Design Project Report

In the design project, I developed two unique layouts for transmission lines that link the wind farm to the broader grid. In this process, I took into account various factors such as the types of conductors, the distance from the New Wind bus to adjacent buses, the capacitance associated with each additional transmission line, as well as the associated costs and power losses.

Before laying out transmission lines onto the existing grid, I calculated the series resistance (R), series reactance (X), and shunt charging (B) values, which are shown below in Table 1.

Conductor Type	R	X	B
Crow	0.1482 ohms/mi	0.746592 ohms/mi	5.68194×10^{-6} Mho/mi
Condor	0.1378 ohms/mi	0.740034 ohms/mi	5.73363×10^{-6} Mho/mi
Cardinal	0.1128 ohms/mi	0.729104 ohms/mi	5.82271×10^{-6} Mho/mi
Pheasant	0.0840 ohms/mi	0.71174 ohms/mi	5.97163×10^{-6} Mho/mi

Table 1. Computed Values for Each Conductor Type

I. Design 1

For Design 1, I connected three transmission lines of conductor type Pheasant to the existing grid. Two of those lines are connected from the New Wind bus to the Ostrich bus, and the third line is connected from Ostrich to Mallard. Figure 1 and Figure 2 showcase Design 1 with the wind farm, New Wind, operating at 600 MW and 0 MW.

