**EE 488 Power System Analysis I**

**Simulation Lab #2**

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**Introduction**

The purpose of this Lab is to perform simulation analysis on the different ways line loss can be minimized on a long haul, High- voltage transmission system by adding extra transmission lines, shunt Capacitors at load bus, and D-FACTS on Transmission lines. The system includes a Garver L transmission system with three Voltage control buses and three load buses. One of the Voltage control buses is used as slack bus.

The experiment helps to analysis how different transmission line configurations help prevent overloading of the transmission lines in the system. The lab also helps to demonstrate what effect does adding shunt switches to the load bus will have on the operating condition of the transmission lines in the system. This is important in long haul, High-voltage transmission system to reduce line loss.

**Methods, Results, and Discussion**

The first part of the experiment consists of making 6 buses in Power World Simulator, this includes 1 Slack bus and 2 Voltage control buses. There were also 3 load buses with different transmission lines connecting the different buses. The circuit is shown in Fig. 1.

A diagram of a circuit

Description automatically generated

Fig. 1. Circuit Model without Transmission Lines

Each load bus has a 35 MVAR shunt switch connected. These shunt switches can improve the power loss at both the load and the transmission lines. The switches are initially left open to see what effect they can have on the overall MVA rating of each transmission line later on. Table 1 shows the Bus information used to make the Garver 6-Bus system and Table 2 shows the transmission line data with the impedance converted to per unit (p.u). The Overall system has a Power base of 100MVA obtain from Power World’s default MVA base, the system is also operating at a base Voltage of 230kV.

Table 1. Bus Information for Garver 6-Bus System

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bus #** | **Type** | **P (MW)** | **Q (MVAR)** | **Vnom** | **Vp.u.** |
| 1 | Slack | 100 |  | 230k | 1.05 |
| 2 | VC | 65 |  | 230k | 1.05 |
| 3 | VC | 65 |  | 230k | 1.05 |
| 4 | Load | 95 | 75 |  |  |
| 5 | Load | 90 | 70 |  |  |
| 6 | Load | 85 | 65 |  |  |

Table 2. Branch Information for 6-Bus System

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **From-To** | **R (Ω)** | **R(p.u)** | **X (Ω)** | **X(p.u)** | **MVA Rating** | **From-To** | **R (Ω)** | **R(p.u)** | **X (Ω)** | **X(p.u)** | **MVA Rating** |
| 1-2 | 13.225 | 0.025 | 52.9 | 0.1 | 75 | 2-6 | 26.45 | 0.05 | 105.8 | 0.2 | 72 |
| 1-4 | 26.45 | 0.05 | 105.8 | 0.2 | 72 | 3-5 | 26.45 | 0.05 | 105.8 | 0.2 | 72 |
| 1-5 | 26.45 | 0.05 | 105.8 | 0.2 | 72 | 3-6 | 26.45 | 0.05 | 105.8 | 0.2 | 72 |
| 2-3 | 13.225 | 0.025 | 52.9 | 0.1 | 75 | 4-5 | 13.225 | 0.025 | 52.9 | 0.1 | 75 |
| 2-4 | 26.45 | 0.05 | 105.8 | 0.2 | 72 | 5-6 | 13.225 | 0.025 | 52.9 | 0.1 | 75 |
| 2-5 | 26.45 | 0.05 | 105.8 | 0.2 | 72 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Power Base | 100 | MVA |  | Given Color | |  |  |  |  |  |  |
| Voltage Base | 230 | kV |  | From Power World | |  |  |  |  |  |  |
| Zbase | 529 | Ω |  | Calculated | |  |  |  |  |  |  |

Using (1) the base impedance Z\_base was determined by dividing the Base Voltage square by the Power base obtained from Power World.

(1)

Fig. 2 shows the completed circuit with the percentage of the MVA rating of each line at normal operating condition with all shunt switches in open position. From the simulation results of Fig. 2, we observed that the transmission lines from the slack bus to the load buses 4 and 5 have higher percent overload than all the other lines, with transmission line 1-4 having about 88% usage and 1-5. This shows that there is greater power loss at lines connecting the Slack bus to the load buses than lines connecting the Voltage control buses to load buses.

A diagram of a machine

Description automatically generated

Fig. 2. Circuit Model with MVA Rating Percentage

Table 3 shows the overall Power produced by the slack bus and the two voltage control buses for the entire system. The difference between the power absorbed at the load buses and the total power produced by the system is the power absorb by the transmission lines. The current configuration shows that there is a 4% real power loss and a 16% reactive power loss at the transmission lines.

