Assignment 3

S2280536 Yifan Chen

Question 1

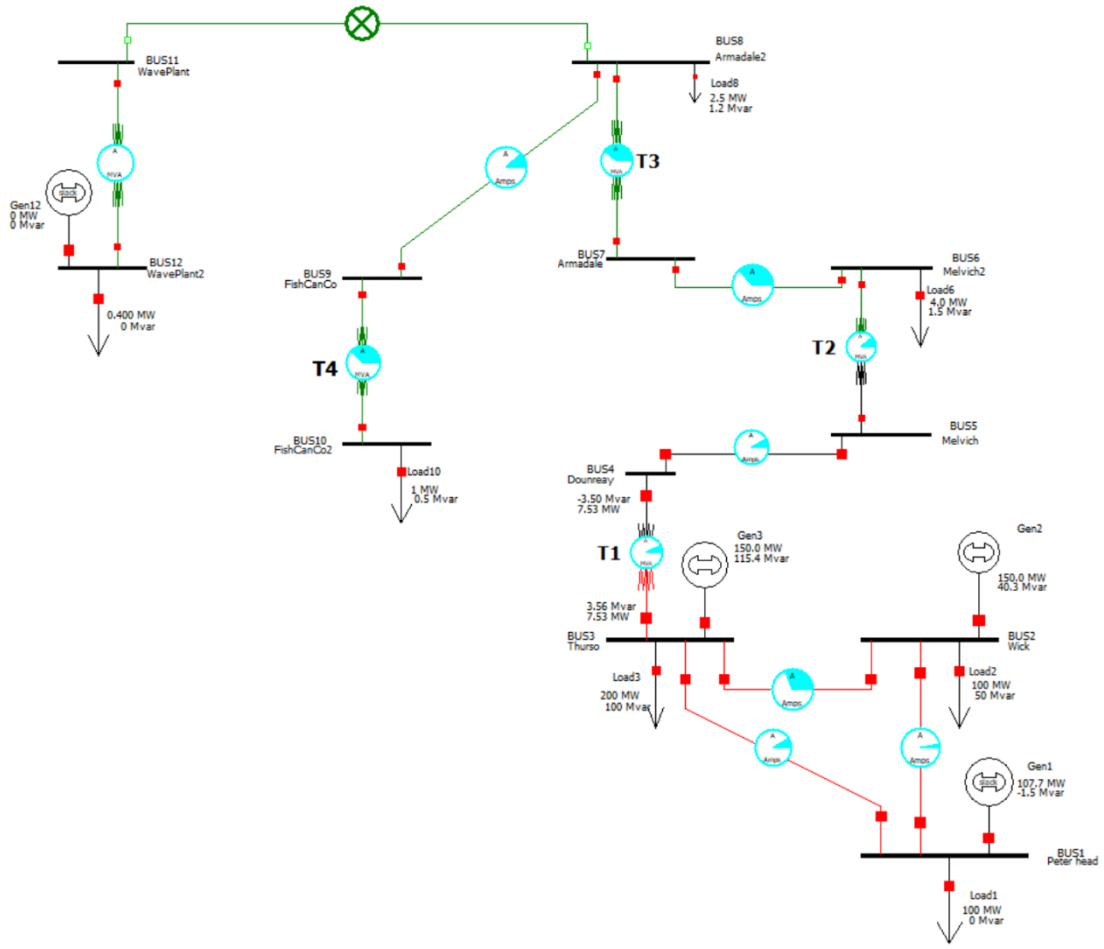

Fig. 1. The 13-bus network single-line diagram.

Table. 1. Input Data (transformer and line impedances)

From bus	To bus	Type	Rating (MVA)	R (pu)	X (pu)	Length (km)
3	4	T	120	0.00000	0.08330	0
5	6	T	75	0.00000	0.10000	0
7	8	T	10	0.00000	0.50000	0
9	10	T	3	0.00000	1.66700	0
1	2	L	150	0.01000	0.04999	100
1	3	L	150	0.01500	0.07498	150
2	3	L	150	0.00500	0.02499	50
4	5	L	115	0.00781	0.04637	20
6	7	L	11	0.14784	0.62810	20
8	9	L	10	0.53719	0.40041	5
Note: All transformer resistances and reactances are converted in per-unit to a base of 100 MVA using formula: $X_{pu}(new) = X_{pu}(old)(\frac{MVA(new)}{MVA(old)})$.						

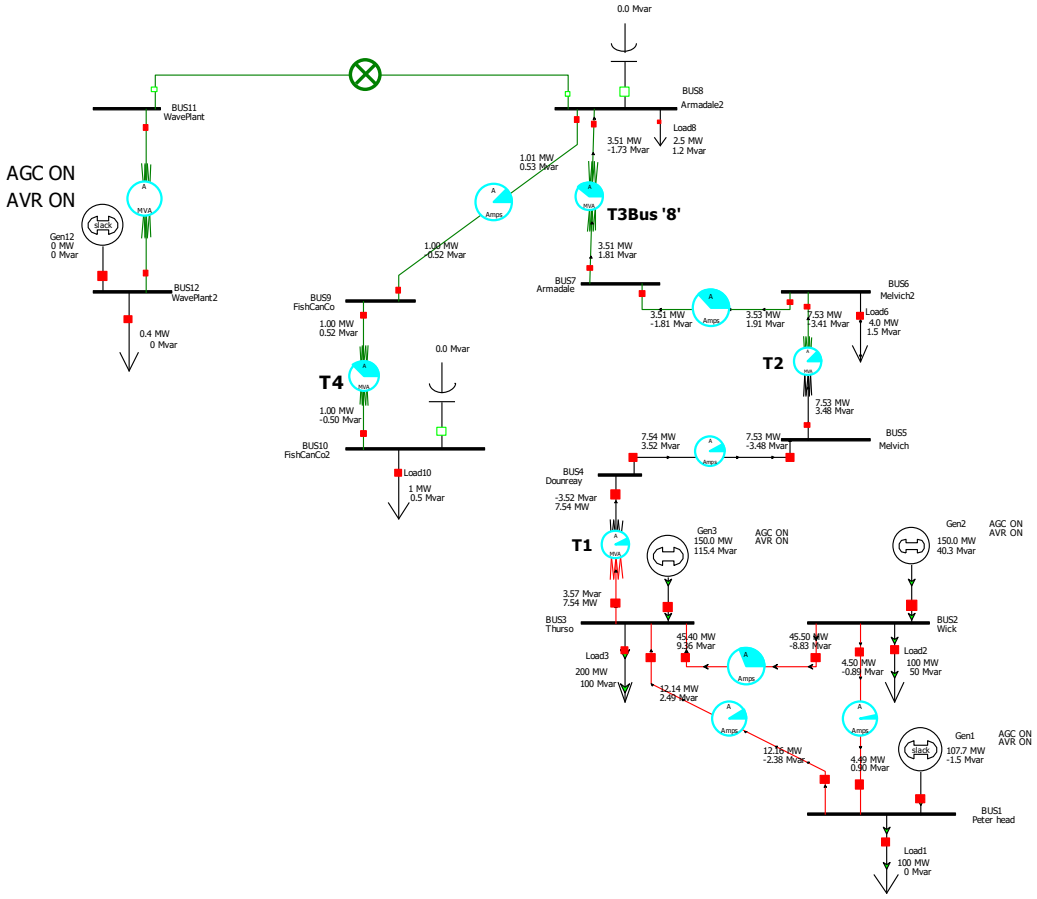

Fig. 2. informative screenshot.

Question 2

Q2.1 Average Loading Conditions

Table. 2. Time-Varying Active Demand Profile

Time (hr)	Active Power demand (MW)					
	Bus 1	Bus 2	Bus 3	Bus 6	Bus 8	Bus 10
0000	47.500	47.500	95.000	1.900	1.187	0.329
0100	44.700	44.700	89.400	1.788	1.118	0.395
0200	44.600	44.600	89.200	1.784	1.100	0.427
0300	42.500	42.500	85.000	1.700	1.063	0.409
0400	42.400	42.400	84.800	1.696	1.100	0.385
0500	44.400	44.400	88.800	1.776	1.110	0.402
0600	60.100	60.100	120.200	2.404	1.503	0.480
0700	83.000	83.000	166.000	3.320	2.075	0.553
0800	94.800	94.800	189.600	3.792	2.370	0.763
0900	97.100	97.100	194.200	3.884	2.427	0.926
1000	97.600	97.600	195.200	3.904	2.440	0.969

1100	97.500	97.500	195.000	3.900	2.437	1.000
1200	97.200	97.200	194.400	3.888	2.430	0.949
1300	93.200	93.200	186.400	3.728	2.330	0.929
1400	89.000	89.000	178.000	3.560	2.225	0.893
1500	89.500	89.500	179.000	3.580	2.238	0.860
1600	99.000	99.000	198.000	3.960	2.475	0.766
1700	100.000	100.000	200.000	4.000	2.500	0.557
1800	98.900	98.900	197.800	3.956	2.472	0.416
1900	99.800	99.800	199.600	3.992	2.495	0.391
2000	97.800	97.800	195.600	3.912	2.445	0.363
2100	91.700	91.700	183.400	3.668	2.293	0.336
2200	80.700	80.700	161.400	3.228	2.018	0.335
2300	61.200	61.200	122.400	2.448	1.530	0.327

Table. 3. Time-Varying Reactive Demand Profile

Time (hr)	Reactive Power demand (Mvar)					
	Bus 1	Bus 2	Bus 3	Bus 6	Bus 8	Bus 10
0000	0.000	23.750	47.500	0.713	0.570	0.164
0100	0.000	22.350	44.700	0.671	0.537	0.197
0200	0.000	22.300	44.600	0.669	0.528	0.213
0300	0.000	21.250	42.500	0.637	0.510	0.204
0400	0.000	21.200	42.400	0.636	0.528	0.192
0500	0.000	22.200	44.400	0.666	0.533	0.201
0600	0.000	30.050	60.100	0.902	0.721	0.240
0700	0.000	41.500	83.000	1.245	0.996	0.277
0800	0.000	47.400	94.800	1.422	1.138	0.381
0900	0.000	48.550	97.100	1.457	1.165	0.463
1000	0.000	48.800	97.600	1.464	1.171	0.484
1100	0.000	48.750	97.500	1.462	1.170	0.500
1200	0.000	48.600	97.200	1.458	1.166	0.475
1300	0.000	46.600	93.200	1.398	1.118	0.465
1400	0.000	44.500	89.000	1.335	1.068	0.446
1500	0.000	44.750	89.500	1.343	1.074	0.430
1600	0.000	49.500	99.000	1.485	1.188	0.383
1700	0.000	50.000	100.000	1.500	1.200	0.279
1800	0.000	49.450	98.900	1.484	1.187	0.208
1900	0.000	49.900	99.800	1.497	1.198	0.195
2000	0.000	48.900	97.800	1.467	1.174	0.181
2100	0.000	45.850	91.700	1.376	1.101	0.168
2200	0.000	40.350	80.700	1.211	0.969	0.167
2300	0.000	30.600	61.200	0.918	0.734	0.163

