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Small Signal Stability Enhancement using STATCOM based on Eigen Value Analysis

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Abstract

In this paper, the advancement in small signal stability via the optimal placement of Static Synchronous Compensator (STATCOM) and its performance is considered. The Eigen values are employed to analyze the stability of the WSCC system and the analysis has been done by PSAT software. It has been studied through light, medium, heavy, heavy one loading conditions unlike the existing system. At heavy one loading condition, the stability of the system collapses and the system has positive Eigen values. The system with STATCOM has the ability to work with stability though it undergoes heavy one loading conditions compared to the system without STATCOM and the positive Eigen values in the system is nil. The outcome of the proposed approach shows that STATCOM enhances the small signal stability excellently in the power system network.

Keywords: Eigen Value, PSAT, Small Signal Stability, STATCOM, WSCC

1. Introduction

Modern day power systems have complicated networks. It has hundreds of power generating stations and sub-stations. The power transfer in multi machine system is constrained by transient stability, small signal stability and voltage stability. These constraints limit a full utilization of available transmission networks. Flexible AC Transmission System (FACTS) is the technology that provides the needed corrections of the transmission functionality in order to fully utilize the existing transmission facilities[1]. In recent times, many FACTS devices have designed and used in power systems for small signal stability and dynamic stability. STATCOM is one of the FACTS devices which are used to control the voltage by absorbing and generating the reactive power. It is also used to improve the small signal stability and dynamic stability and improves the power flow of the system. The Eigen values can be computed using state matrix and Jacobian matrix in power flow[2]. Some papers have been proposed for the damping of low frequency oscillations using PSS and STATCOM[3]. Some papers have been proposed for the designing of STATCOM. Some papers have been presented for the small signal stability and transient stability[4]. Some papers discussed for small signal stability analysis using PSS[5,6] (Power System Stabilizer). However, the optimal location of STATCOM plays a major role to enhance the stability in the 9-bus system. This paper presents the best location of STATCOM to enhance the small signal stability for different loading conditions. Time domain simulation is used to carry out the performance of STATCOM.

2. Small Signal Stability of the Power System

The ability of the power system to maintain synchronism when subjected to small disturbances is called small signal stability[7]. A Differential Algebraic Equation (DAE) set is used for the small signal stability in PSAT in the form:

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$$x = f(x, y) \tag{1}$$

$$0 = g(x, y) \tag{2}$$

Here, x = vector of the state variable, y = vector of the algebraic variable.

3. Concept of Eagen Value in Power System

The Eigen-values are used to determine the system stability. The real Eigen values are related to non oscillatory mode and complex Eigen values are related to oscillatory mode. A negative Eigen value shows the stability in the system and a positive Eigen value shows the instability in the system[8]. The damping is represented by real part of the Eigen values. The frequency of the oscillation is represented by imaginary part of the Eigen values. For complex pair of the Eigen values:

$$\lambda = \sigma + \omega \tag{3}$$

The frequency of the oscillation is signified by:

$$f = \frac{\omega}{2\pi} \tag{4}$$

The damping ratio is signified by $\varsigma = \dfrac{-\sigma}{\sqrt{\sigma^2 + \omega^2}}$ (5)

The rate of the decay is concluded through the damping ratio.

The parameters σ and ω are used to analyze the effects of damping in power system. The damping ratio and the frequency of oscillation are the main factors to calculate the damping of the system[9,10]. If the damping ratio is more, the system will give more damping to oscillate.

4. Proposed Approach for Stability

The time domain simulations have done by PSAT software. It is used to compute the Eigen values of the system. The procedures are followed to determine the optimal location of STATCOM for small signal stability analysis[11,12]. The advantages of the proposed approach that Eigen values are shifted from positive real axis to negative real axis. It gives more damping to reduce oscillations and high precision results in determining the stability of the system[13].

5. Procedure for Power System Stability

Step 1: Prepare the PSAT model.
Step 2: Run the Newton Raphson power flow.
Step 3: Run the Time domain simulation.
Step 4: Run the Eigen value analysis.
Step 5: Check the values of positive Eigen values.
Step 6: If positive Eigen values found, then find the weakest buses of the system.
Step 7: Apply the STATCOM to the weakest buses of the system and tune the parameters of STATCOM.
Step 8: Run the power flow and time domain simulation.
Step 9: Check the values of positive Eigen values in system.
Step 10: If there is a positive Eigen value, continue the process from 7-9.
Step 11: If there is no positive Eigen values in the system system is stable.
Step 12: End the process.

