TEST SYSTEM REPORT

Development of a Comprehensive Power System Simulation Laboratory (PSS-L) at the University of Queensland – Project Funded by Australian Power Institute (API)

Investigators: Dr. Nadarajah Mithulananthan

Prof. Tapan Saha

Prepared by- Md.Rakibuzzaman Shah

Power and Energy Research Group
School of Information Technology and Electrical Engineering
The University of Queensland, Australia

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I. Introduction

Test systems are widely used in power system research and education. The reasons for using test system rather than using a model of practical system are as follows:

- Practical power systems data are partially confidential.
- Dynamic and static data of the systems are not well documented.
- Calculations of numerous scenarios are difficult due to large set of data.
- Lack of software capabilities for handling large set of data.
- Less generic results from practical power system.

In these circumstances, this report tries to compile the available and most commonly used test systems in power system research and education. For better understanding of test application, broadly they can be categorized as follows,

- Transmission system.
- Distribution system (Sub-transmission system).
- Unbalanced distribution system.

The rest of the report is organised as follows. Section II provides a brief description of test systems regarding transmission system followed by section III which compiles test system regarding distribution and sub-transmission system. Section IV briefly describes test system regarding unbalanced distribution system. Finally, in section V summary of the report is presented.

II. Transmission system

A1. Three bus test system: Single line diagram of the simplest test system is shown in Fig.1. Both the generators in the system are modelled in detail assuming IEEE Type –I exciter and hydraulic governors. The static and dynamic data of the system can be found in [1].

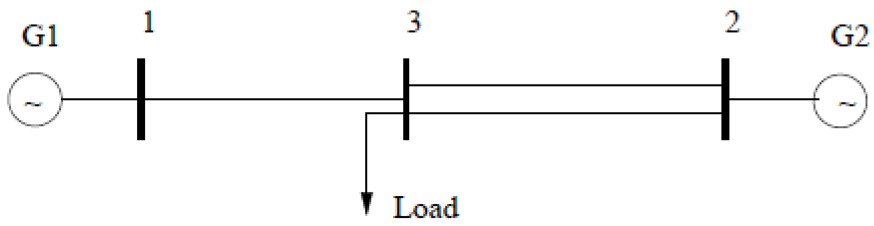

Fig.1 Single line diagram of three bus test system.

A2. Simple 5 bus interconnected system: Single line diagram of the small interconnected system is shown in Fig.2. The system consists of two loads totalling 378 MW. It has one synchronous generator with fix tap transformer. The capacity of the generator is 378 MW. The system is connected to a slack bus generator at bus 1. The static and dynamic data of the system can be found in [2].

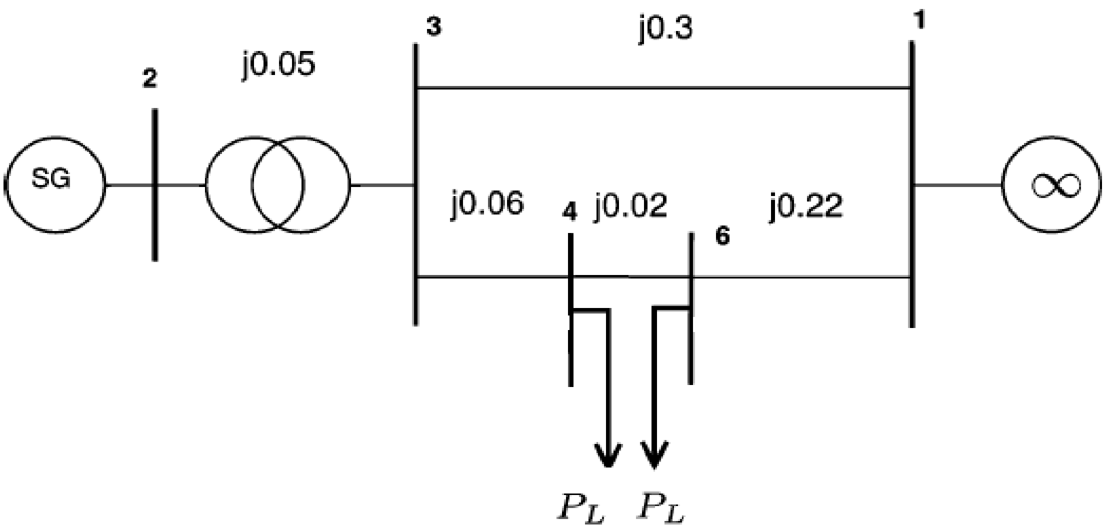

Fig.2 Single line diagram of five bus interconnected test system.

A3. WECC 9-bus test system: A single line diagram of WECC -9 bus test system is shown in Fig.3. It consists of 5 generators and three fix tap transformers. There are three loads in the system totalling 315 MW and 115 Mvar. The static and dynamic data of the system can be found in [1].

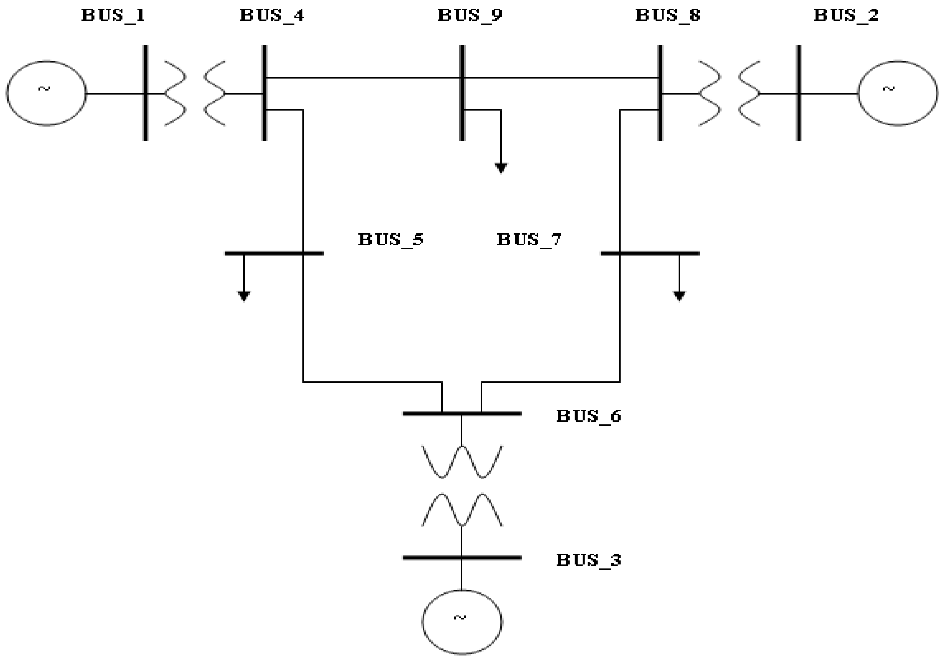

Fig.3. Single line diagram of WECC-9 bus test system.

A4. IEEE-14 Bus test system: A single line diagram of IEEE-14 bus test system is shown in Fig.4. It consists of five synchronous machines with IEEE type-I exciters, three of which are synchronous compensators used only for reactive power support. There are eleven loads in the system totalling 259 MW and 81.3 Mvar. The dynamic and static data of the system can be found in [1]. This system is widely used for voltage stability as well as low frequency oscillatory stability analysis.

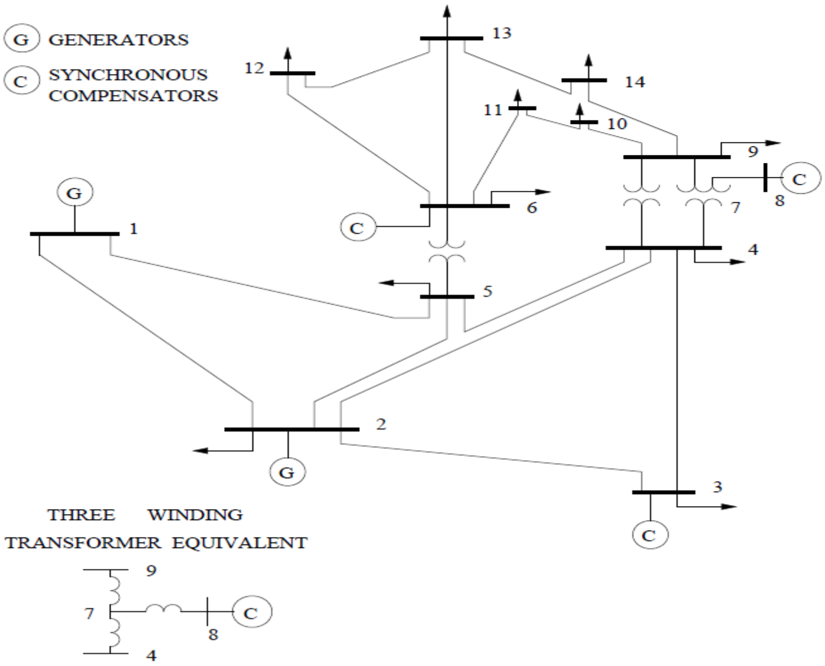

Fig.4. Single line diagram of IEEE-14 bus test system.

A5. Two-area Test System: Fig.5 shows the on line diagram of the Two-area test system which is proposed in [3] for low frequency oscillatory stability studies. The system topology with respect to bus 8 is symmetrical; however, limits of each generator and loads are not equal in both areas. All the generators are modelled as 6th order synchronous generator model. IEEE type-2 exciter model is used for all the generators. A simple turbine generator is used in each of the generator. A total system load is 2734 MW and 200 Mvar. The static and dynamic data for two-area test system can be found in [3].This is very popular system for low frequency oscillatory stability analysis.

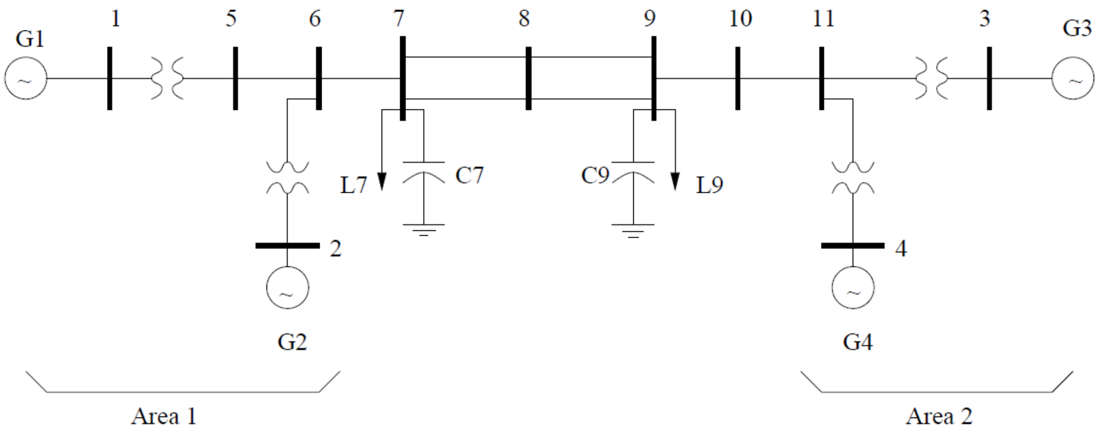

Fig.5. Single line diagram of Two-area test system.

