Load Flow and PV Curve Analysis of a 220kV Substation

Mayur S. Sawant[1], Dr. Govind R. Kunkolienker[2]

[1]P.G. Student, Department of Electrical and Electronics Engineering, Goa College of Engineering, Goa, India
[2]Head of the Department of Electrical and Electronics Engineering, Goa College of Engineering, Goa, India

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Abstract - *Load flow analysis serves as a critical tool for analyzing and optimizing electrical power systems. In this paper, a comprehensive study on load flow analysis and voltage instability analysis is presented, focusing on a 220KV substation. The study encompasses various stages, including data collection, network model formulation, Y bus matrix development, Newton-Raphson analysis, and PV curve analysis. The primary aim of this investigation is to validate the design of new substations and upgrade existing ones, ensuring the safe and reliable operation of the electrical power system. The paper underscores the significance of load flow analysis in identifying potential issues and making informed decisions to enhance the overall performance and efficiency of the power system. This research adds to the existing knowledge in the field of electrical power systems and provides valuable insights for engineers and researchers working in this domain.*

Key Words: Load Flow, Substation, MW, Newton Raphson, Capacitor Compensation

1. INTRODUCTION

Load flow analysis is a vital technique utilized in electrical power system studies to ascertain the magnitude and phase angle of voltage at each bus in the network, as well as the real and reactive power flowing through the branches, and the apparent power transfer between buses. This analysis provides critical insights into the operational state of the power system, including factors such as voltage stability, power transfer capacity, power losses, and identification of potential issues that may lead to power outages. Voltage stability, specifically, pertains to the ability of the power system to maintain a stable voltage level within acceptable limits despite fluctuations in load conditions or other disturbances.

Maintaining voltage stability is a crucial consideration in the operation and planning of power systems, as fluctuations in voltage levels can significantly impact the performance and reliability of electrical devices and equipment.

This paper aims to conduct a detailed investigation into the significance of load flow analysis in substations. It encompasses a thorough examination of various aspects, including the collection of load flow data from the substation, formulation of the network model, analysis using the Newton-Raphson method utilizing MATLAB, and PV curve analysis utilizing PowerWorld simulator. The ultimate objective of this study is to foster a comprehensive understanding of load flow analysis in the context of substations and its practical applications. The findings of this research are expected to contribute towards the development of best practices in power system analysis, enhancing the knowledge and insights into this critical area of study.

2. Theory

Load flow analysis holds immense significance in maintaining the stability, reliability and efficiency of power systems within substations. As a pivotal component that bridges the transmission and distribution systems, substations play a vital role in the overall functioning of the power grid. Load flow analysis within substations facilitates the determination of crucial parameters such as voltage profiles, power flows, and loading conditions of vital components including transformers, switches and other equipment.

The PV curve serves as a valuable tool in analyzing voltage stability, as it depicts the correlation between the magnitude of the system's voltage (V) and power (P) at a specific moment in time. The PV curve delineates the loadability limits of the power system, offering valuable insights into the stability margins of the system.

Capacitor compensation is a technique used in power systems to improve voltage stability and mitigate voltage fluctuations. The effect of capacitor compensation on the PV curve is typically seen in the linear region and the knee point. When shunt capacitors are added to the system, they can shift the PV curve upwards, resulting in an increase in voltage magnitude for a given power level in the linear region. This means that the system can tolerate higher power demand levels without experiencing a significant drop in voltage, thus improving voltage stability.

3. Methodology

The study of load flow and PV curve analysis of a 220KV substation involves several steps, as outlined below:

i. Data collection: The first step is to collect peak load readings and transformer ratings from the substation.

ii. Bus network: The substation is modelled into a bus system network.

iii. Load flow analysis: The load flow analysis is performed using the Newton-Raphson method, which involves iterative calculations of the voltage and phase angles of each bus in the network until convergence is achieved.

iv. Voltage instability study: A PV curve of a particular bus is plotted and permissible real load is determined.

v. Reactive power compensation: Shunt capacitors helps in raising the voltage level and improve voltage stability.

vi. Interpretation of results: The results obtained from the load flow analysis and voltage instability study are interpreted to determine the voltage and current distribution within the substation network, identify potential problems, and make informed decisions to improve the overall performance and efficiency of the power system.

I. Case 1

The circuit diagram shown in figure 1 was drawn using PowerWorld simulator and is a part of the 220kV substation Xeldem, Goa. The 220kV bus 1 is fed using 220kV AP 1 line coming from 220kV substation Ambewadi, Karnataka. It is then step downed using 100 MVA 220KV/110KV transformer. It is further step downed to 33kv using two 40 MVA 110KV/33KV transformers. 10 MVA 33KV/11KV and 6.3 MVA 33KV/11KV transformers are used to stepdown the voltage to 11kV. For station load a 200 KVA transformer is used which steps down the 33kV to 400V.