6. Power System Study in 9 Bus System

The system under consideration is a WSCC (Western Science Coordinated Council) 9 bus system (Figure 1) with 6 transmission lines, 3 generators, 3 loads and a local load D.

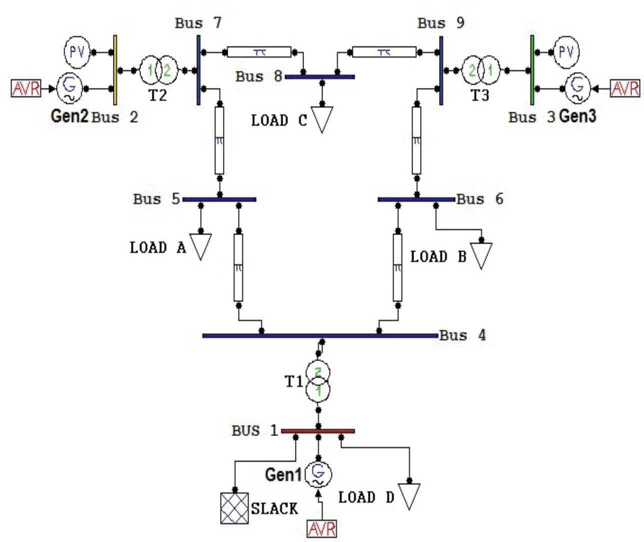

Figure 1. WSCC 9 bus in power system.

7. Small Signal Stability for Loading Conditions for System (Per Unit)

Table 1. Comparison between light and medium load

Load	Light		Medium	
	P	Q	P	Q
Load A	0.7	0.35	1.25	0.50
Load B	0.50	0.30	0.90	0.30
Load C	0.60	0.20	1.00	0.35
Load D	0.6	0.20	1.0	0.35

Table 2. Comparison between heavy and heavy one load

Load	Heavy		Heavy one	
	P	Q	P	Q
Load A	2.00	0.90	2.40	1.30
Load B	1.80	0.60	2.20	1.00
Load C	1.60	0.65	2.00	1.05
Load D	1.6	0.65	2.00	1.05

After the loading conditions, the bus 5 voltage has been identified that it has very low voltage profile and it found as the weakest bus of the system at heavy one loading condition. So, this bus is the suitable place to apply the STATCOM.

8. Eigen Value Analysis of the System and Discussion

The analysis of the Eigen values has been taken after the time domain simulation for heavy one loading. The result is shown in the Table 3. Here the positive Eigen values are two. This shows the system is in unstable condition. It is observed that from the Figure 2, the voltage profile of the buses 4, 5, 6 are low compared to other buses. Figures 3 and 4 shows the voltage waveforms of the bus 5 and bus 6. Because of the heavy loading, the voltage profile of the buses has been affected severely and reached 0.92 p.u without STATCOM. Figure 5 and Figure 6 shows the real power and reactive power (Generation) profile without STATCOM. Figure 7 and Figure 8 shows the real power and reactive power (Load) profile STATCOM.

Table 3. Eigen value analysis for heavy one loading

Without STATCOM in power system	
Dynamic order	24
Buses	9
Positive eigens	2
Negative eigens	20
Complex pairs	6
Zero eigens	2

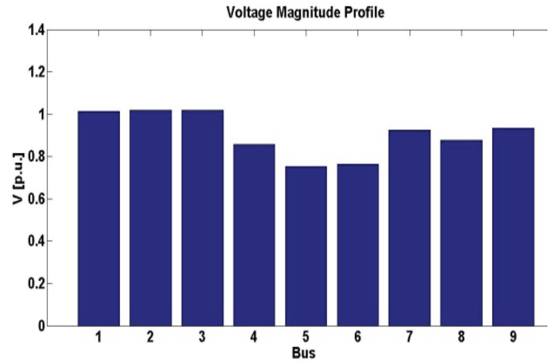

Figure 2. Voltage profiles without STATCOM.

