Frequency Dynamic Impact by a Transmission Overlay in a Renewable Sourced Power System

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Introduction:
The nation’s transmission grid system is currently divided into three main self-sufficient regions: the Eastern Interconnection, Texas, and the West [1]. The few existing transmission lines between these regions have very low capacity because there is little need for transferring energy between regions. However, this need is constantly growing due to further development of renewable energy sources specific to regions of the United States. In order to reach the progressive standard set by the 2008 Department of Energy report maintaining that 20% of the U.S. Energy portfolio can come from Wind Energy by 2030 [2], a complete renovation of the transmission system will be required.

The theorized system is one that would equally link all sections of the United States in a national transmission grid. The nation’s transmission grid system is currently divided into three main self-sufficient regions: the Eastern, the Texas, and the West. The real power balance of a system is what dictates the frequency, which ideally should be relatively constant. However, this need is constantly growing due to further development of renewable energy sources specific to regions of the United States. In order to reach the progressive standard set by the 2008 Department of Energy report maintaining that 20% of the U.S. Energy portfolio can come from Wind Energy by 2030 [2], a complete renovation of the transmission system will be required.

Experimental Methods:

Maps:
In order to simplify our analysis, we combined our control areas into 13 separate regions across the United States and mapped out the existing interconnections. Presented with a proposed future transmission corridor [3] of over 250 additional transmission lines throughout the next 40 years, we situated the interregional connections – according to our defined areas – to use for our analysis. We added another layer to our transmission map in order to view the entire extent of the proposed system.

Calculating Impedance for HVAC – 765kV
We seek to model each interconnection as a single tie-line through estimation. It is necessary to first calculate the effective impedance, Z', of the tie-lines between the areas. By approximating our resistance, R, to be negligible, we arrive at impedance, Z, to be relatively equal to the imaginary part of the reactance, X.

\[ Z = \sqrt{X^2 + R^2} \]

We multiplied the inductive reactance by the theoretical length of the tie-line (in miles), converted to per unit (using a base power of 100MW), and supplied the correction factor that allows us to use our consolidation assumptions for lines longer than the miles [4]. This provided us with a Z' value for our supplementary calculations.

We expanded our data to consider the lengths of each transmission line segment into lines of 300 miles or fewer in order to transmit at 100% loadability [5].

Calculating Power
The surge impedance loading, \( P_{in} \), is the power loading at which the reactive power is not produced or absorbed. The AC network is necessary to determine the number of required circuits needed for each line. It can be calculated by using the per-unit length impedance and admittance along with the Line-to-Line voltage, \( V_{LL} \), of 765 kV and a power base, \( S_0 \), of 100 MW.

This is the maximum power capacity of each circuit per unit, p.u., as determined by the line geometry. With this information, we can calculate the number of circuits necessary to reach the desired power capacity, \( P_{in} \), delivered to the load.

Calculating \( b_i \) and \( \Delta \theta \)
For dynamic analysis, we are looking for the \( b_i \) – a function of the impedance of each tie-line. To calculate this value, we again approximate and assume that the change in voltage across the tie-line is negligible and, since we are working in per-unit, \( V_i \) and \( V_j \) are both approximately to be 1 p.u. The final step is to calculate the \( \Delta \theta \), the phase shift within each circuit. This quantity is later used to determine whether or not an adequate transmission line was designed. A \( b_i \) must be calculated for each tie-line for the first period and the second period of time.

The following table contains the interregional connections that were sifted out from the original data, grouped from one specific region to another. The table contains the length of each line segment (miles), required transmission capacity (GW), number of proposed transmission lines at that capacity, the proposed year, along with the \( b_i \) value and \( \Delta \theta \) for the first and second analysis period.

Determining Line Geometries
The characterizations of line geometry consist of the number of conductors used in each bundle and the bundle diameter and the phase spacing in each circuit, which involves three phases. There is no need to choose one specific line geometry to use through the entire transmission overlay. The requirements of each segment should be carefully studied to choose the best suited geometry for that individual segment.

Minimize:
- Economic Costs
  - # of circuits required
  - # of towers to suspend transmission lines
- Environmental Costs
  - 200m Right-of-Way with each 765kV tower [9]

Maximize:
- Transmitted Power

Dynamic Simulation:
In dynamic simulation, we will use the metaphor of a web of blocks – each representing the individual control areas – connected by springs. Our theoretical “spring constants” will be our \( b_i \) values for each tie-line. The concept is to analyze what happens to the system when one spring is jostled. Ideally, the “springs” are stiff enough to account for a slight disruption and will hold the rest of the system intact by dampening any oscillations. If this is not the case, further improvements to the national transmission overlay will be proposed.

References: