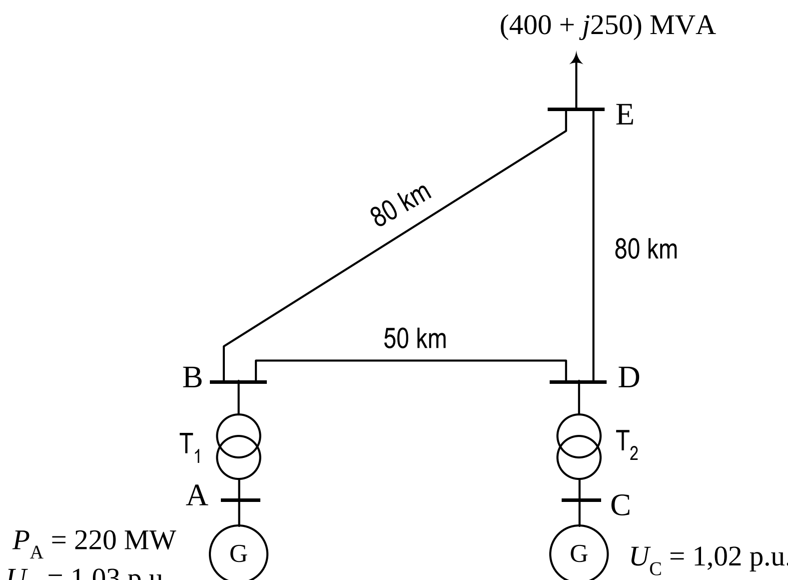
R E P O R T

"*Analysis of the power system operation*"



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This report explains the requirements that were set for us in "Homework No.3", the ways in which they are resolved and what results were obtained. Also, in the continuation of this text, the data of the elements in the network, the respective tables and the networks will be listed.

1. Lines

All the lines used in the analysis of this network have the same parameters which are as following:

$r = 0{,}031\ \Omega/km$
$x = 0{,}327\ \Omega/km$
$b = 3{,}48\ \mu S/km$

whereas the maximum allowed apparent power is $S_{max} = 1200\ MVA$.

From here we can conclude that the maximum allowed current will be:

$$I_d = \frac{S_{max}}{\sqrt{3} \times U_n} = 1732\ A$$

2. Transformers

Transformers T_1 и T_2 have the following nominal parameters:

$S_n = 400\ MVA$
$U_{1n} = 400\ kV$
$U_{2n} = 15{,}75\ kV$
$u_k = 11\%$
$\Delta P_{Cu} = 600\ kW$

The voltage regulation step of the high voltage winding is $1{,}5\%$, and the transformers operate with a ratio of 1 p.u. (the tap changer is in position 0).

Warning:

When entering the data for the transformers, always write as the second node the node in which the tap changer is located, that node is the node with the higher nominal voltage.

3. Generators

In the following table are given the data for the generators used in this problem:

Node	P_{min}(MW)	P_{max}(MW)	a (€/h)	b (€/MWh)	c (€/MW^{2}h)	Q_{min}(MW)	Q_{max}(MW)
A	0	1000	100	20	0,10	0	500
C	0	1000	100	15	0,12	0	500

Table 1. Data for the generators

4. Consumers

The power of the consumer shown in Figure 1. is $(400 + j250)\ MVA$, it needs to be multiplied by the corresponding coefficient k which is different for every student and is given in Table 2. In addition, the active power of the generator in node A should be multiplied by the same coefficient.

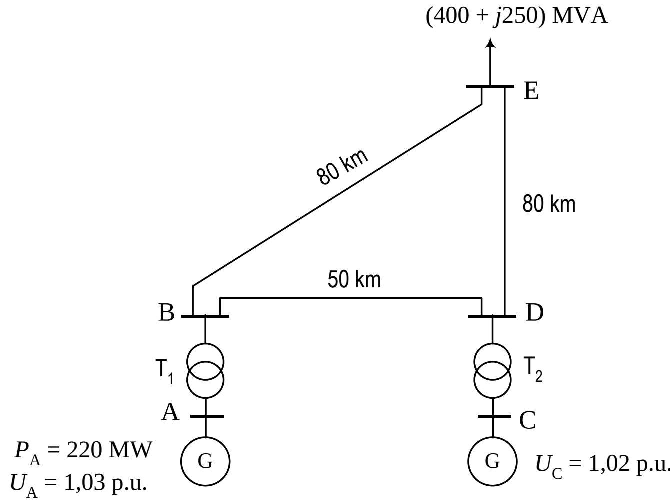

Figure 1. Single line diagram of the power system

For my case, the coefficient k is as following:

No.	Surname and Name	k
12	Nikolov Filip	1,25

Table 2. Data for the coefficient *k*

Then, after the change of the network with the appropriate coefficient, the single line diagram of the power system will get the following appearance:

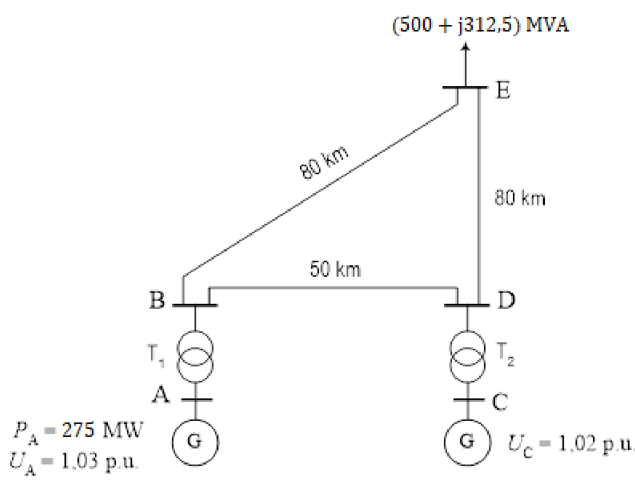

Figure 2. Modified single line diagram of the power system

5. Problems to be solved

Starting from the basic operating mode of the system, by applying the program $NRPF.xlsm$ and using $Excel$ to enter the data for the system, you need to solve the following problems (while considering that each problem is independent and the changes in the operating mode there are must not be taken into account in the other problems):

1) Calculate the voltage in the system and check if the voltage levels are too high or too low depending on the allowed range of change $0{,}95 - 1{,}05\ p.u.$ Then, assume that the transformers can change their transmission ratio in the range of $\pm 10 \times 1{,}5\%$ and determine the position of the tap changers in both transformers so that the voltage in node E is approximately equal to $1\ p.u.$

2) Determine the reactive power of the capacitor bank that needs to be placed in node E so that the voltage in that node is equal to $1\ p.u.$ Also determine the effect of this capacitor bank on the line load and the total active power losses in the system.

3) Another parallel line is added to the system to the $D - E$ line which has the same parameters as that one. Determine the effect of the newly added line over the voltage in node E and the total active power losses.

4) Due to maintenance line $D - E$ is disconnected from operation. In that case, is the operating mode of the system acceptable? By how much do the active power losses increase in that case?

6. Problem 1

When entering and restructuring the system in the given program using the $Excel$ tool, it can be concluded from the results in the table that the voltage conditions in the system are neither too low nor too high. They are in the allowed range of $0{,}95 - 1{,}05\ p.u.$

#	Name	U_n (kV)	P (MW)	Q (Mvar)	|U|	q	U_R	U_X	*it*
1	**Node C**	**16.065**	**1.25**	**1.25**	**(kV)**	**(º)**	**(kV)**	**(kV)**	**3**
1	*Node A*	15.75	0.00	0.00	**16.223**	**0.776**	16.221	0.220	
2	*Node B*	400	0.00	0.00	**396.200**	**-3.442**	395.486	-23.786	
3	*Node C*	15.75	0.00	0.00	**16.065**	**0.000**	16.065	0.000	
4	*Node D*	400	0.00	0.00	**395.699**	**-3.542**	394.944	-24.445	
5	*Node E*	400	400.00	250.00	**384.789**	**-5.825**	382.801	-39.055	

Table 3. Results of the voltages in the nodes

In the continuation of the problem it can be seen from the results that the closest value of the voltage up to $1\ p.u.$ at node E can be $398.647\ kV$ or $0.996\ p.u.$ This is achieved by switching the positions of the tap changer of both transformers by $+3\%$.