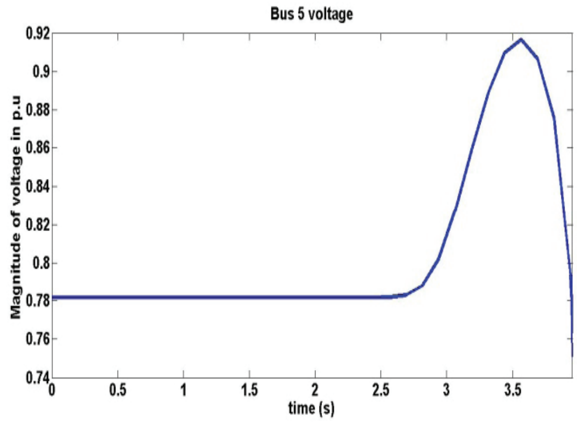

Figure 3. Bus 5 voltage profile without STATCOM.

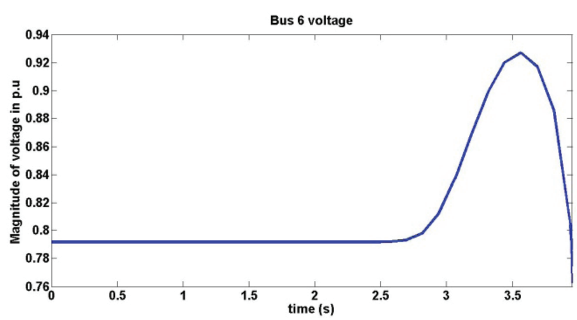

Figure 4. Bus 6 voltage without STATCOM.

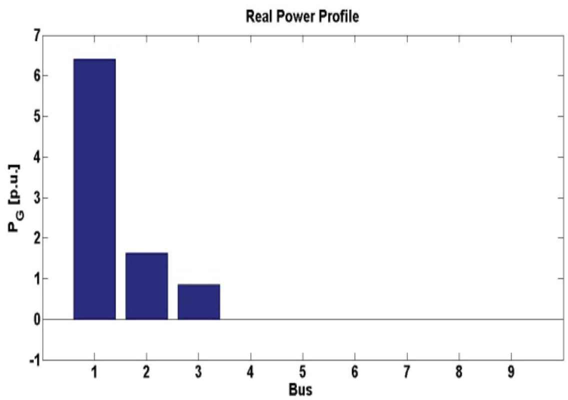

Figure 5. Real power (generator) without STATCOM.

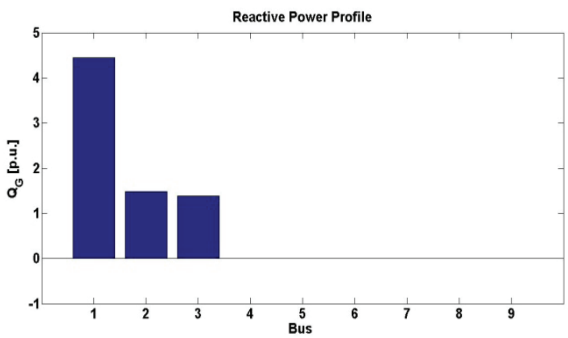

Figure 6. Reactive power (generator) without STATCOM.

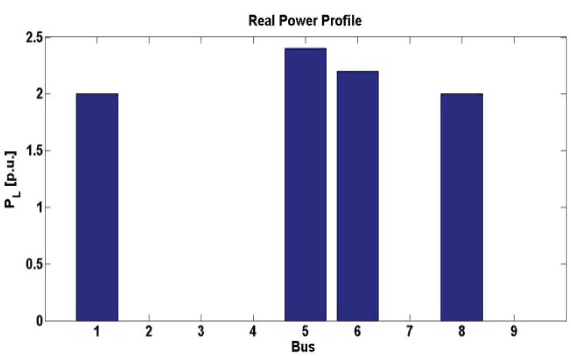

Figure 7. Real power (load) without STATCOM.

