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3 Bus Power System Load Flow Analysis Using ETAP for Various Operating Conditions

Simulation Tool: ETAP 19.0.1C | Method: Newton-Raphson | Frequency: 50 Hz

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Abstract

To study how a power network behaves when subjected to variations of operating condition, load flow analysis is utilized. A three-bus radial network was modelled on ETAP 19.0.1C to study steady-state behaviour and five operating cases namely Normal Loading, Light Loading, Overload the transformer, Poor power factor, Single motor failure have been considered and investigated. The Newton-Raphson was used for solution of load flow with a tolerance of 0.0001p.u.. All results displayed are outputs direct from the ETAP simulation. Beside this increasing reactive power demand shows a profound effect on both voltage profile and apparent power demand despite active power change was minimal.

1. Introduction

Before any electrical power system can be designed and operated it must be possible to determine what will be its behaviour under normal conditions, such as changes of voltage at different buses, power flow at different branches and losses in the system, for example engineers need this to understand the system behaviour. Load flow analysis is a method that allows determining the relationship between voltage and power in an electrical network, nowadays this analysis is more easily obtained with specialized software like ETAP. In this work, a basic radial system of three bus is analyze by using ETAP 19.0.1C in order to see the different operating condition effect without increasing unnecessarily the system size. n this work 5 cases are chosen to simulate some situations commonly encountered in real distribution systems: loads variations and situations with not properly working equipment. Working through these cases, one by one, it was easier to see what was occurring and how the system changed in each case.

2. System Description

In here there are three buses at 132kV, 33kV and 11kV. The 132kV side (Bus1) is connected to the supply, it is used as the reference bus in the simulation. It is assumed to have a short circuit capacity of roughly 2500 MVA and the voltage is 100% with 0 degrees. No load is connected to Bus2 (33kV). The main purpose of the bus is to act as an intermediary connection between Bus1 and Bus3. Bus3 (11kV) is the bus where the loads and Mtr3 and Mtr5 are connected. Two transformers connect the two buses, they are both three phase, Dyn, and with tap changers at the nominal 0% in every single case. The first transformer T1 is between Bus1 and Bus2 and has rating of 10 MVA at 132/33 kV. The leakage impedance is around 8.35% and X/R ratio 13. The second transformer T2 is between Bus2 and Bus3 and is relatively small compared to the other, its rating is 2.5 MVA and works at 33/11 kV. The leakage impedance is 6.25% and X/R ratio 6.

3. Methodology

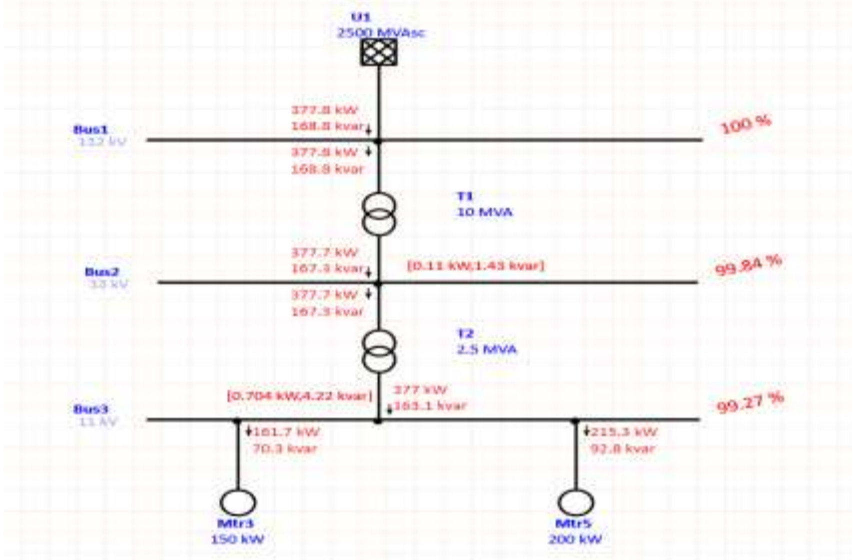
ETAP 19.0.1C is used in this project to simulate load flow calculation. Load flow calculation is performed using Newton-Rapson method, and convergence tolerance is set to 0.0001 p.u and maximum number of iterations to 99. It appears that all the five cases converged within the first iteration. This would be expected as the network is not heavily non-linear at this load level. The loads are assumed as constant kVA, such that the bus voltage value at the load bus will satisfy the specified MW and Mvar load requirement simultaneously. Five study cases were constructed in the project - one per condition, where the value of load at Mtr3 and Mtr5 or the connectivity status of Mtr5 were different for each case. Transformer impedances, tap settings, and topology are maintained same throughout the 5 runs.

