HVDC Dynamic Modeling
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Abstract—The intent of this research is to do studies on these HVDC lines and to determine if they improve dynamic performance. In attempting to do so, tools such as PSS/E and a MATLAB based tool, PSAT, will be used to construct multi-terminal HVDC models on an IEEE 9-bus system and an IEEE 14-bus system. While studying the IEEE 9-bus system, a comparison will be done to see whether using HVDC lines will allow the system to stabilize quicker, as opposed to the lines in the original system. While studying the IEEE 14-bus system, a comparison will be done to see whether or not adding HVDC lines can improve power flow.

Index Terms—fault, HVDC, perturbation, power flow, PSAT

II. INTRODUCTION
A direct current (DC) system that operates at high voltage uses are more efficient than an AC system. HVDC allows for easy transfer of power between grids that are operating at different frequencies and that are long distances apart. To fully understand the goals and methods of this research, one must know a little about power flow, time domain, and HVDC lines.

A. Power Flow Background
Power flow in a system is determined by the voltage at each bus of the system and the impedances of the lines between buses. Power flow into and out of each of the buses that are system terminals is the sum of power flows of all of the lines connected to that bus [1]. One of the main targets of power flow studies is to determine the voltages, phase, and real and reactive power flows in a system, which, together with the system impedances, produces the load flows that are known to be correct at the system terminals. Another purpose of power flow studies is to be able to plan ahead. The major question being asked is: if one part of the system needs repairs, can the remaining parts still function without going over their rated values. First the power system should be seen as a collection of buses, connected together by lines. At each node connected to the bus, an instrument can be connected to supply or remove power from the system. (Note: when talking about power, complex power with real and reactive components is being referred to) [2]. Once the connection is made to a system node, the complex power flow into the system at the node is:

\[ S_k = P_k + jQ_k = V_k I^*_k \]

While calculating power flow, the Newton Raphson Method is commonly used. This method uses iterations and derivations.

When using the power flow feature of PSAT, the Newton Raphson Method is what the program uses to get results. Below are some the equations [5].

\[ \Delta y^{(i)} = -[g_y^{(i)}]^{-1} g^{(i)} \]  
\[ y^{(i+1)} = y^{(i)} + \Delta y^{(i)} \]  
\[ \tau_y g^{(i)} + g_y^{(i)} (y - y^{(i)}) \]  

B. Time Domain Analysis Background
Time domain analysis is analyzing the data over a time period. Electronic signals are one of the many functions being analyzed by using time domain. In a time domain analysis, the variable is always measured against time.

The importance of studying time domain analysis is twofold:

1. Electro-magnetic transient analysis- Studying the electromagnetic behavior of power systems

2. Transient stability analysis- studying the electromagnetic response of power system networks after a large disturbance.

This research is more concerned with transient stability analysis. The main goal of transient stability analysis is to determine the effects of large disturbances on the dynamic response of a given power system [3].

C. High Voltage Direct Current Background
High-voltage direct-current (HVDC) transmission systems have a DC line connected to an AC network by using rectifiers and inverters. These systems can handle valuable position applications which there no other devices can accomplish. The amount of electricity being used is far less by using a DC system operating at high voltage as opposed to using an AC system. HVDC lines can carry more power per conductor because of the constant voltage in a DC line is lower than the peak voltage in an AC line. Thus allowing for an easy transfer of power between grids that are operating at different frequencies. Another upside to HVDC lines is that the cost is lower. A DC line needs only two main conductors, while an AC line needs three, and DC electrical losses are lower since they use less current. HVDC converter stations do cost more than the AC terminal stations, due to rectifier and inverter
costs, a certain distance is required in order for an HVDC system to work out in an economic sense [3].

