Load Flow Assignment

Prepared by:

Matekoa Motsoasele (MTSMAT027)

Prepared for:

EEE4126F

Energy Systems & Grids 2

Department of Electrical Engineering

University of Cape Town

May 29, 2023

Declaration

1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
2. I have used the IEEE convention for citation and referencing. Each contribution to, and quotation in, this report from the work(s) of other people has been attributed, and has been cited and referenced.
3. This report is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as their own work or part thereof.

M.Masoasele

May 29, 2023

Name Surname | Date

Contents

List of Figures

Chapter 1

Executive Summary

The aim of this report is to study the load flow of the power system, fault analysis, contingency analysis and economic dispatch. The study of Load Flow is of great importance in power system planning, system expansion, and power system operation[2]. The objective is to have generation that supplies load demand and associated losses while operating within their real and reactive power limits. It is also to keep bus voltage magnitudes within allowable limits to their rated values, and making sure that transformers and transmission lines are not overloaded [3]. Different Load Flow methods have their strengths and weaknesses. System size impacts the performance of the chosen method. For example, The Gauss-Seidel method has less storage requirements than the Newton-Raphson Method, but its computational time increases rapidly as the system size increases. In the case of the Newton-Raphson method, the relation between the convergence time and the system size is linear [4]. Where fast convergence and accuracy are required, the Newton-Raphson method is preferred.[4] DIgSILENT PowerFactory software package is utilized in this study. This software implements the Newton-Raphson Method in the load flow analysis.

The IEC 60909 standard has been chosen for analysis of the bolted fault that occurs at bus 8. This standard uses the instantaneous short-circuit current to determine breaking capacity. It also has a high accuracy , resulting in a protected grid [5] Figure 1.1 shows the system to be studied for this report.

Economic dispatch calculations are also carried out to determine the optimal economic dispatch and total cost generation. Type 1 and Type 4 wind turbines are used to simulate the addition of wind generators in the system. The Type 1 generator is modeled to have a constant power factor PQ Bus, while the type 4 generator represents a fully asynchronous machine [3]

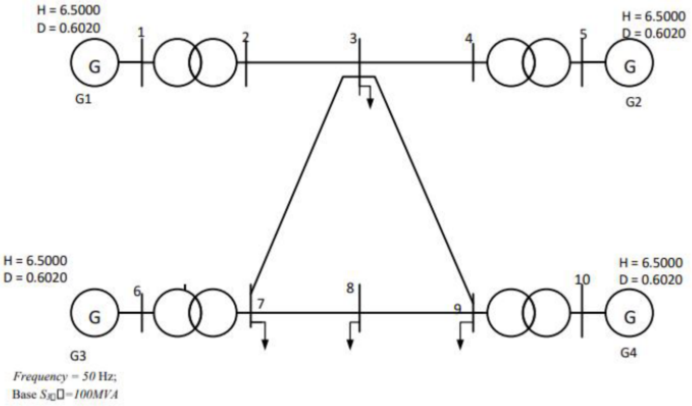


Figure 1.1: Single Line Diagram of the Four Machine 10 Bus System [1]

Chapter 2

Load Flow Analysis

a)