#	Name	U_n (kV)	P (MW)	Q (Mvar)	|U|	q	U_R	U_X	*it*
1	**Node C**	**16.065**	**1.25**	**1.25**	**(kV)**	**(º)**	**(kV)**	**(kV)**	**3**
1	*Node A*	15.75	0.00	0.00	**16.223**	**0.732**	16.221	0.207	
2	*Node B*	400	0.00	0.00	**409.560**	**-3.231**	408.909	-23.081	
3	*Node C*	15.75	0.00	0.00	**16.065**	**0.000**	16.065	0.000	
4	*Node D*	400	0.00	0.00	**409.041**	**-3.324**	408.353	-23.719	
5	*Node E*	400	400.00	250.00	**398.647**	**-5.458**	396.840	-37.915	

Table 4. Results of the voltages in the nodes after changing the tap changer

#	Starting node	Ending node	Type	L or α(%)	P_{start} (MW)	Q_{start} (Mvar)	P_{end} (MW)	Q_{end} (Mvar)	%
1	*Node B*	*Node D*	L101	50.00	17.813	-3.277	17.809	25.829	2.6
2	*Node D*	*Node E*	L101	80.00	245.652	120.266	244.452	153.021	24.0
3	*Node B*	*Node E*	L101	80.00	256.861	127.864	255.548	159.479	25.1
4	*Node A*	*Node B*	TR1	3.00	275.000	148.447	274.675	124.587	78.1
5	*Node C*	*Node D*	TR2	3.00	228.061	110.433	227.843	94.437	63.3

Табела 5. Results for the branches in the power system

Whereas in Table 6 we can see the power losses in the system.

	MW	Mvar
NODE A - Production	228.061	110.433
Loses	3.061	-53.621

Table 6. Power losses in the power system

In Figure 3. we can see the power flows and the voltage conditions in all of the nodes for the first problem.

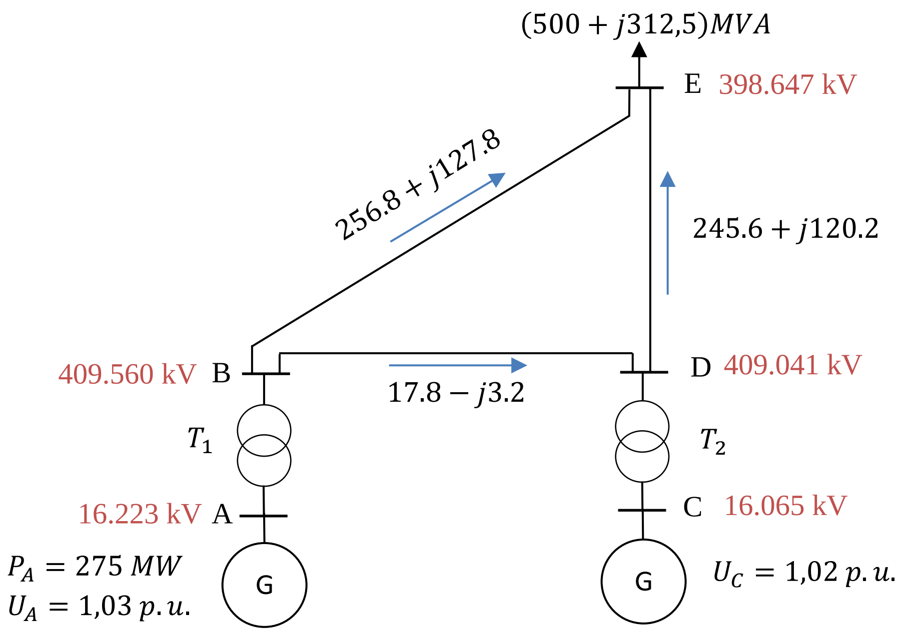

Figure 3. Voltage conditions and power flows in Problem 1

7. Problem 2

In this second problem we are going to try to regulate the voltage drop with a capacitor bank which will be placed in node E, so that we can get the voltage level to $1\ p.u.$

Firstly we notice that we need a capacitor bank of the following size $160\ Mvar$ so that we can achieve the voltage level in node E of $400.390\ kV$ or $1.0009\ p.u.$

#	Name of the node	Q_{cn} (Mvar)	Q_{Ccalc} (Mvar)
1	*Node E*	160.00	160.31

Table 7. Capacitor bank

In the following table we can see the changes in the voltage conditions after placing the capacitor bank.

#	Name	U_n (kV)	*P* (MW)	*Q* (Mvar)	|*U*|	*q*	U_R	U_X	*it*
1	**Node C**	**16.065**	**1.25**	**1.25**	**(kV)**	**(°)**	**(kV)**	**(kV)**	**3**
1	*Node A*	15.75	0.00	0.00	**16.223**	**0.769**	16.221	0.218	
2	*Node B*	400	0.00	0.00	**406.019**	**-3.366**	405.319	-23.840	
3	*Node C*	15.75	0.00	0.00	**16.065**	**0.000**	16.065	0.000	
4	*Node D*	400	0.00	0.00	**405.517**	**-3.463**	404.777	-24.493	
5	*Node E*	400	400.00	250.00	**400.390**	**-5.674**	398.428	-39.588	

Table 8. Voltage conditions after placing the capacitor bank

Whereas in the following two tables we can see the change in the load of the power system, the power flows and the losses as well.