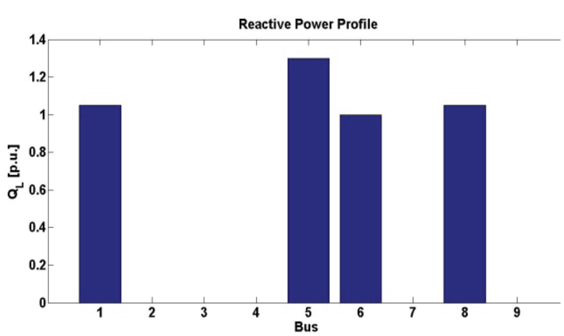

Figure 8. Reactive power (load) without STATCOM.

Table 4. Parameter values without STATCOM

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 1	1.01	0.13	6.4	4.45	2	1.05
Bus 2	1.02	-0.26	1.63	1.48	0	0
Bus 3	1.02	-0.38	0.85	1.39	0	0
Bus 4	0.86	-0.16	0	0	0	0
Bus 5	0.75	-0.43	0	0	2.4	1.3
Bus 6	0.76	-0.44	0	0	2.2	1
Bus 7	0.93	-0.38	0	0	0	0
Bus 8	0.88	-0.49	0	0	2	1.05
Bus 9	0.93	-0.43	0	0	0	0

Table 5. Apparent power (generator) without STATCOM

Bus	Apparent power(generation)	
	Magnitude	Phase angle
Bus 1	7.80	0.61
Bus 2	2.20	0.74
Bus 3	1.63	1.02
Bus 4	0	0
Bus 5	0	0
Bus 6	0	0
Bus 7	0	0
Bus 8	0	0
Bus 9	0	0

Table 6. Apparent power (load) without STATCOM

Bus	Apparent power(load)	
	Magnitude	Phase angle
Bus 1	2.26	0.48
Bus 2	0	0
Bus 3	0	0
Bus 4	0	0
Bus 5	2.73	0.50
Bus 6	2.42	0.43
Bus 7	0	0
Bus 8	2.26	0.48
Bus 9	0	0

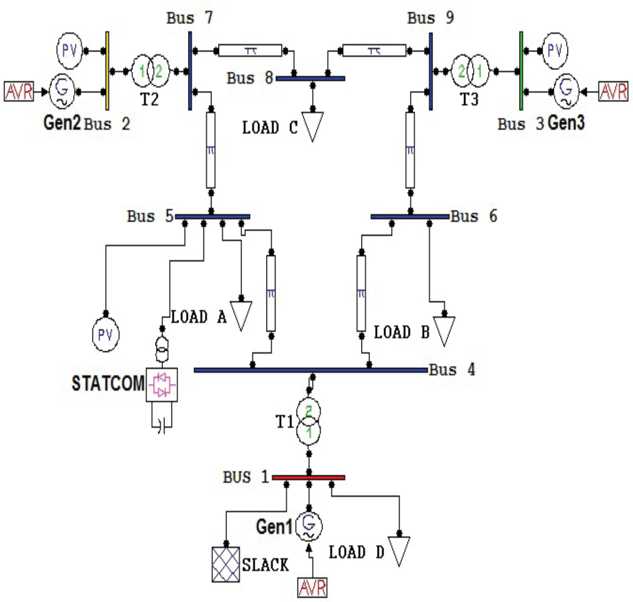

Figure 9. WSCC 9 bus system with STATCOM.

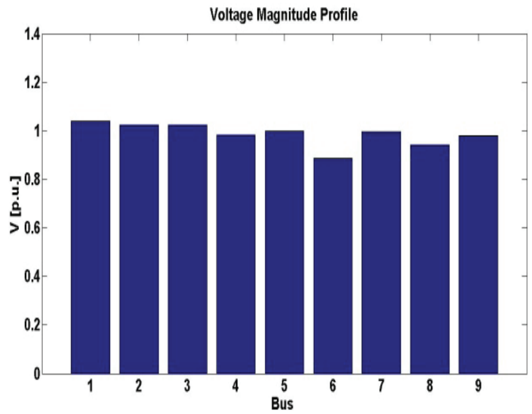

Figure 10. Voltage profile with STATCOM

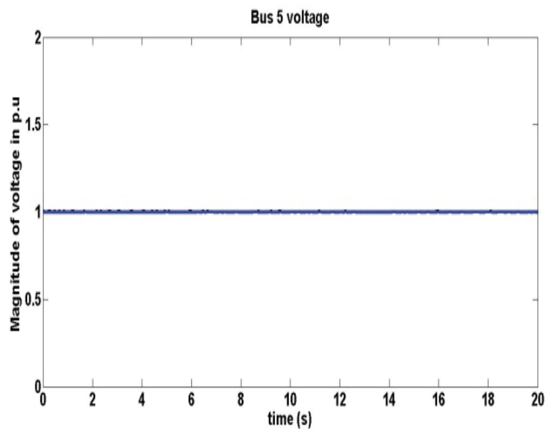

Figure 11. Bus 5 Voltage with STATCOM.

