Power System Study Project (17 Bus System) using PowerWorld Simulator (PWS)

Technical Document Limited Overview on Power Flow, Contingency, Voltage Stability and Renewable Integration using PowerWorld Simulator.

For detailed documentation (40 pages): Contact

Sachin Wagh *(+91) 94034 23640* *ssw.aws.official@gmail.com*

1. Purpose of the Study

The goal of this project is to build the skills needed to carry out analytical studies that support sound engineering decisions in power system planning and operation. The work is based on a simplified but realistic 17-bus power network. PowerWorld Simulator will be used for all analyses. This is an individual project, and students are expected to investigate the system behaviour rather than only produce preset results.

The study outline below is flexible. Each student may use different methods for examining system conditions and interpreting the system's response.

2. Base Case System Setup

Start by building the Base Case model in PowerWorld exactly as provided. This case represents normal high-load operation. Review the system power flow and the voltage profile across the network. All load buses should fall within standard limits (0.95 p.u. to 1.05 p.u.). Be careful when entering transformer tap positions because a primary-side tap of 0.95 has the same effect as using 1/0.95 on the secondary side.

3. N-1 Contingency Behaviour

Check how the system reacts if any single line or transformer is faulted or removed from service. This is the N-1 contingency test. Identify any component whose removal causes voltage levels to move outside the allowed range (0.95 p.u. to 1.05 p.u.), or leads to loading violations on the remaining lines or transformers. Note any equipment that operates close to its limits. The Contingency Analysis tool in PowerWorld can assist in summarising and tabulating these results.

4. Light Load Scenario

Create a light load case by reducing all demands to about 40% of the Base Case values. The Scale Case feature in PowerWorld may help, but save a copy since the Base Case is needed again in part 5. Review the voltages to see if any are too high or too low, and explain why such deviations occur. Propose a corrective method using only existing system controls, since low load occurs daily and should not require new capital investment. Describe the causes and typical issues that appear in lightly loaded power systems.

5. N-1 and N-2 Contingencies at Light Load

Repeat the N-1 contingency test for the light load model. Compare these results with the Base Case. Because maintenance is often scheduled during low-demand periods, determine the system's ability to handle another outage while one line or transformer is already out for maintenance-this is the N-2 contingency test. Summarize the network's capability to withstand these multiple outages under light-load conditions.

6. Recommended System Improvements

Using the findings from parts 2, 3, and 4, propose feasible improvements to address any weakness in system performance. These may include new equipment but should remain cost-effective. The enhanced system must fully meet N-1 criteria at normal load and, with operating adjustments, also meet them at light load. N-2 requirements should be mostly satisfied during light load with reasonable exceptions. Test your proposed upgrades under the same conditions from earlier sections. The final outcome is a more secure and resilient system. Different solutions are acceptable as long as they are technically sound and well justified.

7. Future Load Growth Scenario

Using the improved system from part 5 as the updated Base Case, study future load growth of up to 150% of current levels over a 10-year period. Increase loads in steps of roughly 10% and identify the system limits that will emerge. The aim is to determine which reinforcements—such as new lines, buses, or added generation—are needed as demand rises. If installing new generation, buses 15, 16, and 17 are suitable sites for major wind or solar farms. Plan the sequence of reinforcements over the 10-year period and check compliance with N-1 contingency requirements for the expanded system.

8. PV and VQ Curve Analysis

Develop PV and VQ curves for buses 15 and 17. From these curves, determine the real and reactive power margins and discuss any voltage stability concerns. Identify which of these buses is better suited for placing a shunt capacitor and which location is more appropriate for connecting a new industrial customer with heavy load demand.

9. Transient Stability with Renewable Generation

Examine the transient (generator angle) stability at bus 13 for the system that includes the renewable sources selected in part 6. During a fault, traditional generators at buses 1, 2, and 13 stay connected until large angle changes trigger protective tripping—this ability is known as fault ride-through. In contrast, renewable generators typically disconnect immediately during faults to protect power electronic converters. Model this behaviour by applying a fault near a renewable bus and then disconnecting all other renewable sources. Determine the critical clearing time for the generator at bus 13. Compare these results to the same fault when all generators except the one at the faulted bus remain connected. Discuss how future renewable systems should ideally respond to external faults.