#	Starting node	Ending node	Type	*L* or α(%)	P_{start} (MW)	Q_{start} (Mvar)	P_{end} (MW)	Q_{end} (Mvar)	%
1	*Node B*	*Node D*	L101	50.00	17.986	-3.569	17.982	25.036	2.6
2	*Node D*	*Node E*	L101	80.00	245.291	37.954	244.328	73.000	21.3
3	*Node B*	*Node E*	L101	80.00	256.733	45.120	255.672	79.188	22.3
4	*Node A*	*Node B*	TR1	0.00	275.000	62.153	274.719	41.551	70.5
5	*Node C*	*Node D*	TR2	0.00	227.499	26.786	227.310	12.918	57.3

Table 9. Results for the branches in the power system

	MW	Mvar
NODE A – Production	227.499	26.786
Losses	2.499	-223.560

Table 10. Losses in the power system

On Figure 4. we can see the power flows and voltage conditions in all of the nodes for the second problem.

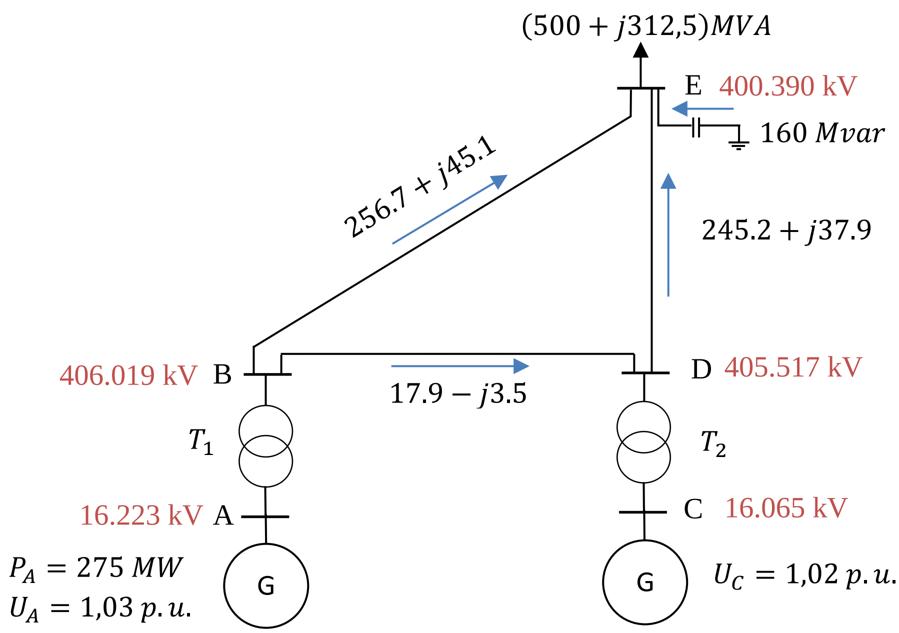

Figure 4. Voltage conditions and power flows in Problem 2

8. Problem 3

In this problem we need to add a line, parallel to the line $D - E$ which will have the exact same parameters. In the following three tables are given the changes in the voltage conditions in node E as well as the losses in the power system.

#	Name	U_n (kV)	*P* (MW)	*Q* (Mvar)	|*U*|	*q*	U_R	U_X	*it*
1	**Node C**	**16.065**	**1.25**	**1.25**	**(kV)**	**(º)**	**(kV)**	**(kV)**	**3**
1	*Node A*	15.75	0.00	0.00	**16.223**	**1.108**	16.219	0.314	
2	*Node B*	400	0.00	0.00	**399.930**	**-3.078**	399.353	-21.475	
3	*Node C*	15.75	0.00	0.00	**16.065**	**0.000**	16.065	0.000	
4	*Node D*	400	0.00	0.00	**398.421**	**-3.507**	397.675	-24.374	
5	*Node E*	400	400.00	250.00	**392.208**	**-4.886**	390.783	-33.403	