Assignment 3

S2280536 Yifan Chen

PWOPFTimePoint																					
Date	Time	Skip	1 PU Volt	1 Angle (D	2 PU Volt	2 Angle (D	3 PU Volt	3 Angle (D	4 PU Volt	4 Angle (D	5 PU Volt	5 Angle (D	6 PU Volt	6 Angle (D	7 PU Volt	7 Angle (D	8 PU Volt	8 Angle (D	9 PU Volt	9 Angle (D	10 PU Volt	10 Angle (
2023/3/6	0:00:00	NO	1.00	0.00	1.00	2.79	1.00	2.67	1.00	2.50	1.00	2.42	1.00	2.22	0.99	1.73	0.99	1.29	0.98	1.26	0.98	0.94
2023/3/6	1:00:00	NO	1.00	0.00	1.00	2.93	1.00	2.83	1.00	2.68	1.00	2.60	1.00	2.40	0.99	1.92	0.99	1.47	0.98	1.44	0.98	1.05
2023/3/6	2:00:00	NO	1.00	0.00	1.00	2.94	1.00	2.84	1.00	2.68	1.00	2.60	1.00	2.41	0.99	1.92	0.99	1.47	0.98	1.44	0.98	1.01
2023/3/6	3:00:00	NO	1.00	0.00	1.00	3.04	1.00	2.97	1.00	2.82	1.00	2.74	1.00	2.55	0.99	2.08	0.99	1.65	0.98	1.62	0.98	1.21
2023/3/6	4:00:00	NO	1.00	0.00	1.00	3.05	1.00	2.97	1.00	2.82	1.00	2.74	1.00	2.56	0.99	2.08	0.99	1.64	0.98	1.61	0.98	1.23
2023/3/6	5:00:00	NO	1.00	0.00	1.00	2.95	1.00	2.85	1.00	2.70	1.00	2.61	1.00	2.42	0.99	1.94	0.99	1.49	0.98	1.46	0.98	1.06
2023/3/6	6:00:00	NO	1.00	0.00	1.00	2.16	1.00	1.90	1.00	1.69	1.00	1.58	1.00	1.32	0.99	0.68	0.98	0.09	0.98	0.05	0.97	-0.43
2023/3/6	7:00:00	NO	1.00	0.00	1.00	1.00	1.00	0.50	1.00	0.22	1.00	0.07	0.99	-0.28	0.98	-1.14	0.97	-1.93	0.97	-1.98	0.97	-2.54
2023/3/6	8:00:00	NO	1.00	0.00	1.00	0.40	1.00	-0.22	1.00	-0.55	1.00	-0.73	0.99	-1.13	0.98	-2.16	0.97	-3.11	0.96	-3.17	0.96	-3.96
2023/3/6	9:00:00	NO	1.00	0.00	1.00	0.28	1.00	-0.36	1.00	-0.71	1.00	-0.89	0.99	-1.31	0.98	-2.41	0.97	-3.43	0.96	-3.50	0.95	-4.47
2023/3/6	10:00:00	NO	1.00	0.00	1.00	0.26	1.00	-0.40	1.00	-0.75	0.99	-0.93	0.99	-1.36	0.97	-2.47	0.97	-3.51	0.96	-3.58	0.95	-4.60
2023/3/6	11:00:00	NO	1.00	0.00	1.00	0.26	1.00	-0.39	1.00	-0.74	0.99	-0.93	0.99	-1.35	0.97	-2.48	0.97	-3.53	0.96	-3.60	0.95	-4.65
2023/3/6	12:00:00	NO	1.00	0.00	1.00	0.28	1.00	-0.37	1.00	-0.72	1.00	-0.90	0.99	-1.32	0.98	-2.43	0.97	-3.46	0.96	-3.53	0.95	-4.53
2023/3/6	13:00:00	NO	1.00	0.00	1.00	0.48	1.00	-0.13	1.00	-0.46	1.00	-0.64	0.99	-1.04	0.98	-2.11	0.97	-3.10	0.96	-3.17	0.95	-4.14
2023/3/6	14:00:00	NO	1.00	0.00	1.00	0.69	1.00	0.13	1.00	-0.19	1.00	-0.36	0.99	-0.74	0.98	-1.76	0.97	-2.71	0.96	-2.78	0.95	-3.70
2023/3/6	15:00:00	NO	1.00	0.00	1.00	0.67	1.00	0.10	1.00	-0.22	1.00	-0.38	0.99	-0.77	0.98	-1.79	0.97	-2.72	0.96	-2.79	0.96	-3.68
2023/3/6	16:00:00	NO	1.00	0.00	1.00	0.19	1.00	-0.48	1.00	-0.82	1.00	-1.00	0.99	-1.42	0.98	-2.48	0.97	-3.47	0.96	-3.53	0.96	-4.32
2023/3/6	17:00:00	NO	1.00	0.00	1.00	0.14	1.00	-0.53	1.00	-0.87	1.00	-1.05	0.99	-1.46	0.98	-2.46	0.97	-3.38	0.97	-3.43	0.96	-4.00
2023/3/6	18:00:00	NO	1.00	0.00	1.00	0.20	1.00	-0.46	1.00	-0.79	1.00	-0.96	0.99	-1.36	0.98	-2.30	0.97	-3.17	0.97	-3.21	0.96	-3.63
2023/3/6	19:00:00	NO	1.00	0.00	1.00	0.15	1.00	-0.52	1.00	-0.85	1.00	-1.02	0.99	-1.42	0.98	-2.36	0.97	-3.23	0.97	-3.26	0.96	-3.66
2023/3/6	20:00:00	NO	1.00	0.00	1.00	0.26	1.00	-0.39	1.00	-0.72	1.00	-0.88	0.99	-1.27	0.98	-2.19	0.97	-3.04	0.97	-3.06	0.97	-3.44
2023/3/6	21:00:00	NO	1.00	0.00	1.00	0.56	1.00	-0.02	1.00	-0.32	1.00	-0.48	0.99	-0.85	0.98	-1.70	0.97	-2.49	0.97	-2.52	0.97	-2.86
2023/3/6	22:00:00	NO	1.00	0.00	1.00	1.12	1.00	0.65	1.00	0.38	1.00	0.24	0.99	-0.08	0.98	-0.85	0.98	-1.55	0.97	-1.58	0.97	-1.92
2023/3/6	23:00:00	NO	1.00	0.00	1.00	2.10	1.00	1.83	1.00	1.62	1.00	1.52	1.00	1.27	0.99	0.66	0.98	0.11	0.98	0.09	0.98	-0.24

Fig. 3. Per-unit values of bus voltages and voltage angles.

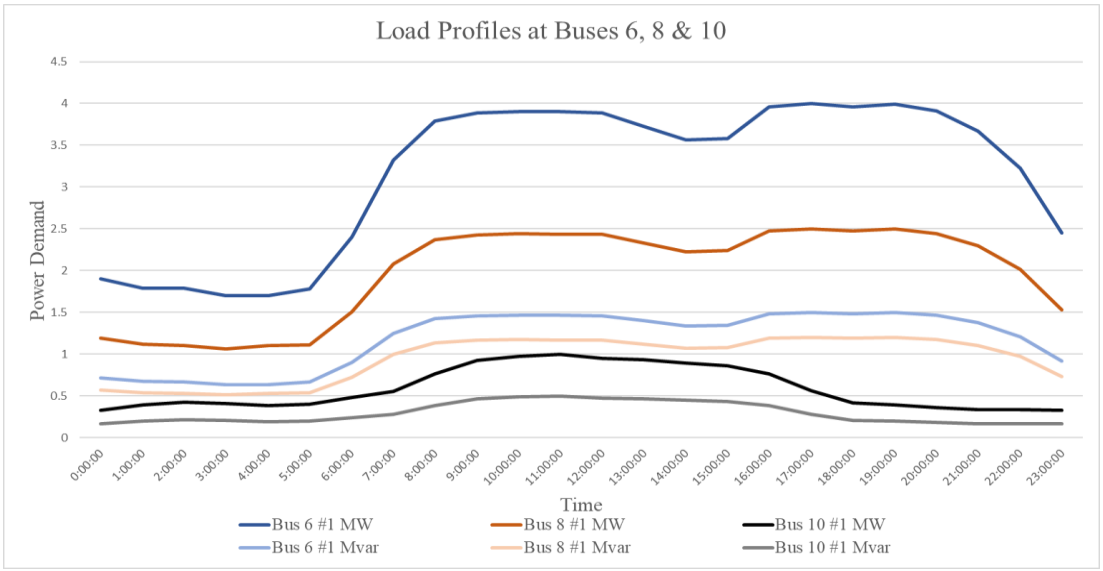

Fig. 4. The plots of the loads profiles at Buses 6, 8 and 10.

- Because the distance from the generations affects the losses and voltages in the radial network. Since the Gen12 is not functioning and there are resistances and reactances in transmission lines and transformers, from equation

$$V_{send} - V_{rec} = \frac{RP_{rec} + XQ_{rec}}{V_{rec}^*} + j\frac{XP_{rev} - RQ_{rec}}{V_{rec}^*}$$

we can know that the further the loads are away from the generations in the radial network, the bigger the R and X, the more losses it produces, and more voltage drop it gets.

- $P_{send} = 7.54MW$
  $Q_{send} = 3.57Mvar$

  $P_{Load_{sum}} = 6.00MW + 2.50MW + 1.00MW = 7.50MW$
  $Q_{Load_{sum}} = 1.50Mvar + 1.20Mvar + 0.50Mvar = 3.20Mvar$

$P_{losses} = 0.00MW + 0.01MW + 0.00MW + 0.02MW + 0.00MW + 0.01MW + 0.00MW = 0.04MW$
$Q_{losses} = 0.06Mvar + 0.03Mvar + 0.07Mvar + 0.10Mvar + 0.08Mvar + 0.01Mvar + 0.02Mvar = 0.37Mvar$

From the Data we can see that:

$$P_{send} = P_{load_{sum}} + P_{losses}$$

$$Q_{send} = Q_{load_{sum}} + Q_{losses}$$

The difference between in the powers sent into the radial network from Bus 3 and the sum of powers of all loads in the radial network is due to the losses during power transmission within transmission lines and transformers.

- Because transformer will cause reactive power losses due to its reactance.

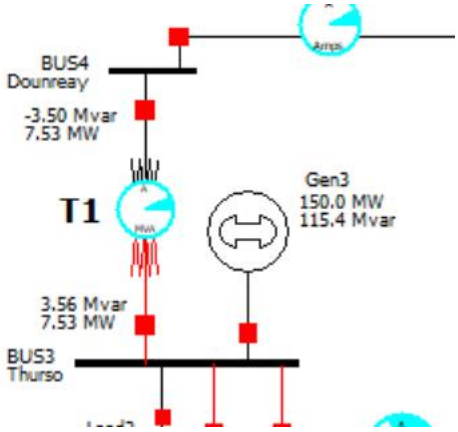

Fig. 5. Reactive Power loss within transformer.

From the Powerworld simulation we can see that there is a 0.06Mvar loss between Bus 3 and Bus 4.

Q2.2 Maximum Loading Conditions

Table. 4. Time-Varying Active Demand Profile

Time (hr)	Active Power demand (MW)					
	Bus 1	Bus 2	Bus 3	Bus 6	Bus 8	Bus 10
0000	47.500	47.500	95.000	3.800	2.375	0.987
0100	44.700	44.700	89.400	3.576	2.235	1.185
0200	44.600	44.600	89.200	3.568	2.230	1.281
0300	42.500	42.500	85.000	3.400	2.125	1.227
0400	42.400	42.400	84.800	3.392	2.120	1.155
0500	44.400	44.400	88.800	3.552	2.220	1.206
0600	60.100	60.100	120.200	4.808	3.005	1.440
0700	83.000	83.000	166.000	6.640	4.150	1.659

0800	94.800	94.800	189.600	7.584	4.740	2.289
0900	97.100	97.100	194.200	7.768	4.855	2.778
1000	97.600	97.600	195.200	7.808	4.880	2.907
1100	97.500	97.500	195.000	7.800	4.875	3.000
1200	97.200	97.200	194.400	7.776	4.860	2.847
1300	93.200	93.200	186.400	7.456	4.660	2.787
1400	89.000	89.000	178.000	7.120	4.450	2.679
1500	89.500	89.500	179.000	7.160	4.475	2.580
1600	99.000	99.000	198.000	7.920	4.950	2.298
1700	100.000	100.000	200.000	8.000	5.000	1.671
1800	98.900	98.900	197.800	7.912	4.945	1.248
1900	99.800	99.800	199.600	7.984	4.990	1.173
2000	97.800	97.800	195.600	7.824	4.890	1.089
2100	91.700	91.700	183.400	7.336	4.585	1.008
2200	80.700	80.700	161.400	6.456	4.035	1.005
2300	61.200	61.200	122.400	4.896	3.060	0.981

Table. 5. Time-Varying Reactive Demand Profile

Time	Reactive Power demand (Mvar)					
(hr)	Bus 1	Bus 2	Bus 3	Bus 6	Bus 8	Bus 10
0000	0.000	23.750	47.500	1.425	1.140	0.494
0100	0.000	22.350	44.700	1.341	1.073	0.593
0200	0.000	22.300	44.600	1.338	1.070	0.641
0300	0.000	21.250	42.500	1.275	1.020	0.614
0400	0.000	21.200	42.400	1.272	1.018	0.578
0500	0.000	22.200	44.400	1.332	1.066	0.603
0600	0.000	30.050	60.100	1.803	1.442	0.720
0700	0.000	41.500	83.000	2.490	1.992	0.830
0800	0.000	47.400	94.800	2.844	2.275	1.145
0900	0.000	48.550	97.100	2.913	2.330	1.389
1000	0.000	48.800	97.600	2.928	2.342	1.454
1100	0.000	48.750	97.500	2.925	2.340	1.500
1200	0.000	48.600	97.200	2.916	2.333	1.424
1300	0.000	46.600	93.200	2.796	2.237	1.394
1400	0.000	44.500	89.000	2.670	2.136	1.340
1500	0.000	44.750	89.500	2.685	2.148	1.290
1600	0.000	49.500	99.000	2.970	2.376	1.149
1700	0.000	50.000	100.000	3.000	2.400	0.836
1800	0.000	49.450	98.900	2.967	2.374	0.624
1900	0.000	49.900	99.800	2.994	2.395	0.587
2000	0.000	48.900	97.800	2.934	2.347	0.545
2100	0.000	45.850	91.700	2.751	2.201	0.504
2200	0.000	40.350	80.700	2.421	1.937	0.503
2300	0.000	30.600	61.200	1.836	1.469	0.491