Introduction

This report presents a comprehensive study of a 17-Bus power system using PowerWorld Simulator 12_GSO Educational Version [7,10], focusing on system performance under various loading and contingency scenarios. The test case is a 17-Bus power system with 5 generators (most of which are voltage-controlled Buses for reactive power support only), 15 loads, 25 transmission lines (branches including 3 step-down transformers) and 2 switched shunts. Primarily this looks like a modified IEEE 14-Bus system with total 17 Buses with 2 parallel lines between Bus 1 and 2 to increase power transfer capability without being getting overloaded. Highest capacity Bus 1 is selected as a slack Bus. One line view and tables including all input details are presented in Appendix. By default, PowerWorld Simulator assigns extremely permissive limits to newly added generators, typically setting Maximum MW at 1000 MW, and reactive power limits between -9999 MVAr and +9999 MVAr [10]. These placeholder values are not representative of actual generator capabilities and serve only to prevent solver constraints during initial setup. In this project, I manually replaced these defaults with realistic constraints by entering the actual MW and MVAr limits based on the generator ratings provided. This ensures accurate modeling of both active power dispatch and reactive power absorption/injection capabilities, as required for meaningful load flow and contingency analysisThe study specification provided is flexible, so for voltage-controlled Buses 2, 8, and 13 minimum reactive power capacity is taken as -20, -6, and -6 MVAr respectively. Furthermore tap settings for transformers will be treated differently under light and heavy load conditions differently. Switched shunts at Bus 6 and 9 are considered as a fixed one with continuous element use with maximum susceptance 0.11 p.u. (nominal

MVAr = 11) and 0.05 p.u. (nominal MVAr = 5) respectively as S_{base} is 100 MVA. Respective tap settings and switched shunt values are provided in the Annexure.

The study and report align with the objective of developing analytical skills for responsible power system planning and decision-making. The power system is analyzed under base case and light load conditions, with N-1 and N-2 contingency analysis, voltage control strategies, and future expansion planning. Additionally, PV and V-Q curve assessments, and transient stability with renewable integration are performed. Emphasis is placed on realistic operation and cost-effective reinforcement proposals to maintain voltage stability, reliability, and future readiness.