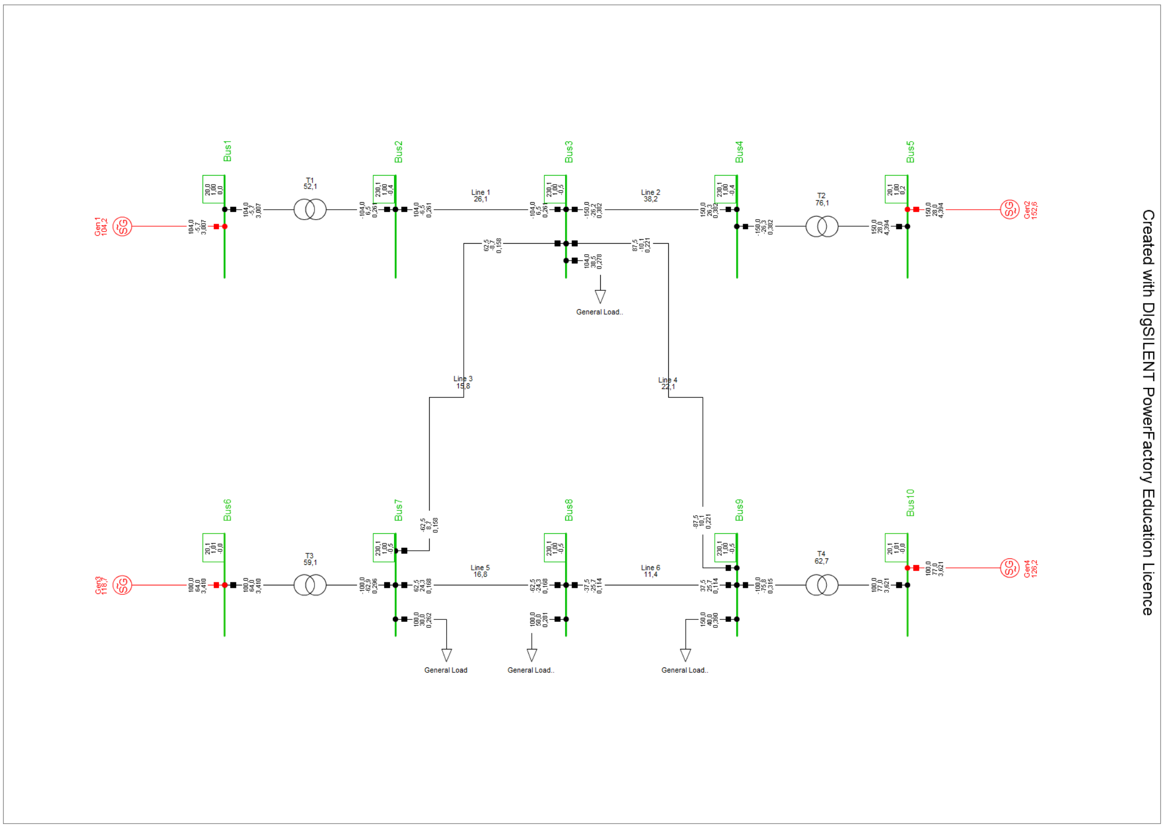


Figure 2.1: Initial Load Flow Outputs

1. **Satisfactory System Operations**:
    - All of the bus voltages are within acceptable ranges.
    - No Transmission lines and transformers are overloaded as shown in Figure 2.1
2. **Loads**:
    - From the table above, The total load in the system is, [454MW, 158.46Mvar]. The losses are [0,02MW, 4,83Mvar]. The total generation is [454.02MW, 163.28Mvar]
    - Generation at the slack bus is [104MW, -5,72Mvar]

Total System Summary					Study Case: Study Case			Annex:	/ 4
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	No load Losses [MW]/ [Mvar]
\matek\Load Flow Resubmission\Network Model\Network Data\10 Bus System									
	454,02	0,00	454,00	0,00	0,00	0,00	0,02	0,02	0,00
	163,28	0,00	158,46	0,00	0,00	0,00	4,83	4,87	-0,05
Total:									
	454,02	0,00	454,00	0,00	0,00		0,02	0,02	0,00
	163,28	0,00	158,46	0,00	0,00		4,83	4,87	-0,05

Figure 2.2: System Summary after Initial Load Flow Analysis

		rated Voltage [kV]	Bus-voltage [p.u.]	[kV]	[deg]	Active Power [MW]	Reactive Power [Mvar]	Power Factor [-]	Current [kA]	Loading [%]
Bus1										
		20,00	1,00	20,00	0,00					
Cub_2	/Sym		Gen 1			104,02	-5,72	1,00	3,01	104,17
Cub_1	/Tr2		T1			104,02	-5,72	1,00	3,01	52,09

Figure 2.3: Generation at Slack bus

- The total real power loss (%) can be calculated as follows:

$$\frac{P_{loss}}{P_{total}} * 100\% = \frac{0.02}{454.02} * 100\% = 0.0044\%$$

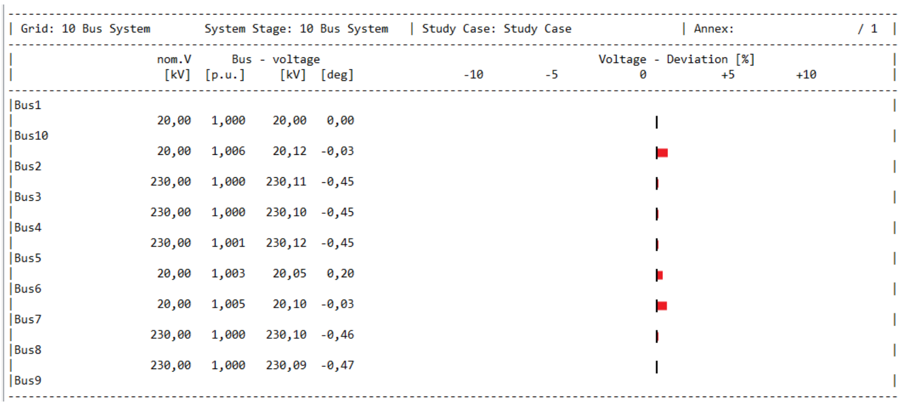
- Comparison between the MVA used in the generators, line charging, and loads is seen below with the generators using up the most MVA.

Total System Summary			Study Case: Study Case			Annex:	/ 1
No. of Substations	0	No. of Busbars	10	No. of Terminals	0	No. of Lines	6
No. of 2-w Trfs.	4	No. of 3-w Trfs.	0	No. of syn. Machines	4	No. of asyn. Machines	0
No. of Loads	4	No. of Shunts/Filters	0	No. of SVS	0		

Generation	= 454,02 MW	163,28 Mvar	482,49 MVA
External Infeed	= 0,00 MW	0,00 Mvar	0,00 MVA
Load P(U)	= 454,00 MW	158,46 Mvar	480,86 MVA
Load P(Un)	= 454,00 MW	158,46 Mvar	480,86 MVA
Load P(Un-U)	= -0,00 MW	-0,00 Mvar	
Motor Load	= 0,00 MW	0,00 Mvar	0,00 MVA
Grid Losses	= 0,02 MW	4,83 Mvar	
Line Charging	=	-0,05 Mvar	
Compensation ind.	=	0,00 Mvar	
Compensation cap.	=	0,00 Mvar	
Installed Capacity	= 320,00 MW		
Spinning Reserve	= -134,02 MW		
Total Power Factor:			
Generation	= 0,94 [-]		
Load/Motor	= 0,94 / 0,00 [-]		

Figure 2.4: System Summary

3. **Voltage Levels**: The following voltage profiles are obtained. These show that the buses are within the acceptable ranges