Assignment 3

S2280536 Yifan Chen

PWOPFTimePoint																						
Date	Time	Skip	1 PU Volt	1 Angle (D	2 PU Volt	2 Angle (D	3 PU Volt	3 Angle (D	4 PU Volt	4 Angle (D	5 PU Volt	5 Angle (D	6 PU Volt	6 Angle (D	7 PU Volt	7 Angle (D	8 PU Volt	8 Angle (D	9 PU Volt	9 Angle (D	10 PU Volt	10 Angle (
2023/3/6	0:00:00	NO	1.00	0.00	1.00	2.74	1.00	2.58	1.00	2.24	1.00	2.06	0.99	1.64	0.98	0.54	0.97	-0.48	0.96	-0.55	0.95	-1.59
2023/3/6	1:00:00	NO	1.00	0.00	1.00	2.88	1.00	2.75	1.00	2.42	1.00	2.24	0.99	1.83	0.97	0.71	0.97	-0.33	0.96	-0.42	0.95	-1.67
2023/3/6	2:00:00	NO	1.00	0.00	1.00	2.88	1.00	2.76	1.00	2.42	1.00	2.24	0.99	1.83	0.97	0.68	0.97	-0.40	0.95	-0.49	0.94	-1.85
2023/3/6	3:00:00	NO	1.00	0.00	1.00	2.99	1.00	2.89	1.00	2.56	1.00	2.40	0.99	2.00	0.98	0.90	0.97	-0.12	0.96	-0.21	0.95	-1.50
2023/3/6	4:00:00	NO	1.00	0.00	1.00	2.99	1.00	2.90	1.00	2.57	1.00	2.41	0.99	2.02	0.98	0.95	0.97	-0.05	0.96	-0.13	0.95	-1.34
2023/3/6	5:00:00	NO	1.00	0.00	1.00	2.89	1.00	2.77	1.00	2.43	1.00	2.26	0.99	1.85	0.97	0.73	0.97	-0.31	0.96	-0.40	0.95	-1.67
2023/3/6	6:00:00	NO	1.00	0.00	1.00	2.08	1.00	1.79	1.00	1.34	0.99	1.11	0.99	0.57	0.97	-0.91	0.96	-2.30	0.94	-2.41	0.93	-3.98
2023/3/6	7:00:00	NO	1.00	0.00	1.00	0.90	1.00	0.35	1.00	-0.25	0.99	-0.56	0.99	-1.30	0.96	-3.27	0.94	-5.14	0.93	-5.26	0.91	-7.15
2023/3/6	8:00:00	NO	1.00	0.00	1.00	0.28	1.00	-0.40	0.99	-1.11	0.99	-1.47	0.98	-2.35	0.94	-4.75	0.92	-7.07	0.90	-7.25	0.88	-9.99
2023/3/6	9:00:00	NO	1.00	0.00	1.00	0.16	1.00	-0.55	0.99	-1.30	0.99	-1.69	0.98	-2.61	0.94	-5.22	0.91	-7.80	0.89	-7.99	0.86	-11.44
2023/3/6	10:00:00	NO	1.00	0.00	1.00	0.13	1.00	-0.59	0.99	-1.35	0.99	-1.74	0.98	-2.67	0.93	-5.34	0.91	-7.99	0.89	-8.17	0.86	-11.83
2023/3/6	11:00:00	NO	1.00	0.00	1.00	0.13	1.00	-0.58	0.99	-1.35	0.99	-1.74	0.98	-2.68	0.93	-5.39	0.91	-8.07	0.88	-8.25	0.85	-12.06
2023/3/6	12:00:00	NO	1.00	0.00	1.00	0.15	1.00	-0.56	0.99	-1.31	0.99	-1.70	0.98	-2.63	0.94	-5.27	0.91	-7.88	0.89	-8.06	0.86	-11.63
2023/3/6	13:00:00	NO	1.00	0.00	1.00	0.36	1.00	-0.31	0.99	-1.03	0.99	-1.41	0.98	-2.30	0.94	-4.84	0.92	-7.35	0.89	-7.53	0.86	-10.98
2023/3/6	14:00:00	NO	1.00	0.00	1.00	0.58	1.00	-0.04	0.99	-0.74	0.99	-1.09	0.98	-1.94	0.94	-4.37	0.92	-6.75	0.90	-6.92	0.87	-10.19
2023/3/6	15:00:00	NO	1.00	0.00	1.00	0.55	1.00	-0.07	0.99	-0.76	0.99	-1.12	0.98	-1.97	0.94	-4.36	0.92	-6.71	0.90	-6.88	0.87	-10.01
2023/3/6	16:00:00	NO	1.00	0.00	1.00	0.07	1.00	-0.66	0.99	-1.40	0.99	-1.77	0.98	-2.68	0.94	-5.15	0.92	-7.57	0.90	-7.73	0.88	-10.51
2023/3/6	17:00:00	NO	1.00	0.00	1.00	0.03	1.00	-0.70	0.99	-1.42	0.99	-1.78	0.98	-2.65	0.95	-4.92	0.93	-7.10	0.91	-7.23	0.90	-9.17
2023/3/6	18:00:00	NO	1.00	0.00	1.00	0.09	1.00	-0.63	0.99	-1.31	0.99	-1.66	0.98	-2.50	0.95	-4.59	0.93	-6.59	0.92	-6.69	0.91	-8.10
2023/3/6	19:00:00	NO	1.00	0.00	1.00	0.04	1.00	-0.68	0.99	-1.37	0.99	-1.72	0.98	-2.56	0.95	-4.64	0.93	-6.63	0.92	-6.72	0.91	-8.05
2023/3/6	20:00:00	NO	1.00	0.00	1.00	0.15	1.00	-0.55	0.99	-1.22	0.99	-1.57	0.98	-2.38	0.95	-4.40	0.94	-6.32	0.93	-6.41	0.92	-7.63
2023/3/6	21:00:00	NO	1.00	0.00	1.00	0.46	1.00	-0.17	0.99	-0.80	0.99	-1.12	0.98	-1.88	0.96	-3.76	0.94	-5.54	0.93	-5.62	0.92	-6.74
2023/3/6	22:00:00	NO	1.00	0.00	1.00	1.03	1.00	0.52	1.00	-0.04	0.99	-0.33	0.99	-1.00	0.96	-2.69	0.95	-4.28	0.94	-4.35	0.93	-5.45
2023/3/6	23:00:00	NO	1.00	0.00	1.00	2.03	1.00	1.73	1.00	1.29	0.99	1.07	0.99	0.55	0.97	-0.80	0.96	-2.05	0.95	-2.12	0.94	-3.17

Fig. 6. Per-unit values of bus voltages and voltage angles.

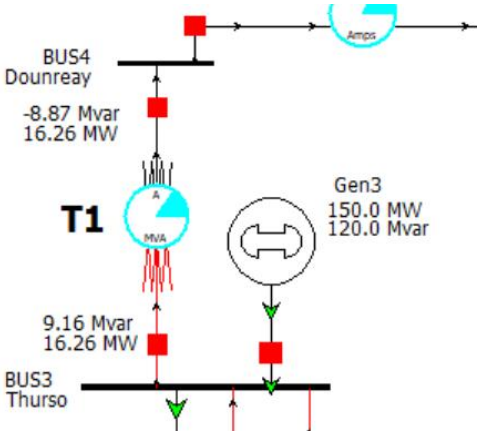

Fig. 7. Powers sent from Bus 3 to the network.

- From Fig. 5 & 6 we can see that powers now sent from Bus 3 to the network has increased.

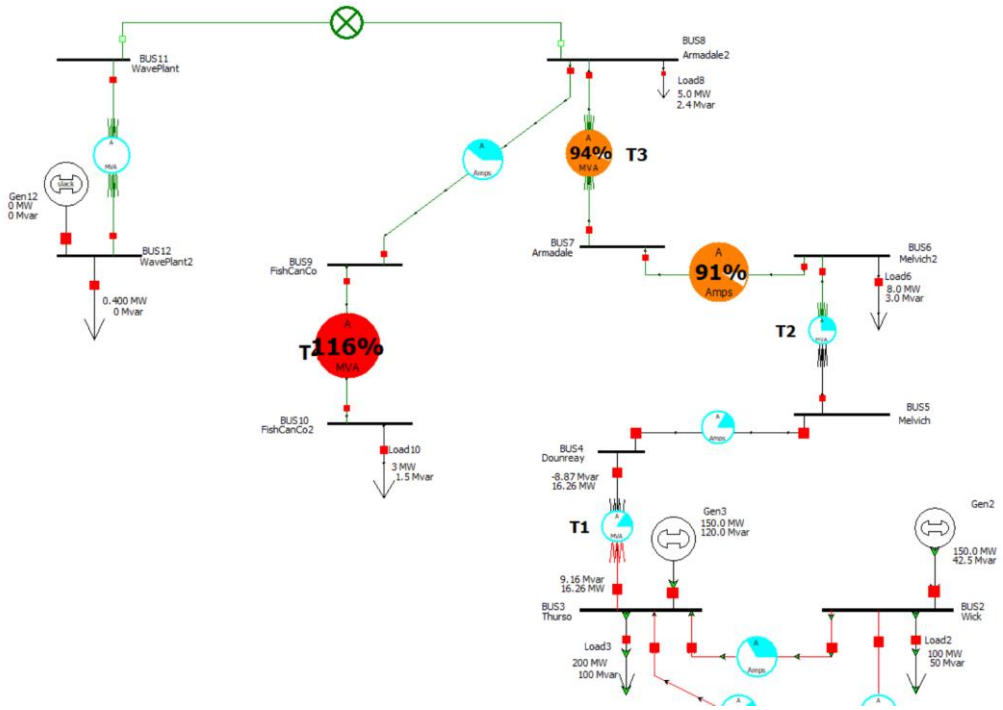

Fig. 8. Power flow under maximum loading conditions.

- Form the simulation result we can see that the loading of L6-7 is 91%, loading of L7-8 is 94% and loading of L9-10 is 116%. The further increase of loads at Buses 8 and 10 could mean loading beyond maximum loading conditions, which results in overloading in the transmission lines. Overloading will cause exceeding heat which the system could not bare.

Table. 6. Voltage Profile between 'Average' and 'Maximum loading conditions'.

Bus number	Average loading voltage	Maximum loading voltage
Bus 1	1.00∠0.00°	1.00∠0.00°
Bus 2	1.00∠0.13°	1.00∠0.00°
Bus 3	1.00∠-0.54°	1.00∠-0.73°
Bus 4	1.00∠−0.90°	0.99∠-1.52°
Bus 5	0.99∠-1.09°	0.99∠-1.92°
Bus 6	0.99∠-1.53°	0.98∠-2.88°
Bus 7	0.97∠-2.68°	0.93∠-5.63°
Bus 8	0.97∠-3.74°	0.91∠-8.37°
Bus 9	0.96∠-3.82°	0.88∠-8.56°
Bus 10	0.95∠-4.87°	0.85∠-12.38°

- We can see from Table. 6 that the voltage drop in maximum loading condition is faster when further to the end of the radial network compared to the average loading condition. And the voltage angle increases faster.

Q2.3 Network Upgrade

	Date	Time	6 PU Volt	6 Angle (Deg)	7 PU Volt	7 Angle (Deg)	8 PU Volt	8 Angle (Deg)	9 PU Volt	9 Angle (Deg)	10 PU Volt ▲	10 Angle (Deg)
1	2023/3/6	11:00:00	0.98	-2.68	0.93	-5.39	0.91	-8.07	0.88	-8.25	0.85	-12.06
2	2023/3/6	10:00:00	0.98	-2.67	0.93	-5.34	0.91	-7.99	0.89	-8.17	0.86	-11.83
3	2023/3/6	12:00:00	0.98	-2.63	0.94	-5.27	0.91	-7.88	0.89	-8.06	0.86	-11.63
4	2023/3/6	9:00:00	0.98	-2.61	0.94	-5.22	0.91	-7.80	0.89	-7.99	0.86	-11.44
5	2023/3/6	13:00:00	0.98	-2.30	0.94	-4.84	0.92	-7.35	0.89	-7.52	0.86	-10.98
6	2023/3/6	14:00:00	0.98	-1.94	0.94	-4.37	0.92	-6.75	0.90	-6.92	0.87	-10.19
7	2023/3/6	15:00:00	0.98	-1.97	0.94	-4.36	0.92	-6.71	0.90	-6.88	0.87	-10.01
8	2023/3/6	16:00:00	0.98	-2.68	0.94	-5.15	0.92	-7.57	0.90	-7.73	0.88	-10.51
9	2023/3/6	8:00:00	0.98	-2.35	0.94	-4.74	0.92	-7.07	0.90	-7.25	0.88	-9.99
10	2023/3/6	17:00:00	0.98	-2.65	0.95	-4.92	0.93	-7.10	0.91	-7.23	0.90	-9.17
11	2023/3/6	7:00:00	0.99	-1.30	0.96	-3.27	0.94	-5.14	0.93	-5.26	0.91	-7.15
12	2023/3/6	18:00:00	0.98	-2.50	0.95	-4.59	0.93	-6.59	0.92	-6.69	0.91	-8.10
13	2023/3/6	19:00:00	0.98	-2.56	0.95	-4.64	0.93	-6.63	0.92	-6.72	0.91	-8.05
14	2023/3/6	20:00:00	0.98	-2.38	0.95	-4.40	0.94	-6.32	0.93	-6.41	0.92	-7.63
15	2023/3/6	21:00:00	0.98	-1.88	0.96	-3.76	0.94	-5.54	0.93	-5.62	0.92	-6.74
16	2023/3/6	22:00:00	0.99	-1.00	0.96	-2.69	0.95	-4.28	0.94	-4.35	0.93	-5.45
17	2023/3/6	6:00:00	0.99	0.57	0.97	-0.91	0.96	-2.30	0.94	-2.41	0.93	-3.98
18	2023/3/6	2:00:00	0.99	1.83	0.97	0.68	0.97	-0.40	0.95	-0.49	0.94	-1.85
19	2023/3/6	23:00:00	0.99	0.55	0.97	-0.80	0.96	-2.05	0.95	-2.12	0.94	-3.17
20	2023/3/6	5:00:00	0.99	1.85	0.97	0.73	0.97	-0.31	0.96	-0.40	0.95	-1.67
21	2023/3/6	1:00:00	0.99	1.83	0.97	0.71	0.97	-0.33	0.96	-0.42	0.95	-1.67
22	2023/3/6	3:00:00	0.99	2.00	0.98	0.90	0.97	-0.12	0.96	-0.21	0.95	-1.50
23	2023/3/6	4:00:00	0.99	2.02	0.98	0.95	0.97	-0.05	0.96	-0.13	0.95	-1.34
24	2023/3/6	0:00:00	0.99	1.64	0.98	0.54	0.97	-0.48	0.96	-0.55	0.95	-1.59

Fig. 9. Identify the time of the worst case operation condition.

From the simulation outcome we can see that the the time of the worst case operation condition is at 11:00.

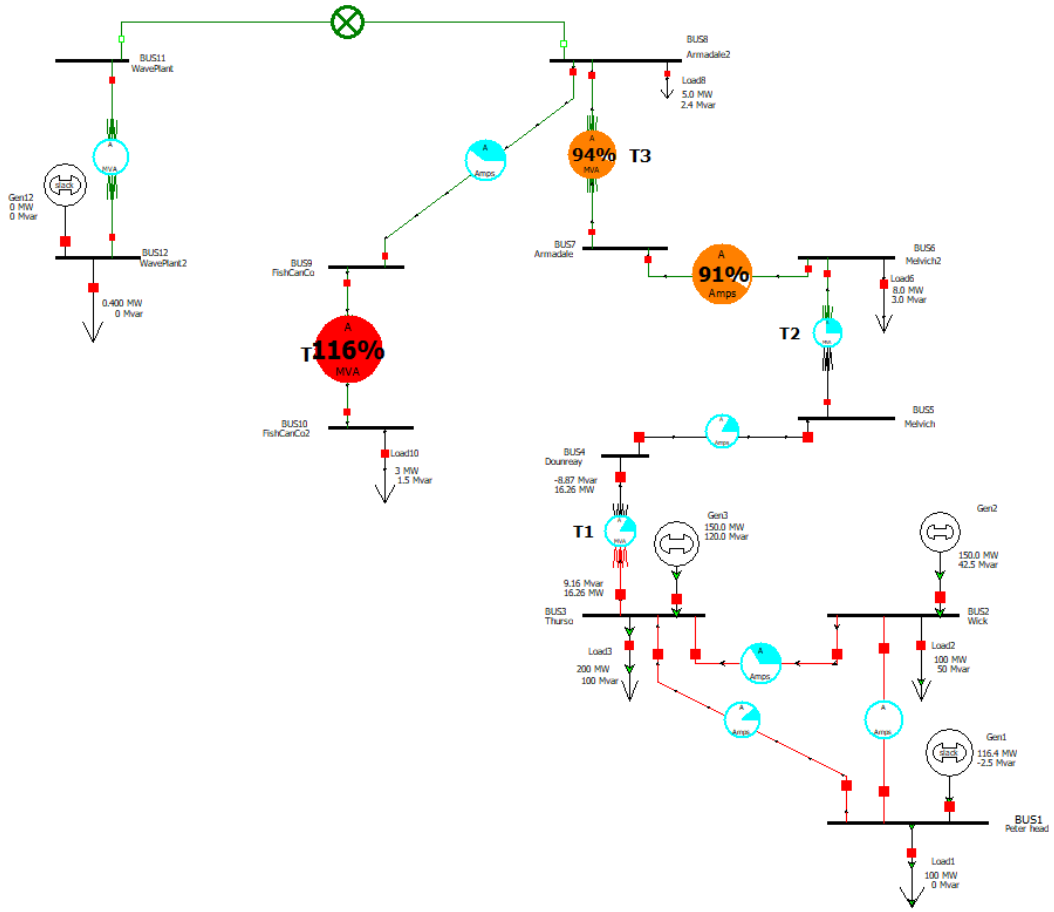

Fig. 10. Maximum loading condition without and voltage control.