1. Base Case Power Flow Analysis

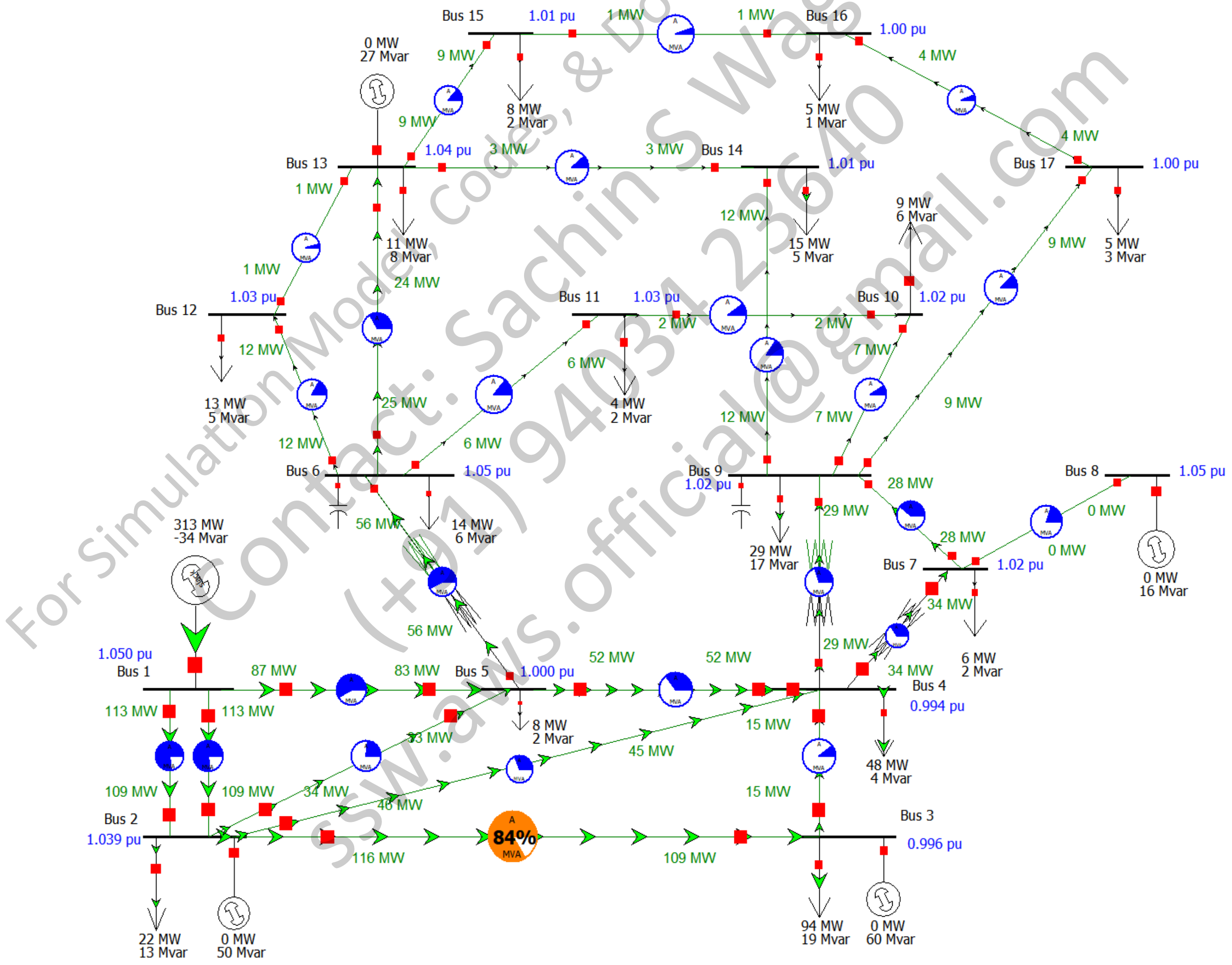

Figure 1: One-line View of 17 Bus Power System with Higher Loading Condition using PowerWorld Simulator 12_GSO Version Educational.

Table II: Power Flow Analysis of 17-Bus System by NR Method Heavy Load Condition.

Bus No.	kV	Bus Voltage		Generation		Load		Shunt
		|V| (pu)	δ (deg.)	P (MW)	Q (MVAR)	P (MW)	Q(MVAR)	Q (MVAr)
01	132	1.0500	0.00	313.2	-33.95	0.0	0.0	0.0
02	132	1.0387	-7.46	0.0	50.0	21.7	12.7	0.0
03	132	0.9961	-9.93	0.0	60.0	94.2	19.0	0.0
04	132	0.9938	-11.57	0.0	0.0	47.8	3.9	0.0
05	132	0.9998	-10.29	0.0	0.0	7.6	1.6	0.0
06	33	1.0526	-17.51	0.0	0.0	13.5	5.8	-12.19
07	33	1.0239	-15.54	0.0	0.0	6.2	1.5	0.0

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2. N-1 Contingency Analysis

Contingency analysis is conducted by simulating the outage of each transmission line or transformer, one at a time. The PowerWorld Contingency Analysis Tool automates this process, identifying system components that cause voltage violations or MVA loading limits [10]. This part of the study evaluates system resilience and identifies critical links. According to NERC reliability standards, N-1 contingency planning is a basic requirement for secure system operation [2]. The integrity and reliability of a power system are significantly influenced by its ability to withstand component outages without violating operational limits. A widely adopted criterion to assess this robustness is the N-1 contingency analysis, which evaluates the system's response to the outage of a single component, be it a transmission line, or transformer, while ensuring the system remains stable and within operational constraints.

2.1 Overloading of Branches

MVA violations are identified at four branches (mainly transmission lines) towards the generation side of the power system under certain contingencies. There are two parallel lines between Bus 1 and Bus 2 and categorized as circuit 1 and circuit 2.

Table III: Overloading (MVA) Violations Observed for Branches.

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2.2. Voltage Violations at Buses

Voltage violations (mainly undervoltage) were identified at three Buses under certain contingencies.

Table IV: Voltage (p.u.) Violations Observed for Buses.