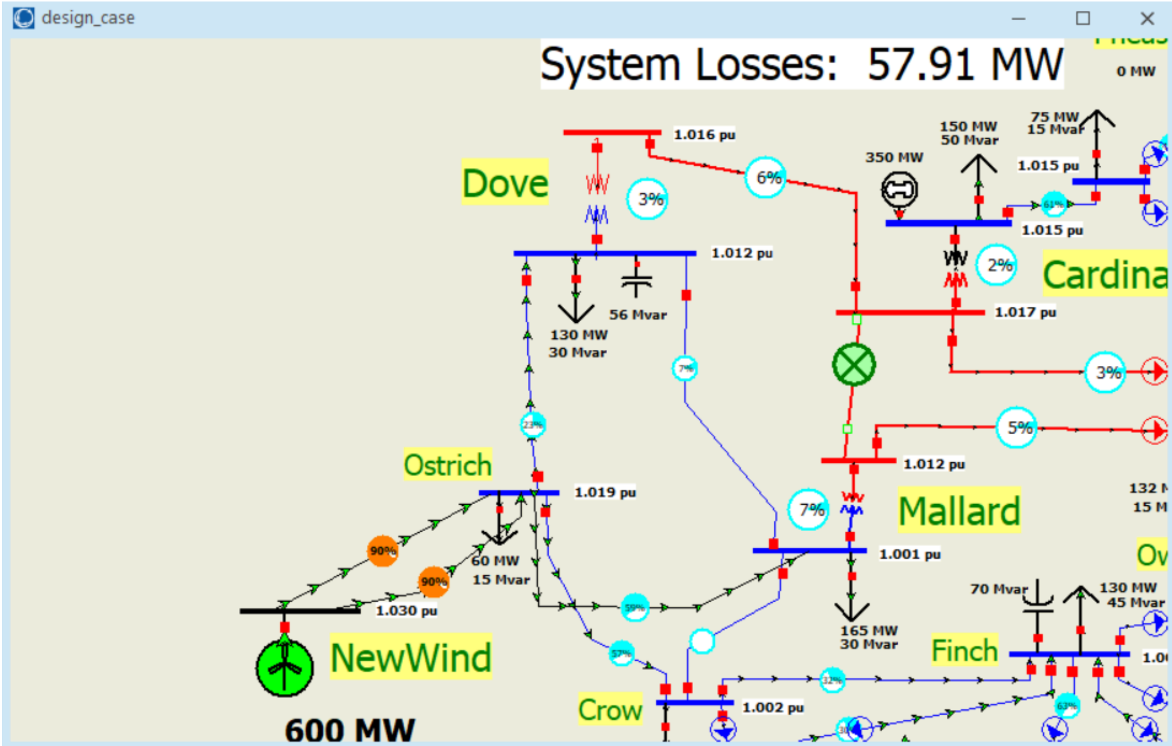

Figure 1. Design 1 with New Wind Outputting 600 MW

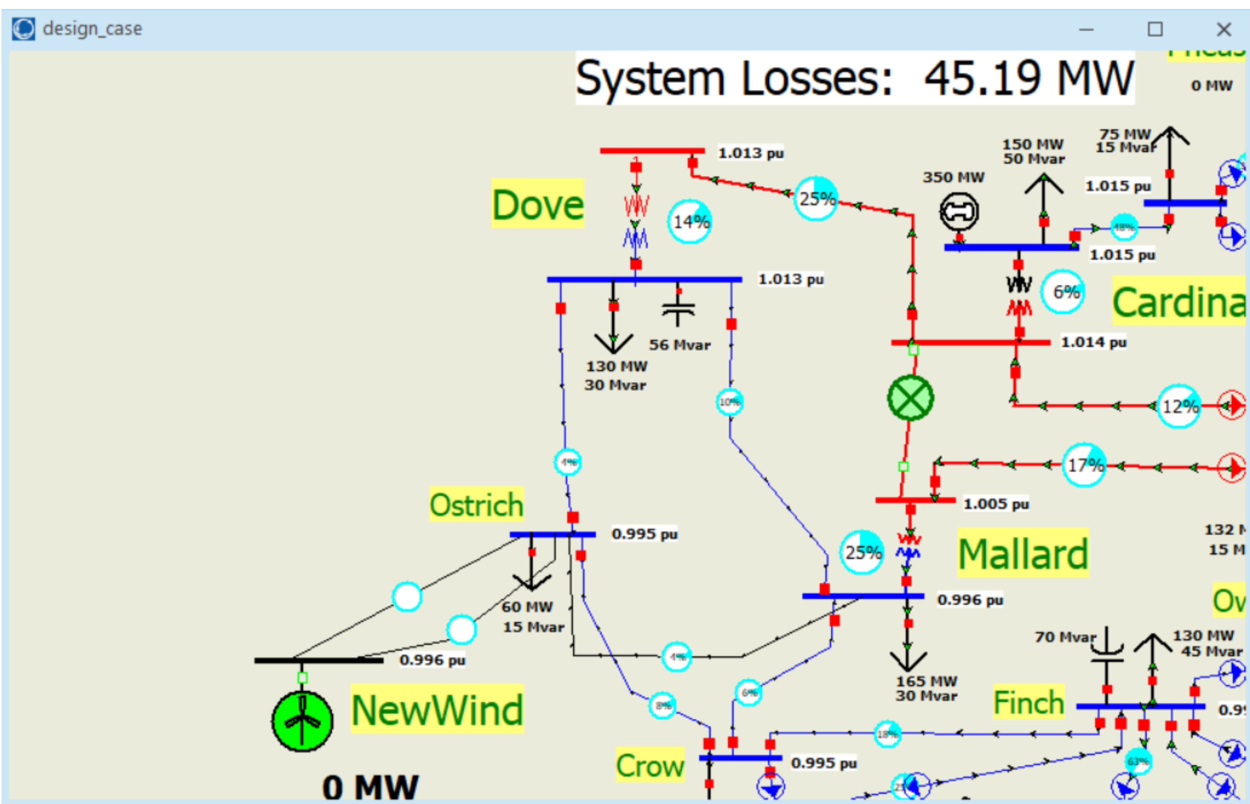

Figure 2. Design 1 with New Wind Outputting 0 MW

My choice to use the Pheasant conductor comes from prioritizing the minimization of power losses. Although Pheasant is the most costly from the selection of conductors, it is the best option in terms of system losses, which is valued at $50/MWh. It's tempting to use the Crow conductor due to it being the least expensive conductor. However, Crow has the highest resistance value while Pheasant has the lowest. Resistance values have a direct relationship with power losses, which can be calculated using the equation,

$$P = I^2 R,$$

where *I* represents the current value, R is the resistance value, and the power losses are denoted by *P*. It's also important to note that using the Pheasant conductor instead of the Crow conductor eliminated the violations listed when running the contingency analysis, using the same configuration of added transmission lines on the grid. The reason for this is that the Crow conductor made transmission lines more prone to thermal overloads under high power flow or contingency conditions. Therefore, the use of the Pheasant conductor for the lines made the network more reliable as it helped maintain system voltages within acceptable bounds.