Grid: 10 Bus System	System Stage: 10 Bus System	Study Case: Study Case		Annex: / 1
	nom.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
Bus1	20,00	1,000	20,00	0,00
Bus10	20,00	1,006	20,12	-0,03
Bus2	230,00	1,000	230,11	-0,45
Bus3	230,00	1,000	230,10	-0,45
Bus4	230,00	1,001	230,12	-0,45
Bus5	20,00	1,003	20,05	0,20
Bus6	20,00	1,005	20,10	-0,03
Bus7	230,00	1,000	230,10	-0,46
Bus8	230,00	1,000	230,09	-0,47
Bus9				

Figure 2.5: Voltage Profiles after Initial Load Flow Analysis

b) Increasing The load at Bus 8 by 30% means that the new P = 130MW and Q = 65 Mvar. The main difference after increasing the load is that generation increases. With this, the grid losses also increase.

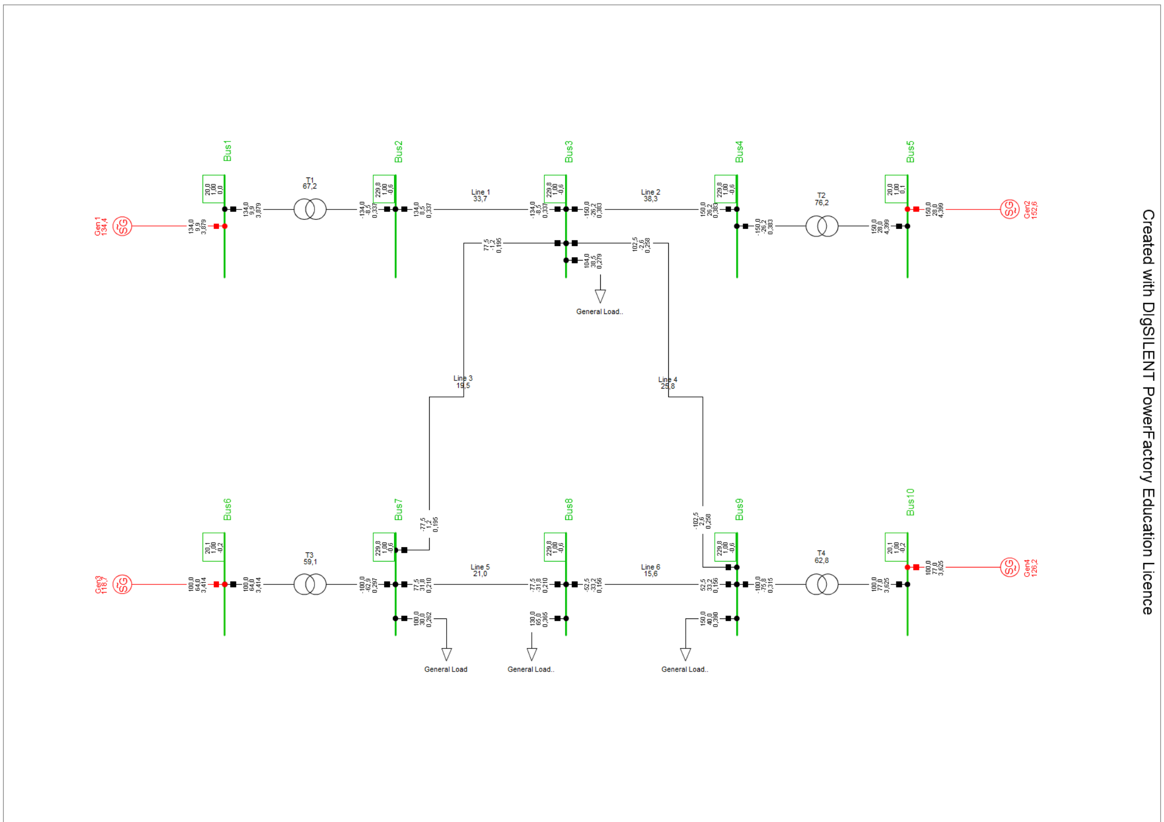


Figure 2.6: Load Flow after The Load at Bus 8 is Increased By 30%

1. **Satisfactory System Operations**:
   - All of the bus voltages are within acceptable ranges.
   - No Transmission lines and transformers are overloaded as shown in Figure 2.6
2. **Loads**:

Total System Summary						Study Case: Study Case			Annex: / 4
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	No load Losses [MW]/ [Mvar]
\matek\Load Flow Resubmission\Network Model\Network Data\10 Bus System									
	484,02	0,00	484,00	0,00	0,00	0,00	0,02	0,02	0,00
	178,86	0,00	173,46	0,00	0,00	0,00	5,40	5,45	-0,05
Total:									
	484,02	0,00	484,00	0,00	0,00		0,02	0,02	0,00
	178,86	0,00	173,46	0,00	0,00		5,40	5,45	-0,05

Figure 2.7: System Summary When Load at Bus 8 Is Increased by 30%

- The total load in the system is, [484.00MW, 173.46Mvar]. The losses are [0,02MW, 4.4Mvar]. The total generation is [484.02MW, 178.86Mvar]
- Generation at the slack bus is [134.02MW, 9.86Mvar]

		rated Voltage [kV]	Bus-voltage [p.u.]	[kV]	[deg]	Active Power [MW]	Reactive Power [Mvar]	Power Factor [-]	Current [kA]	Loading [%]
Bus1										
		20,00	1,00	20,00	0,00					
Cub_2	/Sym		Gen 1			134,02	9,86	1,00	3,88	134,38
Cub_1	/Tr2		T1			134,02	9,86	1,00	3,88	67,19