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2.3 Observations and System Implications

Table V: Summary of Contingency Analysis

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3. Power Flow Analysis, Analysis, and Constrained Remedial Solutions under Light Load (40%) Condition

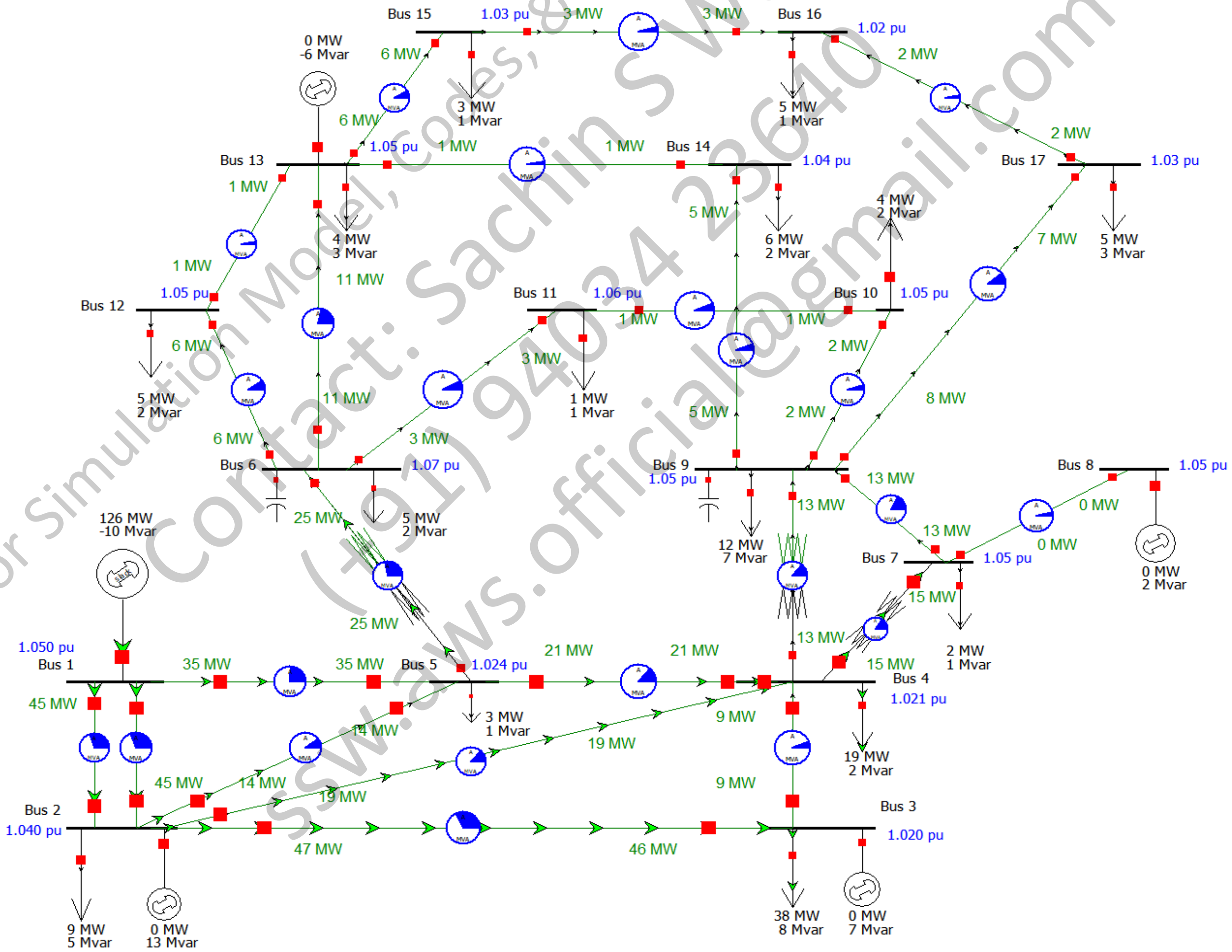

Figure 2: One-line View of 17 Bus Power System with Light Load Condition (40% only) using PowerWorld Simulator 12_GSO Version Educational.

Table VI: Power Flow Analysis of 17-Bus System by NR Method Under Light Load Condition.

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3.1 Nature and Source of the Problem

3.2 System Loading

3.2 Suggested Remedial Strategy

4. Contingency Comparison (N-1) under Different Loading Conditions and N-2 Contingency Evaluation During Light Load Condition

4.1 N-1 Contingency Comparison

This part of report presents a comparative analysis of the power system behavior under N-1 contingency scenarios for two different loading conditions: Normal Load and Light Load (40%). When a stricter voltage threshold of 0.95 to 1.05 p.u. was initially applied, it produced hundreds of violations. Hence, contingency voltage violation limit is set between 0.90 and 1.10 p.u.