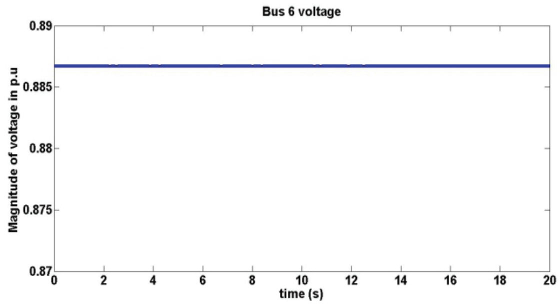

Figure 12. Bus 6 voltage with STATCOM.

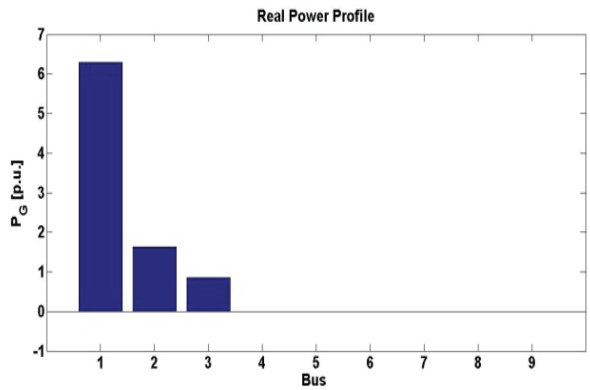

Figure 13. Real P\power (generator) with STATCOM.

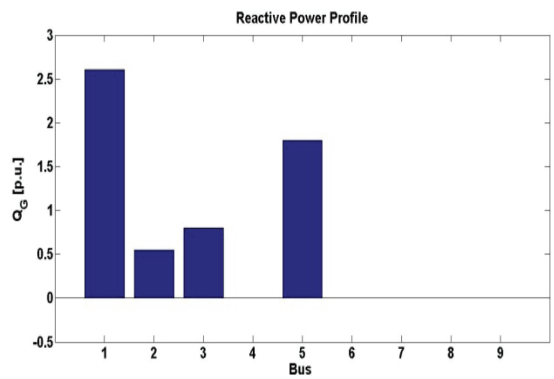

Figure 14. Reactive Power (generator) with STATCOM.

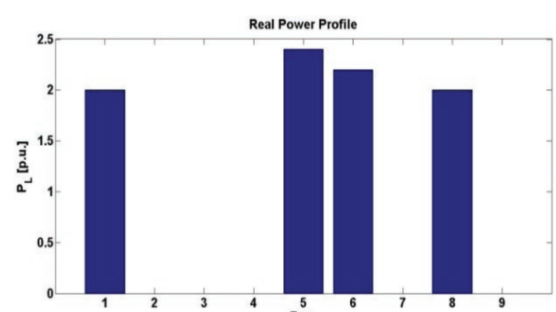

Figure 15. Real Power (load) with STATCOM.

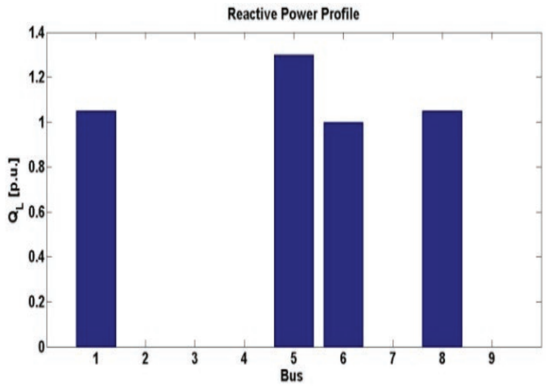

Figure 16. Reactive power (load) with STATCOM.