Table 11. Voltage conditions in the system after adding the parallel line

#	Starting node	Ending node	Type	*L* or α(%)	P_{start} (MW)	Q_{start} (Mvar)	P_{end} (MW)	Q_{end} (Mvar)	%
1	*Node B*	*Node D*	L101	50.00	75.869	16.058	75.804	43.103	7.3
2	*Node D*	*Node E*	L101	80.00	151.444	59.914	150.980	98.535	15.0
3	*Node D*	*Node E*	L101	80.00	151.444	59.914	150.980	98.535	15.0
4	*Node B*	*Node E*	L101	80.00	198.814	79.926	198.039	115.430	19.1
5	*Node A*	*Node B*	TR1	0.00	275.000	119.273	274.682	95.984	74.9
6	*Node C*	*Node D*	TR2	0.00	227.301	92.648	227.084	76.724	61.4

Table 12. Results for the branches in the power system

In the following table we can see the losses in the power system after adding the parallel line.

	MW	Mvar
NODE A – Production	227.301	92.648
Losses	2.301	-100.579

Table 13. Losses in the power system

On Figure 5. we can see the power flows and voltage conditions in all of the nodes for the second problem once the parallel line is added.

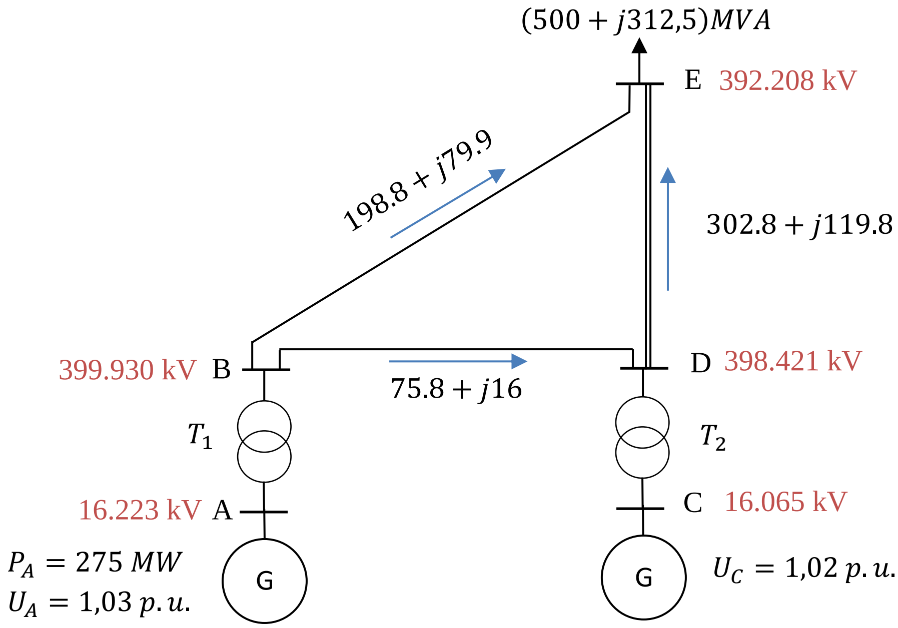

Figure 5. Voltage conditions and power flows in Problem 3

9. Problem 4

In this last problem the line $D - E$ is disconnected from operation due to maintenance. From the following tables where we have the voltage conditions and power flows we need to determine if the operating mode of the system is acceptable and how big are the losses in it.

#	Name	U_n (kV)	P (MW)	Q (Mvar)	$\|U\|$	q	U_R	U_X	it
1	**Node C**	**16.065**	**1.25**	**1.25**	**(kV)**	**(º)**	**(kV)**	**(kV)**	**4**
1	*Node A*	15.75	0.00	0.00	**16.223**	**-0.684**	16.221	-0.194	
2	*Node B*	400	0.00	0.00	**387.291**	**-4.981**	385.828	-33.626	
3	*Node C*	15.75	0.00	0.00	**16.065**	**0.000**	16.065	0.000	
4	*Node D*	400	0.00	0.00	**393.581**	**-3.628**	392.792	-24.907	
5	*Node E*	400	400.00	250.00	**361.012**	**-10.048**	355.474	-62.989	

Table 14. Voltage conditions in the power system after disconnecting line $D - E$

From the voltage conditions in the system we can see that there is a drastic voltage drop in all of the nodes. Although the voltage conditions in nodes B and D are still in the allowed range, however the voltage in node E drops to a value of $361.012\ kV$ or $0.902\ p.u.$ With that we can conclude that this system mode is unacceptable!