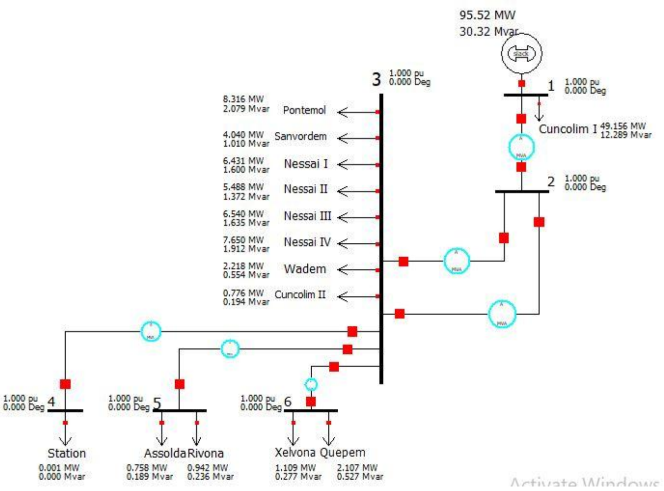

Fig -1: Circuit 1

II. Case 2

The circuit diagram shown in figure 2 was drawn using PowerWorld simulator and is a part of 220kV substation Xeldem, Goa. The 220kV bus 1 is fed using 220kV PXR line coming from 220kV substation Ponda, Goa. It is then step downed using 100 MVA 220KV/110KV transformer. 50 MVA 220KV/33KV transformers is used to stepdown the 220kV voltage to 33 kV. For station load a 200 KVA transformer is used which steps down the 33kV to 400V.

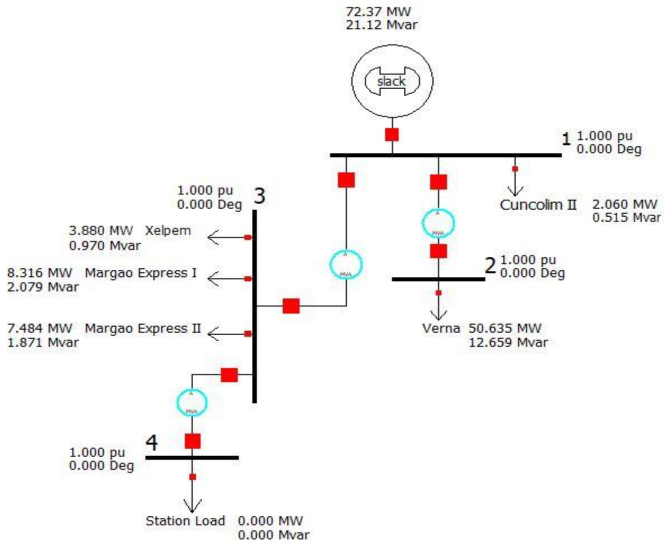

Fig -2: Circuit 2

3. RESULTS

I. Case 1

In this case the results of load flow analysis and voltage instability study of circuit 1 as shown in figure 1 is discussed. Figure 3 shows the results of Newton Raphson analysis using MATLAB of the six bus system given in figure 1. Figure 4 shows line flows and line losses of circuit 1. Figure 5 shows the magnitudes and phase angles of the bus voltages using MATLAB. Figure 6 gives the results of power flow analysis using PowerWorld simulator. A PV curve was plotted using PowerWorld simulator for 11kv bus (bus no.6) as shown in figure 7. The resulting changes in the system can be seen in figure 8. The knee point of the curve is achieved at a pu voltage of 0.80462 and at a maximum load of 28.22MW. Capacitor compensation of 10Mvar is then provided by connecting capacitor in shunt to the 11kv bus (bus no.6) and the improved results can be seen in figure 9.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 05 | May 2023 www.irjet.net p-ISSN: 2395-0072

Newton Raphson Loadflow Analysis

Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0000	0.0000	46.376	18.054	95.532	30.343	49.156	12.289
2	0.9833	-2.6628	-0.000	-0.000	-0.000	-0.000	0.000	0.000
3	0.9613	-7.0523	-41.459	-10.356	0.000	0.000	41.459	10.356
4	0.9613	-7.0645	-0.001	-0.000	-0.000	0.000	0.001	0.000
5	0.9575	-7.9359	-1.700	-0.425	0.000	0.000	1.700	0.425
6	0.9510	-9.3406	-3.216	-0.804	0.000	0.000	3.216	0.804
Total			0.000	6.469	95.532	30.343	95.532	23.874

