

n-1 Reliability Example

Idaho Power must adhere to what's known as an "n-1" criterion.

For multiple transmission lines delivering power to the same point, if one of the lines goes out of service, the remaining lines must be able to carry both the load they were carrying before the event, plus the load carried by the line that is out of service.

- This is true even if the line with the highest capacity is the one that goes out of service.
- Only holds true for major transmission lines.

Take for example three, extra-high voltage, 345,000-volt transmission lines operating electrically in parallel as shown in Figure 1. This means that they all originate in the same location and deliver power to the same location. Each line might take a different path to get there, but all three begin and end in the same locations.

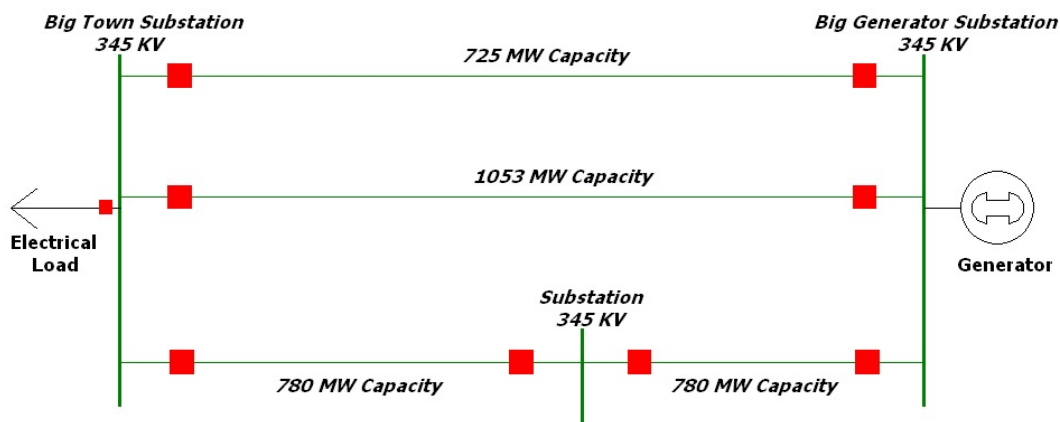


Figure 1. Three Parallel Transmission Lines

The top line is 100 miles long and has a capacity of 725 MW. The middle line is also 100 miles long and has a capacity of 1,053 MW. The bottom line is 200 miles long and has a capacity of 780 MW. There is a substation located at the halfway point on the bottom line but it has no effect on the power flow.

Normal Operation, No Lines Out

The three lines in Figure 2 are carrying a total of 1,400 MW to a load located at Big Town Substation. Note that the generator is producing 1,406 MW of power while the load is only consuming 1,400 MW. The difference between the two is due to losses on the transmission system...losses that must be provided for by the generator. The green arrows shown on the drawings indicate the direction of power flow.

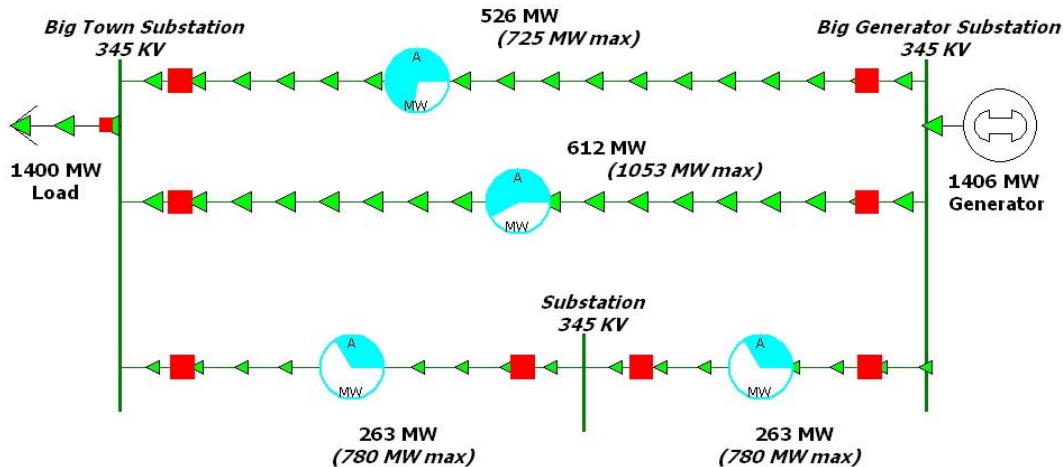


Figure 2. Three Parallel Transmission Lines During Normal Operation.