4. Results and Analysis

Below, the ETAP output is included for each scenario. In each sub-section, the same table of bus voltages, branch flows and currents, transformer percentage loading and losses has been copied verbatim from the ETAP report

4.1 Light Load Operation (Mtr3=150 kW, Mtr5=200 k W)

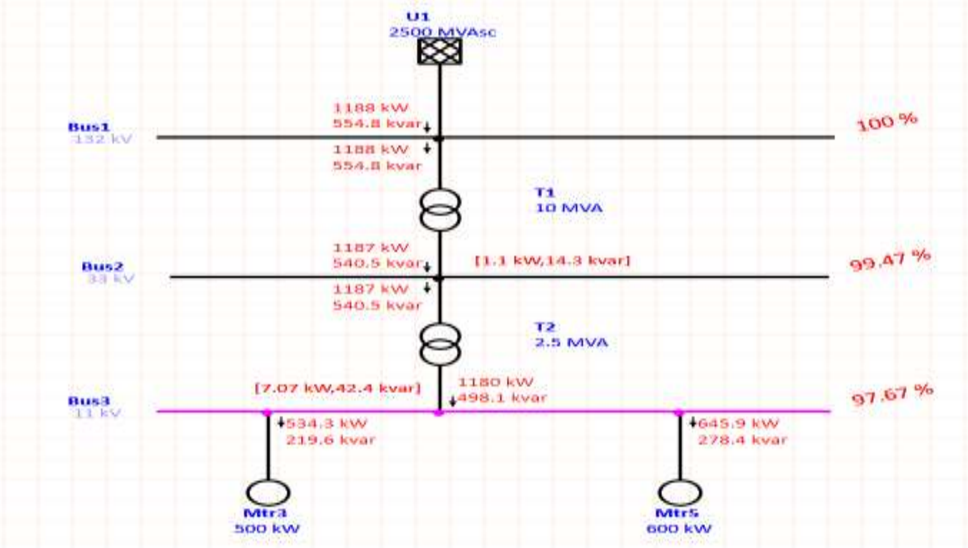
Both motors are at nameplate so total load is 0.377MW / 0.163Mvar. Bus3 voltage is restored back to 99.271% (this acceptable) and no warning messages are present. Losses have been reduced to only 0.8k W and show the usual I2 R characteristics. The swing bus is providing 0.378MW / 0.169 Mvar (0.414MVA at 91.31% PF lag).



Bus	Voltage (%)	Angle (°)	Branch	MW / Mvar Flow	I (A)	Transformer	Loading (%)	Losses (kW / kVar)	Vd (%)
Bus1 (132 kV)	100.000	0.0	T1 (Bus1→2)	0.378 / 0.169	1.8 A	T1	4.1%	0.1 / 1.4	0.16
Bus2 (33 kV)	99.836	-0.2	T2 (Bus2→3)	0.378 / 0.167	7.2 A	T2	16.5%	0.7 / 4.2	0.57
Bus3 (11 kV)	99.271	-0.7	Bus3 Load	0.377 / 0.163	21.7 A	Total	—	0.8 / 5.6	—