Fig -3: Results of Newton-Raphson load flow analysis of circuit 1 using MATLAB

Line FLow and Losses

From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	46.376	18.054	2	1	-46.376	-15.615	0.000	2.440
2	3	46.376	15.615	3	2	-46.376	-11.751	0.000	3.864
3	4	0.001	0.000	4	3	-0.001	-0.000	0.000	0.000
3	5	1.700	0.453	5	3	-1.700	-0.425	0.000	0.028
3	6	3.216	0.942	6	3	-3.216	-0.804	0.000	0.138
Total Loss								0.000	6.469

Fig -4: Line flow and losses of circuit 1 using MATLAB

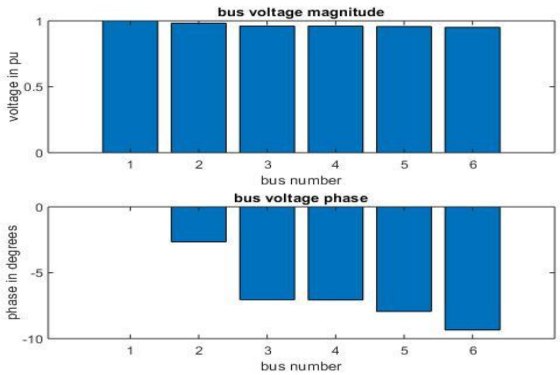

Fig -5: Magnitudes and phase angles of the bus voltages using MATLAB

Number	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	220KV bus 1	220.00	1.00000	220.000	0.00	49.16	12.29	95.53	30.34
2	110KV bus 2	110.00	0.98328	108.161	-2.66				
3	33KV bus 3	33.00	0.96134	31.724	-7.05	41.46	10.36		
4	400V bus 4	0.4000	0.96128	0.385	-7.07	0.00	0.00		
5	11KV bus 5	11.00	0.95752	10.533	-7.94	1.70	0.43		
6	11KV bus 6	11.00	0.95102	10.461	-9.34	3.22	0.80		

Fig -6: Results of power flow analysis using Power World simulator

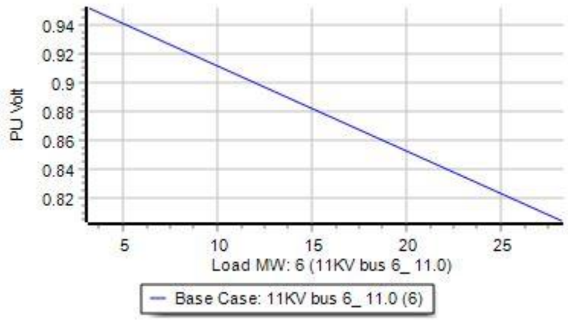

Fig -7: PV curve of 11KV bus (bus no.6)

Number	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	220KV bus 1	220.00	1.00000	220.000	0.00	49.16	12.29	120.55	55.66
2	110KV bus 2	110.00	0.95986	105.585	-4.20				
3	33KV bus 3	33.00	0.90799	29.964	-11.54	41.46	10.36		
4	400V bus 4	0.4000	0.90794	0.363	-11.56	0.00	0.00		
5	11KV bus 5	11.00	0.90393	9.943	-12.53	1.70	0.43		
6	11KV bus 6	11.00	0.80462	8.851	-37.57	28.22	0.80		

Fig -8: Results of voltage instability analysis

Number	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW
1	220KV bus 1	220.00	1.00000	220.000	0.00	49.16	12.29	120.53
2	110KV bus 2	110.00	0.97654	107.420	-4.13			
3	33KV bus 3	33.00	0.95037	31.362	-11.02	41.46	10.36	
4	400V bus 4	0.4000	0.95031	0.380	-11.03	0.00	0.00	
5	11KV bus 5	11.00	0.94650	10.411	-11.92	1.70	0.43	
6	11KV bus 6	11.00	0.99889	10.988	-30.74	28.22	0.80	

Fig -9: Results after capacitor compensation

II. Case 2

In this case the results of load flow analysis and voltage instability study of circuit 2 shown in figure 2 is discussed. Figure 10 shows the results of Newton Raphson analysis using MATLAB of the four bus system given in figure 2. Figure 11 shows line flows and line losses of circuit 2. Figure 12 shows the magnitudes and phase angles of the bus voltages using MATLAB. Figure 13 gives the results of power flow analysis using PowerWorld simulator. A PV curve was plotted using PowerWorld simulator for 110kv bus (bus no.2) as shown in figure 14. The resulting changes in the system can be seen in figure 15. The knee point of the curve is achieved at a pu voltage of 0.72393 and at a maximum load of 810.63MW. Capacitor compensation of 224.8Mvar is then provided by connecting capacitor in shunt to the 110kv bus (bus no.2) and the improved results can be seen in figure 16.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 05 | May 2023 www.irjet.net p-ISSN: 2395-0072