Table 7. System parameter value with STATCOM

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	*[rad]*	*[p.u.]*	*[p.u.]*	*[p.u.]*	*[p.u.]*
Bus 1	1.04	0	6.30	2.61	2	1.05
Bus 2	1.03	-0.29	1.63	0.55	0	0
Bus 3	1.03	-0.39	0.85	0.80	0	0
Bus 4	0.98	-0.24	0	0	0	0
Bus 5	1	-0.44	0	1.80	2.4	1.3
Bus 6	0.89	-0.45	0	0	2.2	1
Bus 7	1.00	-0.39	0	0	0	0
Bus 8	0.94	-0.49	0	0	2	1.05
Bus 9	0.98	-0.44	0	0	0	0

Table 8. Apparent power (generation) with STATCOM

Bus	Apparent power(generation)	
	Magnitude	**Phase angle**
Bus 1	6.82	0.39
Bus 2	1.72	0.33
Bus 3	1.17	0.76
Bus 4	0	0
Bus 5	1.8	0
Bus 6	0	0
Bus 7	0	0
Bus 8	0	0
Bus 9	0	0

Table 9. Apparent power (load) with STATCOM

Bus	**Apparent power(load)**	
	Magnitude	**Phase angle**
Bus 1	2.26	0.48
Bus 2	0	0
Bus 3	0	0
Bus 4	0	0
Bus 5	2.73	0.50
Bus 6	2.42	0.43
Bus 7	0	0
Bus 8	2.26	0.48
Bus 9	0	0

Table 10. Comparison of Eigen value analysis with and without STATCOM

Without STATCOM		**With STATCOM**	
Dynamic order	24	Dynamic order	25
Buses	9	Buses	9
Positive Eigens	2	Positive eigens	0
Negative Eigens	20	Negative eigens	23
Complex pairs	6	Complex pairs	8
Zero eigens	2	Zero eigens	2

The Eigen value analysis has been taken after time a domain simulation result which is shown in above Table 10. It is observed that Figure 10 shows how the voltage profile of the system has been improved. Figure 11 and Figure 12 are showed the voltage waveforms of bus 5 and bus 6 are stabilized by the STATCOM. Figure 13 shows the real power profile. But there is no change in real power profile. Figure 14 shows the reactive power profile. STATCOM has injected the reactive power in the system. Figure 13 and Figure 14 are showed the real power and reactive power profile with STATCOM. Figure 15 and Figure 16 are showed real and reactive power profile of the system with STATCOM.

9. Conclusion

The performance of stability improvement has been achieved by STATCOM and the Eigen values has been changed from 2 to 0. The graphs show voltage profile increased and stabilized when STATCOM is used. The Eigen value analysis has been carried out for each loading conditions and the small signal stability of the system has been analyzed using PSAT (Power System Analysis Tool) software. The future work can be carried out using computational algorithms.

10. References

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Appendix

The generator G1 parameters: 100 MVA, 16.5 KV, 50 Hz.

X_d= 0.1460, X'_d= 0.0608, X''_d= 0.0.

Xq= 0.0969, X'q= 0.0969, X''q= 0.0.

The generator G2 parameters: 100 MVA, 18 KV, 50 Hz.

X_d= 0.8958, X'_d= 0.1198, X''_d= 0.0.

Xq= 0.8645, X'q= 0.1969, X''q= 0.0.

The generator G3 parameters: 100 MVA, 13.8 KV, 50 Hz.

X_d=1.3125, X'_d=0.1813, X''_d= 0.0.

Xq= 1.2578, X'q= 0.2500, X''q= 0.0.

The transformer T1 (which is connected between bus 1 and bus 4) parameters: 100 MVA, 16.5 KV, 50 Hz.

Primary and secondary voltage ratio (KV/KV): 16.5/230.

Resistance =0.0, reactance= 0.0576.

The transformer T2 (which is connected between bus 2 and bus 7) parameters: 100 MVA, 18 KV, 50 Hz.

Primary and secondary voltage ratio (KV/KV): 18/230.

Resistance =0.0, reactance= 0.0625.

The transformer T3 (which is connected between bus 3 and bus 9) parameters: 100 MVA, 13.8 KV, 50 Hz.
Primary and secondary voltage ratio (KV/KV): 13.8/230.
Resistance =0.0, reactance= 0.0586.