Assignment 3

S2280536 Yifan Chen

Use of On-Load Tap Changing(OLTC) transformers for voltage control

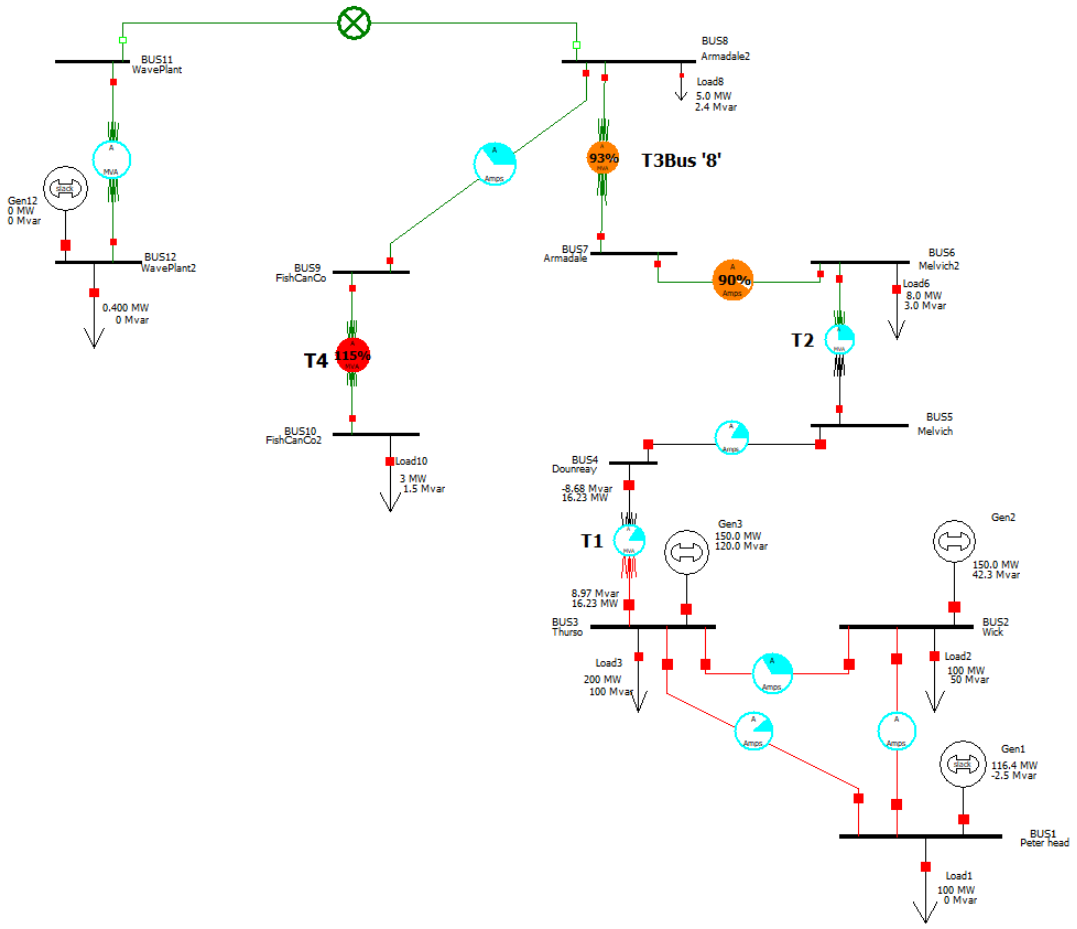

Fig. 11. Maximum loading condition with OLTC transformers for voltage control.

- From the topological structure of the network, T1 and T2 are between Bus 7 and the generators, so these two transformers can stabilize the voltage at Bus 7.

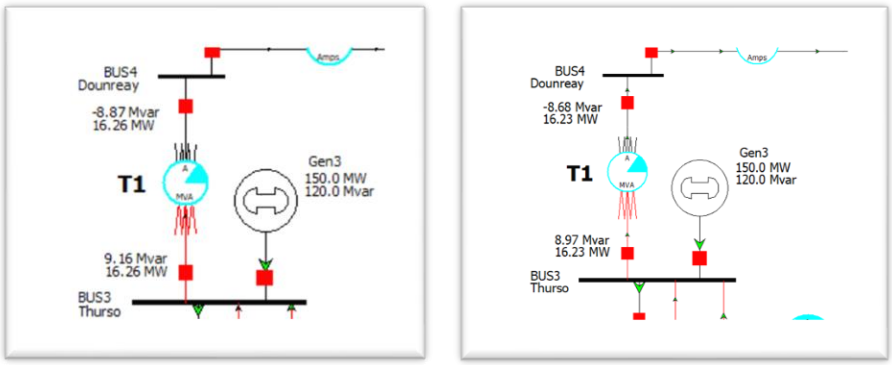

Fig. 12. Power sent at Bus 3 without power control(left) & with OLTC control(right).

- From the simulation results we can see that when adding OLTC transformer for voltage control, the active and reactive power sent at Bus 3 into the radial network decreased a little bit. That is because in order to increase the voltage, transformer need to increase the number of coils at the secondary side, which means that more

power loss during transmitting.

Use of Reactive Power Compensation(Capacitor Banks) for voltage control:

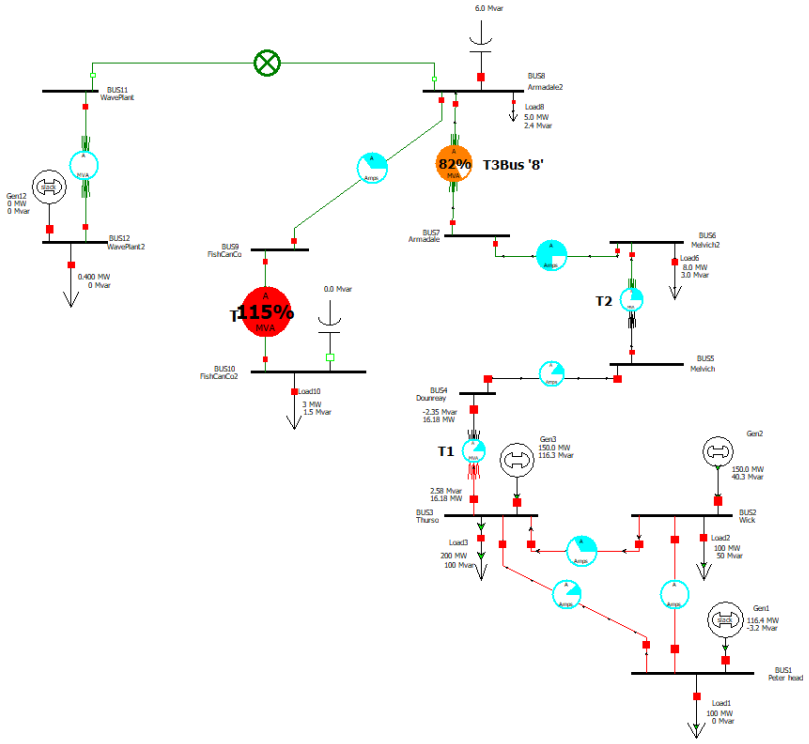

Fig. 13. Use of Shunt 1 at Bus 8 for voltage control.

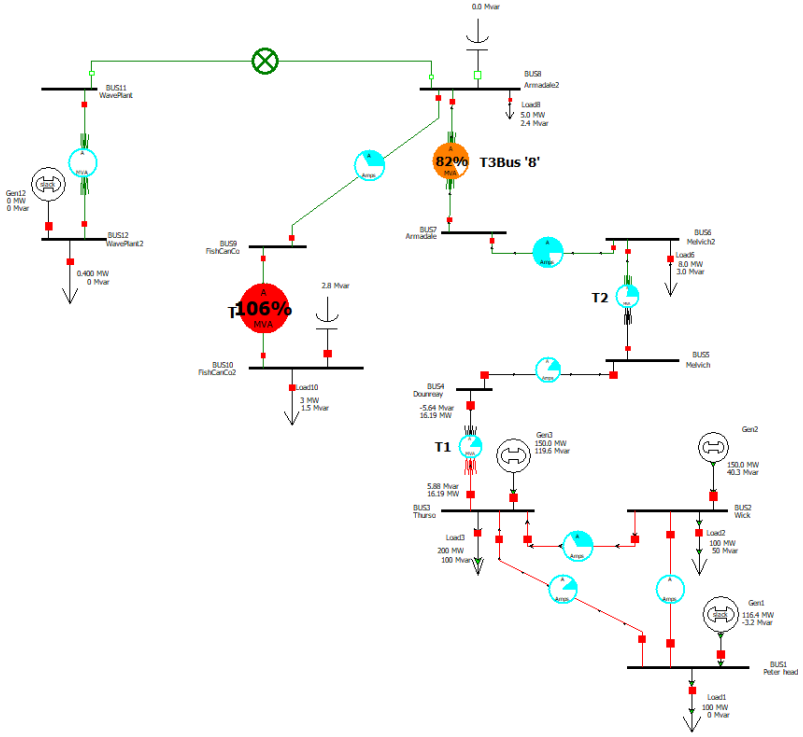

Fig. 14. Use of Shunt 2 at Bus 10 for voltage control.

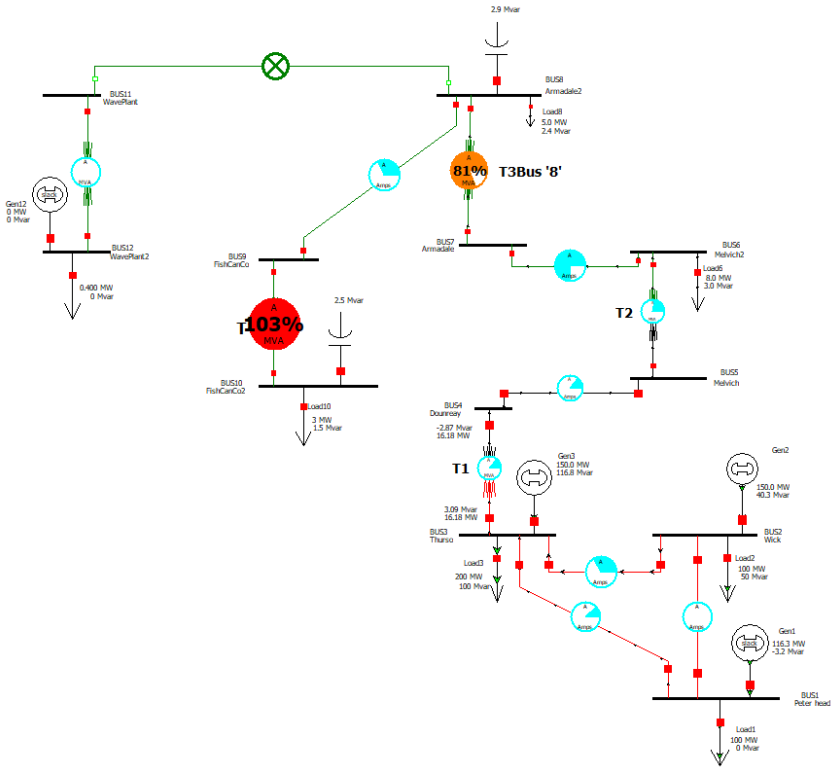

Fig. 15. Use of both Shunt 1 & 2 for voltage control.

- The separate effects of two shunt capacitors is on their location. Shunt can compensate the Q needed locally. When only connected shunt1, the loading condition at Line 8-7 is eased.

$$\Delta V = \frac{PR + QX}{V} \approx \frac{QX}{V}$$

Since Q needed at load end is compensated, the Q flow within network is decreased, from the equation we can see that the voltage drop at that bus is decrease. The voltage magnitude at bus 8 in raised to almost 1pu.

When only connected shunt 2, the voltage magnitude at Bus 12 is raised. However, shunt 2 is not enough to raised the voltage magnitude at Bus 12 to 1pu. But the loading condition at Line 9-10 is eased.

- After connecting both shunt, the voltage magnitude at the end of the radial network, which is Bus 12, is raised to almost 1pu.

Explain:

- Because shunt can compensate the Q needed at local demand. Which decreased the Q flow within the network.

$$\Delta V = \frac{PR + QX}{V} \approx \frac{QX}{V}$$

From the equation we can know that Q flow is decreased, voltage drop is decreased, so the voltage magnitude is increased.

- The P sent from Bus 3 decrease a little since there are extra components connected to the radial network. The Q sent from Bus 3 decrease a lot since Q needed by the radial network decreased, due to the compensation from shunts.