A6. IEEE-30 bus test system: Fig. 6 shows the single line diagram of IEEE-30 bus test system. The system consists of 6 synchronous generators and 4 transformers. The system has 21 load points totalling 283.4 MW and 126.2 Mvar. The detail system data can be found in [4].

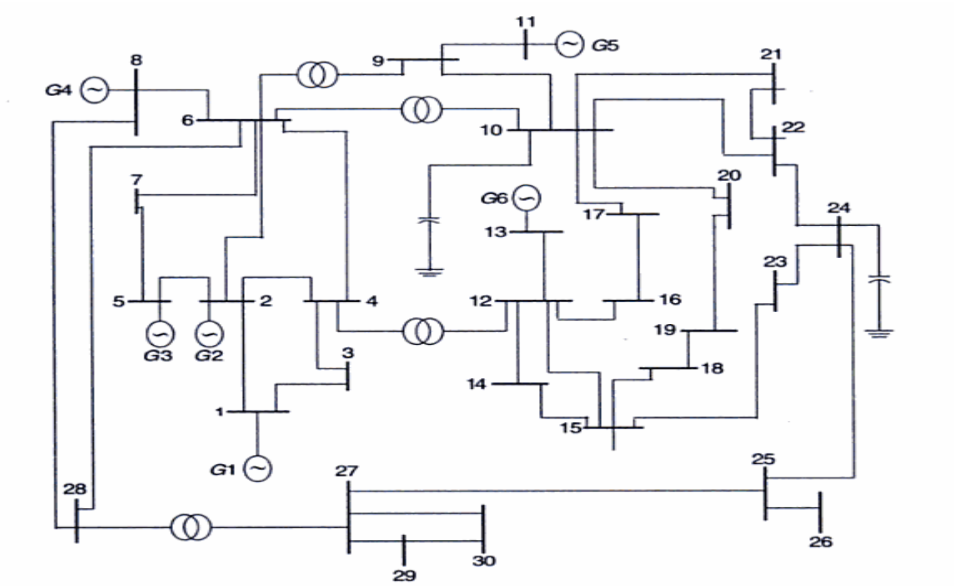

Fig.6. Single line diagram of IEEE-30 bus system.

A7. IEEE-39 Bus test system: Fig.7 shows the single line diagram of IEEE-39 bus system which is also known as New England test system [5]. This system is widely used for power system stability studies. The system contains 39 buses with 10 generators. It has 19 load points totalling 6150.1 MW and 1233.9 Mvar. All the generators are modelled as 4th order synchronous generator model with IEEE type-2 exciter except the generator at bus 31. A simple turbine governor is used in every generator except generator 1 which is an aggregation of large number of generators. This test system is mostly used to study stability and power market problems.

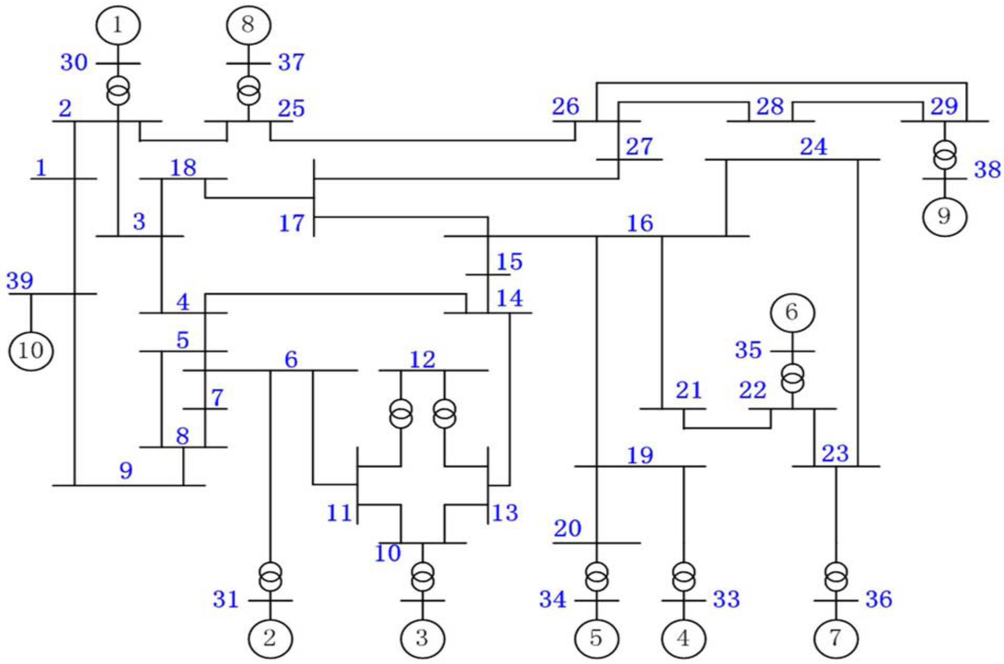

Fig.7. Single line diagram of IEEE-39 bus test system.

A8. IEEE-57 Bus test system: Fig. 8 gives the single line diagram of IEEE-57 bus test system. The system has seven generators, 80 branches and 36 load points. Detail system static data are available in ref [4].

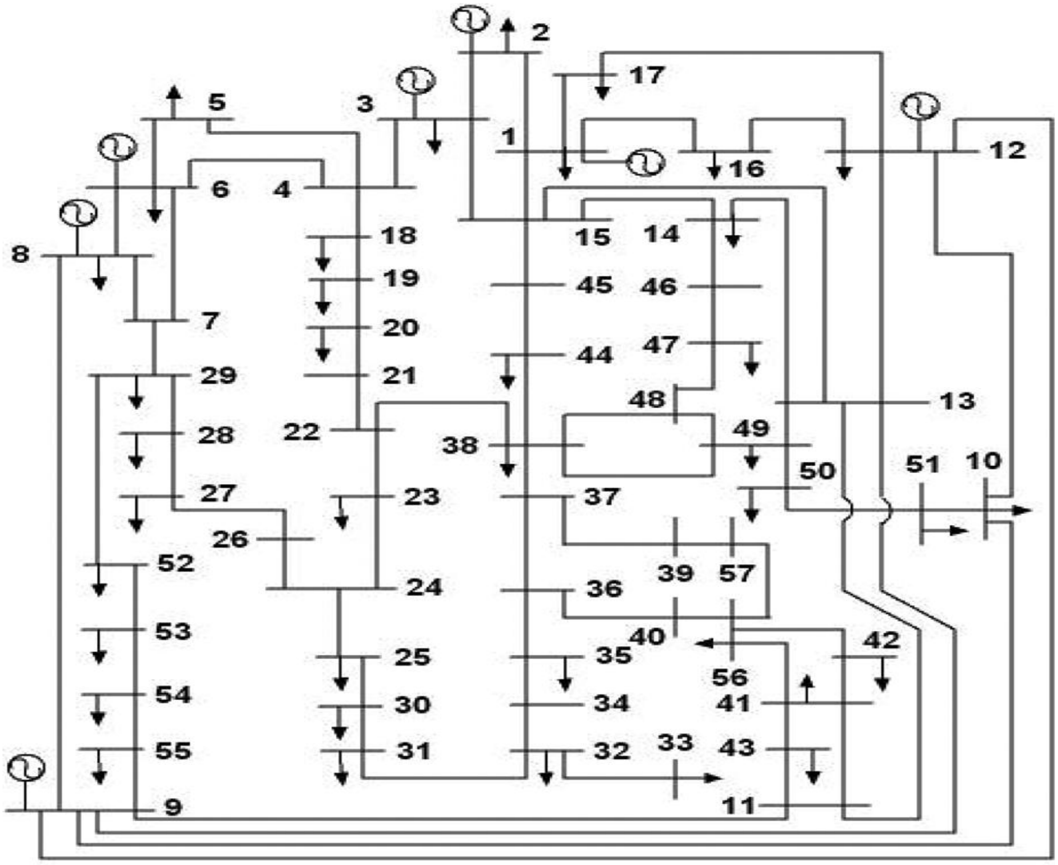

Fig.8. Single line diagram of IEEE-57 bus test system.

A9. 16 Machine 68 bus test system: Fig.9 shows the single line diagram of 16 generator 68 bus test system which is reduced order equivalent interconnected model of the New England test system /New York Power system [6]. The system has 5 geographical regions. In the system, generator G1-G9 is the equivalent representation of New England Test System whilst generator G10-G13 present the generation in New York Power system, generator G14-G16 are the dynamic equivalence of area 3-5 generators connected to New York Power system. There are three major transmission corridors in between New England test system and New York Power system and all this transmission corridors are double circuit tie lines. Six order model of synchronous generator is considered for all the generators in the system. Generator 1 to 8 is equipped with IEEE type-II AVR. Generator 9 is equipped with IEEE-Type III AVR and fourth order PSS type II. This system has so far been widely used by many researchers for the impact study of new controllers on power system stability.

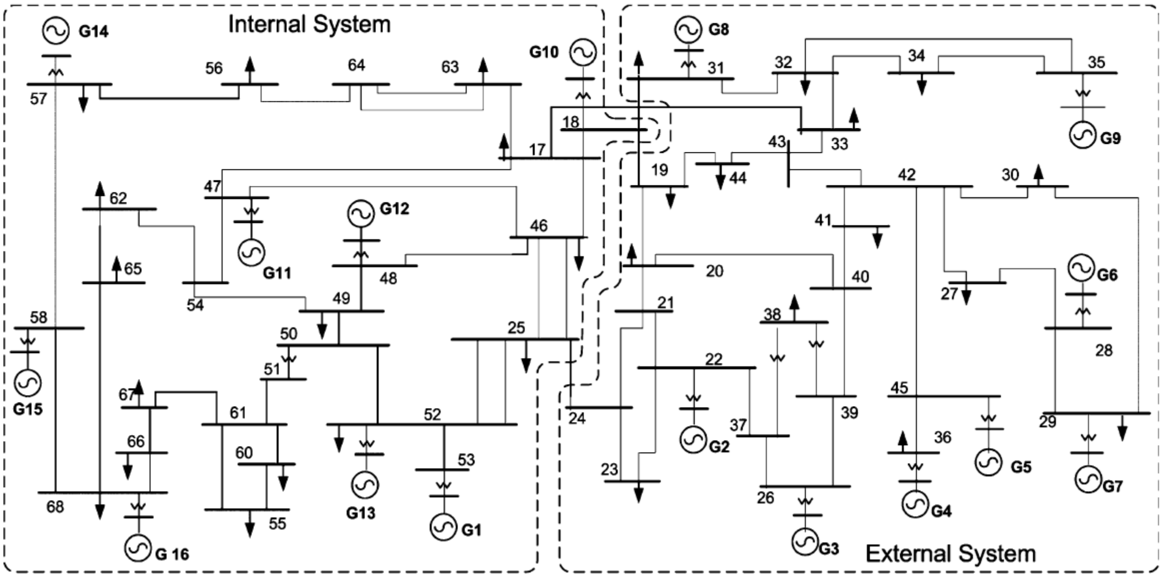

Fig.9. Single line diagram of 16 Machine 68 bus test system.