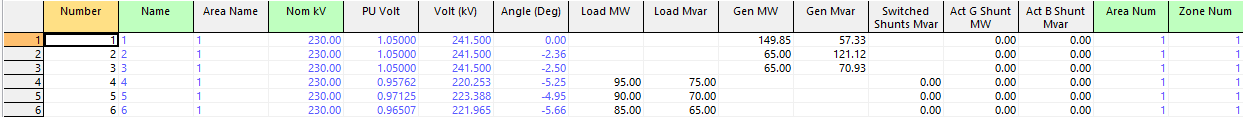
The system’s slack bus accounts for the total line losses and the power absorbed at the load. Before simulation the line losses and power absorbed by the load is unknow so one of the voltage generator buses is designated as slack or swing bus to account for the difference in power produce to power absorbed and this is usually the biggest generator in the system [1]

Table 3. Power Produce vs Power loss

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Voltage Control + Slack Bus | | | Load Bus | | | Line losses | |
| Bus # | Real Power (MW) | Reactive Power (MAR) | Bus # | Real Power (MW) | Reactive Power (MAR) | Real Power Loss (MW) | Reactive Power loss (MAR) |
| 1 | 150 | 57 | 4 | 95 | 75 | 10 | 39 |
| 2 | 65 | 121 | 5 | 90 | 70 | % (MW) loss | % (MVAR) loss |
| 3 | 65 | 71 | 6 | 85 | 65 | 4% | 16% |
| Total Power Produced | 280 | 249 | Total Power Absorbed at Load Bus | 270 | 210 |  |  |

The simulated bus results are shown in Table 4. The real power at the two voltage control buses did not change, however the slack bus accounted for the difference in power produced and power absorbed at both the lines and load buses.

Table 4. Bus Results after simulation of Fig. 1



The Orange condition from the circuit in Fig. 1. can be fixed by the addition of more transmission lines. The additional lines help to reduce line losses. and thereby reducing the real and reactive power at the slack bus. The extra lines reduce the amount of power flow through the existing lines thereby reducing the line losses. Fig. 3 shows how the additional lines affect the percent power rating at each line.

A diagram of a power supply system

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Fig. 3. Effect of additional line on MVA Rating Percentage

Table 4 shows how the different configuration of the two additional lines affect the status of the orange line. When the circuit breaker on both new lines was off the result is similar to Fig. 1. When one of the new lines were closed, all lines started operating below their 80% MVA rating, but some of the lines where above 70% of their MVA rating. When both additional lines are closed all the other lines started operating below their 70% MVA rating

Table 4. Effect of additional lines on the line loss

|  |  |  |
| --- | --- | --- |
| **New Line Status** | | **Lines in Orange Status** |
| **1-6** | **3-4** |
| Off | Off | 1-4 in Orange Status |
| Off | On | None |
| On | Off | None |
| On | On | None |

The different shunt switches at the load bus can also help reduce the percent power rating of the transmission lines. After simulating the different configuration. It was confirmed that the addition of a shunt switch at the loads drops the percent power rating at the transmission line. Table 4. Shows the different configurations and their effect on the lines in orange status, while Fig. 4. Shows the simulated circuit of one of the configurations.

Table 5. Shunt switch configuration and Lines in Orange Status

|  |  |  |  |
| --- | --- | --- | --- |
| **Shunt Status by Bus** | | | **Lines in Orange Status** |
| **4** | **5** | **6** |
| Off | Off | Off | 1-4 |
| Off | Off | On | 1-4 |
| Off | On | Off | 1-4 |
| Off | On | On | 1-4 |
| On | Off | Off | 1-4 |
| On | Off | On | None |
| On | On | Off | None |
| On | On | On | None |

A diagram of a machine

Description automatically generated

Fig. 4. Effect of shunt switches at load bus on MVA Rating Percentage

In the third method of this experiment a D-FACTS device was used on the orange line to reduce line loss. The D-FACTS used has a 47µH with zero capacitance. The percent set Num Module was adjusted until the line turns blue at 25%, but this turned transmission line from bus 1 to 5 orange. Another D-FACT device with similar characteristics was added to the Line 1-5 and the set Num Module was set to 10%. This changed both line blue and their percent MVA rating was about 78%.

The addition of the D-FACT device reduce the impedance on both lines, which reduce the amount of power loss on the line [2]. Maple-soft was used to determine the new per unit impedance on both lines where the D-FACT was added. Fig.4. shows the simulated circuit with the D\_FACTS devices. Fig 5 shows a snip of the maple code used to determine the per unit impedance at each line with the D-FACTS. Line 1-4 has an impedance of 0.02+j0.028 (p.u) and line 1-5 has 0.012+j0.024.

A diagram of a machine

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Fig. 5. D-FACTS added to the circuit.

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Fig. 6. Maple Soft code for line impedance

**Conclusion**

The lab shows that power loss in a grid system can be managed in different ways. In the first part we saw the addition of an extra transmission line help reduce power lost at lines, the additional lines reduce the percentage power rating at all lines but most important it brought the overloaded line to below 80%. Another method used to reduce the line overload was the use of shunt switches at the load. The addition of these switches help reduces line loss and bring all lines to below 80% of MVA rating. Finally, the addition of D-FACTS on the line helps to balance the line loads. This seems to be the most efficient way since the demand on the load side is always changing. Previous DATA from Power usage can be use program the D\_FACTS with set limits to manage line overloads.

**List of References**

[1] [Re-examing the distributed slack bus | Electrical Energy Systems Group (mit.edu)](https://eesg.mit.edu/eesg-seminar/2021-fa/dhople/)

[2] [A review of FACTS device implementation in power systems using optimization techniques | Journal of Engineering and Applied Science | Full Text (springeropen.com)](https://jeas.springeropen.com/articles/10.1186/s44147-023-00312-7)