- Shunt is only used to compensate the Q needed at local demand. So shunt 1 is only compensating Bus 8 to get the voltage magnitude at Bus 8 to 1pu. If shunt1 is adjusted to inject its maximum reactive power, extra Q will flow into the network, which will result in voltage drop at other buses.
- From the simulation result we can notice that shunt 2 is almost injecting all of its reactive power to the network, however, it still can't get voltage magnitude at Bus 10 to 0.99pu, it can only means that the Q capacity of shunt 2 is not big enough.
- By connecting shunt 1 to the network, voltage magnitude at Bus 8 is increased to almost 1pu. Starting from Bus 8 till the end of the radial network, the voltage magnitudes at buses are all raised. So the voltage magnitude at Bus 10 is also raised.

Q3

Q3.1 Offshore Installation

- equivalent transformer impedance

$$X_{pu}(new) = X_{pu}(old)\left(\frac{MVA(new)}{MVA(old)}\right) = 4\% \times \frac{100MVA}{1MVA} = 4pu$$

number of Pelamis devices connected

$$number_{Pelamis\ devices} = \frac{12MW}{0.75MW} = 16$$

total equivalent transformer impedance with all devices connected in parallel

$$X_{pu}(total) = \frac{1}{\frac{1}{4pu} \times 16} = 0.25pu$$

- Set up the single equivalent generator

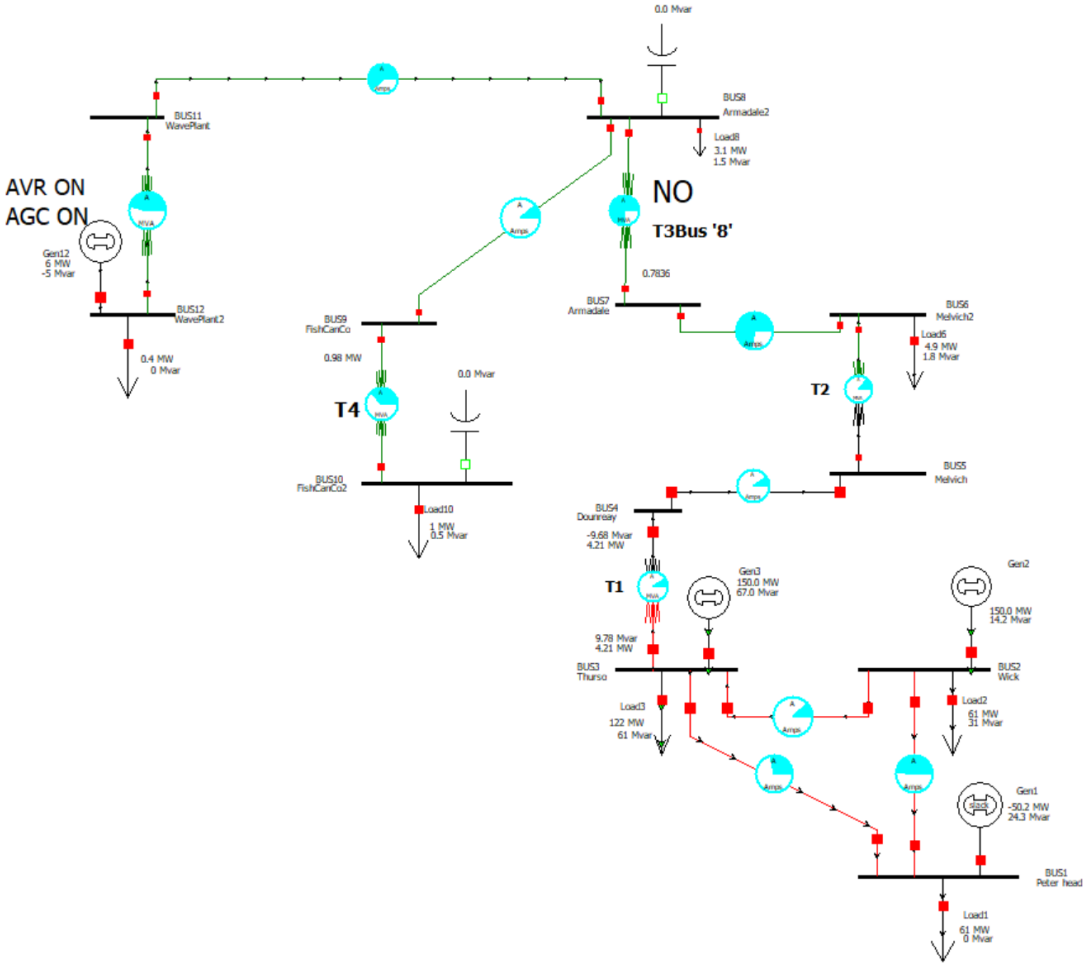

Fig. 16. Adding Wave Plant.

total internal load on Bus 12

$$P_{load} = 25kW \times 16 = 0.4MW$$

From Q2 we know that the worst case is at 11:00. From Table B.II & Fig. B.I we can identify that at 11:00, each Pelamis device has 546kW power.

Total Generation Power at Bus 12

$$P_{gen} = 546kW \times 16 = 8.736MW$$

- Busbar voltages and angles are shown in Table A.I.
- Discuss the impact of the wave plant on

Case	Bus Number								
	4	5	6	7	8	9	10	11	12
Q2.3 at 11:00	0.99263 ∠-1.35°	0.98735 ∠-1.74°	0.97886 ∠-2.68°	0.93393 ∠-5.39°	0.91005 ∠-8.07°	0.88385 ∠-8.25°	0.85259 ∠-12.06°	1.00000 ∠0.00°	1.00000 ∠0.00°
Q3.1	0.99174 ∠-0.83°	0.98648 ∠-1.02°	0.97665 ∠-1.53°	0.93284 ∠-1.23°	0.89888 ∠-1.47°	0.87230 ∠-1.66°	0.84051 ∠-5.57°	1.00326 ∠-6.87°	1.00000 ∠-8.07°

After adding the wave plant, the voltage magnitude on buses dropped slightly, that is because adding wave plant has changed the P & Q flow inside the network.

$$\Delta V = \frac{PR + QX}{V} \approx \frac{QX}{V}$$

Because the Gen at Bus 12 has turned on the AVR, its voltage magnitude is fixed at 1pu, in order to achieve so, it needs to absorb Q from the network, the Q flow inside the network has increased, so the voltage drop increased.

- The network performance

  From the power generation at slack bus we can notice that P generated by slack bus has decreased due to the P generated by wave plant. However, since the voltage magnitude at Bus 12 is also 1pu and the Gen at Bus 12 is demanding Q to achieve so, the amount of Q needed by the network has increased, as shown at slack Bus, the amount of Q absorbed by the slack bus has decreased.

Q3.2

Calculate the time-varying generation data

Table. 5. Wave Plant Time-Varying Generation Profile

Time(hr)	Power (MW)
0000	12.000
0100	12.000
0200	12.000
0300	12.000
0400	12.000
0500	12.000
0600	8.928
0700	8.928
0800	8.912
0900	8.912
1000	8.992
1100	8.736
1200	6.784
1300	3.808
1400	3.680
1500	3.808

1600	3.808
1700	3.696
1800	5.312
1900	6.032
2000	6.144
2100	6.032
2200	6.144
2300	6.032

Discuss changes in

- Voltage Profiles

PWOPFTimePoint																									
Date	Time	1 PU Volt	1 Angle (D	2 PU Volt	2 Angle (D	3 PU Volt	3 Angle (D	4 PU Volt	4 Angle (D	5 PU Volt	5 Angle (D	6 PU Volt	6 Angle (D	7 PU Volt	7 Angle (D	8 PU Volt	8 Angle (D	9 PU Volt	9 Angle (D	10 PU Volt	10 Angle (	11 PU Volt	11 Angle (	12 PU Volt	12 Angle (D
2023/3/6	0:00:00	1	0	1	2.87	1	2.79	0.99	2.89	0.99	2.98	0.98	3.11	0.94	6.13	0.9	8.17	0.89	8.09	0.88	6.89	1.01	21.53	1	23.18
2023/3/6	1:00:00	1	0	1	3.01	1	2.96	0.99	3.06	0.99	3.17	0.98	3.3	0.94	6.3	0.9	8.32	0.89	8.23	0.88	6.77	1.01	21.67	1	23.32
2023/3/6	2:00:00	1	0	1	3.02	1	2.96	0.99	3.06	0.99	3.16	0.98	3.29	0.94	6.26	0.9	8.25	0.89	8.15	0.87	6.57	1.01	21.59	1	23.23
2023/3/6	3:00:00	1	0	1	3.12	1	3.09	0.99	3.21	0.99	3.32	0.98	3.46	0.94	6.5	0.9	8.53	0.89	8.43	0.88	6.93	1.01	21.9	1	23.54
2023/3/6	4:00:00	1	0	1	3.13	1	3.1	0.99	3.22	0.99	3.33	0.98	3.48	0.94	6.54	0.9	8.61	0.89	8.51	0.88	7.1	1.01	21.98	1	23.63
2023/3/6	5:00:00	1	0	1	3.03	1	2.98	0.99	3.08	0.99	3.18	0.98	3.32	0.94	6.32	0.9	8.34	0.89	8.24	0.88	6.76	1.01	21.69	1	23.33
2023/3/6	6:00:00	1	0	1	2.19	1	1.95	0.99	1.85	0.99	1.83	0.98	1.72	0.95	3.34	0.92	4.28	0.91	4.16	0.89	2.46	1.01	13.74	1	14.96
2023/3/6	7:00:00	1	0	1	1.01	1	0.52	0.99	0.27	0.99	0.17	0.98	-0.14	0.94	1	0.91	1.5	0.9	1.38	0.88	-0.63	1.01	10.66	1	11.87
2023/3/6	8:00:00	1	0	1	0.39	1	-0.23	0.99	-0.58	0.99	-0.74	0.98	-1.18	0.94	-0.5	0.9	-0.4	0.88	-0.56	0.86	-3.44	1	8.41	1	9.63
2023/3/6	9:00:00	1	0	1	0.27	1	-0.38	0.99	-0.78	0.99	-0.96	0.98	-1.44	0.93	-0.99	0.9	-1.1	0.88	-1.29	0.85	-4.87	1	7.54	1	8.76
2023/3/6	10:00:00	1	0	1	0.24	1	-0.42	0.99	-0.82	0.99	-1	0.98	-1.5	0.93	-1.07	0.9	-1.22	0.87	-1.4	0.84	-5.19	1	7.47	1	8.69
2023/3/6	11:00:00	1	0	1	0.24	1	-0.42	0.99	-0.83	0.99	-1.02	0.98	-1.53	0.93	-1.22	0.9	-1.47	0.87	-1.65	0.84	-5.56	1	6.89	1	8.08
2023/3/6	12:00:00	1	0	1	0.24	1	-0.43	0.99	-0.9	0.99	-1.13	0.98	-1.72	0.94	-2.04	0.91	-2.71	0.89	-2.89	0.86	-6.44	1	3.24	1	4.15
2023/3/6	13:00:00	1	0	1	0.41	1	-0.23	0.99	-0.8	0.99	-1.09	0.98	-1.78	0.95	-3.14	0.94	-4.52	0.91	-4.69	0.89	-7.97	1	-2.36	1	-1.88
2023/3/6	14:00:00	1	0	1	0.62	1	0.03	0.99	-0.51	0.99	-0.79	0.98	-1.45	0.96	-2.72	0.94	-4.02	0.92	-4.19	0.89	-7.31	1	-1.88	1	-1.41
2023/3/6	15:00:00	1	0	1	0.6	1	0	0.99	-0.53	0.99	-0.8	0.98	-1.45	0.96	-2.64	0.94	-3.88	0.92	-4.05	0.89	-7.05	1	-1.55	1	-1.06
2023/3/6	16:00:00	1	0	1	0.12	1	-0.58	0.99	-1.16	0.99	-1.46	0.98	-2.17	0.96	-3.43	0.94	-4.73	0.92	-4.88	0.9	-7.54	1	-2.45	1	-1.96
2023/3/6	17:00:00	1	0	1	0.07	1	-0.63	0.99	-1.19	0.99	-1.48	0.98	-2.16	0.96	-3.25	0.94	-4.38	0.93	-4.5	0.92	-6.37	1	-2.03	1	-1.56
2023/3/6	18:00:00	1	0	1	0.16	1	-0.52	0.99	-0.99	0.99	-1.21	0.98	-1.78	0.96	-2.08	0.94	-2.61	0.93	-2.71	0.91	-4.12	1	1.95	1	2.66
2023/3/6	19:00:00	1	0	1	0.12	1	-0.56	0.99	-1	0.99	-1.21	0.98	-1.75	0.95	-1.77	0.93	-2.12	0.92	-2.21	0.91	-3.55	1	3.34	1	4.14
2023/3/6	20:00:00	1	0	1	0.23	1	-0.44	0.99	-0.85	0.99	-1.05	0.98	-1.56	0.95	-1.47	0.93	-1.72	0.92	-1.81	0.91	-3.04	1	3.96	1	4.78
2023/3/6	21:00:00	1	0	1	0.54	1	-0.06	0.99	-0.43	0.99	-0.61	0.98	-1.07	0.96	-0.89	0.93	-1.04	0.93	-1.12	0.92	-2.26	1	4.6	1	5.41
2023/3/6	22:00:00	1	0	1	1.11	1	0.63	0.99	0.33	0.99	0.19	0.98	-0.18	0.96	0.24	0.94	0.29	0.93	0.21	0.92	-0.91	1	6.23	1	7.05
2023/3/6	23:00:00	1	0	1	2.11	1	1.85	1	1.66	0.99	1.58	0.99	1.36	0.96	2.1	0.94	2.43	0.93	2.36	0.93	1.28	1	8.49	1	9.29

Fig. 17. Voltage Simulation result after adding Wave Plant.

