have shunt capacitors already connected to a limited number of buses.

## Master Case

There is also a Power World simulator “Master Case” file that contains all four weeks of time-varying load data, as well as the full range of the switched shunt injections. The time-varying data is included in a Power World MasterCase.tsb file and must be read into Simulator’s “Time Step Simulation” tool. The switched shunt values are included as voltage-controlled switched shunts that have between 1 and 4 discrete steps of between 10 and 40 MVar depending on the bus. A total “max capacity” of 3134 MVar of switched shunts are installed at just over half (91 buses) of the unique geographic locations. The shunts will switch one discrete level in or out when the bus voltages go beyond 0.95 pu or 1.04 pu, respectively.

To provide an initial condition for a time-varying optimal power flow, the generation values have been scaled such that each generator supplies an equal percentage of the total system load, based on the maximum power output of the generator. For each hour in the time-varying simulation, the equation is as follows: where is the power output of the ith generator and is the load power of the jth load bus.

A user may utilize the “Time Step Simulation” tool to run a time-varying power flow or economic dispatch (that respects generator and transmission line limits) and view the results in a variety of formats (tabular data, graphs, etc)

## Easy Cases

There are 3 cases in the “easy” category included in the initial release of the New England 250 Bus System (NE 250), and would be suitable for security constrained optimal power flow. All 3 cases have the “generous” bus voltage and generator reactive power limits. The easy cases are all feasible in the MatPower OPF solver. When the generators are scaled proportionally to match the load, all cases except 1 have all buses within their voltage limits, and only 2-3 generators hit their reactive power limit in the power flow calculations. None of the easy cases have shunt capacitors connected to any of the buses. Finally

### Fall 116 Generous

This case represents the 116th hour in the 168-hour long time varying load data for the fall season. The word “generous” in the title indicates that the generous bus voltage limits are used. The initial generation levels are assigned by uniformly scaling the generator power outputs up from the minimum MW output level (or down from the MW max output, whichever results in fewer generators outputting at their limits) until the load is properly matched.

Total load: 16.1 GW.

### Winter 12 Generous

Total load: 14.3 GW

### Winter 68 Generous

Total load: 17.5 GW

## Medium Cases

There are 6 cases included in the NE 250 system that are categorized as a “medium” difficulty for optimal power flow algorithms. 5 of the 6 cases have the “tight” bus voltage limits. Due to the wide range of loads, 3 of the cases have “generous” generator reactive power limits and some shunt capacitors connected to buses, while the other 3 have “tight” reactive power limits and no shunt capacitors connected. Since these cases are all feasible in MatPower, they are suitable for security constrained optimal power flow with a more limited contingency list, as well as optimal power flow.

### Fall 106 Tight

This case uses both the tight voltage limits and the tight generator reactive power limits. At uniform generator loading, there are only 4 buses outside of the voltage limits, and 10 generators at the reactive power limits.

Total load: 14.8 GW

### Fall 116 Tight

This case uses both the tight voltage limits and the tight generator reactive power limits. At uniform generator loading, there are 11 buses outside of the voltage limits, and 14 generators at the reactive power limits.

Total load: 16.1 GW

### Spring 4 Generous

This case uses generous voltage limits and tight generator reactive power output limits. Also, this case requires 12 generators to be shut down so that the total generator can meet the load and still be within the minimum generator MW output levels. Thus, it is recommended to run a unit commitment algorithm in conjunction with an optimal power flow algorithm to get a proper result. Also, at uniform scaling of the generators, there are 2 buses over the voltage limits, and 2 generators at the minimum MVar output levels. Finally, this case represents the “base load” or lowest loading level across all 4 weeks of time-varying load data.

Total load: 9.4 GW

### Summer 69 Tight

This case uses tight bus voltage limits and generous generator reactive power limits. It also has 150 MVar of shunt reactive power injected at a total of 4 buses. After uniformly scaling the generators down from their maximum real power output, the power flow resulted in 29 buses under their voltage limits, and 6 generators at their reactive power limits.

Total Load: 20.0 GW

### Summer 90 Tight

This case uses tight bus voltage limits and generous generator reactive power limits. It also has 750 MVar of shunt reactive power injected at a total of 17 buses. After uniformly scaling the generators down from their maximum real power output, the power flow resulted in 47 buses under their voltage limits, and 12 generators at their reactive power limits. This case also represents the peak loading condition across all 4 weeks of time-varying load data.

Total Load: 24.0 GW

### Winter 68 Tight

This case uses tight bus voltage limits and generous generator reactive power limits, but with the limits on 3 generators changed to 300 MVar. This caused the generators to hit their reactive limits during the power flow, and created a “harder” case for optimal power flow algorithms. The case has 20 MVar of shunt reactive power injected at one bus. After uniformly scaling the generators down from their maximum real power output, the power flow resulted in 9 buses under their voltage limits, and 3 generators at the reactive power limits.

Total Load: 17.5 GW

## Hard Cases

The NE 250 System includes 3 “hard” cases, which are only feasible using optimal power flow algorithms that can change the generator setpoint voltages as a decision variable. Thus, these 3 cases are not feasible in the MatPower OPF solver.

### Spring 13 Tight

First, the power flow for this case was unable to converge with all generators connected, due to the lower MW output limits. Thus, 5 generators have been manually disconnected to reach a power flow that converges. Thus, it is recommended that a unit commitment algorithm be run in conjunction with an optimal power flow algorithm to reach the true optimal cost.

This case uses tight bus voltage limits and generator reactive power limits. It has no shunt reactive power injection at any buses. After uniformly scaling the generator MW setpoints up from the minimum limit to match the system load, the power flow resulted in 8 buses violating the bus voltage limits. What makes this case “hard” is that 1 bus is under the minimum voltage limit, while 7 buses are over the upper voltage limit, due to the low loading levels and tight generator reactive power limits. Also, 5 generators are at their lower reactive power limit, while another 4 are at their upper reactive power limits.

Total System Load: 12.9 GW

### Summer 90 Generous

This case uses generous bus voltage limits and generator reactive power limits. It is a unique case because shunt reactive power injections were iteratively added to each bus under the minimum voltage limit until all buses were above the minimum voltage limit. This resulted in a total of 3040 MVar of shunt reactive power being injected at a total of 94 buses. Also, 3 generators are at their maximum reactive power limits. However, since the reactive power injections were determined using generation levels that had been uniformly scaled down from the maximum MW output level to the total system load, when the optimal power flow algorithm was run in MatPower, it resulted in a new set of generation MW setpoints that caused the voltage limits to not be met, resulting in an infeasible case. However, algorithms that treat the generator voltage setpoints as decision variables can solve this case.

Total System Load: 24.0 GW

### Summer 93 Generous

This case uses generous bus voltage limits and generator reactive power limits. After uniformly scaling the generators down from their maximum real power output, the power flow resulted in 13 buses under their voltage limits, and 10 generators at their reactive power limits. What makes this case “hard” is that there is no shunt reactive power injected in this case, resulting in a lowest bus voltage of 0.875 per unit. Thus, optimal power flow algorithms that don’t treat the generator voltage setpoints as decision variables are unable to find a feasible solution. Finally, this case represents the 2nd of the double reactive power peaks in the summer time-varying load profile.

Total System Load: 22.8 GW