4.2 Heavy Load Condition (Mtr3 = 500 kW, Mtr5 = 600 kW)

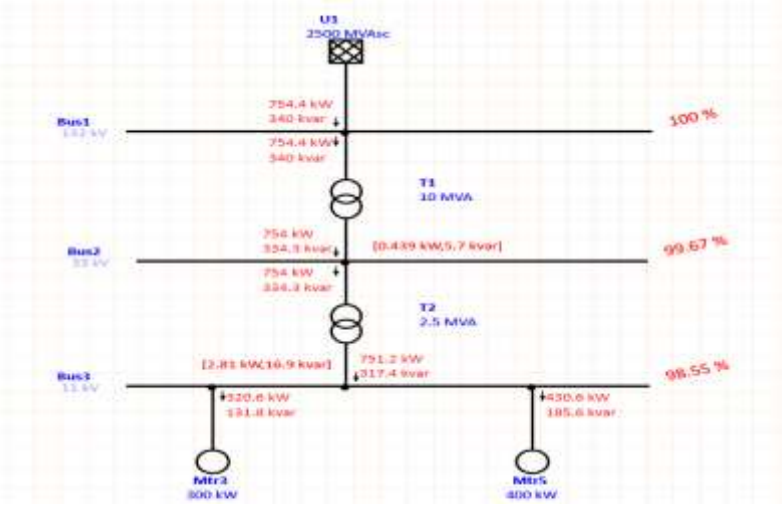
The swing bus provides 1.188 MW / 0.555 Mvar (1.311 MVA, PF 90.61% lag). ETAP alarms Bus3 as a critical under-voltage (only warning in any of the 5 cases), which means T2 loading is the highest 52.2%, the total losses are 8.2 kW.



Bus	Voltage (%)	Angle (°)	Branch	MW / Mvar Flow	I (A)	Transformer	Loading (%)	Losses (kW / kVar)	Vd (%)
Bus1 (132 kV)	100.000	0.0	T1 (Bus1→2)	1.188 / 0.555	5.7 A	T1	13.1%	1.1 / 14.3	0.53
Bus2 (33 kV)	99.467	-0.5	T2 (Bus2→3)	1.187 / 0.540	22.9 A	T2	52.2%	7.1 / 42.4	1.79
Bus3 (11 kV) ⚠	97.674	-2.1	Bus3 Load	1.180 / 0.498	68.8 A	Total	—	8.2 / 56.7	—

4.3 Transformer Overload Condition (Mtr3 = 300kW, Mtr5 = 400kW)

The two generators are operating above their nameplate ratings and consequently, the active demand reaches 700 kW at Bus3. T2 is loaded to 33.0% and Bus3 voltage is at 98.548%, which is still above the 98% marginal value, thus no alarm is activated. Total losses are increased four times to 3.3 kW from the value calculated for Light Load. Swing bus is supplying 0.754 MW / 0.340 Mvar (0.827 MVA, PF 91.17% lag).