Figure 2.8: Generation at Slack bus When Load at bus 8 is increased by 30%

- The total real power loss (%) can be calculated as follows:

$$\frac{P_{loss}}{P_{total}} * 100\% = \frac{0.02}{454.02} * 100\% = 0.0044\%$$

- MVA in the loads, the MVA from line charging and the MVA from generators.

```
| Total System Summary                      | Study Case: Study Case        | Annex:             / 1 |
|
| No. of Substations    0      No. of Busbars      10     No. of Terminals     0     No. of Lines          6
| No. of 2-w Trfs.      4      No. of 3-w Trfs.     0     No. of syn. Machines 4     No. of asyn. Machines 0
| No. of Loads          4      No. of Shunts/Filters 0    No. of SVS           0
|
| Generation          =    484,02  MW        178,86  Mvar     516,01  MVA
| External Infeed     =      0,00  MW          0,00  Mvar       0,00  MVA
| Load P(U)           =    484,00  MW        173,46  Mvar     514,14  MVA
| Load P(Un)          =    484,00  MW        173,46  Mvar     514,14  MVA
| Load P(Un-U)        =      0,00  MW         -0,00  Mvar
| Motor Load          =      0,00  MW          0,00  Mvar       0,00  MVA
| Grid Losses         =      0,02  MW          5,40  Mvar
| Line Charging       =                       -0,05  Mvar
| Compensation ind.   =                        0,00  Mvar
| Compensation cap.   =                        0,00  Mvar
|
| Installed Capacity  =    320,00  MW
| Spinning Reserve    =   -164,02  MW
|
| Total Power Factor:
|   Generation        =      0,94  [-]
|   Load/Motor        = 0,94 / 0,00  [-]
```

Figure 2.9: System summary

The main difference is that the total MVA has increased, and so have the losses.

- **Voltage Levels**: The following voltage profiles are obtained. These show that the buses are within the acceptable ranges

3. Contingency Analysis Failure in different zones affects the systems differently. Below is an investigation of the severity of each failure one at a time. The contingencies are ranked according to their severity as shown below. From the following investigation, the severity is seen to be

Grid: 10 Bus System	System Stage: 10 Bus System	Study Case: Study Case	Annex:	/ 1

	nom.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
Bus1	20,00	1,000	20,00	0,00	
Bus10	20,00	1,005	20,10	-0,17	
Bus2	230,00	0,999	229,84	-0,58	
Bus3	230,00	0,999	229,83	-0,59	
Bus4	230,00	0,999	229,85	-0,58	
Bus5	20,00	1,001	20,03	0,07	
Bus6	20,00	1,004	20,08	-0,16	
Bus7	230,00	0,999	229,82	-0,59	
Bus8	230,00	0,999	229,81	-0,60	
Bus9					

Figure 2.10: Voltage Profiles after Load Is Increased by 30%

highest at Transformer T1 which is connected to the slack bus. Since the slack bus is the point of reference for the system, any deviation from the acceptable range at this bus is likely to have the most significant impact on the system's stability.

Component	Branch, Substation or Site	Loading Continuous [%]	Loading Short-Term [%]	Loading Base Case [%]	Contingency Number	Contingency Name	Base Case and Continuous Loading [0 % - 128 %]
T1		127,6	127,6	52,1	2	Line 2	

Figure 2.11: Contingency Analysis Worst Loading

Component	Branch, Substation or Site	Loading Continuous [%]	Loading Short-Term [%]	Loading Base Case [%]	Base Case and Continuous Loading [0,000 - 76,101]
T2		76,1	76,1	76,1	
T4		62,7	62,7	62,7	
T3		59,1	59,1	59,1	
T1		52,1	52,1	52,1	
Line 2		38,2	38,2	38,2	
Line 1		26,1	26,1	26,1	
Line 4		22,1	22,1	22,1	
Line 5		16,8	16,8	16,8	
Line 3		15,8	15,8	15,8	
Line 6		11,4	11,4	11,4	

Figure 2.12: Contingency Analysis Per Case

Chapter 3

Short-Circuit (Bolted) Fault Analysis

c)

1. When a three-phase bolted fault occurs in bus 8, The fault current and bus voltages are shown below

Grid: Fault Grid   System Stage: Fault Grid   Annex: / 1

	rtd.V. [kV]	Voltage [kV]	[deg]	c-Factor	Sk" [MVA]	Ik" [kA]	[deg]	ip [kA]	Ib [kA]	Sb [MVA]	Ik [kA]	Ith [kA]
Bus8	230,00	0,00	0,00	1,10	2150,57 MVA	5,40 kA	-87,23	14,26 kA	4,10	1631,41	4,10	5,09
Line 5	Bus7				1075,29 MVA	2,70 kA	92,77	7,13 kA				
Line 6	Bus9				1075,29 MVA	2,70 kA	92,77	7,13 kA				

Figure 3.1: Bolted Fault At Bus 8

2. With line resistances, line charging admittances, shunt capacitors and loads neglected, the bus voltages below are obtained.