The addition of the transmission line between Ostrich and Mallard was needed, since the 600 MW that were being fed into the Ostrich bus from New Wind overloaded the lines. The Ostrich to Mallard line relieves Ostrich by giving it a second downstream escape route.

The incorporation of three Pheasant conductor transmission lines allowed Design 1 to complete the contingency analysis without any violations. A comprehensive cost analysis for this configuration will be presented in a subsequent section. For the moment, I will outline an alternative design strategy for comparison purposes.

II. Design 2

The configuration of Design 2 has a variation in both configuration and conductor types used, contrasting it from Design 1. For Design 2, I also used three transmission lines. However, they all stem from the New Wind bus, and each one ends up being connected to different surrounding buses. For the transmission lines used, two of them consist of the Pheasant conductor type, and one of them uses the Crow conductor type. The Pheasant conductor lines are connected from New Wind to Ostrich and from New Wind to Crow. Similarly, the Crow conductor line is connected from New Wind to Dove. Figure 3 and Figure 4 showcase Design 2 with the wind farm operating at 600 MW and 0 MW.

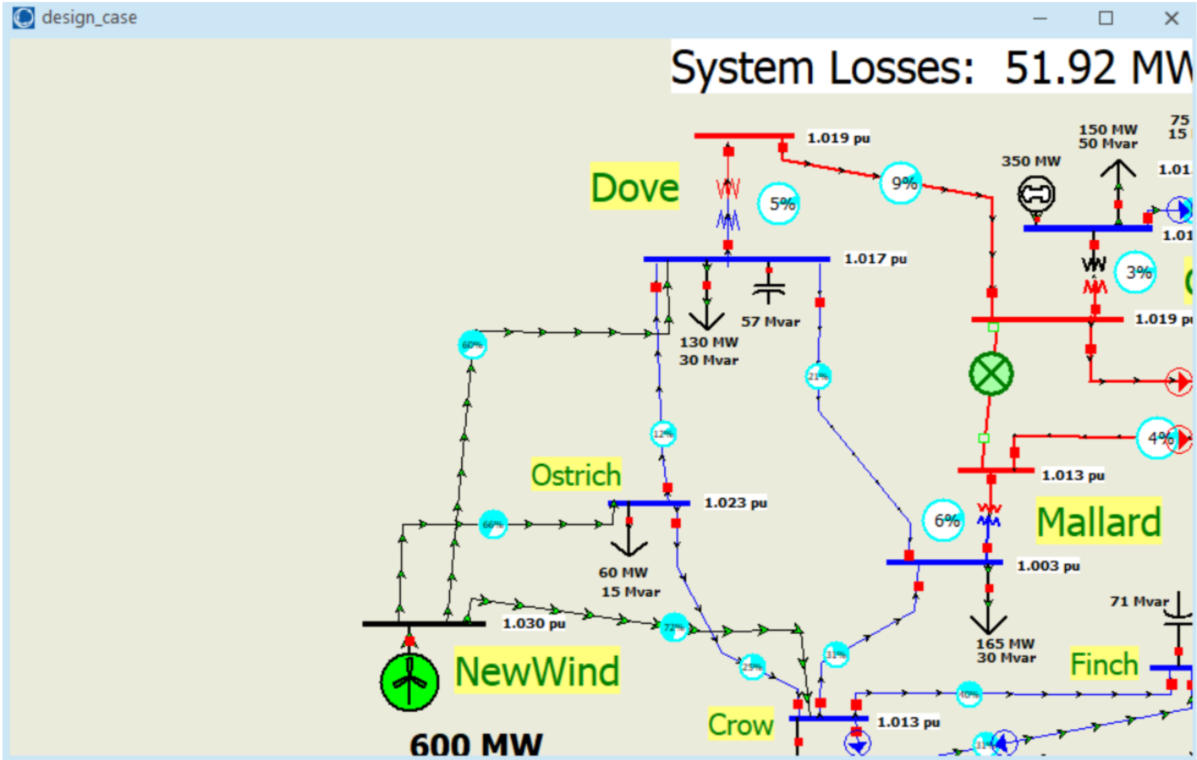

Figure 3. Design 2 with New Wind Outputting 600 MW

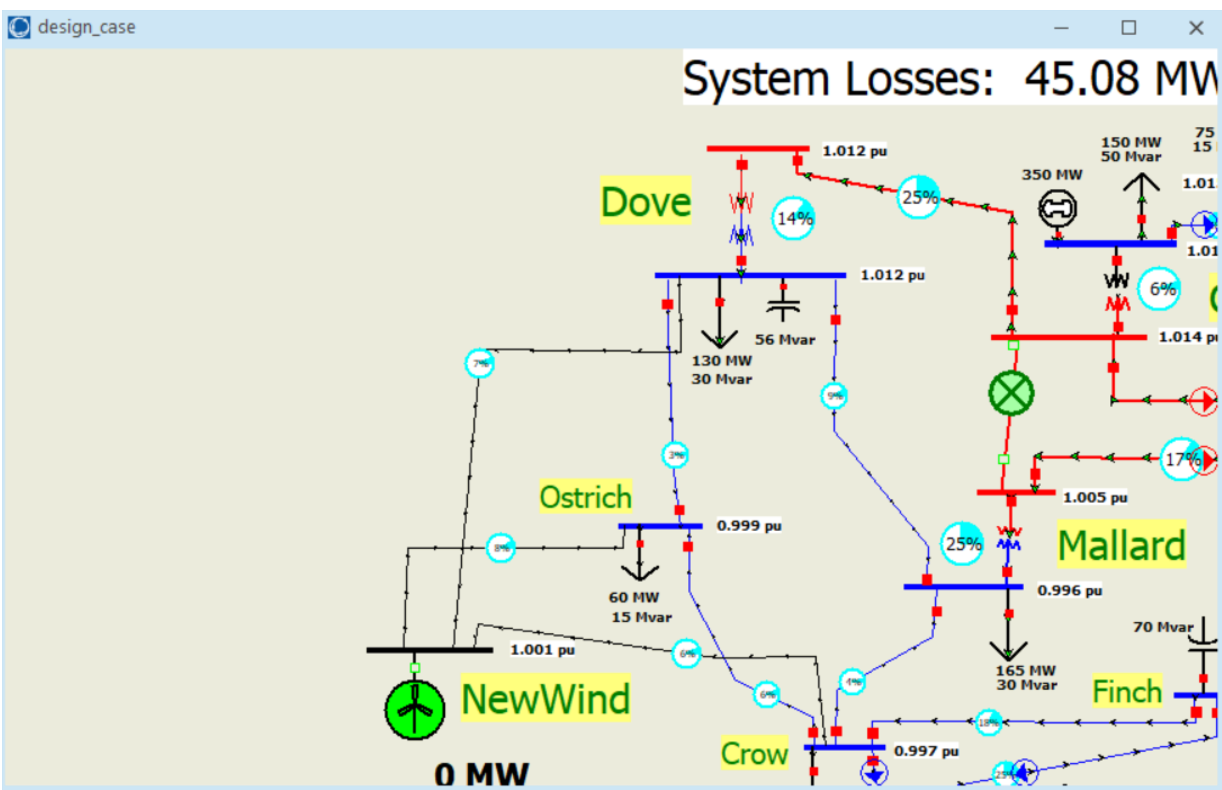

Figure 4. Design 2 with New Wind Outputting 0 MW

The deciding factor in choosing the Crow conductor for the New Wind to Dove connection was the cost to put up the transmission line. Because New Wind to Dove is 55 km, it is most reasonable to use the least expensive conductor, since the cost is dependent on the distance between the two buses. The Crow conductor was also sufficient to mitigate potential overloading of lines.