Newton Raphson Loadflow Analysis

Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0000	0.0000	70.315	20.610	72.375	21.125	2.060	0.515
2	0.9918	-1.7730	-50.635	-12.659	0.000	-0.000	50.635	12.659
3	0.9821	-3.6420	-19.680	-4.920	0.000	0.000	19.680	4.920
4	0.9821	-3.6420	0.000	-0.000	0.000	0.000	0.000	0.000
Total			0.000	3.031	72.375	21.125	72.375	18.094

Fig -10: Results of Newton-Raphson load flow analysis of circuit 2 using MATLAB

Line FLow and Losses

From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	50.635	14.337	2	1	-50.635	-12.659	0.000	1.678
1	3	19.680	6.272	3	1	-19.680	-4.920	0.000	1.352
3	4	0.000	0.000	4	3	0.000	0.000	0.000	0.000
Total Loss								0.000	3.031

Fig -11: Line flow and losses of circuit 2 using MATLAB

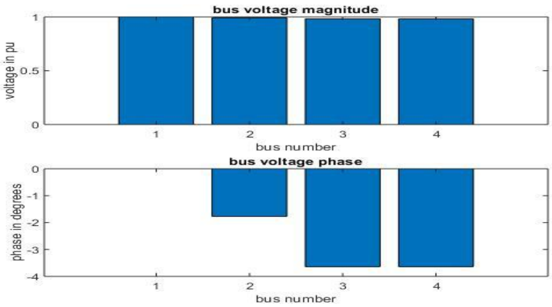

Fig -12: Magnitudes and phase angles of the bus voltages using MATLAB

Number	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	220KV bus 1	220.00	1.00000	220.000	0.00	2.06	0.51	72.37	21.12
2	110KV bus 2	110.00	0.99179	109.096	-1.77	50.63	12.66		
3	33KV bus 3	33.00	0.98211	32.410	-3.64	19.68	4.92		
4	400V bus 4	0.4000	0.98211	0.393	-3.64	0.00	0.00		

Fig -13: Results of power flow analysis using Power World simulator

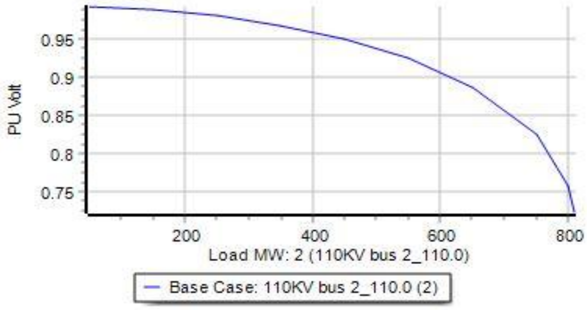

Fig -14: PV curve of 110KV bus (bus no.2)

Number	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	220KV bus 1	220.00	1.00000	220.000	0.00	2.06	0.51	832.37	779.49
2	110KV bus 2	110.00	0.72393	79.632	-42.73	810.63	12.66		
3	33KV bus 3	33.00	0.98210	32.409	-3.64	19.68	4.92		
4	400V bus 4	0.4000	0.98210	0.393	-3.64	0.00	0.00		

Fig -15: Results of voltage instability analysis

Number	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	220KV bus 1	220.00	1.00000	220.000	0.00	2.06	0.51	832.37	220.60
2	110KV bus 2	110.00	0.99948	109.943	-29.44	810.63	12.66		
3	33KV bus 3	33.00	0.98210	32.409	-3.64	19.68	4.92		
4	400V bus 4	0.4000	0.98210	0.393	-3.64	0.00	0.00		

Fig -16: Results after capacitor compensation

4. CONCLUSIONS

In this paper Newton Raphson load flow analysis was performed using MATLAB. The various line flows and losses were also noted. Also PV curve was plotted to study the voltage instability of the power system network. Capacitor compensation is provided with the help of shunt capacitors, which are connected in parallel to the power system. Shunt capacitors inject reactive power into the system, which helps to raise the voltage level and improve voltage stability. The findings highlight the importance of accurate load flow analysis for determining steady-state operating points and the impact of voltage instability on power system performance.

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BIOGRAPHIES

Mr. Mayur S. Sawant – Has received B.E. Degree in Electrical & Electronics Engineering from Goa College of Engineering, Farmagudi, Goa, India. Currently he is pursuing M.E. in Power and Energy System Engineering at Goa College of Engineering, Farmagudi, Goa, India.

Dr. Govind R. Kunkolienker - Has completed his graduation in Electrical Engineering from University of Bombay and PhD from India Institute of Science, Bangalore in High Voltage Engineering. Presently he is serving as Professor and Head of Electrical & Electronics Engg. Dept. at Goa College of Engineering, Farmagudi, Goa, India.