Grid: Neglected Line Resis System Stage: Neglected Line   Annex: / 1

	rtd.V. [kV]	Voltage [kV]	[deg]	c-Factor	Sk" [MVA]	Ik" [kA]	[deg]	ip [kA]	Ib [kA]	Sb [MVA]	Ik [kA]	Ith [kA]
Bus8	230,00	0,00	0,00	1,10	2156,01 MVA	5,41 kA	-87,24	14,30 kA	4,10	1633,06	4,10	5,10
Line 5	Bus7				1078,01 MVA	2,71 kA	92,76	7,15 kA				
Line 6	Bus9				1078,01 MVA	2,71 kA	92,76	7,15 kA				

Figure 3.2: Bolted Fault At Bus 8 With Line Resistances neglected

Emphasis is placed on the voltages and currents on bus 1,5,6,10. These are the buses to which the generators are connected.

For the hand calculations,shown below: With 100MVA as the Sbase, the Ibase can be calculated and then is found to be:

$$\frac{S_{base}}{\sqrt{3} * V_{base}} = \frac{100MVA}{\sqrt{3} * 230kV} = 251.02A$$

From there, the fault current in kA is:

$$I_{base} * I_{pu} = 3.58kA$$

This is lower than the fault current found using DigSilent, which was 4.10kA

```
-------------------------------------------------------------------------------------------------------------
| Grid: Neglected Line Resis System Stage: Neglected Line  |                               | Annex:       / 1    |
-------------------------------------------------------------------------------------------------------------
|                                              rtd.V.       Voltages           Sk"         Currents         |
|                                               [kV]     [kV]    [deg]       [MVA]      [kA]     [deg]      |
-------------------------------------------------------------------------------------------------------------
| Values at Observation Location                                                                           |
-------------------------------------------------------------------------------------------------------------
| Bus5                                         20,00      0,46     2,76                                     |
|    Cub_2    /Tr2      T2                      LV-Side                      539,004     15,560   -87,24    |
|    Cub_1    /Sym      Gen2                                                 539,004     15,560   -87,24    |
| Values at Observation Location                                                                           |
-------------------------------------------------------------------------------------------------------------
| Bus10                                        20,00      0,46     2,76                                     |
|    Cub_2    /Tr2      T4                      LV-Side                      539,004     15,560   -87,24    |
|    Cub_1    /Sym      Gen4                                                 539,004     15,560   -87,24    |
| Values at Observation Location                                                                           |
-------------------------------------------------------------------------------------------------------------
| Bus1                                         20,00      0,46     2,76                                     |
|    Cub_1    /Tr2      T1                      LV-Side                      539,004     15,560   -87,24    |
|    Cub_2    /Sym      Gen 1                                                539,004     15,560   -87,24    |
-------------------------------------------------------------------------------------------------------------

-------------------------------------------------------------------------------------------------------------
| Grid: Neglected Line Resis System Stage: Neglected Line  |                               | Annex:       / 2    |
-------------------------------------------------------------------------------------------------------------
|                                              rtd.V.       Voltages           Sk"         Currents         |
|                                               [kV]     [kV]    [deg]       [MVA]      [kA]     [deg]      |
-------------------------------------------------------------------------------------------------------------
| Values at Observation Location                                                                           |
-------------------------------------------------------------------------------------------------------------
| Bus8                                        230,00      0,00     0,00                                     |
|    Cub_2    /Lne      Line 5                  Terminal j                  1078,007      2,706    92,76    |
|    Cub_3    /Lne      Line 6                  Terminal i                  1078,007      2,706    92,76    |
| Values at Observation Location                                                                           |
-------------------------------------------------------------------------------------------------------------
| Bus6                                         20,00      0,46     2,76                                     |
|    Cub_2    /Tr2      T3                      LV-Side                      539,004     15,560   -87,24    |
|    Cub_1    /Sym      Gen3                                                 539,004     15,560   -87,24    |
-------------------------------------------------------------------------------------------------------------
```