Figure A: HVDC System

II. METHODOLOGY

A. Time Domain Analysis

To study the time domain of the system, PSAT, a MATLAB toolbox was used. There were two systems being compared; one without the HVDC lines, and one with HVDC lines, figure 4. There were three variables being studied; omega, voltage magnitude of a bus, and the relative angle of a bus. The data was separated into cases in order to make the comparison process easier. Case one was noted as the simplest case, it studied the time domain of the systems as a fault was applied at bus 1. Case two then added instruments like an exciter or a turbine governor to see if these tools could help speed up the stabilization process. In case three a less severe disturbance was applied to both systems, a perturbation file. Applying an exciter or turbine governor also was done within this case. Plotting the results of the simulation allowed for a quick and easy analysis.

B. Power Flow Analysis

PSAT was also used to study the power flow of the 14-bus system. We compared the original system with the connections of HVDC lines to buses that were not previously connected. When comparing results, we took a look at the change in phase angle, reactive, and active power. When looking at power, if the voltage and current are too out of phase, the power is not as efficient. When looking at reactive power, if there is too much, it will be less efficient. There are two cases that we will be taking a look at. With some connections, it didn’t work because the change in the angles were far too great, as shown in Figure 4. In a case that did work we will be taking a look at the difference in reactive power.

Figure B: IEEE 9 Bus System

III. RESULTS AND DISCUSSION

A. Time Domain Analysis Results

Careful analysis of many graphs was done in order to determine if adding HVDC to a system improved dynamic performance. As stated before there were three variables examined. Figure 1 shows the results of the rotor speed (omega), Figure 2 shows the results of the voltage speed on a bus, and Figure 3 shows the results of the relative bus angle.
The images in the first column of figure 1 are each system with the fault applied at bus 1. The second column show the same systems with the help of a turbine governor. The time difference is small, but the system with HVDC stabilized less than a second quicker than the system without it. Even though the recovery was small, in the case of rotor speed HVDC lines do improve dynamic performance.

**Figure 2. Voltage magnitude of a bus**

In figure 2, the results of the voltage magnitude of two buses. In both buses, the system with HVDC stabilized quicker than the non-HVDC system, therefore HVDC lines improve dynamic performance in the case of the voltage magnitude on a bus Since turbine governors or exciters did not help, their results are not shown.

**Figure 3. Relative Angle of a Bus**

In figure 3, the results of the relative bus angle are shown. In both buses, even though slight, the relative angle on the system with HVDC is higher than the relative angle on the system with non-HVDC, therefore HVDC lines improve dynamic performance in the case of relative bus angle

**B. Power Flow Analysis Results**

In figure 4, the phase angles are compared. The blue represents the angles with the HVDC lines connected between buses 4 and 6, and the orange is without. Looking at the chart we can see a drastic difference. This case is one that didn’t work. Adding the HVDC lines between these two buses caused too much of a difference in the phase angle. They were too out of phase. Connections between bus 1 and 12 did not work on account of this reason as well.
In Figure 5 we are taking a look at the change in reactive power. The blue represents the system with HVDC lines and the other color represents the system without HVDC lines. There are two different representations so we can evaluate it easier. In a system, more reactive power results in inefficient power. Looking at these charts, we can see that by adding HVDC lines, the reactive power throughout the system is lower than that of the original system. This is one connection that helps power flow to be more efficient. There are several connections that fit this case, more than those that fit the first case. Some connections are: 3-13, 5-12, 8-12,1-14, etc.

IV. CONCLUSION

While alternating current has dominated the power lines for a century, solid-state thyristors have made direct current a practical alternative in certain circumstances. While it most likely won’t replace alternating current as the leading form of electrical power, it has become more cost efficient than AC for overhead lines beyond 800 km and undersea or underground lines exceeding 50 km, which ultimately makes DC the ideal choice for especially long connections and connections to isolated power plants and consumers [4]. HVDC lines will keep evolving the same way technology that uses them evolves. From this research, it is seen that HVDC lines can improve dynamic performance. In the examples shown in this paper, it is seen that the systems with HVDC stabilize quicker than the systems without HVDC lines even though the time difference is very small, this research still shows the improvement of dynamic performance with HVDC lines. The research also shows that adding HVDC lines can improve power flow. It shows that the lines won’t work being placed everywhere, they have to be added in places that affect the components of power in a positive way. Doing this study on different systems in the future would be the next step in continuing this research.

REFERENCES