#	Starting node	Ending node	Type	L or α(%)	P_{start} (MW)	Q_{start} (Mvar)	P_{end} (MW)	Q_{end} (Mvar)	%
1	*Node B*	*Node D*	L101	50.00	-231.873	-137.478	-232.589	-118.500	22.5
-	*Node D*	*Node E*	L101	80.00					24.0
3	*Node B*	*Node E*	L101	80.00	506.406	341.051	500.000	312.500	50.9
4	*Node A*	*Node B*	TR1	0.00	275.000	237.836	274.533	203.573	90.9
5	*Node C*	*Node D*	TR2	0.00	232.853	137.853	232.589	118.500	67.6

Table 15. Changes in the power flow of the system after disconnecting line $D - E$

In the following table we can see the losses in the power system after the disconnection of line $D - E$.

	MW	Mvar
NODE A – Production	232.853	137.853
Losses	7.853	63.188

Table 16. Losses in the power system

In Figure 6. we can see the power flows and voltage conditions of the system once line $D-E$ gets disconnected from operation.

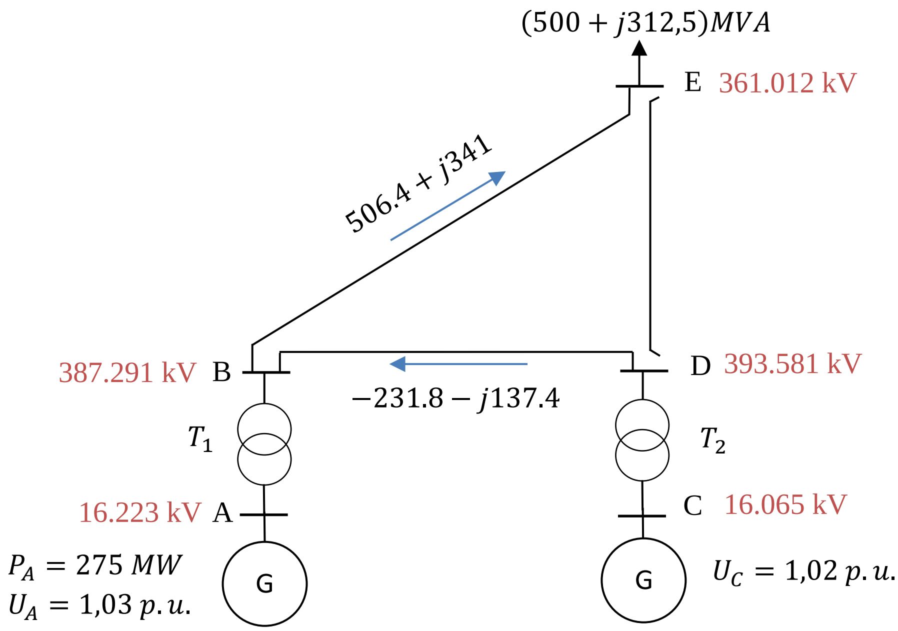

Figure 6. Voltage conditions and power flows in Problem 4

Conclusion:

From the analysis of this simple power system it can be concluded that if it is necessary to correct the voltage conditions in the network, it would be best to do that by regulating the voltage with the tap changers of both transformers. That would be the most economical solution that contributes to satisfactory results in both voltage conditions and power flow.

While voltage regulation with the help of a capacitor bank in node E leads to slightly better voltage conditions as well as power flow, it would still be an expensive investment that is not worthwhile in such a system given the difference between the previous voltage regulation and need from investing in a capacitor bank of such a large capacity.

In the third problem, by adding a parallel line we don't get some significantly better voltage conditions, but the power flow improves and thus the lines are not under such a big load. This means that in the future if we have significant changes in the load, this type of system could better handle those changes. However, as the previous problem stated, the need for an investment for an additional parallel line needs to be taken into account.

In the last problem we are observing that the line $D - E$ is being disconnected due to maintenance. In this way we get a system mode which is unacceptable given that we have a significant voltage drop in node E in terms of the range of values that must be observed. Although we have a sudden change in the power flow in the system, the lines $B - D$ and $B - E$ can still withstand the load, but it must be taken into account that the reliability of the system is compromised. In case of an increase in the load, it is inevitable that there will be an overload of the elements of the power system, or if there is a case of a failure of an element or an accident that will cause the system to fail. Which means that this mode of operation of the system is undesirable and unacceptable.