A10. IEEE 14 generator 59 bus test system: This is a simplified model of the Southern and eastern Australian network. It consists of five areas in which area 1 and 2 are closely coupled. In the system there are 14 large generators and 5 SVC s. Total generations in medium heavy condition are 21590 MW and 21000 MW, respectively. The details of the system can be found in [7].

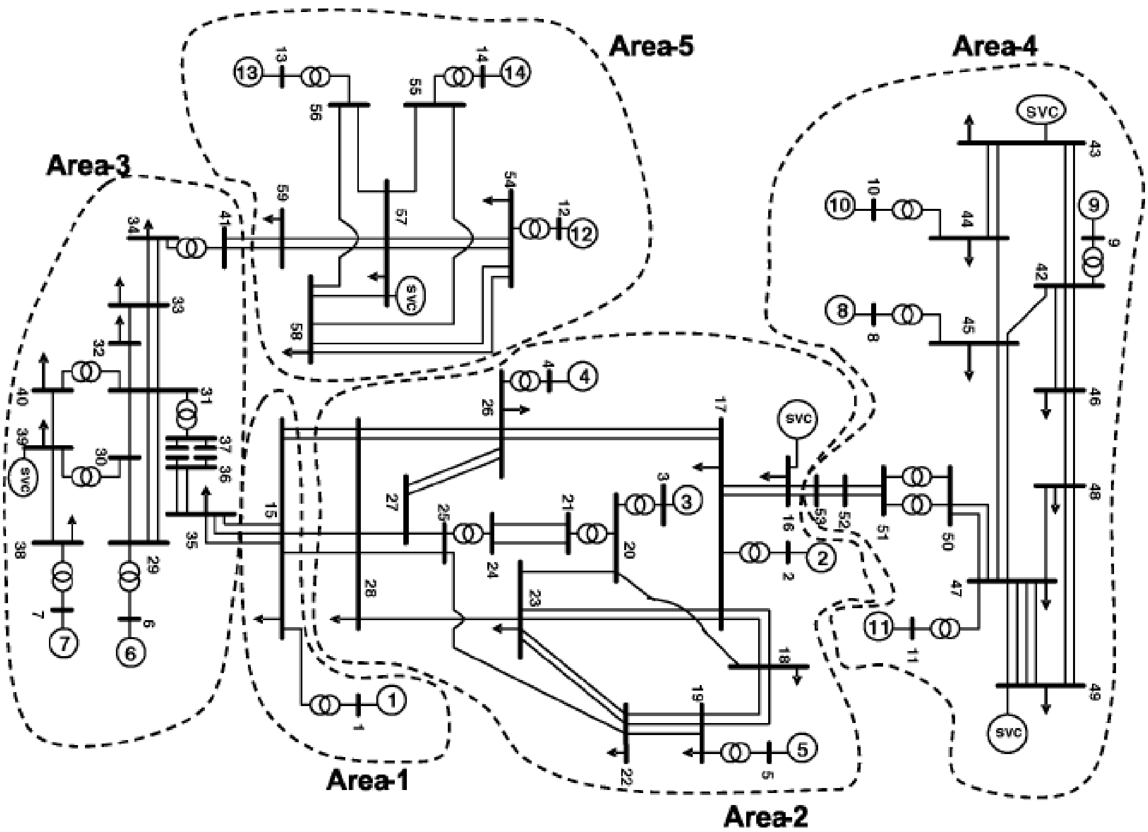

Fig.10. IEEE-14 generator 59 bus test system.

A11. IEEE-50 machine test system: IEEE-50 machine system shown in Fig is an approximated model of an actual power system and was developed for stability studies in 1990. It consists of 145 buses and 453 lines including 52 fixed tap transformers. There are 60 loads for total of 2.83 GW and 0.80 Gvar. In detail dynamic and static data of the system can be found in [4].

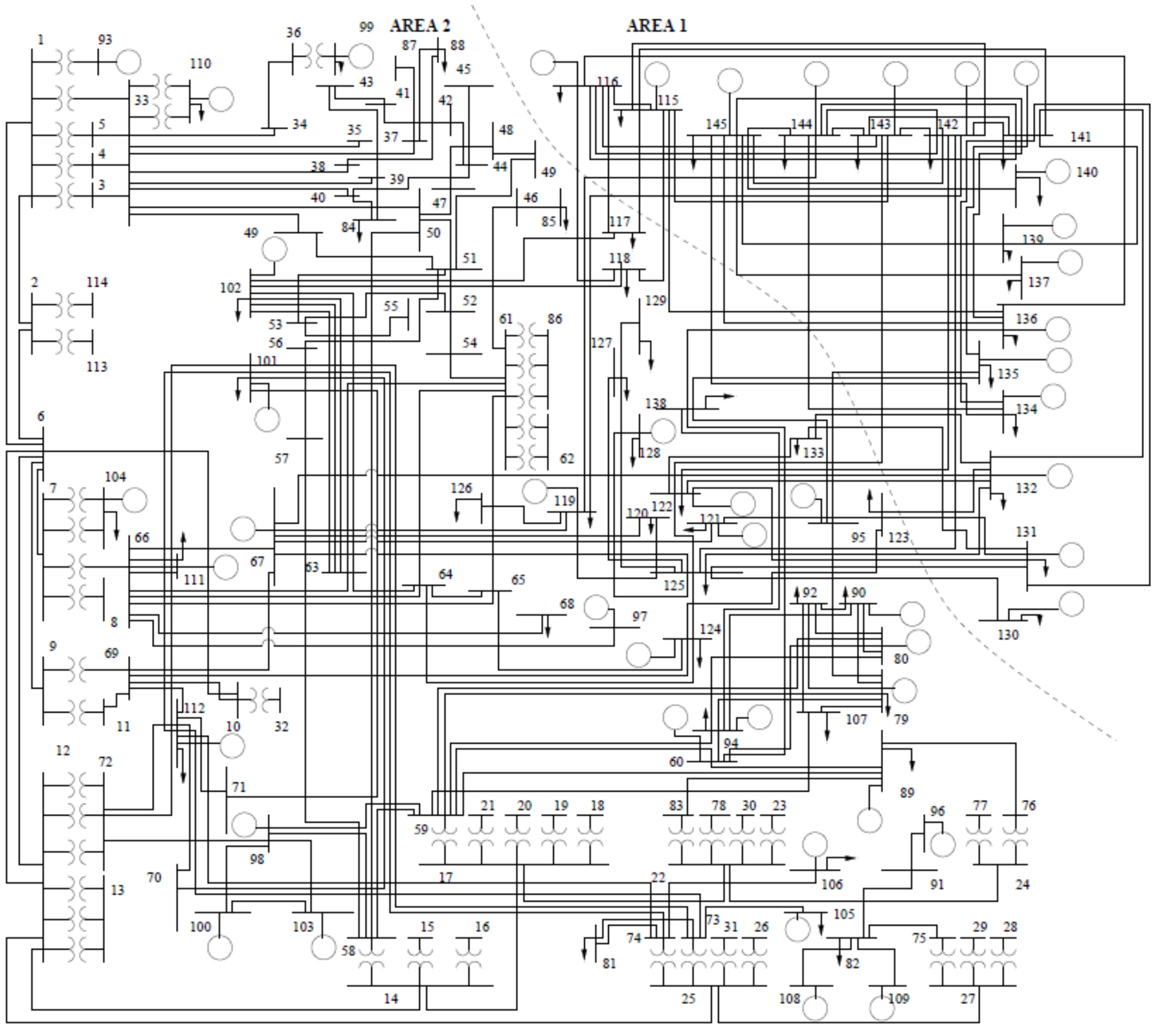

Fig.11. Single line diagram of IEEE 50 Machine test system.

A12. WECC 179 bus test system: WECC 179 bus test system shown in Fig.12 is the reduced system that models the major transmission corridors of the WSCC system [8]. The system has 179 buses, 29 generators and 263 transmission branches. The system has a verity of generation units such as hydro, steam-coal, steam –gas, nuclear, combustion turbine, combine cycle, hydro-pump, geothermal. The total generation capacity of the system is over 158 GW.

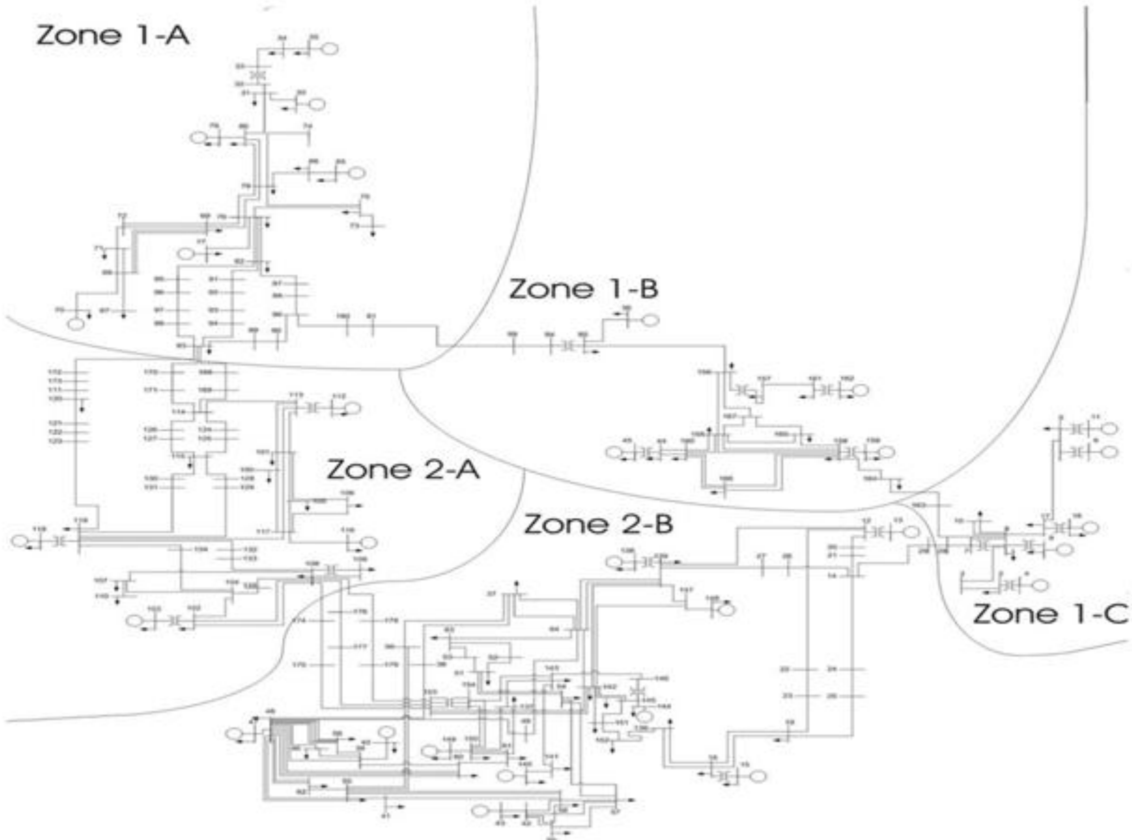

Fig.12. Single line diagram of WSCC 179 bus test system.