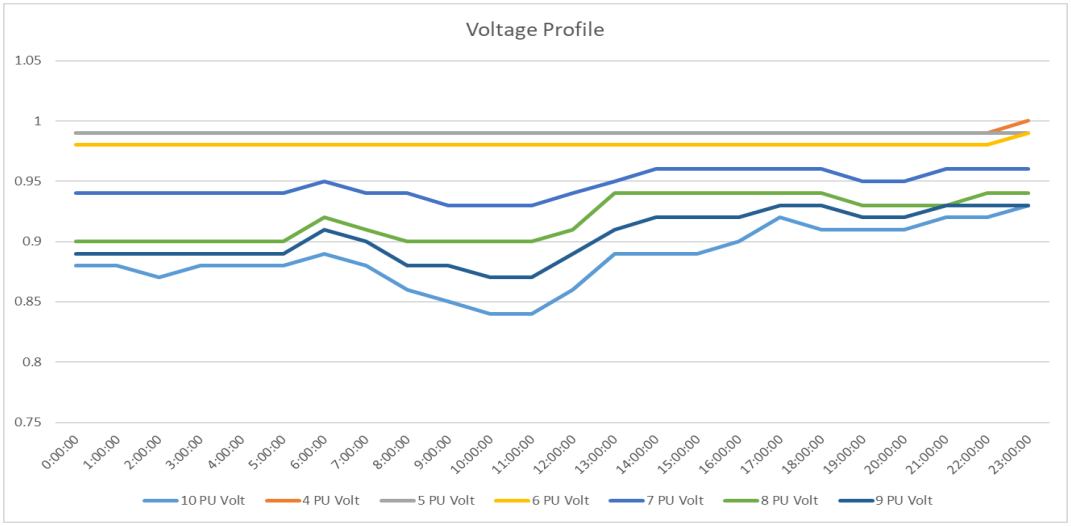

Fig. 18. Voltage Magnitude Profile after adding Wave Plant.

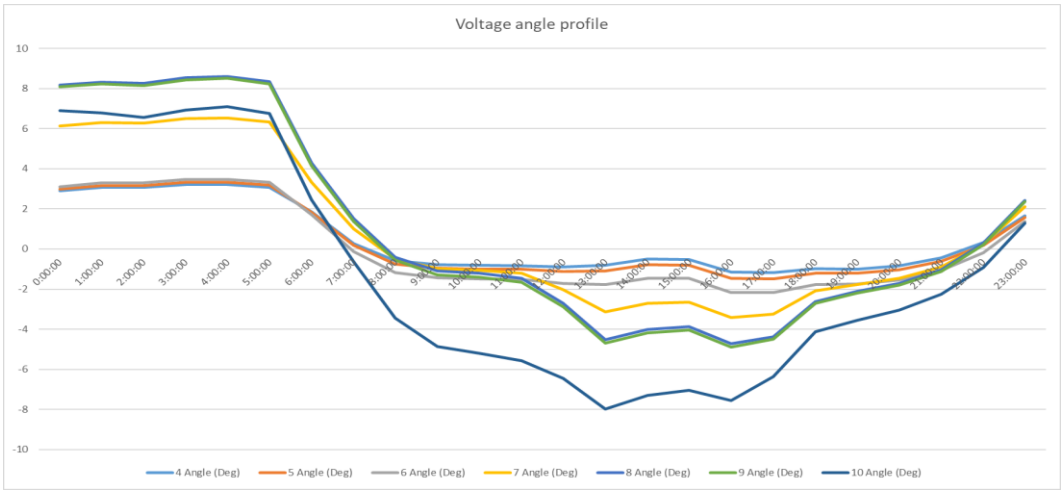

Fig. 19. Voltage Angle Profile after adding Wave Plant.

$$\Delta V = \frac{PR + QX}{V} + j\frac{PX - QR}{V} \approx \frac{QX}{V} + j\frac{PX}{V} \quad (X \gg R)$$

The voltage magnitude and angle in the system are affected by Q and P, respectively, due to the higher reactance X compared to the resistance R within the network.

Load demand follows a pattern throughout the day, with low demand during night hours and high demand during peak hours. Generation from wave plant also follows a pattern throughout the day, with high generation at midnight and low during daytime.

From the equation we can know that these patterns affect the voltage magnitude and angles by influencing P generation. During high demand, P is high, which increase the voltage angles. During high generation at wave plant at midnight, the demand is low, since the AVR is turned on at Bus 12, the voltage at Bus 12 is fixed at 1pu, it needs to absorb more Q to achieve so, Q flow from slack bus flowing into the network is increased, the voltage magnitude drops more.

- Line loadings

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	PWOPFTimePoint													
2	Date	Time	1 TO 2 CI	3 TO 1 CI	2 TO 3 CI	3 TO 4 CI	4 TO 5 CI	5 TO 6 CI	7 TO 6 CI	7 TO 8 CI	9 TO 8 CI	11 TO 8 (	9 TO 10 (	12 TO 11 (
3	2023/3/6	0:00:00	65.54	42.42	3.84	8.17	8.53	13.08	91.67	100.84	12.53	100.38	41.76	75.28
4	2023/3/6	1:00:00	68.74	44.99	2.51	8.15	8.51	13.04	91.53	100.68	15.1	100.35	50.32	75.26
5	2023/3/6	2:00:00	68.83	45.05	2.49	8.15	8.51	13.04	91.18	100.3	16.37	100.29	54.58	75.22
6	2023/3/6	3:00:00	71.29	47.05	1.44	8.15	8.5	13.03	91.86	101.04	15.65	100.39	52.17	75.29
7	2023/3/6	4:00:00	71.43	47.17	1.36	8.15	8.51	13.04	92.17	101.39	14.7	100.43	49.01	75.32
8	2023/3/6	5:00:00	69.08	45.26	2.37	8.15	8.51	13.04	91.51	100.66	15.38	100.34	51.27	75.26
9	2023/3/6	6:00:00	49.99	29.69	10.93	6.8	7.1	10.88	60.86	66.95	18.04	73.79	60.14	55.34
10	2023/3/6	7:00:00	23.11	7.95	22.38	8.59	8.96	13.74	58.83	64.72	21.07	72.97	70.23	54.72
11	2023/3/6	8:00:00	9.01	3.49	28.48	10.11	10.55	16.18	60.02	66.02	29.75	72.14	99.16	54.11
12	2023/3/6	9:00:00	6.13	5.85	29.8	10.72	11.19	17.16	61.86	68.05	36.6	71.87	122	53.91
13	2023/3/6	10:00:00	5.51	6.36	30.08	10.9	11.37	17.43	63.07	69.37	38.63	72.44	128.77	54.33
14	2023/3/6	11:00:00	5.53	6.36	30.13	10.96	11.43	17.53	62.14	68.35	39.86	70.28	132.88	52.71
15	2023/3/6	12:00:00	5.44	6.52	30.42	10.95	11.42	17.51	53.28	58.61	36.97	53.5	123.23	40.13
16	2023/3/6	13:00:00	9.35	3.51	29.25	11.36	11.85	18.17	51.94	57.14	35.14	29.07	117.12	21.32
17	2023/3/6	14:00:00	14.26	0.45	27.17	10.81	11.28	17.3	49.34	54.27	33.59	28.12	111.95	20.65
18	2023/3/6	15:00:00	13.75	0.05	27.34	10.72	11.19	17.15	48.17	52.98	32.29	28.97	107.62	21.39
19	2023/3/6	16:00:00	2.64	8.9	31.99	11.54	12.05	18.47	49.48	54.43	28.59	29.08	95.3	21.43
20	2023/3/6	17:00:00	1.67	9.65	32.29	11.11	11.59	17.77	44.06	48.47	20.29	27.86	67.63	20.64
21	2023/3/6	18:00:00	3.59	7.98	31.11	10.02	10.46	16.04	39.5	43.45	15.27	41.34	50.9	31.01
22	2023/3/6	19:00:00	2.79	8.58	31.32	9.88	10.31	15.81	41.19	45.31	14.45	47.49	48.16	35.62
23	2023/3/6	20:00:00	5.18	6.64	30.27	9.58	10	15.33	41.01	45.11	13.35	48.73	44.52	36.54
24	2023/3/6	21:00:00	12.36	0.84	27.24	8.89	9.28	14.22	39.22	43.14	12.3	47.95	40.99	35.96
25	2023/3/6	22:00:00	25.3	9.62	21.74	7.74	8.07	12.38	38.6	42.46	12.23	49.31	40.78	36.98
26	2023/3/6	23:00:00	48.15	28.09	12.05	5.89	6.14	9.42	37.72	41.49	11.85	48.94	39.5	36.7

Fig. 20. Line loading Simulation Result after adding Wave Plant.

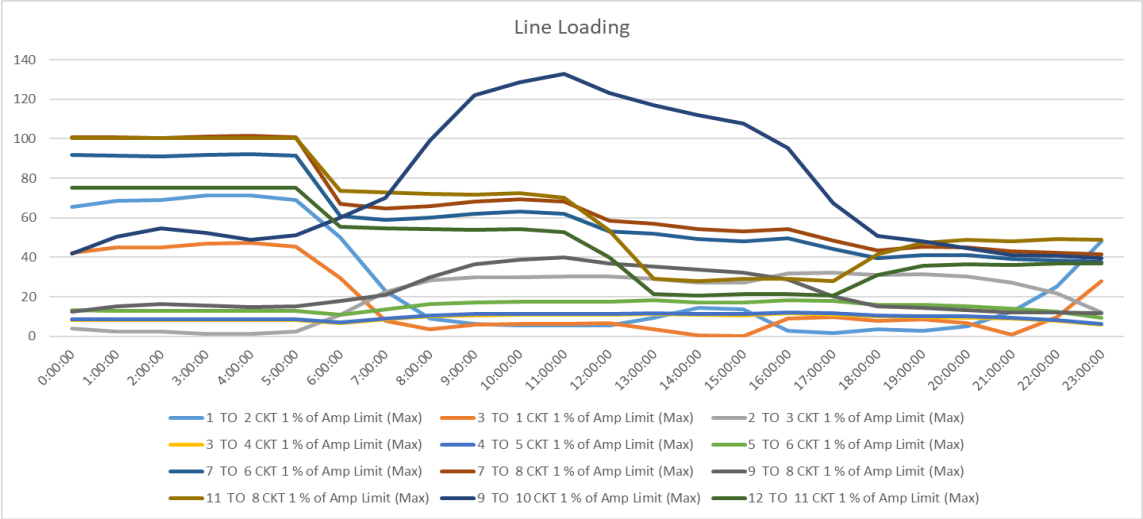

Fig. 21. Line loading Profile after adding Wave Plant.

From previous analysis, we know that load demand follows a pattern throughout the day, with low demand during night hours and high demand during peak hours. Generation from wave plant also follows a pattern throughout the day, with high generation at midnight and low during daytime.

During night hours, the wave plant operates at maximum power output, leading to high power flow through line 11 to 8. As demand is low, excess power flows through T3, making the line 7-8 highly loaded. In the morning, the output power of the wave plant decreases, and demand increases, causing all lines to run below their limits. During peak loading periods, Gen 1 ,2 ,3 must generate enough power to meet high demand, which makes the loading of the network go high, resulting loading at Line 9 to 10 exceeds its limit. In the evening, as load demand decreases, the wave plant's output power rises, and the loading condition for each line remains under the limit.