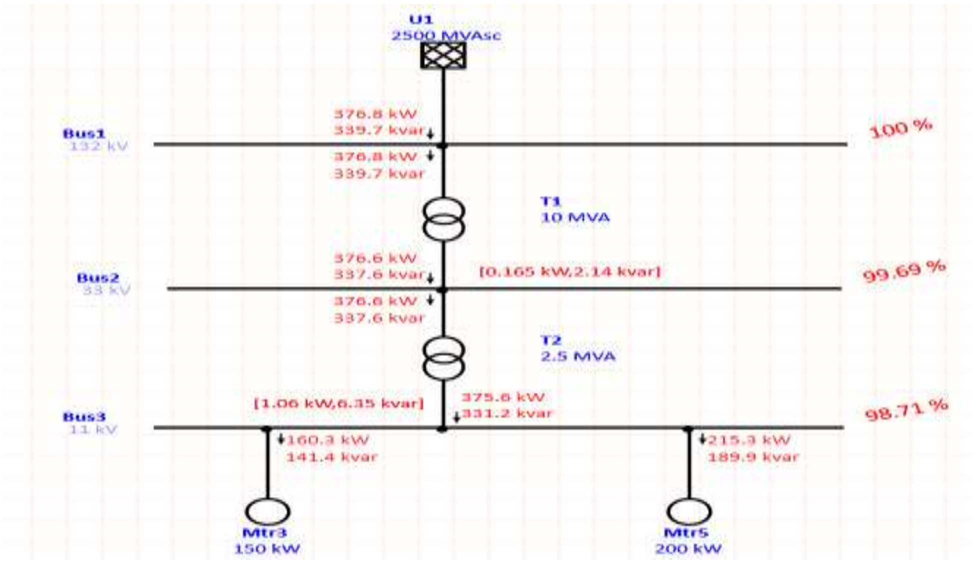


Bus	Voltage (%)	Angle (°)	Branch	MW / Mvar Flow	I (A)	Transformer	Loading (%)	Losses (kW / kVar)	Vd (%)
Bus1 (132 kV)	100.000	0.0	T1 (Bus1→2)	0.754 / 0.340	3.6 A	T1	8.3%	0.4 / 5.7	0.33
Bus2 (33 kV)	99.670	-0.3	T2 (Bus2→3)	0.754 / 0.334	14.5 A	T2	33.0%	2.8 / 16.9	1.12
Bus3 (11 kV)	98.548	-1.4	Bus3 Load	0.751 / 0.317	43.4 A	Total	—	3.3 / 22.6	—

4.4 Power Factor Variation Condition (~75% PF)

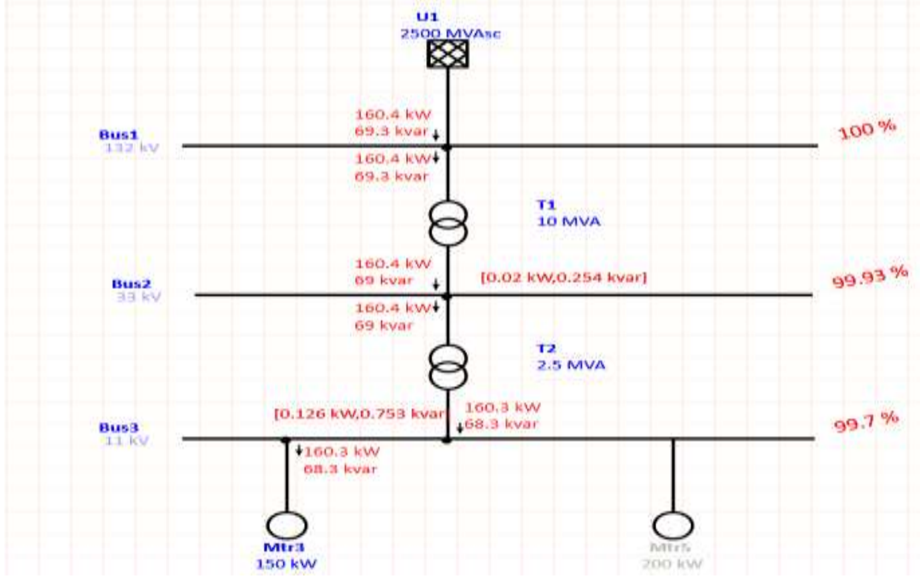
The active load is the same as in the Light Load case, but Bus3 reactive demand is double 0.331 Mvar, forcing load power factor down to approx. 75%. As apparent, it consumes nearly the same active power, but apparent consumption reaches 0.507 MVA against 0.414 MVA in Light Load case, which is 22.7% increase. The bus3 voltage also goes down to 98.706%, below Light Load level, and T2 loss increases up to 1.1 kW. It provides clear figure showing the voltage and loss penalty imposed by non-reactive compensation load.

Bus	Voltage (%)	Angle (°)	Branch	MW / Mvar Flow	I (A)	Transformer	Loading (%)	Losses (kW / kVar)	Vd (%)
Bus1 (132 kV)	100.000	0.0	T1 (Bus1→2)	0.377 / 0.340	2.2 A	T1	5.1%	0.2 / 2.1	0.31
Bus2 (33 kV)	99.693	-0.2	T2 (Bus2→3)	0.377 / 0.338	8.9 A	T2	20.2%	1.1 / 6.3	0.99
Bus3 (11 kV)	98.706	-0.6	Bus3 Load	0.376 / 0.331	26.6 A	Total	—	1.2 / 8.5	—



4.5 Motor-5 Out-of-Service Contingency (Mtr3 = 150 kW, Mtr5 disconnected)

Removing Mtr5 reduces Bus3 active demand to 0.160 MW / 0.068 Mvar. Bus3 voltage reaches 99.696% (largest out of all 5) total losses minimal at 0.1kw, load on T2 is minimal at 7.0%. System is well within limits in all areas proving system is able to sustain N-1 on load outage, swing bus output minimal at 0.160MW/0.069Mvar (0.175MVA @ 91.80% lag).