A13. IEEE 17 machine 162 bus test system: Fig.13 shows the major 345 KV line diagram of IEEE-17 machine 162 bus test system. The system has 284 branches and all the 17 generator of the system are modelled as classical generator model. System static and dynamic data can be found in ref [4].

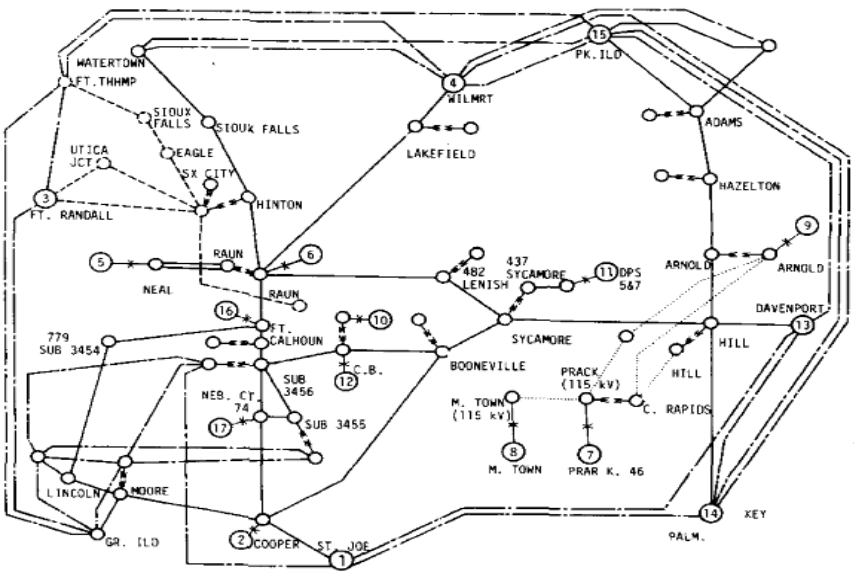

Fig.13. IEEE-17 machine 162 bus test system.

A14. Japanese Power system model: Institute of Electrical Engineers Japan (IEEJ) has developed some common system model for power system research and education [9]. This are –

- IEEJ East 10 machine system.
- IEEJ West 10 machine system.
- IEEJ East 30 machine system.
- IEEJ West 30 machine system.

IEEJ East 10 machine system: The "EAST 10-machine system" model is a simplified 10-machine model that is a prototype of the 50 Hz of the Japanese systems. It has the structural characteristics of the 500 kV loop and that of different voltage levels, the 500 kV, 275 kV loops. Fig.11 shows the single line diagram of IEEJ East 10 machine system.

IEEJ West 10 machine system: The Japanese 60 Hz systems are linked to each electric power company by 500 kV transmission lines. The long trunk line from the east to the west is over 1,000 km. Therefore, the systems present a typical longitudinal structure that stretches from east to west (tandem type system). The "WEST 10-machine system" model described in this section is a 10-machine tandem model that is a prototype of the Japanese 60 Hz systems. It presents the long time oscillation characteristics of a tandem system. In developing this system, attention was given to the following points:

i. The frequency of the long period oscillations is almost similar to that of the real system.
ii. The system capacity is also virtually the same as that of the real system.
iii. The length of the tie-line is almost the same as that of the real system.
iv. The system was developed to have as much as possible a simple tandem structure.
v. The VAR Compensator equipments are not directly considered. The difference of their operation states during the daytime and night-time is controlled by the power factor of loads.

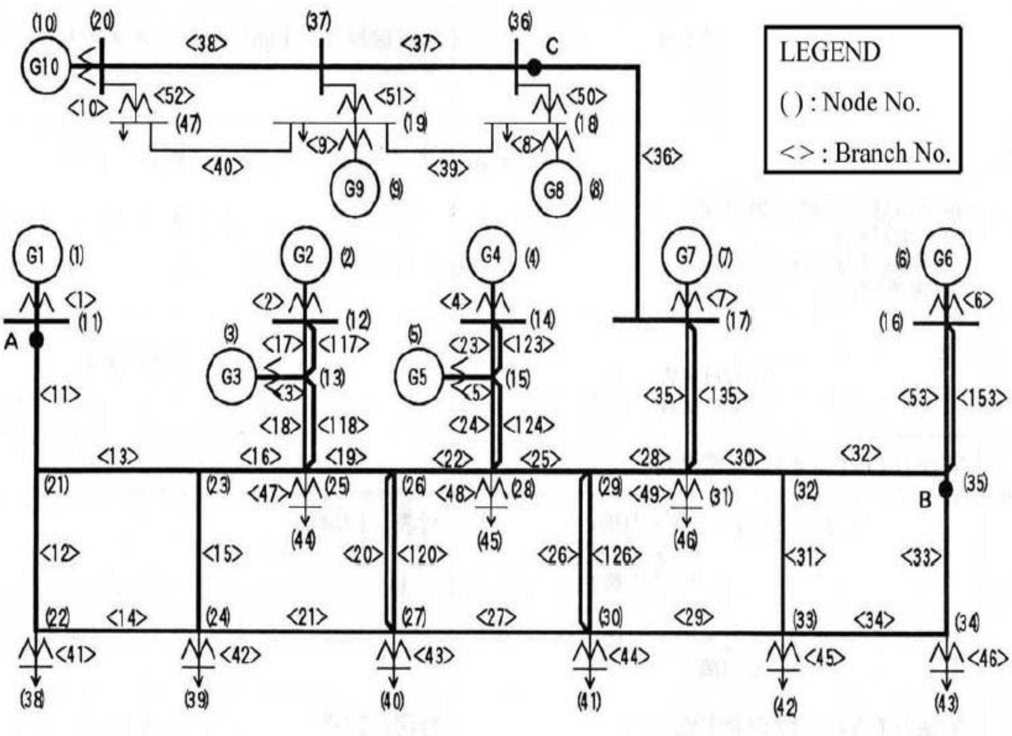

Fig.14. Single line diagram of IEEJ East 10 machine system.

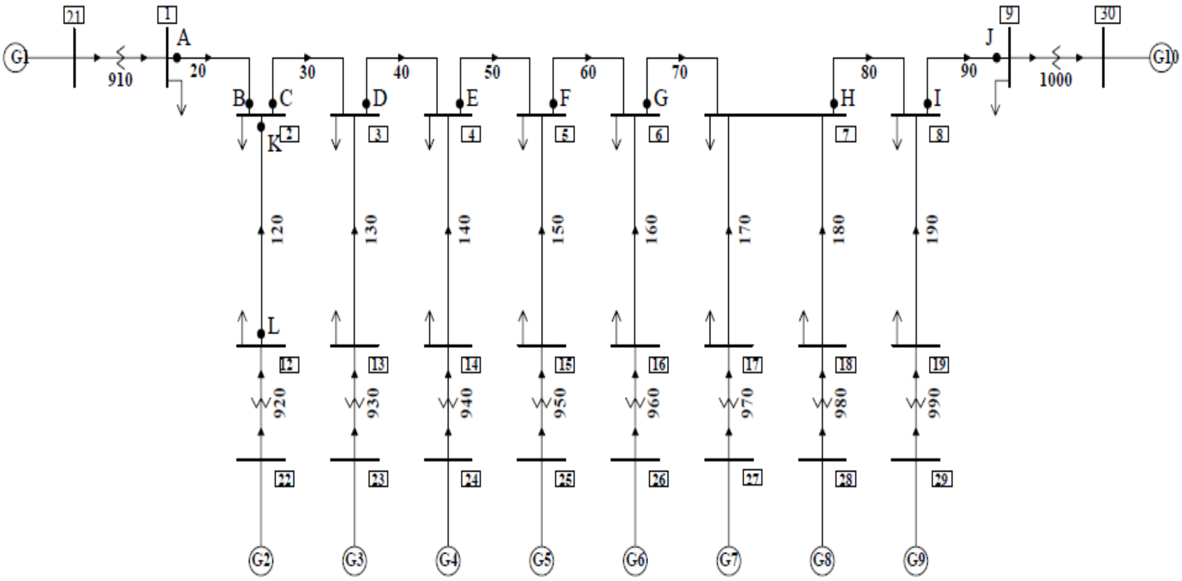

Fig.15. Single line diagram IEEJ West 10 machine system.

IEEJ East 30 machine system: As large-scale system models, these models reflect the characteristics of the real systems more closely than the 10-machine system models; they have been developed based on the reduction of the real systems. However, as mentioned above, since the power flow conditions are modified, the stability conditions of the systems are more severe than those of the real systems. This large system model has 500 KV loops and 275 KV loops with 30 machines, 105 nodes and 191 branches. The two loading level for this system has been considered. The day time load level is 72500 MW and the night time load level is 40180.