Figure 3.3: Voltages and currents on bus 1,5,6,10 For Bolted Fault At Bu8

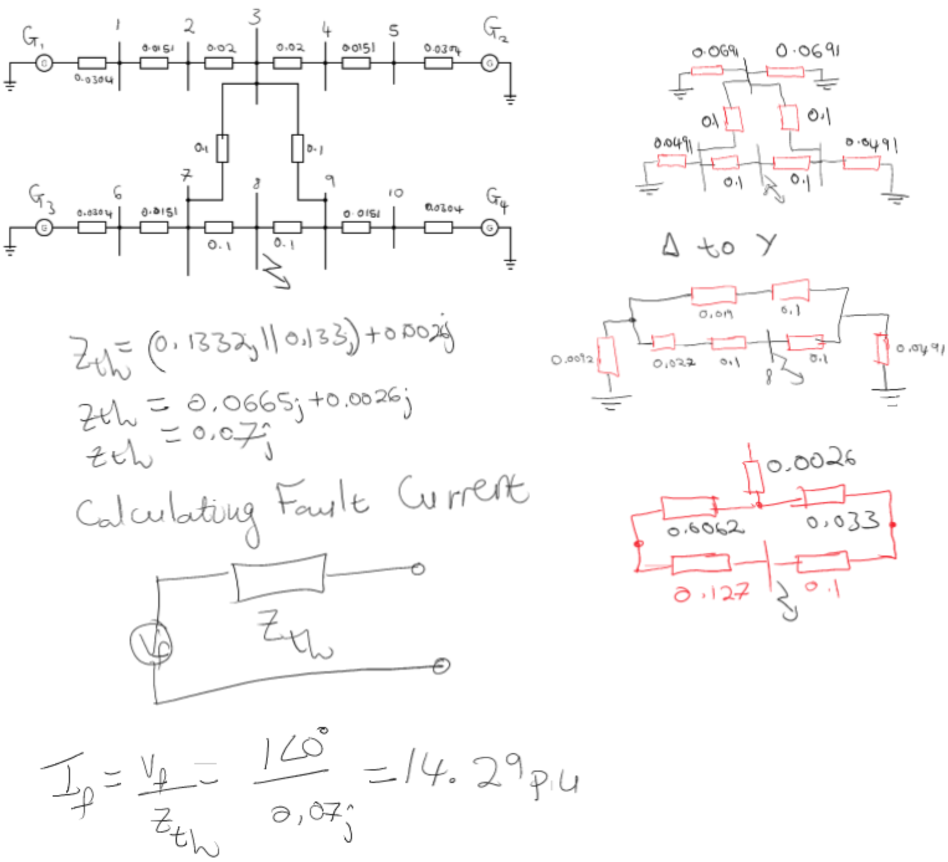


Figure 3.4: Hand Calculations For The Fault At Bus 8

3. d)

- From the transient analysis plot for RMS simulation at 50hz, because the system eventually reaches a steady-state and does not continue to oscillate indefinitely, then a conclusion is drawn that it is stable.

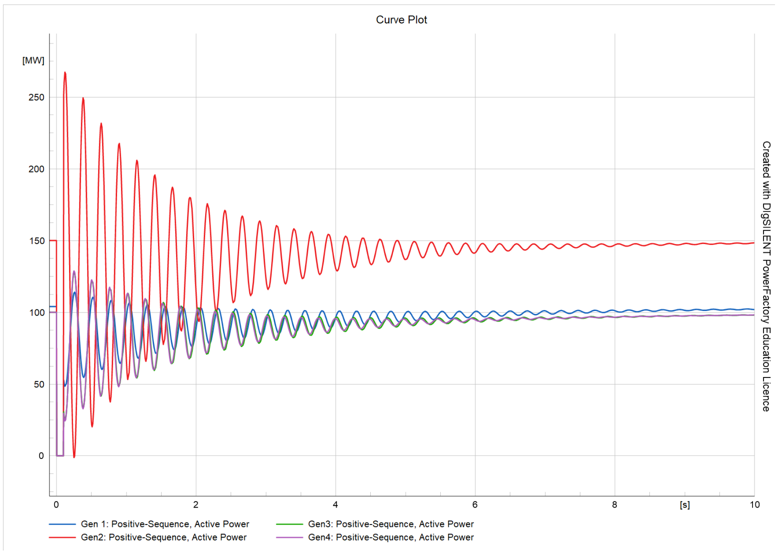


Figure 3.5: RMS Simulation at 50Hz

- When the Frequency is set to 60Hz, the critical clearing time can be seen to be about 0.5s

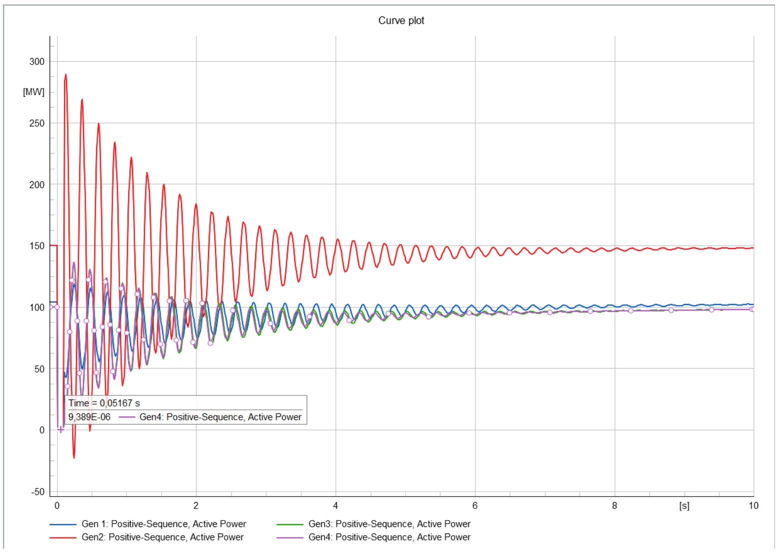


Figure 3.6: RMS Simulation at 60Hz

Chapter 4

Economic Dispatch

Fuel-Cost Function of the Four Generators

C1= 305+2.4P$_1$ + $0.001{P_1}^2$
$C2 = 242 + 2.7P_2 + 0.003{P_2}^2$
$C3 = 326 + 2.7P_3 + 0.002{P_3}^2$
$C4 = 312 + 2.2P_4 + 0.0025{P_4}^2$
$P_{loss} = 0.00001{P_1}^2 + 0.00003{P_2}^2 + 0.00005{P_3}^2 + 0.00004{P_4}^2$

1. **The Incremental Cost Of The Generators**

$\frac{\partial C_1}{\partial P_1} = 2.4 + 0.002P_1$

$\frac{\partial C_2}{\partial P_2} = 2.7 + 0.006P_2$

$\frac{\partial C_3}{\partial P_3} = 2.7 + 0.004P_3$

$\frac{\partial C_4}{\partial P_4} = 2.2 + 0.005P_4$

2. **Outputs For Optimal Economic Dispatch**

$\frac{\partial C_1}{\partial P_1}\left(\frac{1}{1-\frac{\partial P_{loss}}{\partial P_1}}\right) = \frac{2.4+0.002P_1}{1-0.00002} = \lambda$

$\frac{\partial C_2}{\partial P_2}\left(\frac{1}{1-\frac{\partial P_{loss}}{\partial P_2}}\right) = \frac{2.7+0.006P_2}{1-0.00006} = \lambda$

$\frac{\partial C_3}{\partial P_3}\left(\frac{1}{1-\frac{\partial P_{loss}}{\partial P_3}}\right) = \frac{2.7+0.004P_3}{1-0.0001} = \lambda$

$$\frac{\partial C_4}{\partial P_4}\left(\frac{1}{1-\frac{\partial P_{loss}}{\partial P_4}}\right) = \frac{2.2+0.005P_4}{1-0.00008} = \lambda$$

The total Load calculated = 454 MW and was calculated to be the sum of all the loads.