The blue circle on each transmission line is a visual indication of how much each line is loaded. The top circle indicates that the line is carrying about $\frac{3}{4}$ of the amount it is capable of. If the circle turns orange, it indicates that the line is approaching its maximum capacity. A red circle indicates that the line has exceeded its capacity.

All three lines are operating within their capacity and could operate like this indefinitely.

- Top line capacity = 725 MW
- Top line operating at 526 MW
- Middle line capacity = 1053 MW
- Middle line operating at 612 MW
- Bottom line capacity = 780 MW
- Bottom line operating at 263 MW

Bottom Line Out of Service

Now let's see what happens if we take the bottom line out of service. The circuit breaker located on the right side of the line (red box in upper drawing) turns to a hollow green when the circuit breaker is open, de-energizing the line.

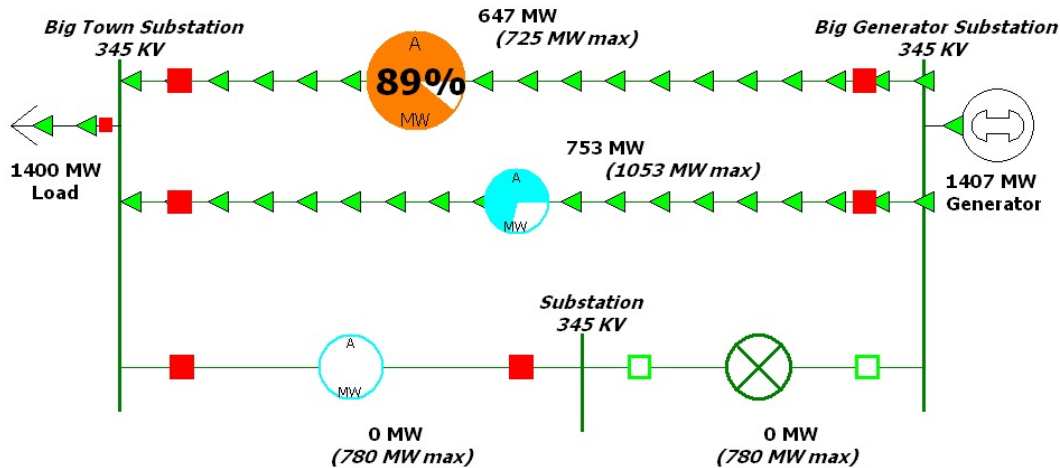


Figure 3. Three Parallel Transmission Lines, Bottom Line Out of Service.

Notice that no power flows on the bottom line now. The middle line, which has the highest capacity of all three, is now operating to about $\frac{3}{4}$ of its capability. The top line indicates that it is operating at 89% of its capability, giving us a warning. However, these lines could operate like this indefinitely so no action is required. In this case, we have met the n-1 criteria.

Top line capacity = 725 MW
Top line operating at 647 MW

Middle line capacity = 1053 MW
Middle line operating at 753 MW

Bottom line capacity = 780 MW
Bottom line operating at 0 MW

Note that the generator on the right side of the drawing is producing more power compared to the last case. This is because the power losses are higher with one of the lines out of service because there is more resistance to power flow.

Top Line Out of Service

Now we will put the bottom line back in-service and take the top line out of service. Again, the circuit breaker on the right of the top line will go from solid red to hollow green indicating that the line is out of service.