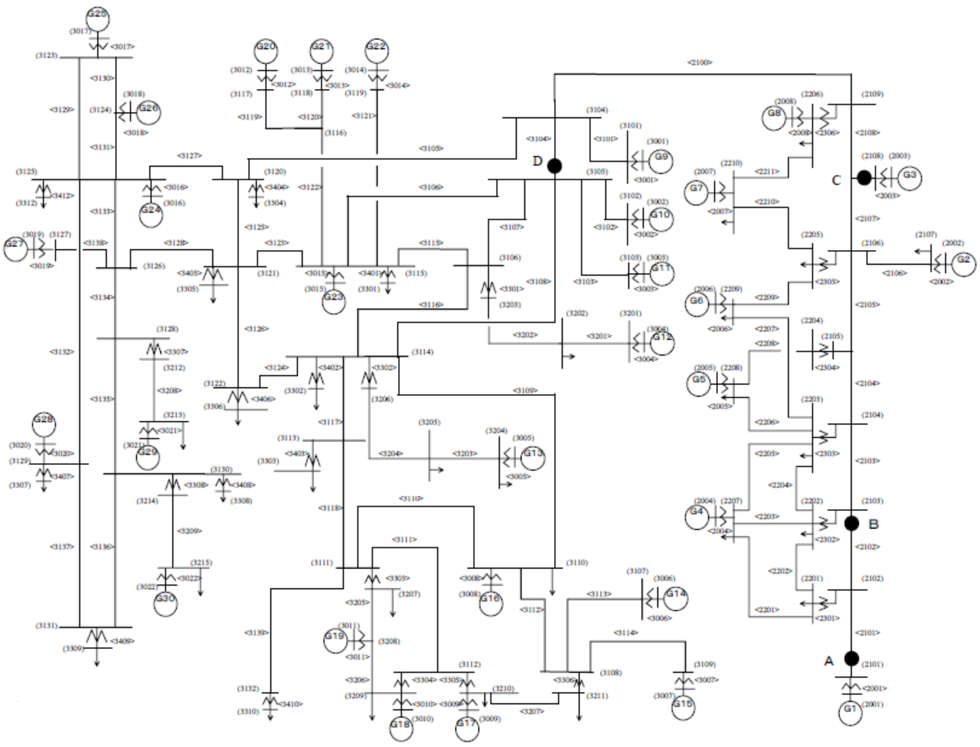

Fig.16. Single line diagram of IEEJ East 30 machine system.

IEEJ West 30 machine system: As large-scale system models, these models reflect the characteristics of the real systems more closely than the 10-machine system models; they have been developed based on the reduction of the real systems. However, as mentioned above, since the power flow conditions are modified, the stability conditions of the systems are more severe than those of the real systems. The system consists of 30 machines, 115 nodes and 129 branches. As like IEEJ East 30 machine system, this system has two different load levels. For day time load level is 100,200 MW and the night time load is 43730 MW.

A15. IEEE-118 bus test system: Fig.18 shows the single line diagram of IEEE-118 bus test system. The system consists of 41 synchronous generators and 27 synchronous compensators with 186 branches. The static and dynamic data of the system can be found at ref [4].

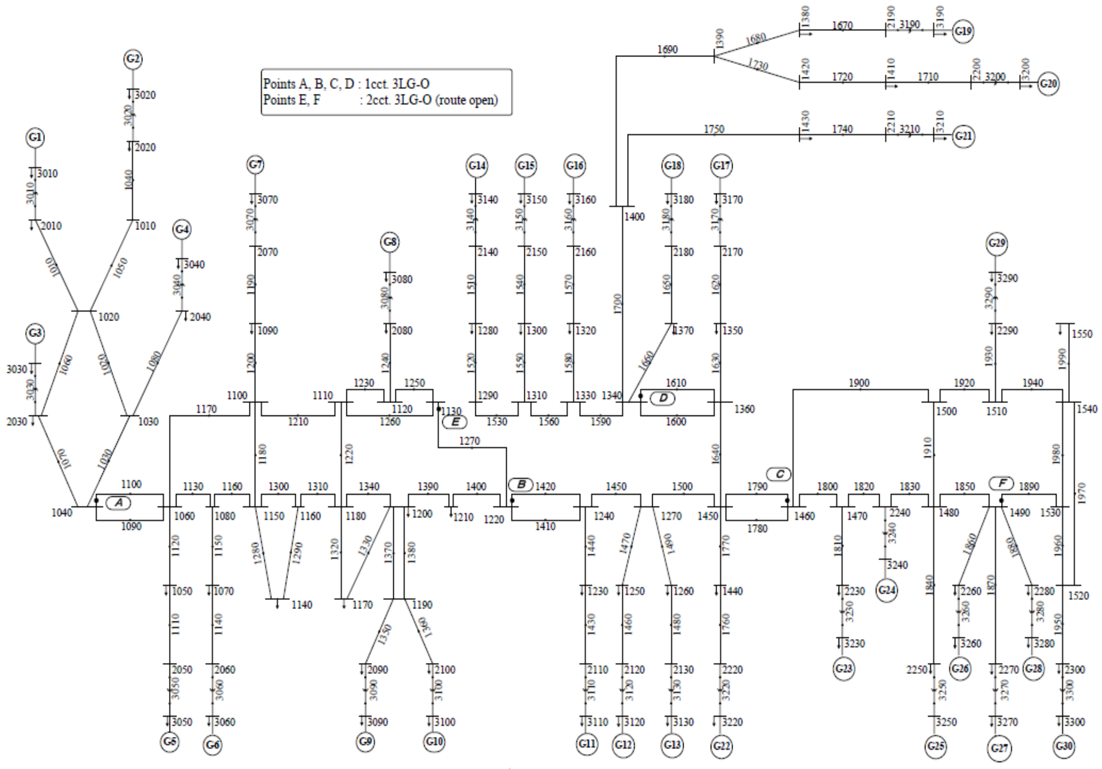

Fig.17. Single line diagram of IEEJ West 30 machine system.

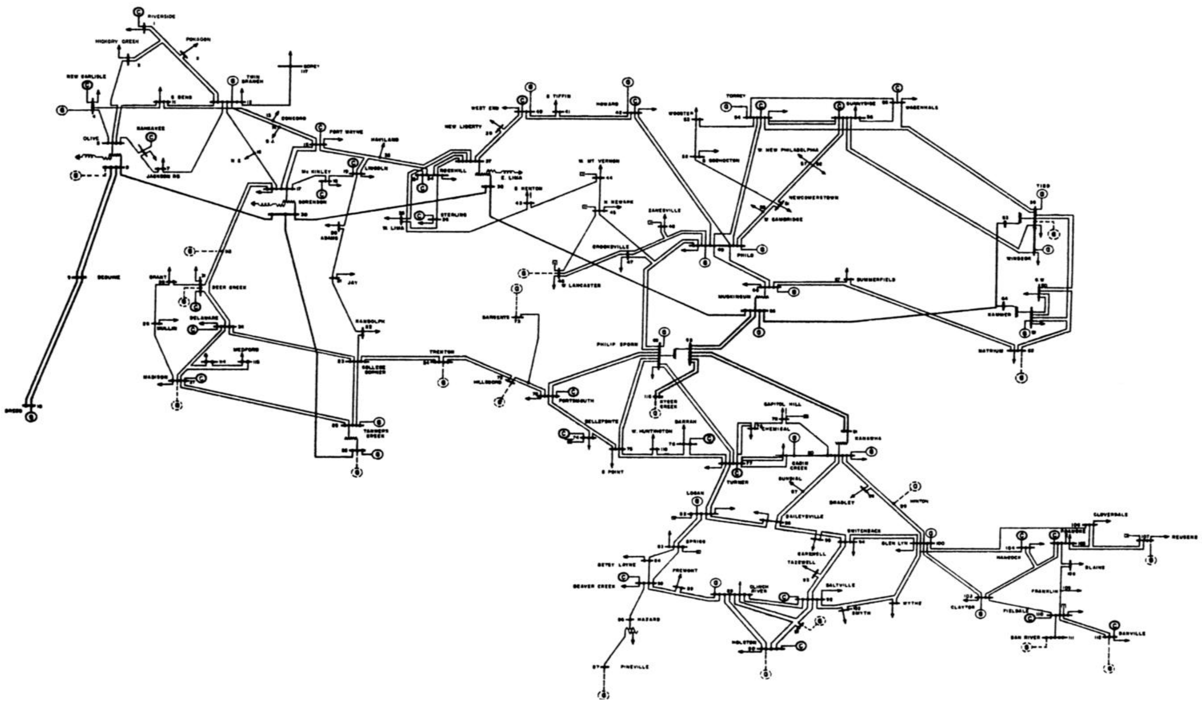

Fig.18. Single line diagram of IEEE-118 bus test system.

A16. IEEE-300 bus test system: Fig.19 shows the single line diagram of IEEE-300 bus test system. This system consists of three systems, namely, system 1, system 2 and system 3. System 1 has 26 synchronous generators. System two consists of 21 synchronous generators and HVDC link whereas in system 3 it has 15 synchronous generators. The detail system static and dynamic data are available in ref [4].

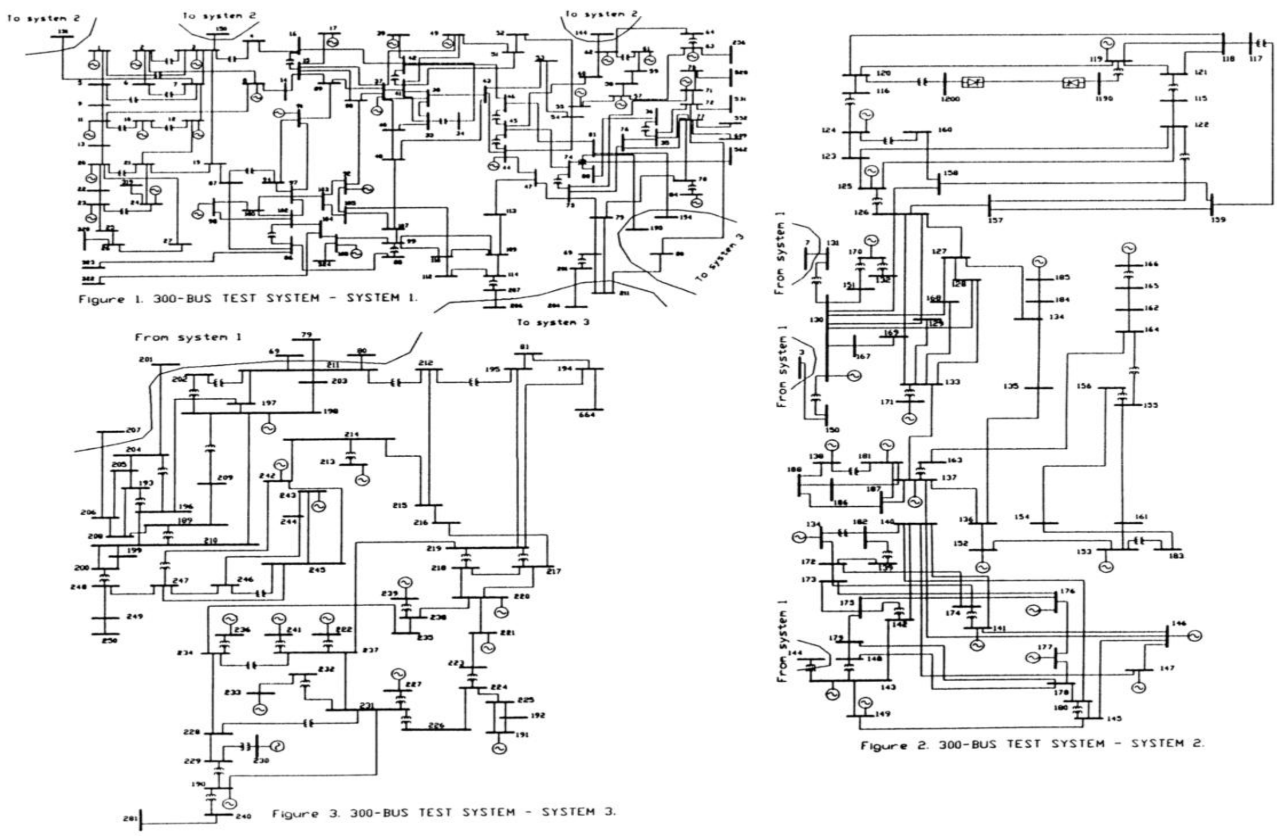

Fig.19. Single line diagram of IEEE-300 bus test system.