Table VII: Comparison of N-1 Contingency Test Results

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Table VIII: N-2 Contingency Test Configuration Overview

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Table IX: N-2 Contingency Violations Observed

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Result Analysis

Recommendations

5. Remedial Strategy and Effectiveness under Power Flow Constraints and Contingency Compliance

Based on these observations, the following remedial course of action is designed and implemented to enhance the security and resilience of the power system, while ensuring cost effectiveness.

5.1 Remedial Course of Action for Base Case (Normal Load Condition)

a) Proposed Modifications:

b) Effectiveness of the Modifications:

2) Remedial Course of Action for Light Load Condition (40% Loading):

a) Additional Adjustments for Light Load:

b) Effectiveness Under Light Load:

The proposed remedial strategy successfully improved the system's resilience and ensured full N-1 contingency compliance under both normal and light loading conditions. Furthermore, the N-2 contingency was also largely satisfied under light load with reasonable exemptions. The interventions, particularly the addition of strategic lines and voltage-controlled shunt devices are cost-effective and provided robust voltage and load flow control. The result is a more secure and flexible power network capable of handling a wide range of operating scenarios.

6. Future Expansion Planning (Load Growth) and Reinforcement Plan

6.1 Load Growth Forecast and System Behavior

Table X: Anticipated Growth Over Next 10 Years and Limiting Factors for Base case

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6.2 Proposed Reinforcement Strategy (Staged over 10 Years)

7. PV and V-Q Curve Analysis

Table XI: Power Flow and Bus Voltage Sensitivities for 17 Buses of Base case

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7.1 Interpretation-Based Analysis of PV and VQ Curves

7.2. Determination of Real and Reactive Power Margins

7.3. Voltage Stability Issues

7.4. Recommendations

8. Transient Stability and Renewable Energy

8.1 Scenario I: Disconnection of All Renewable Sources

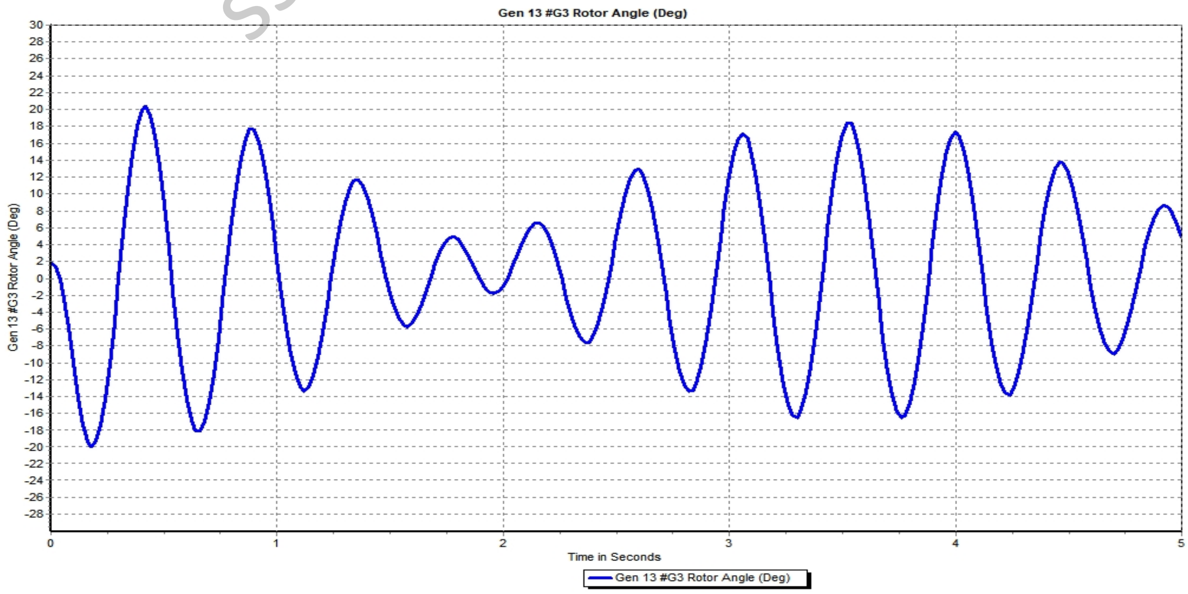

Figure 3: Generator Rotor Angle at Bus 13.