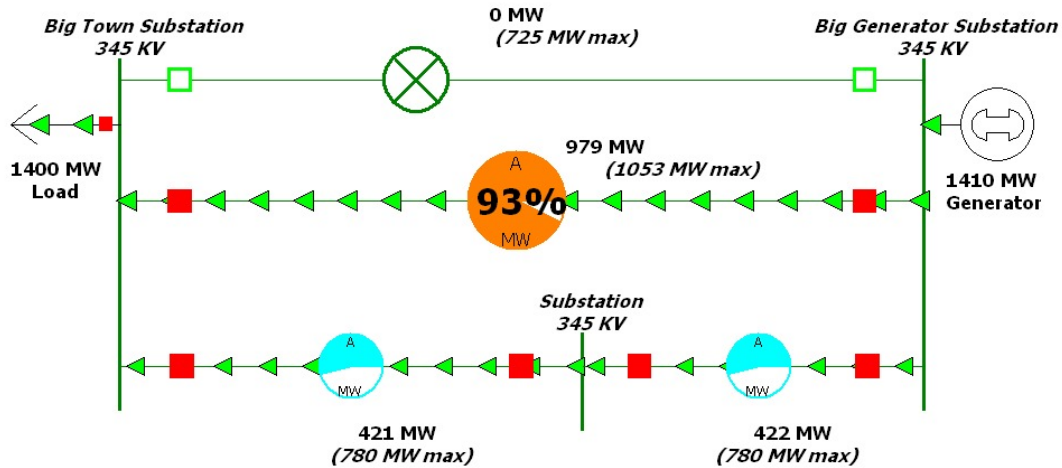


Figure 4. Three Parallel Transmission Lines, Top Line Out of Service.

Notice that no power flows on the top line now. The bottom line indicates that it is operating at about 2/3 of its capability while the middle line is warning us that it is operating at 93% of its capability. These two lines could operate like this indefinitely so again no action is required.

Top line capacity = 725 MW
Top line operating at 0 MW

Middle line capacity = 1053 MW
Middle line operating at 979 MW

Bottom line capacity = 780 MW
Bottom line operating at 421 to 422 MW

Again, notice that the generator is now producing more power due to the higher line losses with one of the lines out of service.

Middle Line Out of Service

The top line is put back in service and the middle line is taken out of service. This is indicated in Figure 5 by the circuit breaker located on the right side of the middle line changing from a solid red box to a hollow green box.

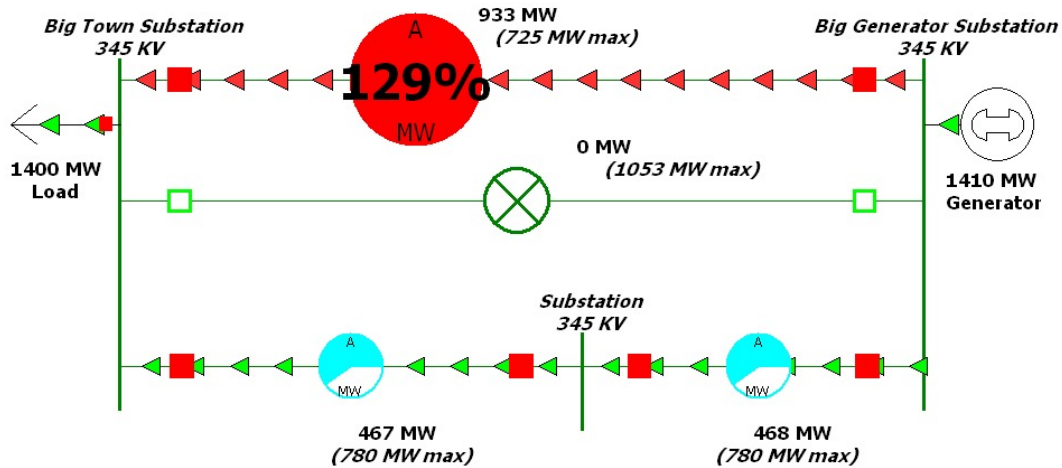


Figure 5. Three Parallel Transmission Lines, Middle Line Out of Service.

Figure 4 indicates that the bottom line is operating at about 2/3 of its capability and this can be maintained indefinitely. However, notice that the top line's indicator shows that it is now operating at 129% of its capability. A transmission line cannot operate like this for very long because the line gets too hot and can be damaged to the point of breaking. So, in this case, our three transmission lines have failed the n-1 test. When the largest transmission line was taken out of service, the other two could not safely carry the power it was carrying plus the power they were carrying before the incident.

Top line capacity = 725 MW
Top line operating at **933 MW**

Middle line capacity = 1053 MW
Middle line operating at 0 MW

Bottom line capacity = 780 MW
Bottom line operating at 467 to 468 MW