A17. IEEE -24 test system: Fig.20 shows the single line diagram of IEEE-24 bus test system which is widely used by the researchers for reliability analysis. The system consists of 11 synchronous generators with 37 branches and 20 load points. The total demand real and reactive power demand of the system is 2850 MW and 665 Mvar, respectively. Detail static data of the system can be found in [1].

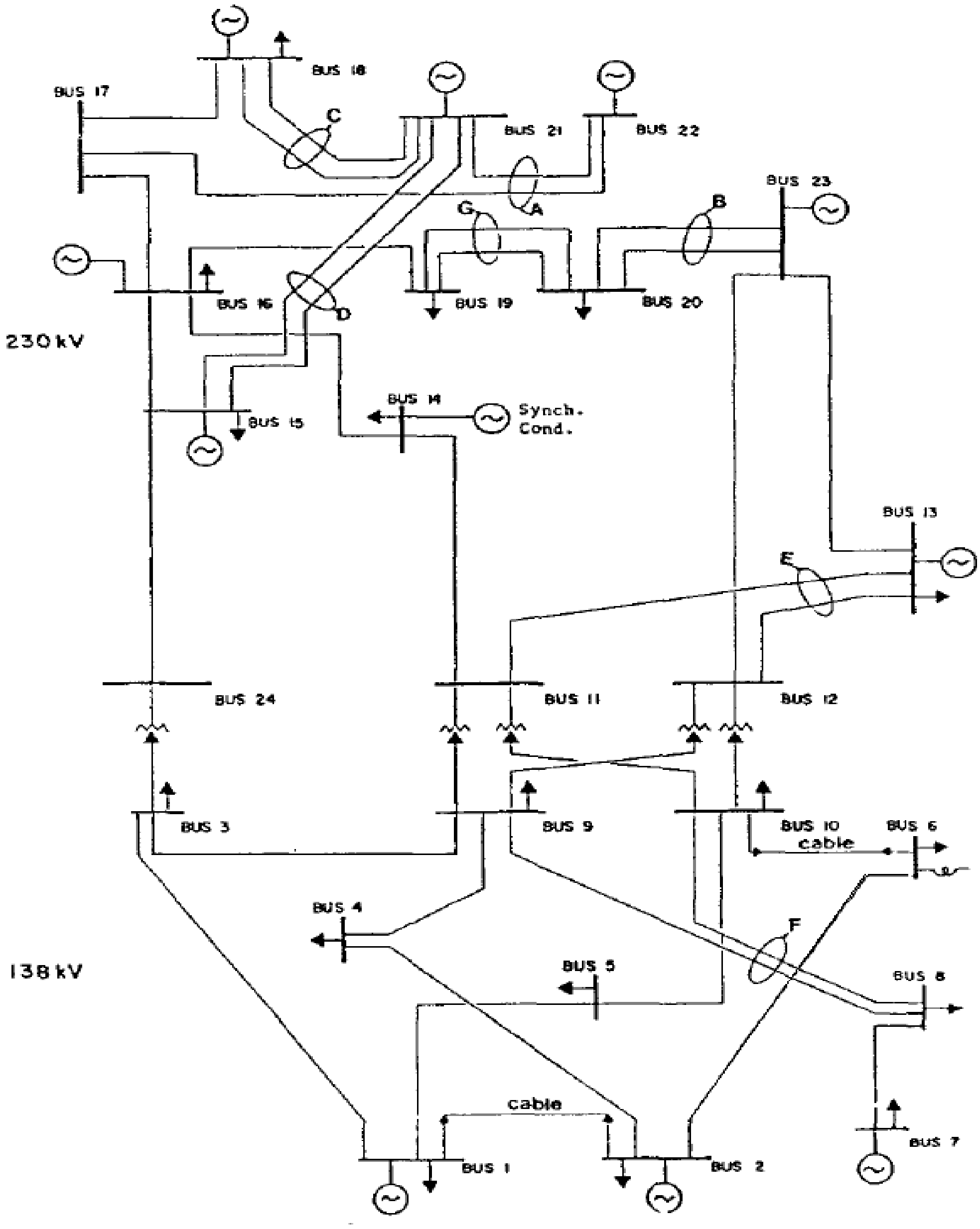

Fig.20. Single line diagram of IEEE-24 test system.

A18. Twenty three-machine test system-Nordic 32: Fig. 21 shows the single line diagram of 23 machine test system – Nordic 32. The twenty-three machine test system in [CIGRÉ 1995] is intended for studies of transient and voltage stability. Using the model for small disturbance analysis motivates some modifications. The system has two different voltage levels, 130 KV and 400 KV, respectively. The system dynamic and static data can be found in ref [11].

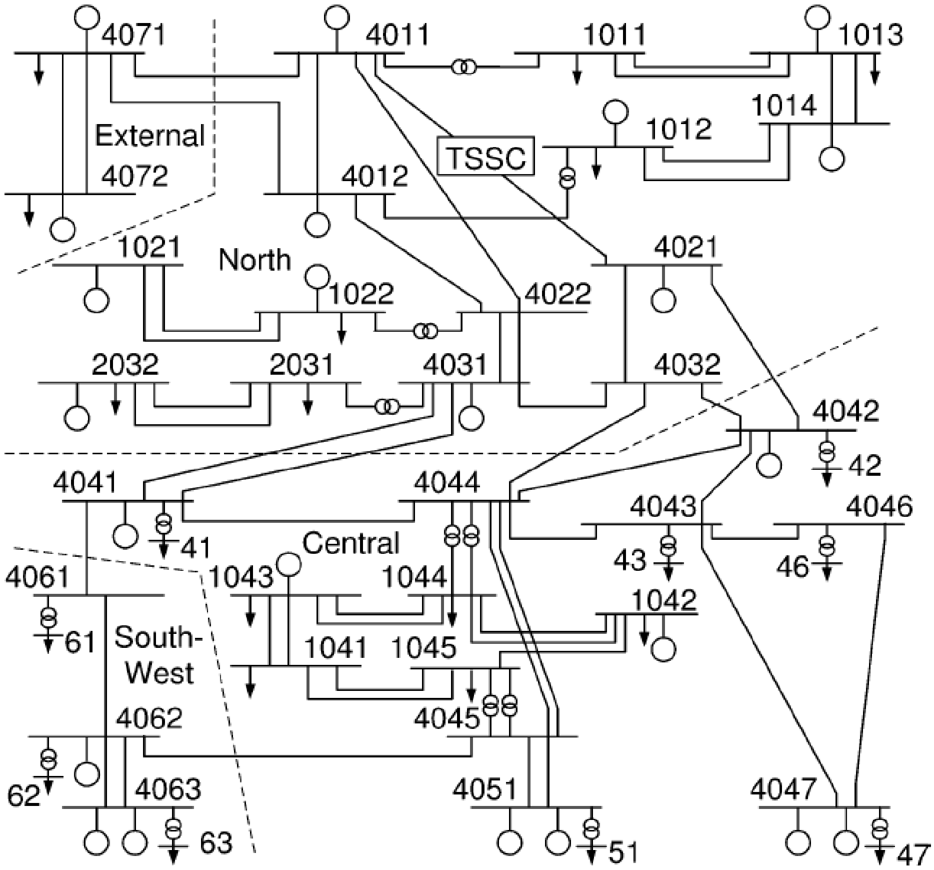

Fig.21. Single line diagram of twenty-three machine test system-Nordic 32.

A19. IEEE-9 bus system: Fig. 22 shows the single line diagram of IEEE-9 bus system. The system consists of 4 synchronous generators. Among them two generators are modelled as 6th order generator model and rest of them modelled as classical generator model. In this system there are five load points totalling 95,000 MW and 20,870 Mvar load. Detail static and dynamic data of the system can be found in [12].

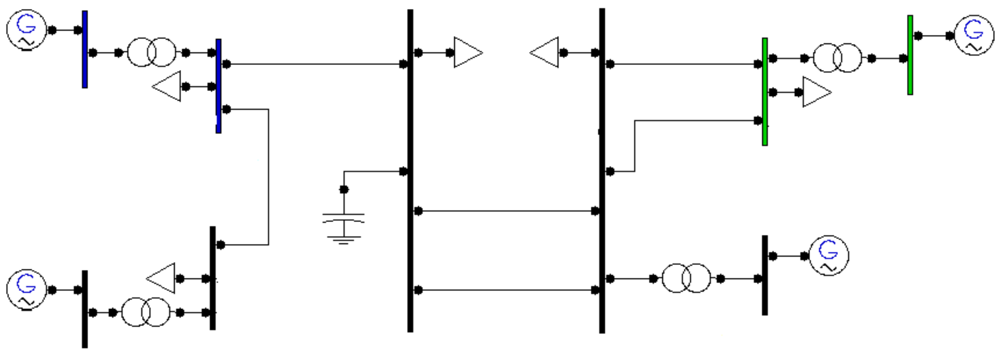

Fig.22.Single line diagram of IEEE-9 bus system.

A20. Lower south Island of New Zealand test system: Lower south island of New Zealand test system is mainly used for power system electromagnetic transient analysis. Fig.23 shows the single line diagram of the system. The system voltage is 220 KV. Detail system data can be found in ref [13].