8.2 Scenario II: Selective Renewable Disconnection: Buses 16 and 17 Remain Connected

8.3 Critical Clearing Time (CCT) Assessment for Bus 13 Generator

8.4 Recommended Fault Response Strategy for Future Renewable Installations

9. Extended Discussion on Reinforcements, Renewable Energy Modelling, Stability and Recent Advances

9.1 Reinforcement with New Equipment

9.2 Modelling Renewable Generators

9.3 Integrating Advanced Control Techniques

9.4 Fault Ride-Through Capability in Renewable Generators

9.5 Recent Advances Supporting Stability Under High Renewable Penetration

References

1. PowerWorld Simulator User's Guide Version 12.

APPENDIX

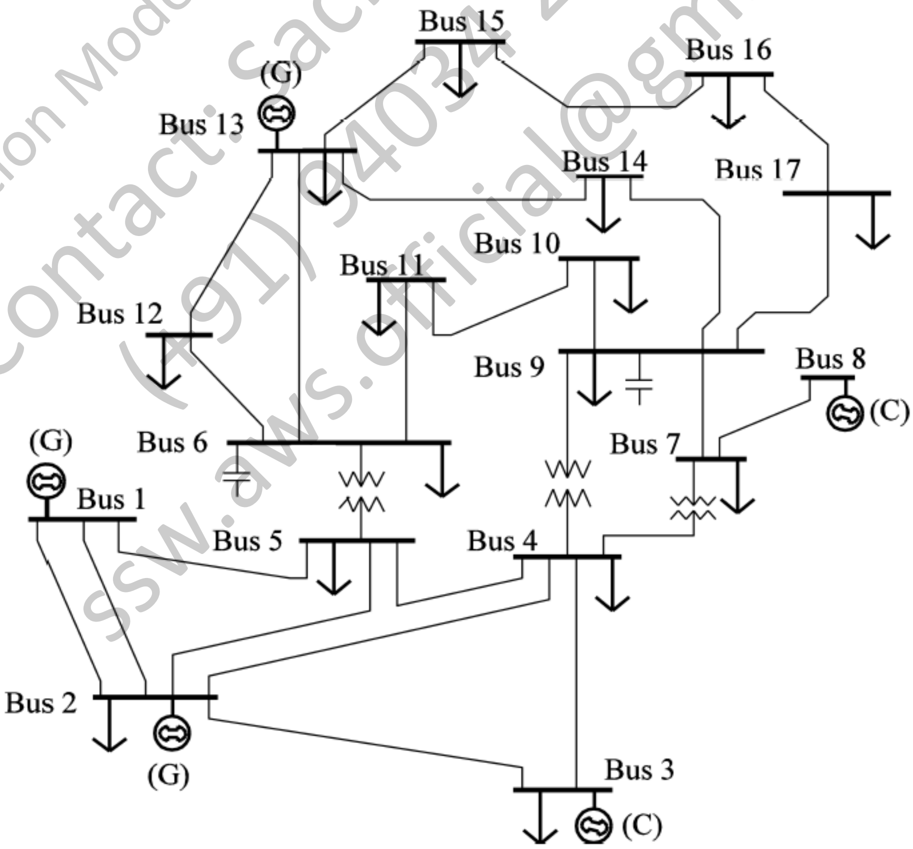

Figure 4: 17-Bus Power System (Test Case)

Table XII: Bus Data - Load and Generation, S_{base} = 100 MVA.

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Where,
V: Magnitude of Line voltage in kV or per unit (p.u.)
δ: Voltage angle in degrees
P_G and Q_G: Active (MW) and reactive power (MVAr) generation respectively
P_L and Q_L: Active (MW) and reactive power (MVAr) load demand respectively
Q_{Gmin} and Q_{Gmax}: Minimum and maximum reactive power generation limit in MVAr respectively

Table XIII: Transmission Line and Transformer Impedance Data, S_{base} = 100 MVA.

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Table XIV: Transformer Tap Settings (Taps on the HV side).

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Table XV: Static Capacitor Data

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