- Operation of voltage control elements

1). Connecting shunt 1&2

PWOPFTimePoint

Date	Time	1 PU Volt	1 Angle (D	2 PU Volt	2 Angle (D	3 PU Volt	3 Angle (D	4 PU Volt	4 Angle (D	5 PU Volt	5 Angle (D	6 PU Volt	6 Angle (D	7 PU Volt	7 Angle (D	8 PU Volt	8 Angle (D	9 PU Volt	9 Angle (D	10 PU Volt	10 Angle (	11 PU Volt	11 Angle (	12 PU Volt	12 Angle (D
44991.00	0.00	1.00	0.00	1.00	2.86	1.00	2.77	1.00	2.84	1.00	2.90	0.99	2.98	0.99	5.02	0.99	6.57	0.98	6.19	0.99	5.22	1.02	22.73	1.00	24.36
44991.00	0.04	1.00	0.00	1.00	3.00	1.00	2.94	1.00	3.02	1.00	3.07	0.99	3.16	0.99	5.13	0.99	6.63	0.99	6.07	1.00	4.92	1.02	22.92	1.00	24.55
44991.00	0.08	1.00	0.00	1.00	3.01	1.00	2.95	1.00	3.02	1.00	3.07	0.99	3.15	0.99	5.09	0.99	6.57	0.99	6.01	1.00	4.77	1.02	22.85	1.00	24.47
44991.00	0.13	1.00	0.00	1.00	3.11	1.00	3.08	1.00	3.16	1.00	3.22	0.99	3.33	1.00	5.32	0.99	6.84	0.99	6.28	1.00	5.09	1.02	23.13	1.00	24.76
44991.00	0.17	1.00	0.00	1.00	3.12	1.00	3.09	1.00	3.18	1.00	3.24	0.99	3.34	1.00	5.36	0.99	6.90	0.99	6.36	1.00	5.25	1.02	23.21	1.00	24.83
44991.00	0.21	1.00	0.00	1.00	3.02	1.00	2.96	1.00	3.04	1.00	3.09	0.99	3.18	0.99	5.15	0.99	6.65	0.99	6.09	1.00	4.93	1.02	22.93	1.00	24.56
44991.00	0.25	1.00	0.00	1.00	2.18	1.00	1.94	1.00	1.83	1.00	1.77	0.99	1.63	0.99	2.53	0.99	3.21	0.99	2.64	1.00	1.25	1.02	15.49	1.00	16.69
44991.00	0.29	1.00	0.00	1.00	1.01	1.00	0.51	1.00	0.24	1.00	0.10	0.99	-0.22	0.99	0.15	0.99	0.44	0.99	-0.14	1.00	-1.75	1.02	12.73	1.00	13.93
44991.00	0.33	1.00	0.00	1.00	0.39	1.00	-0.24	1.00	-0.62	1.00	-0.82	0.99	-1.28	1.00	-1.43	1.00	-1.52	0.99	-2.29	1.00	-4.49	1.02	10.94	1.00	12.14
44991.00	0.38	1.00	0.00	1.00	0.26	1.00	-0.40	1.00	-0.81	1.00	-1.03	0.99	-1.53	0.99	-1.87	0.99	-2.13	0.98	-2.93	0.99	-5.66	1.02	10.19	1.00	11.39
44991.00	0.42	1.00	0.00	1.00	0.23	1.00	-0.43	1.00	-0.85	1.00	-1.08	0.99	-1.59	1.00	-2.01	1.00	-2.31	0.99	-3.28	1.00	-6.09	1.02	10.24	1.00	11.45
44991.00	0.46	1.00	0.00	1.00	0.23	1.00	-0.43	1.00	-0.86	1.00	-1.10	0.99	-1.62	1.00	-2.14	1.00	-2.51	0.99	-3.47	1.00	-6.38	1.02	9.72	1.00	10.90
44991.00	0.50	1.00	0.00	1.00	0.23	1.00	-0.44	1.00	-0.92	1.00	-1.18	0.99	-1.77	0.99	-2.70	1.00	-3.40	0.99	-4.35	1.00	-7.11	1.01	6.10	1.00	7.01
44991.00	0.54	1.00	0.00	1.00	0.41	1.00	-0.23	1.00	-0.80	1.00	-1.11	0.99	-1.80	0.99	-3.46	1.00	-4.73	0.98	-5.69	1.00	-8.39	1.01	0.36	1.00	0.85
44991.00	0.58	1.00	0.00	1.00	0.62	1.00	0.03	1.00	-0.51	1.00	-0.80	0.99	-1.46	0.99	-3.02	0.99	-4.23	0.98	-4.98	0.99	-7.62	1.01	0.57	1.00	1.04
44991.00	0.63	1.00	0.00	1.00	0.60	1.00	0.00	1.00	-0.53	1.00	-0.82	0.99	-1.47	0.99	-2.97	0.99	-4.12	0.98	-4.90	0.99	-7.43	1.01	0.90	1.00	1.38
44991.00	0.67	1.00	0.00	1.00	0.11	1.00	-0.59	1.00	-1.17	1.00	-1.48	0.99	-2.18	0.99	-3.75	0.99	-4.96	0.98	-5.73	1.00	-7.97	1.01	0.01	1.00	0.49
44991.00	0.71	1.00	0.00	1.00	0.07	1.00	-0.64	1.00	-1.19	1.00	-1.49	0.99	-2.17	0.99	-3.55	0.99	-4.61	0.99	-5.17	0.99	-6.80	1.01	0.17	1.00	0.64
44991.00	0.75	1.00	0.00	1.00	0.15	1.00	-0.53	1.00	-1.00	1.00	-1.25	0.99	-1.82	0.99	-2.56	1.00	-3.11	0.99	-3.51	1.00	-4.72	1.01	4.25	1.00	4.95
44991.00	0.79	1.00	0.00	1.00	0.12	1.00	-0.57	1.00	-1.01	1.00	-1.25	0.99	-1.79	0.99	-2.28	0.99	-2.66	0.99	-3.05	0.99	-4.20	1.01	5.52	1.00	6.31
44991.00	0.83	1.00	0.00	1.00	0.22	1.00	-0.44	1.00	-0.87	1.00	-1.09	0.99	-1.60	0.99	-1.99	0.99	-2.29	0.99	-2.68	1.00	-3.74	1.01	6.08	1.00	6.89
44991.00	0.88	1.00	0.00	1.00	0.54	1.00	-0.06	1.00	-0.45	1.00	-0.65	0.99	-1.12	0.99	-1.42	1.00	-1.64	0.99	-2.02	1.00	-3.00	1.01	6.70	1.00	7.50
44991.00	0.92	1.00	0.00	1.00	1.10	1.00	0.63	1.00	0.31	1.00	0.14	0.99	-0.24	1.00	-0.32	1.00	-0.36	0.99	-0.74	1.00	-1.70	1.01	8.24	1.00	9.06
44991.00	0.96	1.00	0.00	1.00	2.11	1.00	1.84	1.00	1.64	1.00	1.54	1.00	1.31	1.00	1.59	1.00	1.82	0.99	1.44	1.00	0.50	1.01	10.20	1.00	11.00

Fig. 22. Voltage Simulation Result after connecting Shunt 1&2.

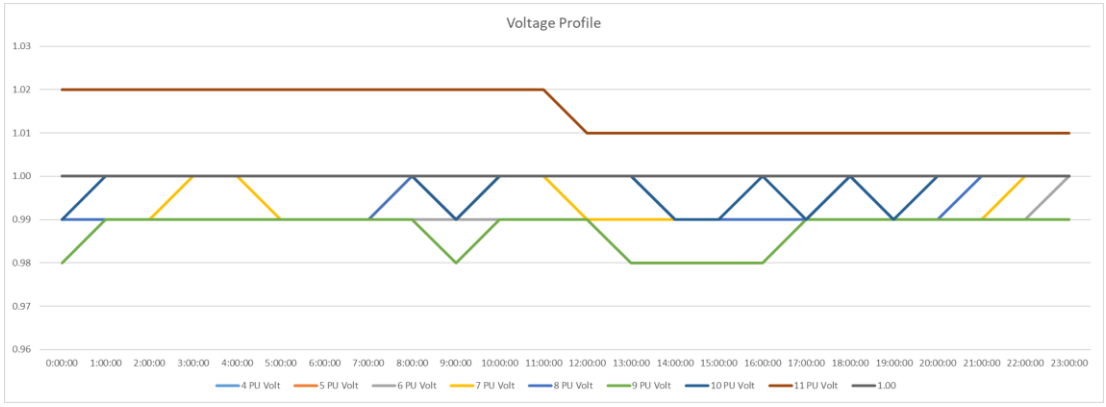

Fig. 23. Voltage Profile after connecting Shunt 1&2.

Connecting shunts directly influences the Q flow within the network, because capacitors can provide Q to compensate the local load demand. Hence, the Q needed from the network at the local demand is reduced, from equation $\Delta V = \frac{PR+QX}{V} \approx \frac{QX}{V}$ we can know that when Q flow is reduced, voltage drop ΔV is reduced.

2). Use of (OLTC) transformers on T3 for voltage control

PWOPFTimePoint

Date	Time	1 PU Volt	1 Angle (D	2 PU Volt	2 Angle (D	3 PU Volt	3 Angle (D	4 PU Volt	4 Angle (D	5 PU Volt	5 Angle (D	6 PU Volt	6 Angle (D	7 PU Volt	7 Angle (D	8 PU Volt	8 Angle (D	9 PU Volt	9 Angle (D	10 PU Volt	10 Angle (	11 PU Volt	11 Angle (	12 PU Volt	12 Angle (D
2023/3/6	0:00:00	1	0	1	2.86	1	2.78	0.99	2.85	0.98	2.96	0.97	3.05	0.9	6.39	0.95	8.07	0.94	8	0.93	6.93	1.02	23.21	1	24.85
2023/3/6	1:00:00	1	0	1	3	1	2.95	0.99	3.03	0.98	3.14	0.97	3.24	0.9	6.56	0.95	8.23	0.94	8.14	0.93	6.85	1.02	23.35	1	24.99
2023/3/6	2:00:00	1	0	1	3.01	1	2.95	0.99	3.03	0.98	3.14	0.97	3.24	0.9	6.52	0.95	8.16	0.94	8.07	0.93	6.67	1.02	23.27	1	24.91
2023/3/6	3:00:00	1	0	1	3.12	1	3.08	0.99	3.18	0.98	3.29	0.97	3.41	0.9	6.75	0.95	8.44	0.94	8.35	0.93	7.01	1.02	23.57	1	25.21
2023/3/6	4:00:00	1	0	1	3.12	1	3.09	0.99	3.19	0.98	3.3	0.97	3.43	0.9	6.79	0.95	8.5	0.94	8.42	0.93	7.16	1.02	23.65	1	25.29
2023/3/6	5:00:00	1	0	1	3.02	1	2.96	0.99	3.05	0.98	3.16	0.97	3.26	0.9	6.57	0.95	8.24	0.94	8.15	0.93	6.84	1.02	23.37	1	25
2023/3/6	6:00:00	1	0	1	2.18	1	1.94	0.99	1.83	0.98	1.81	0.97	1.67	0.91	3.55	0.97	4.29	0.96	4.19	0.95	2.68	1.01	15.84	1	17.04
2023/3/6	7:00:00	1	0	1	1.01	1	0.51	0.99	0.25	0.98	0.15	0.97	-0.18	0.91	1.21	0.96	1.57	0.95	1.46	0.94	-0.33	1.01	12.82	1	14.03
2023/3/6	8:00:00	1	0	1	0.39	1	-0.24	0.99	-0.61	0.98	-0.76	0.97	-1.22	0.9	-0.29	0.96	-0.28	0.94	-0.43	0.92	-2.98	1.01	10.67	1	11.87
2023/3/6	9:00:00	1	0	1	0.26	1	-0.39	0.99	-0.8	0.98	-0.97	0.97	-1.48	0.9	-0.78	0.95	-0.95	0.93	-1.12	0.9	-4.29	1.01	9.83	1	11.04
2023/3/6	10:00:00	1	0	1	0.24	1	-0.42	0.99	-0.84	0.98	-1.01	0.97	-1.53	0.9	-0.86	0.95	-1.06	0.93	-1.23	0.9	-4.58	1.01	9.77	1	10.98
2023/3/6	11:00:00	1	0	1	0.24	1	-0.42	0.99	-0.85	0.98	-1.03	0.97	-1.57	0.9	-1.02	0.95	-1.29	0.93	-1.47	0.9	-4.92	1.01	9.22	1	10.41
2023/3/6	12:00:00	1	0	1	0.23	1	-0.43	0.99	-0.92	0.98	-1.14	0.97	-1.75	0.91	-1.84	0.97	-2.49	0.95	-2.65	0.92	-5.79	1.01	5.84	1	6.75
2023/3/6	13:00:00	1	0	1	0.41	1	-0.24	0.99	-0.81	0.99	-1.09	0.98	-1.8	0.92	-2.92	0.99	-4.15	0.97	-4.31	0.94	-7.22	1.01	0.77	1	1.25
2023/3/6	14:00:00	1	0	1	0.62	1	0.03	0.99	-0.52	0.99	-0.79	0.98	-1.47	0.92	-2.51	1	-3.68	0.97	-3.84	0.95	-6.61	1.01	1.19	1	1.66
2023/3/6	15:00:00	1	0	1	0.6	1	0	0.99	-0.54	0.99	-0.8	0.98	-1.47	0.92	-2.44	0.99	-3.56	0.97	-3.71	0.95	-6.37	1.01	1.49	1	1.98
2023/3/6	16:00:00	1	0	1	0.11	1	-0.58	0.99	-1.17	0.98	-1.46	0.97	-2.18	0.92	-3.23	0.99	-4.4	0.98	-4.54	0.95	-6.9	1.01	0.59	1	1.07
2023/3/6	17:00:00	1	0	1	0.07	1	-0.63	0.99	-1.2	0.99	-1.47	0.98	-2.18	0.93	-3.04	1	-4.07	0.99	-4.19	0.97	-5.85	1.01	0.96	1	1.43
2023/3/6	18:00:00	1	0	1	0.16	1	-0.52	0.99	-1	0.98	-1.22	0.97	-1.8	0.92	-1.86	0.99	-2.37	0.98	-2.46	0.97	-3.7	1.01	4.72	1	5.42
2023/3/6	19:00:00	1	0	1	0.12	1	-0.56	0.99	-1.02	0.98	-1.22	0.97	-1.78	0.92	-1.57	0.98	-1.93	0.98	-2.01	0.96	-3.2	1.01	5.94	1	6.74
2023/3/6	20:00:00	1	0	1	0.22	1	-0.44	0.99	-0.87	0.98	-1.06	0.97	-1.6	0.92	-1.28	0.98	-1.56	0.98	-1.63	0.97	-2.74	1.01	6.51	1	7.32
2023/3/6	21:00:00	1	0	1	0.54	1	-0.06	0.99	-0.45	0.99	-0.63	0.97	-1.11	0.92	-0.69	0.99	-0.89	0.98	-0.96	0.97	-1.97	1.01	7.15	1	7.95
2023/3/6	22:00:00	1	0	1	1.1	1	0.62	0.99	0.3	0.99	0.17	0.98	-0.23	0.92	0.44	0.99	0.42	0.98	0.35	0.97	-0.66	1.01	8.72	1	9.53
2023/3/6	23:00:00	1	0	1	2.1	1	1.84	0.99	1.64	0.99	1.57	0.98	1.32	0.93	2.31	1	2.52	0.99	2.45	0.98	1.49	1.01	10.93	1	11.73

Fig. 24. Voltage Simulation Result after using OLTC at T3.

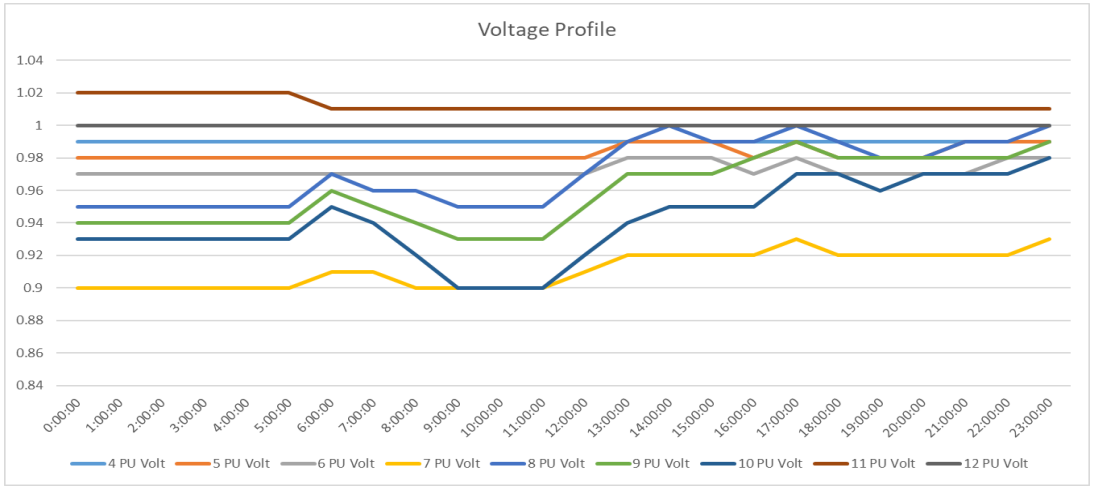

Fig. 25. Voltage Profile after using OLTC at T3.