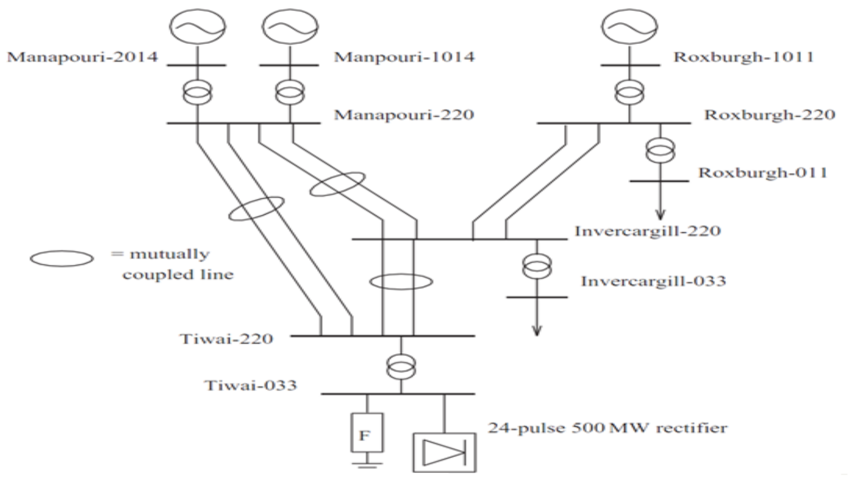

Fig.23. Lower South Island of New Zealand test system.

A21. South/Southeast Brazilian equivalent test system: The test system is a modified seven bus, five machine equivalent model of South/Southeast Brazilian network, which has widely been used for low frequency oscillatory stability analysis and PSS design for oscillation damping. The system consists of five synchronous generators with seven load points. The detail dynamic and static data of the system can be found in [18].

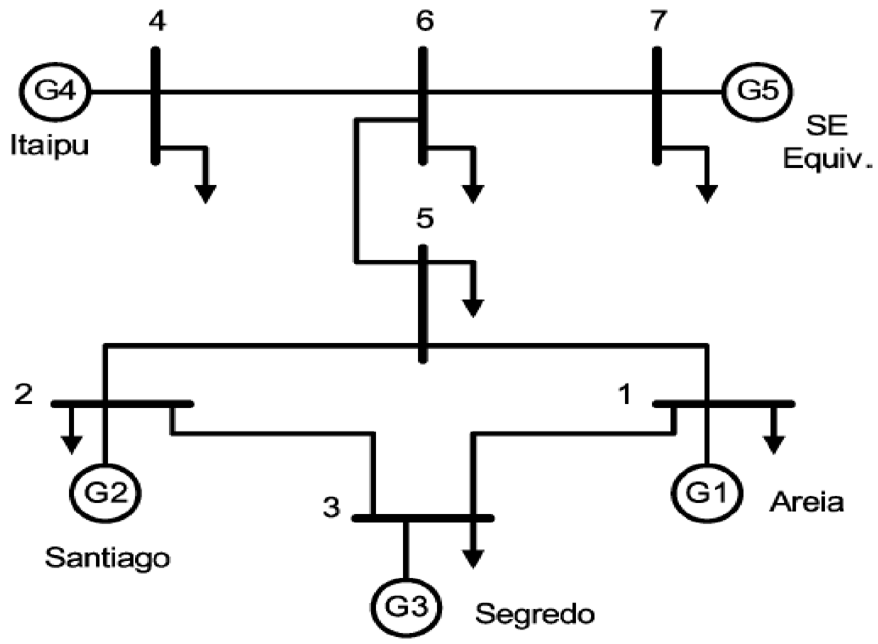

Fig.24. Single line diagram of south/southeast Brazilian network.

III. Distribution system (Sub-transmission system)

B.1 IEEE recommended distribution system: Table 1 illustrates the feature of IEEE recommended distribution system.

Table.1: Main features of the IEEE-recommended distribution system

Features	16 BUS	30 BUS	33 BUS	94 BUS
Load Types	a. All spot loads b. balanced load	a. All spot loads b. balanced load c. Load factors for feeders and sub feeders connected to different buses are given	a. All spot loads b.. balanced load	a. All spot loads b. balanced load
No. Of Feeders	3	1	1	11
Nominal voltage	23 kV	11kV	12.66kV	11.4kV
No. of sectionalizing branches	13	29	32	83
No. of Tie switches	3	1	5	13

B.2 69 bus test system: The test system for the case study is a 12.66 kV radial distribution system with 69 buses, 7 laterals and 5 tie-lines (looping branches), as shown in Fig. 24. The current carrying capacity of branch No.1-9 is 400 A, No. 46-49 and No. 52-64 are 300 A and the other remaining branches including the tie lines are 200 A. It is a long radial system with 47 load points totalling 3.8 MW and 2.69 Mvar load. Detail data of the system can be found in [15].

B.3 119 bus test system: The test system is a hypothetical 11 kV with 118 sectionalizing switches, 119 node, and 15 tie lines. The system data is given in Ref. [16]. The schematic diagram of the test system is shown in Fig. 25. The total power loads are 22,709.7kW and 17,041.1 kV Ar.

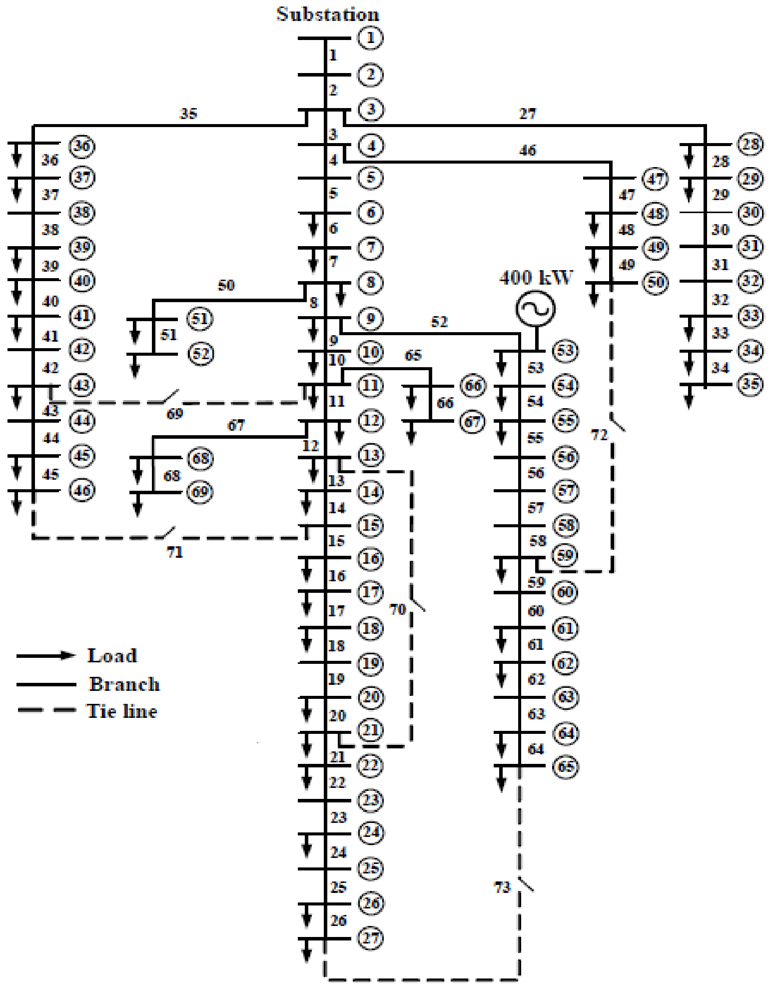

Fig.24. Single line data of 69 bus test system.

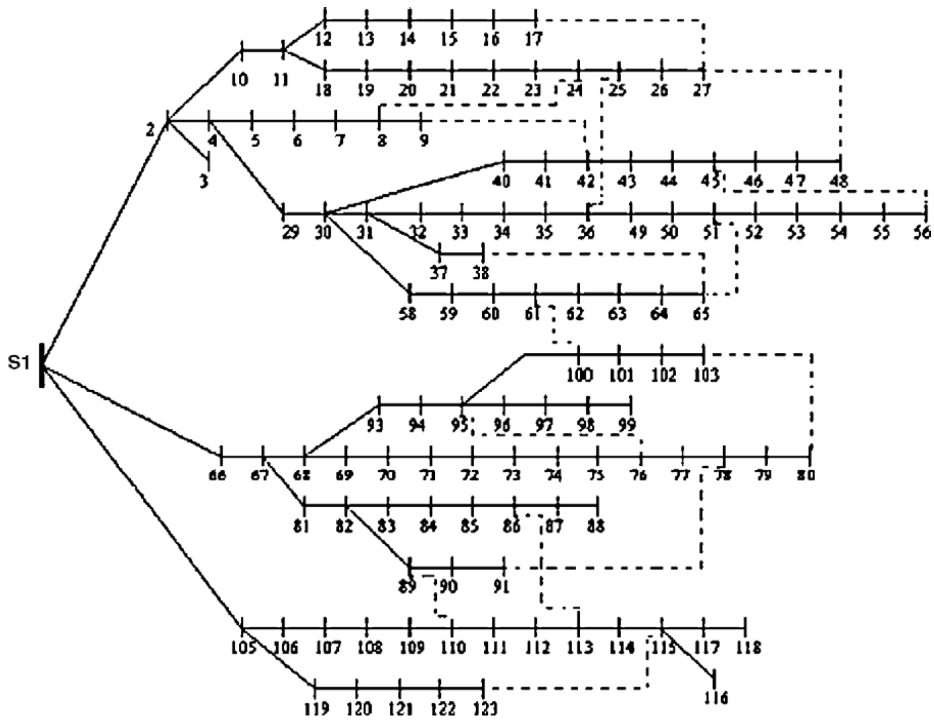

Fig.25. Single line diagram of 119 bus test system.

IV. Unbalance distribution system

C.1 IEEE recommended unbalanced distribution system: Table 2 illustrates the features of the IEEE recommended unbalanced test system [17].

Table.2: Main features of the IEEE-recommended unbalanced distribution system

Features	IEEE 123 bus Y	IEEE 34 bus Y	IEEE 13 bus Y	IEEE 37 bus Δ
Load Types	a. All spot loads b. Wye and delta connected c. Mixture of constant kW, kvar, Constant Z and constant I. d. Unbalanced load	a. Spot and distributed loads b. All wye connected c. All constant kW, kvar d. Unbalanced load	a. Spot and distributed loads b. Wye and delta connected c. Mixture of constant kW, kvar, Constant Z and constant I. d. Unbalanced load	a. Delta connected spot loads b. Mixture of constant kW, kvar, Constant Z and constant I. d. Unbalanced load
Line Types	a. Three-phase overhead (all combinations of a , b , c) b. Two-phase overhead (Combinations of a,b,c) c. Single-phase overhead (a-n, b-n and c-n) d. Three-phase underground	a. Three-phase overhead b. Single-phase overhead (a-n, b-n and c-n)	a. Three-phase overhead & underground b. Single-phase overhead & underground	All three-phase delta underground
Nominal voltage	4.16kV	24.9kV	4.16kV	4.8kV
Shunt capacitors	a. Three-phase b. Single-phase	balanced three-phase	a. Balanced three-phase b. Single-phase	No Shunt Capacitors
Voltage regulators	a. Three-phase, gang operated b. Three single-phase, wye connected c. Two single-phase, open wye connected d. Single-phase, line-to-neutral connected	single-phase regulators wye connected	single-phase regulators wye connected	single-phase regulators open-delta connected
Substation transformer	5,000 kVA 115 delta-4.16 grounded wye kV Z = 1.0 + j8.0 %	2 , 500 kVA 345 delta-24.9 grounded wye kV z = 1.0 + j8.0 %	5,000 kVA 115 delta-4.16 grounded wye kV Z = 1.0 + j8.0 %	2 , 500 kVA 230 delta-4.8 delta kV Z = 2.0 + j8.0 %

Fig. 24-27 shows the single line diagram of IEEE-123, IEEE-34, IEEE-37 and IEEE-13 bus test system respectively.