The other two transmission lines used in Design 2 used the Pheasant conductor for the same reason as stated in the previous section. The Pheasant conductor has shown to be the most reliable despite being the most expensive. It made sense to use the Pheasant conductor for the connections from New Wind to both Ostrich and Crow because of the shorter distances, which were 15 km and 30 km, respectively. This would lower costs since using the Pheasant conductor for the New Wind to Dove connection would turn out to be very pricey.

The combination of these three lines ended up successfully passing the contingency analysis with no violations as well. Like Design 1, this design was also able to keep MVA flows at or below 100% of their limit values, and all voltage levels between 0.92 and 1.10 per unit. To decide which design is better overall for the installation of the wind farm, we must do a comparison between their power losses and costs.

III. Comparison

Referring back to Figures 1-4, we see the power losses for each design with New Wind outputting 0 MW and 600 MW. Table 2, shown below, helps us visualize who generates more losses.

New Wind Output	Design 1	Design 2
0 MW	45.19 MW	45.08 MW
600 MW	57.91 MW	51.92 MW

Table 2. Power Loss Comparison

Table 2 shows that Design 2 is better in terms of power losses. With the values in the table above, we will calculate how costly these power losses are in five years, assuming the NewWind generation is at 600 MW. Table 3 below presents the calculated cost of power losses over the five-year period.

	Design 1		**Design 2**	
Steps	**Formula**	**Result**	**Formula**	**Result**
1. **Energy Lost per Year**	57.91 MW × 8,760 hours	507,291.6 MWh/year	51.92 MW × 8,760 hours	454,819.2 MWh/year
2. **Cost of Losses per Year**	507,291.6 MWh/year × $50/MWh	$25,364,580	454,819.2 MWh/year × $50/MWh	$22,740,960
3. **Total 5-Year Cost**	$22,740,960/year × 5 years	$126,822,900	$22,740,960/year × 5 years	$113,704,800

Table 3. Cost of Power Losses Over 5 Years

Having established the power loss costs for both designs, we can now compute the total expenses for each design by factoring in the costs associated with the construction of the transmission lines. This thorough cost analysis will assist in determining the more appropriate design to recommend to Island Electric Company (IEC). Table 4 shows us the cost of putting up the lines as well as the overall total cost for both designs.

	Design 1			**Design 2**		
Connection	New Wind to Ostrich	New Wind to Ostrich	Ostrich to Mallard	New Wind to Dove	New Wind to Ostrich	New Wind to Pheasant
Distance	15 km	15 km	45 km	55 km	15 km	30 km
Conductor Type	Pheasant	Pheasant	Pheasant	Crow	Pheasant	Pheasant
Construction Cost	430,000/km x 15 km = $6.45 M	430,000/km x 15 km = $6.45 M	430,000/km x 45 km = $19.35 M	390,000/km x 55 km = $21.45 M	430,000/km x 15 km = $6.45 M	430,000/km x 30 km = $12.9 M
Total Construction Cost	$32.25 M			$40.8 M		
Overall Cost	$126,822,900 + $32,250,000 = $159,072,900			$113,704,800 + $40,800,000 = $154,504,800		

Table 4. Overall Total Cost for Design 1 and Design 2

Based on the values displayed in Table 4, we can see that Design 1 is less expensive when it comes to construction compared to Design 2. However, when we incorporate the cost of power losses in addition to the construction costs for each design, Design 1 ends up surpassing the overall cost for Design 2.

IV. Conclusion

When we compare the costs and power losses between the two designs, Design 2 is a clear front-runner in meeting IEC's operational goals. In addition, another reason that solidifies my decision to recommend Design 2 to IEC is the difference in line loading between the lines used in Design 1 and Design 2. Referring to Figure 1, we see that the two lines that were added for the New Wind to Ostrich connection line are operating at 90% of their thermal capacity. While this is technically below the limit, operating lines near their maximum capacity leaves little safety margin. If we look at this long-term– let's say the 5-year period considered in this study– a 90% capacity rate poses potential risks. Those lines are less reliable since there is little headroom for contingencies. For example, if a line or transformer ends up failing, it might trigger overloads. In comparison, Design 2 presents us with reduced loading levels, enhancement in reliability, and diminished system losses. All things considered, Design 2 checks all the boxes.