The generator values picked for the first iteration P1 = 104MW, P2 = 100MW, P3 = 100MW, and P4 = 150MW

$P_1 + P_2 + P_3 + P_4 - Ploss - 454 = 0$

Solving for λ after rearranging:
$\frac{\lambda(1-00002)}{2.4+002} + \frac{\lambda(1-0.00006)}{2.7+0.006} + \frac{\lambda(1-0.0001)}{2.7+0.004} + \frac{\lambda(1-0.00008)}{2.2+0.005} - 0.017 - 454 = 0$

After several iterations, $\lambda = 2.91R/MWh$
P1 = 206.1MW , P2 = 18.69MW,P3 =78.1MW and P4 = 162.46MW for optimal economic dispatch

3. **Total Cost Of Generation**

The total cost is given by: $C_T = C_1 + C_2 + C_3 + C_4$

The total cost of generation is R2418/MW

Chapter 5

Wind Energy Integration

For this section, the Wind Turbine Generators were imported from the DigSilent Templates.

1. The generator at bus 10 was removed and replaced with wind turbines as follows:

    - The voltage profiles for adding Type 1 and Type 2 generators can be seen below. The effect of a Type 2 generator is that its configuration allows for variable-speed operation, enabling the generator to adjust its rotational speed based on wind conditions. This is evident in that due to Type 1's fixed speed, its voltage profile is close to operating limits, while Type 2's operation is better. The expected result from the simulation when the generator is under-excited was for buses 8,9, and 10 to be operating at lower voltages, but this is not reflected in the voltage profile tables. This is likely an effect of the use of wind turbine templates provided by the DigSilent software.

	nom.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
Bus1	20,00	1,000	20,00	0,00	
Bus2	230,00	0,995	228,77	-0,89	
Bus3	230,00	0,995	228,77	-0,89	
Bus4	230,00	0,995	228,77	-0,89	
Bus5	20,00	0,997	19,93	-0,23	
Bus6	20,00	0,999	19,99	-0,45	
Bus7	230,00	0,995	228,77	-0,89	
Bus8	230,00	0,995	228,77	-0,89	
Bus9	230,00	0,995	228,77	-0,89	
WT Type 1 LV	20,00	1,044	20,88	-149,69	

Figure 5.1: Type 1 WTG

	nom.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
Bus1	20,00	1,000	20,00	0,00	
Bus2	230,00	0,995	228,77	-0,89	
Bus3	230,00	0,995	228,77	-0,89	
Bus4	230,00	0,995	228,77	-0,89	
Bus5	20,00	0,997	19,93	-0,23	
Bus6	20,00	0,999	19,99	-0,45	
Bus7	230,00	0,995	228,77	-0,89	
Bus8	230,00	0,995	228,77	-0,89	
Bus9	230,00	0,995	228,77	-0,89	
WT Type 2 LV	20,00	1,014	20,27	-149,35	

Figure 5.2: Type 2 WTG

- By adding a shunt capacitor at bus 10, the bus voltages at bus 8,9 and 10 are within acceptable levels as shown,