After using OLTC, it directly change the voltage magnitude. However, using OLTC at transformer, the change at P & Q flow within network is neglectable, hence the

voltage angle is almost unchanged.

3)Using both OLTC & shunts.

PWOPFTimePoint																									
Date	Time	1 PU Volt	1 Angle (D	2 PU Volt	2 Angle (D	3 PU Volt	3 Angle (D	4 PU Volt	4 Angle (D	5 PU Volt	5 Angle (D	6 PU Volt	6 Angle (D	7 PU Volt	7 Angle (D	8 PU Volt	8 Angle (D	9 PU Volt	9 Angle (D	10 PU Volt	10 Angle (	11 PU Volt	11 Angle (	12 PU Volt	12 Angle (D
2023/3/6	0:00:00	1	0	1	2.86	1	2.77	0.99	2.82	0.99	2.9	0.98	2.97	0.93	5.7	1	7.11	0.99	6.89	0.99	5.94	1.02	23.68	1	25.31
2023/3/6	1:00:00	1	0	1	3	1	2.94	0.99	3	0.99	3.08	0.98	3.16	0.93	5.87	1	7.27	0.99	7.04	0.99	5.88	1.02	23.83	1	25.46
2023/3/6	2:00:00	1	0	1	3	1	2.94	0.99	3	0.99	3.08	0.98	3.16	0.93	5.84	1	7.21	0.99	6.97	0.99	5.72	1.02	23.75	1	25.38
2023/3/6	3:00:00	1	0	1	3.11	1	3.07	0.99	3.15	0.99	3.23	0.98	3.33	0.93	6.06	1	7.48	0.99	7.24	0.99	6.05	1.02	24.05	1	25.67
2023/3/6	4:00:00	1	0	1	3.12	1	3.08	0.99	3.16	0.99	3.25	0.98	3.35	0.93	6.11	1	7.54	0.99	7.31	0.99	6.19	1.02	24.12	1	25.75
2023/3/6	5:00:00	1	0	1	3.01	1	2.96	0.99	3.02	0.99	3.1	0.98	3.18	0.93	5.89	1	7.29	0.99	7.05	0.99	5.88	1.02	23.84	1	25.47
2023/3/6	6:00:00	1	0	1	2.18	1	1.94	0.99	1.81	0.99	1.79	0.98	1.63	0.93	3.24	1	3.89	0.99	3.48	0.99	2.08	1.02	16.33	1	17.54
2023/3/6	7:00:00	1	0	1	1	1	0.51	0.99	0.23	0.99	0.12	0.98	-0.23	0.93	0.81	1	1.07	0.99	0.65	0.99	-0.96	1.02	13.55	1	14.75
2023/3/6	8:00:00	1	0	1	0.39	1	-0.24	0.99	-0.63	0.99	-0.79	0.97	-1.27	0.93	-0.71	1	-0.79	0.98	-1.4	0.99	-3.65	1.02	11.56	1	12.76
2023/3/6	9:00:00	1	0	1	0.26	1	-0.4	0.99	-0.82	0.99	-1.01	0.98	-1.53	0.93	-1.24	1	-1.49	0.98	-2.29	0.99	-5.01	1.02	10.88	1	12.08
2023/3/6	10:00:00	1	0	1	0.23	1	-0.43	0.99	-0.86	0.99	-1.06	0.98	-1.59	0.93	-1.37	1	-1.66	0.99	-2.62	1	-5.43	1.02	10.91	1	12.12
2023/3/6	11:00:00	1	0	1	0.23	1	-0.43	0.99	-0.87	0.99	-1.08	0.98	-1.62	0.93	-1.52	1	-1.88	0.99	-2.84	1	-5.74	1.02	10.4	1	11.57
2023/3/6	12:00:00	1	0	1	0.23	1	-0.44	0.99	-0.93	0.99	-1.17	0.98	-1.78	0.93	-2.12	1	-2.79	0.99	-3.73	1	-6.48	1.01	6.75	1	7.65
2023/3/6	13:00:00	1	0	1	0.41	1	-0.24	0.99	-0.81	0.99	-1.1	0.98	-1.81	0.93	-3.01	1	-4.23	0.99	-4.85	0.99	-7.57	1.01	1.28	1	1.76
2023/3/6	14:00:00	1	0	1	0.62	1	0.03	0.99	-0.53	0.99	-0.79	0.98	-1.47	0.93	-2.6	1.01	-3.76	0.99	-4.38	0.99	-6.98	1.01	1.69	1	2.16
2023/3/6	15:00:00	1	0	1	0.6	1	0	0.99	-0.55	0.99	-0.81	0.98	-1.48	0.93	-2.53	1.01	-3.64	0.99	-4.26	1	-6.75	1.01	1.99	1	2.47
2023/3/6	16:00:00	1	0	1	0.11	1	-0.59	0.99	-1.18	0.99	-1.47	0.98	-2.19	0.93	-3.32	1.01	-4.48	0.99	-5.09	1	-7.3	1.01	1.09	1	1.57
2023/3/6	17:00:00	1	0	1	0.07	1	-0.63	0.99	-1.2	0.99	-1.48	0.98	-2.18	0.93	-3.11	1.01	-4.13	1	-4.53	1	-6.13	1.01	1.26	1	1.73
2023/3/6	18:00:00	1	0	1	0.15	1	-0.53	0.99	-1	0.99	-1.22	0.98	-1.81	0.93	-1.93	1	-2.46	0.99	-2.85	1	-4.05	1.01	4.99	1	5.69
2023/3/6	19:00:00	1	0	1	0.12	1	-0.57	0.99	-1.02	0.98	-1.23	0.97	-1.79	0.92	-1.65	0.99	-2.02	0.99	-2.41	0.99	-3.55	1.01	6.2	1	7
2023/3/6	20:00:00	1	0	1	0.22	1	-0.44	0.99	-0.88	0.99	-1.07	0.97	-1.61	0.92	-1.36	0.99	-1.65	0.99	-2.04	1	-3.1	1.01	6.76	1	7.57
2023/3/6	21:00:00	1	0	1	0.54	1	-0.06	0.99	-0.46	0.99	-0.63	0.98	-1.12	0.93	-0.77	1	-0.99	0.99	-1.37	1	-2.34	1.01	7.39	1	8.19
2023/3/6	22:00:00	1	0	1	1.1	1	0.63	0.99	0.3	0.99	0.17	0.98	-0.23	0.93	0.4	0.99	0.37	0.99	0.15	0.99	-0.83	1.01	8.84	1	9.65
2023/3/6	23:00:00	1	0	1	2.1	1	1.84	0.99	1.63	0.99	1.56	0.98	1.31	0.93	2.26	1	2.47	1	2.25	1	1.3	1.01	11.05	1	11.84

Fig. 26. Voltage Simulation Result after using OLTC at T3 and shunts 1&2.

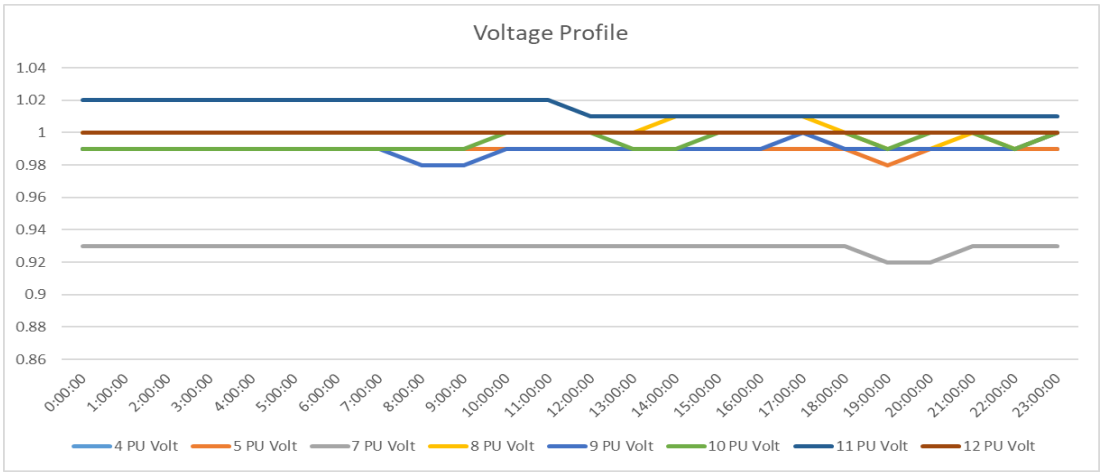

Fig. 27. Voltage Profile after using OLTC at T3 and shunts 1&2.

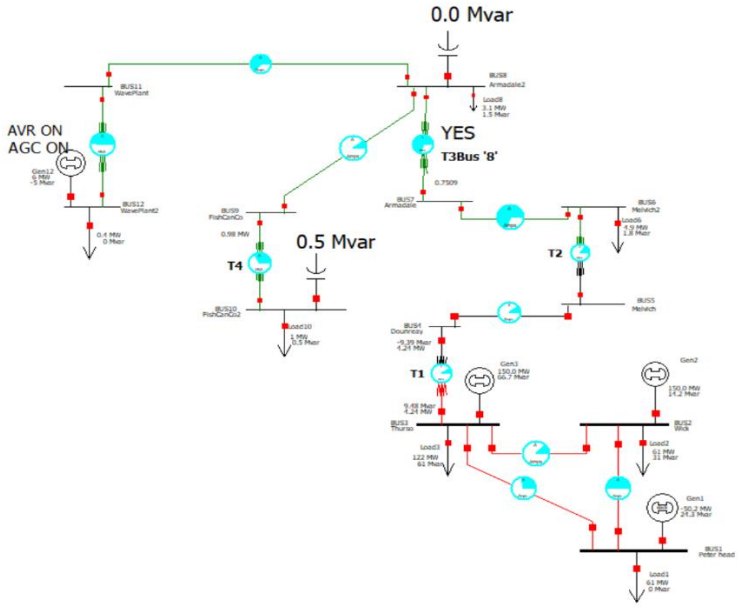

Fig. 28. Diagram after using OLTC at T3 and shunts 1&2.

By using both methods, we can see that the voltage magnitude is well limited. However, from network diagram we can notice that shunt 1 is basically not compensating any Q to the network. When using both methods, we can leave shunt 1 out to achieve the same result, hence to reduce some cost.

Q3.3 Discussion

- The operation conditions of most interest to the network operatior is when the difference between generation and load demand is high within the network, which means max demand with min generation and max generation with min demond.

Q4

Q4.1 Fault study

- From the result we can see that the fault level is higher in the case of wave plant (with AVR) connected, because wave plant is also considered as a generation. When a fault occurred, wave plant and the other generation are all generating power to the fault, which means they all are sending current to the fault end, hence increase the fault level.
- simulation results are in Table A.II.

Pull-out

- Yes, it should be replaced. From the simulation result we can see that after connecting wave plant, the fault level at Bus 8 is 101.2MVA, which is higher than 100MVA.
- From the simulation result we can see that after connecting wave plant, the fault level at Bus 10 is 30.4MVA, which is 30MVA. If a 30MVA-fault-rated switchboard is connected to it, when the network is connecting to the wave plant, the switchboard will be damaged.

Assignment 3

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Appendix

Table A.I. Change of voltages in the radial network

Case	Bus Number								
	4	5	6	7	8	9	10	11	12
Q1	0.99704 ∠-0.90°	0.99482 ∠-1.09°	0.99135 ∠-1.53°	0.97416 ∠-2.68°	0.96504 ∠-3.74°	0.95724 ∠-3.82°	0.94830 ∠-4.87°		
Q2.3 at 11:00	0.99263 ∠-1.35°	0.98735 ∠-1.74°	0.97886 ∠-2.68°	0.93393 ∠-5.39°	0.91005 ∠-8.07°	0.88385 ∠-8.25°	0.85259 ∠-12.06°		
Q2.3 OLTC at 11:00	0.99278 ∠-1.35°	0.98758 ∠-1.74°	0.97927 ∠-2.68°	0.93547 ∠-5.39°	0.99688 ∠-7.63°	0.97328 ∠-7.79°	0.94540 ∠-10.91°		
Q2.3 Shunt1 at 11:00	0.99811 ∠-1.34°	0.99589 ∠-1.75°	0.99397 ∠-2.67°	0.99060 ∠-5.70°	0.99928 ∠-8.00°	0.97575 ∠-8.17°	0.94795 ∠-11.27°		
Q2.3 Shunt2 at 11:00	0.99536 ∠-1.34°	0.99161 ∠-1.74°	0.98638 ∠-2.67°	0.96217 ∠-5.53°	0.95448 ∠-8.01°	0.94181 ∠-9.15°	0.96254 ∠-12.31°		
Q2.3 Shunt1&2 at 11:00	0.99768 ∠-1.34°	0.99523 ∠-1.75°	0.99279 ∠-2.67°	0.98622 ∠-5.67°	0.99234 ∠-8.00°	0.97903 ∠-8.96°	0.99401 ∠-11.90°		
Q3.1	0.99174 ∠-0.83°	0.98648 ∠-1.02°	0.97665 ∠-1.53°	0.93284 ∠-1.23°	0.89888 ∠-1.47°	0.87230 ∠-1.66°	0.84051 ∠-5.57°	1.00326 ∠-6.87°	1.00000 ∠-8.07°

Table A.II. Change of fault levels in the radial network

Case	Bus Number								
	8			9			10		
	If(pu)	If(kA)	FL(MVA)	If(pu)	If(kA)	FL(MVA)	If(pu)	If(kA)	FL(MVA)
Wave plant Disconnected	0.706	3.703	70.6	0.500	2.625	50.0	0.272	39.311	27.2
Wave plant (with AVR) Connected	1.012	5.311	101.2	0.611	3.206	61.1	0.304	43.908	30.4