Bus	Voltage (%)	Angle (°)	Branch	MW / Mvar Flow	I (A)	Transformer	Loading (%)	Losses (kW / kVar)	Vd (%)
Bus1 (132 kV)	100.000	0.0	T1 (Bus1→2)	0.160 / 0.069	0.8 A	T1	1.7%	0.0 / 0.3	0.07
Bus2 (33 kV)	99.932	-0.1	T2 (Bus2→3)	0.160 / 0.069	3.1 A	T2	7.0%	0.1 / 0.8	0.24
Bus3 (11 kV)	99.696	-0.3	Bus3 Load	0.160 / 0.068	9.2 A	Total	—	0.1 / 1.0	—

5. Comparative Discussion

Condition	Bus3 V (%)	Bus3 kV	T1 Load (%)	T2 Load (%)	Total Loss (kW)	System PF (%)	Alert
Light Load (150+200 kW)	99.271	10.920	4.1	16.5	0.8	91.31	None
Heavy Load (500+600 kW)	97.674	10.744	13.1	52.2	8.2	90.61	**Undervoltage**
XFMR Overload (300+400 kW)	98.548	10.840	8.3	33.0	3.3	91.17	None
PF Variation (~75% PF)	98.706	10.858	5.1	20.2	1.2	74.27	None
Mtr5 Out-of-Service	99.696	10.967	1.7	7.0	0.1	91.80	None

The five sets of results read across are inconsistent in a different way and bring out three trends. The first is one of voltage sensitivity, Bus3 voltage is very close to being proportional to load in each case varying from 99.696% at light load to 97.674% at full load. Single branch voltage drops are also not proportionate and for all conditions are greatest across T2 (ranging from 1.79% at Normal to 2.56% at Peak load) more than three times across T1 (ranging from 0.53% to 1.36%) which is not surprising given that the per-unit resistance on 100MVA basis for T2 (41.10%) is more than six times higher than that for T1 (6.40%). The other two trends are associated with the level of system losses and they are that T2 accounts for 80% or more of the total system losses measured under each test condition. For the Normal Condition the T2 losses were 7.1kW against 1.1k W for T1. As losses are proportional to current squared the lower rating of T2 implies that higher per-unit currents are required at similar MVAs. The third trend is that of the magnified effect of reactive power. If we take out the Light Load and PF Variation cases from the group we remove everything except for 57%. Reactive current actually physically passes through the transformer windings and cables where it is performing no useful real power, but merely increases conductor temperature and drops the voltage at the terminals. The removal of many of these penalties at negligible initial capital cost to that of a transformer would have been achieved by simply adding a small capacitor bank at Bus3 and would provide local reactive compensation. According to contingency point of view the Motor-5 outage results in the most acceptable study figure, and this is also a expected conclusion given that load loss will decrease network stress. However the loss of T2 would have been interesting to analyze, since such event will cause total collapse of supply at Bus3. Such calculation, together with adequate reactive compensation selection and tap changer adjustment, would seem natural future work of this study.

6. Conclusion

All of the 5 load flow simulations described above were carried out on a 132/33/11 kV, 3 bus radial system using ETAP 19.0.1C with the Newton-Raphson method. All of the above results are directly derived from the results files obtained from the simulations and from all of the above it can be deduced that:

The transformer T2 (2.5 MVA, 33/11 kV) is the one that will always be saturated in all situations; for a normal condition the T2 load is 52.2% in peak time and represents 86.6% of all active loss (7.1 kW of 8.2 kW).

It can be directly observed, an effect of reactive power on voltage. When reactive load at Bus3 is raised from 0.163 to 0.331Mvar with active power remaining constant, voltage at Bus3 decreased by 0.565% while apparent power at the system has been raised by 22.7%, confirming cost effectiveness of PF correction.

Motor-5 contingency (N-1 outage of load): here we see Bus3 at 99.696% and the total loss is as low as 0.1kW. This does tell us the voltage margin is adequate when load is reducing but is not revealing the most important aspect which is T2 supply failure.

7. References

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