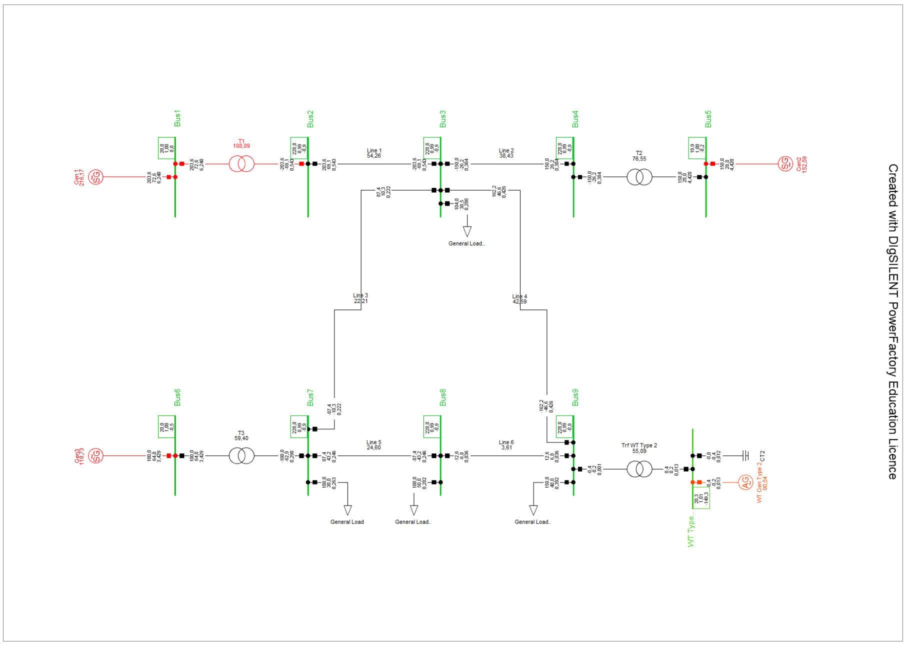


Figure 5.3: Type 2 WTG With Shunt Capacitor

- Type 4 WTG is added to the system as shown below

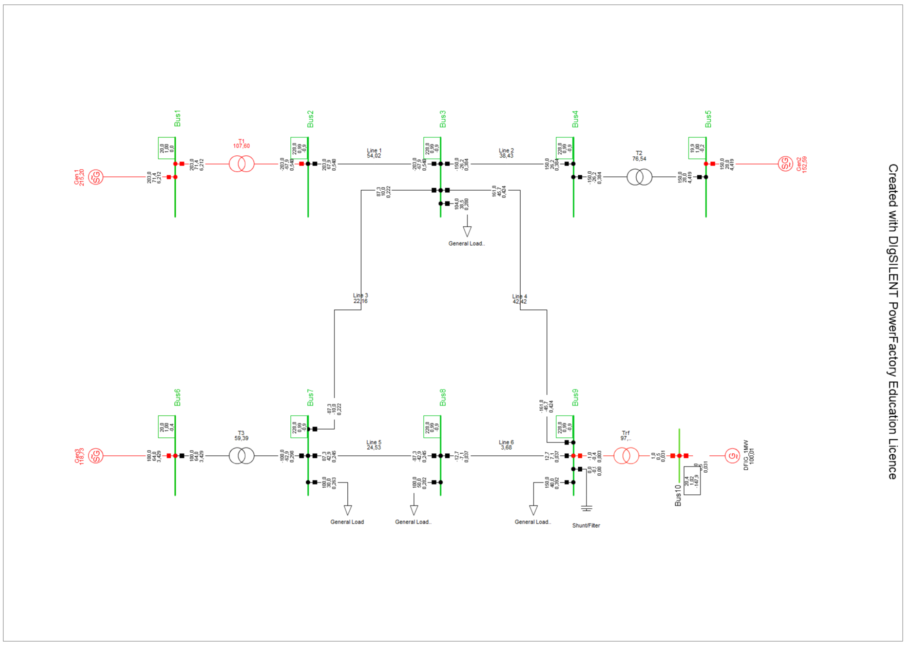
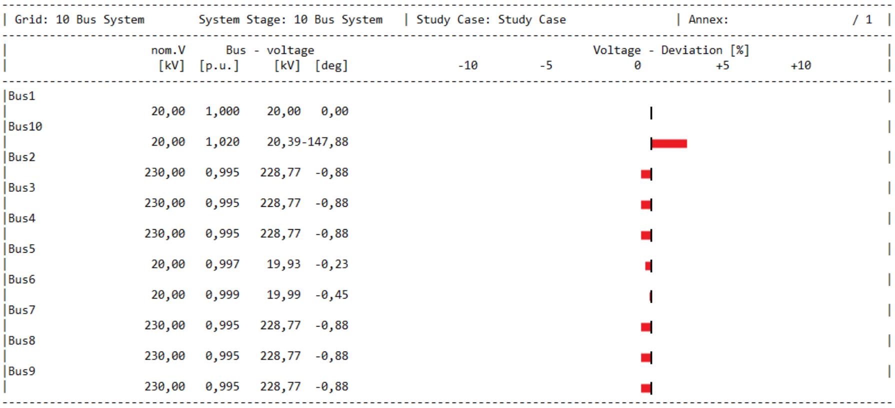


Figure 5.4: Type 4 WTG

The voltage profiles are as follows:



Grid: 10 Bus System	System Stage: 10 Bus System	Study Case: Study Case	Annex: / 1	
	nom.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
Bus1	20,00	1,000	20,00	0,00
Bus10	20,00	1,020	20,39	-147,88
Bus2	230,00	0,995	228,77	-0,88
Bus3	230,00	0,995	228,77	-0,88
Bus4	230,00	0,995	228,77	-0,88
Bus5	20,00	0,997	19,93	-0,23
Bus6	20,00	0,999	19,99	-0,45
Bus7	230,00	0,995	228,77	-0,88
Bus8	230,00	0,995	228,77	-0,88
Bus9	230,00	0,995	228,77	-0,88

Figure 5.5: Type 4 WTG Voltage Profiles

As highlighted, the Type 1 generator is modeled to have a constant power factor PQ Bus, while the type 4 generator represents a fully asynchronous machine [3]. In Load flow analysis, Type 1 generators consume reactive power, while Type 4 share similar characteristics to traditional PV bus generators.

Bibliography

[1] "Eee4126f: Load flow assignment," April 2023.

[2] K. A. Folly, "Eee3100s: Power flow notes," 2022.

[3] J. D. Glover, T. J. Overbye, and M. S. Sarma, *Power System Analysis and Design*, 5th ed. CENGAGE Learning Custom Publishing, 2011.

[4] S. Chatterjee and S. Mandal, "A novel comparison of gauss-seidel and newton- raphson methods for load flow analysis," pp. 1–7, 2017.

[5] Y. N. Lafta, N. A. Shalash, Y. N. Abd, and A. A. Al-Lami, "IEC 60909 and ANSI standards comparison with ASCC based fault calculations of iraqi power system," *Cogent Eng.*, vol. 6, no. 1, p. 1705654, 2019.