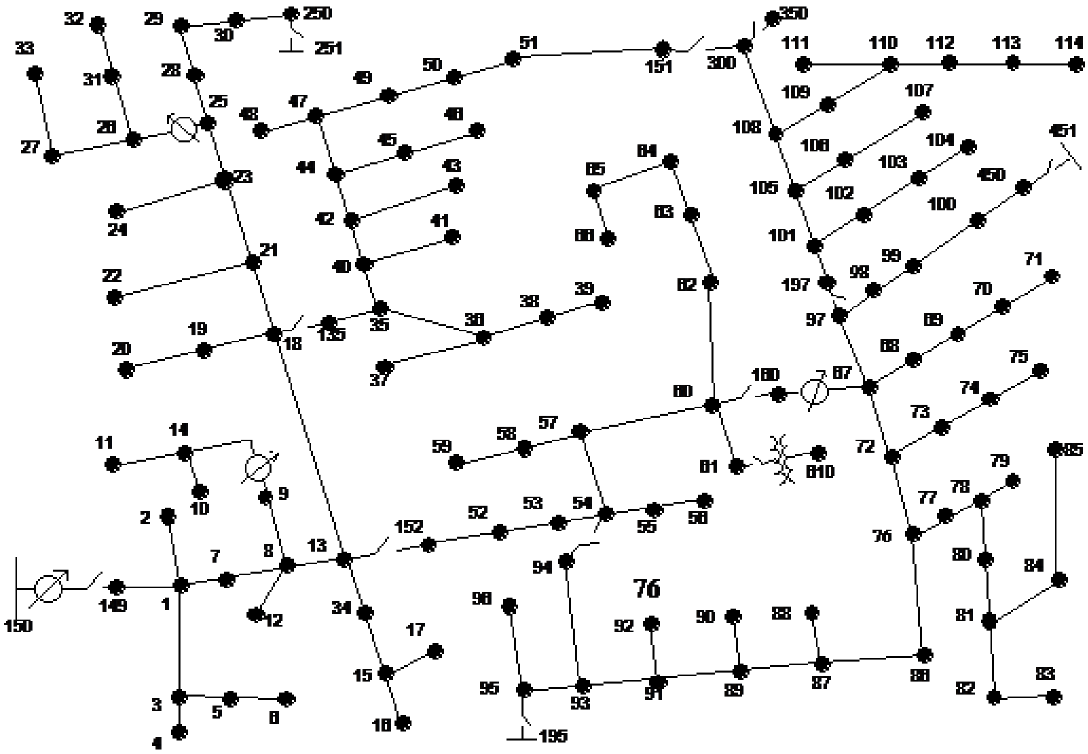

Fig.26. Single line diagram of IEEE-123 bus test system.

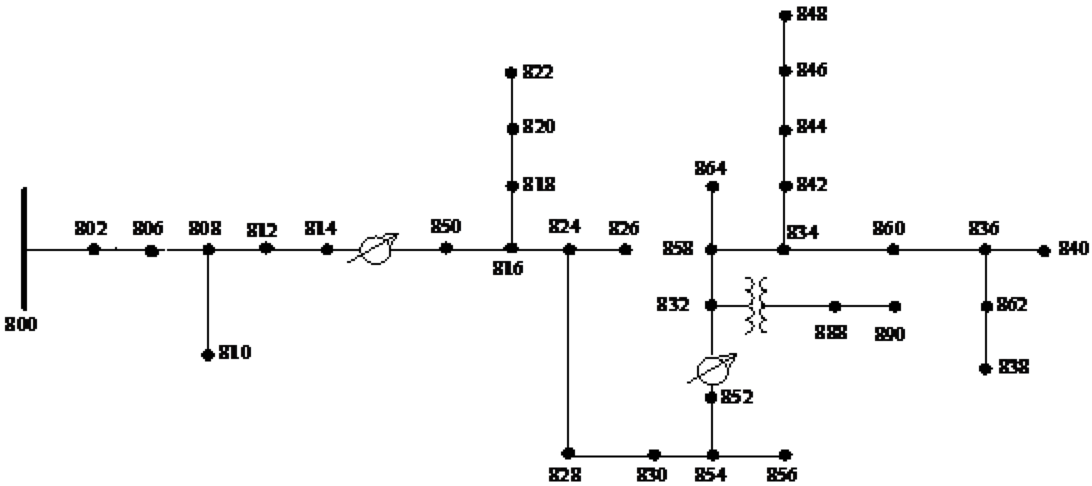

Fig.27. Single line diagram of IEEE-34 bus test system.

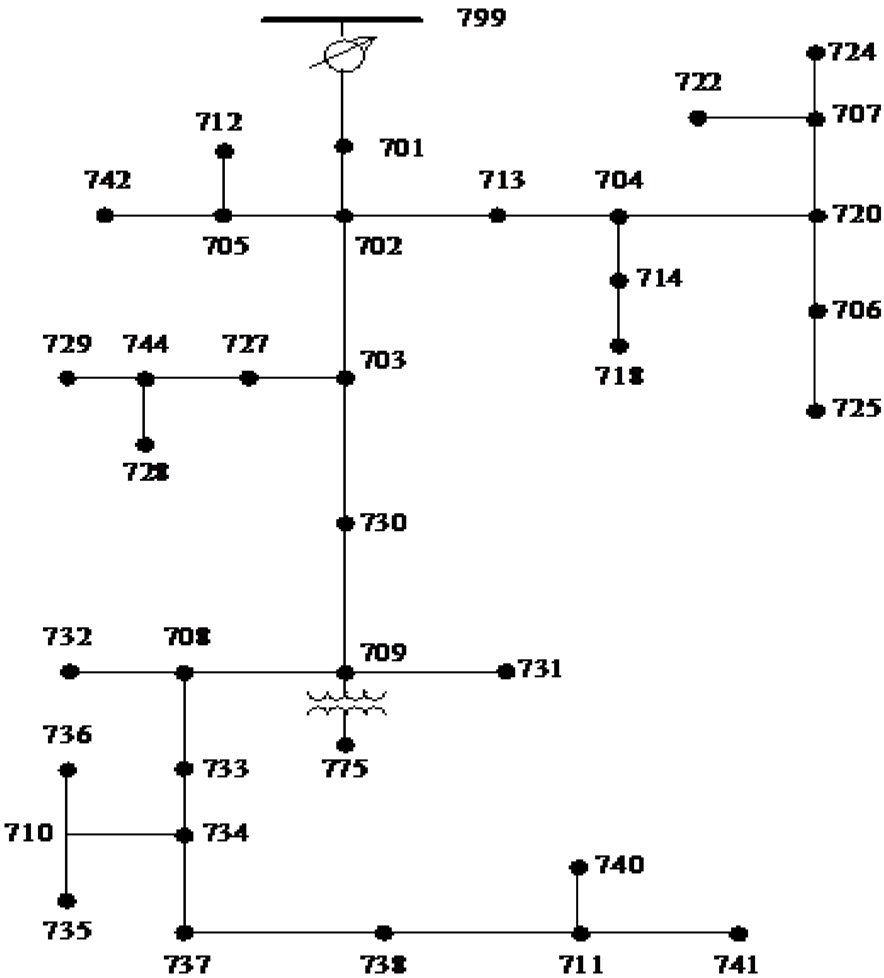

Fig.28. Single line diagram of IEEE-37 bus test system.

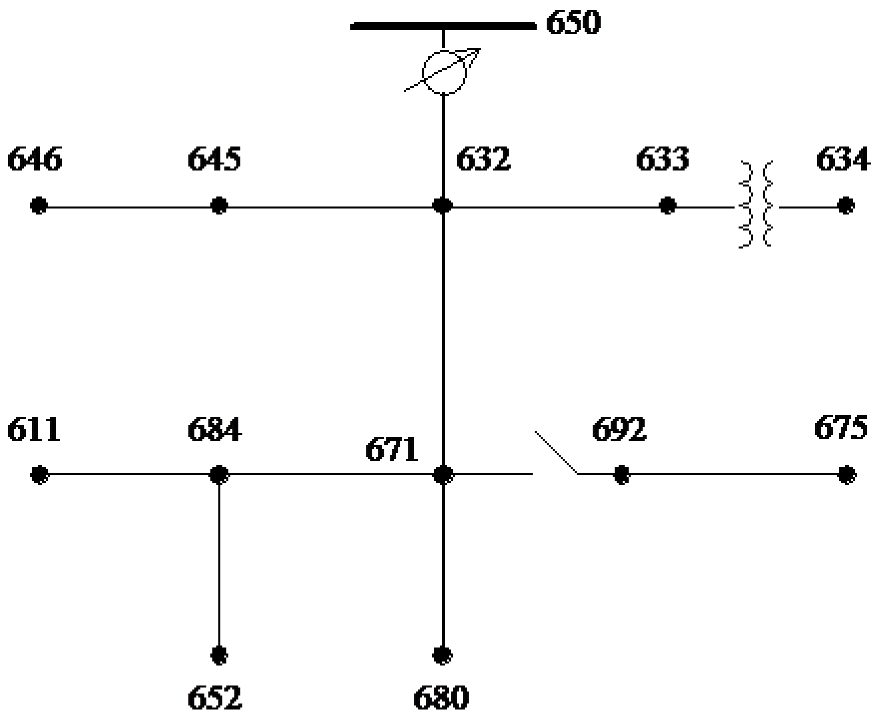

Fig.29. Single line diagram of IEEE-13 Bus test system.

C.2 Comprehensive test system: Fig.1 displays the one-line diagram for the comprehensive feeder. The comprehensive IEEE test feeder has been developed in order to test the models of all distribution components and to test the convergence qualities of a verity of switching schemes. The actual data for the feeder can be found in [17]. The test system has both underground and overhead lines. There are four three-phase switched shunt capacitor banks in the system. he loads on the centred tapped transformers will be modelled the same as spot loads. For single phase centred tapped transformers there will be two 120 volt loads and one 240 volt load. For three-phase banks the centre tapped transformer will have the two 120 volt loads, one 240 volt load and a three-phase load. Some of the three phase loads are static loads and others will be induction machines.

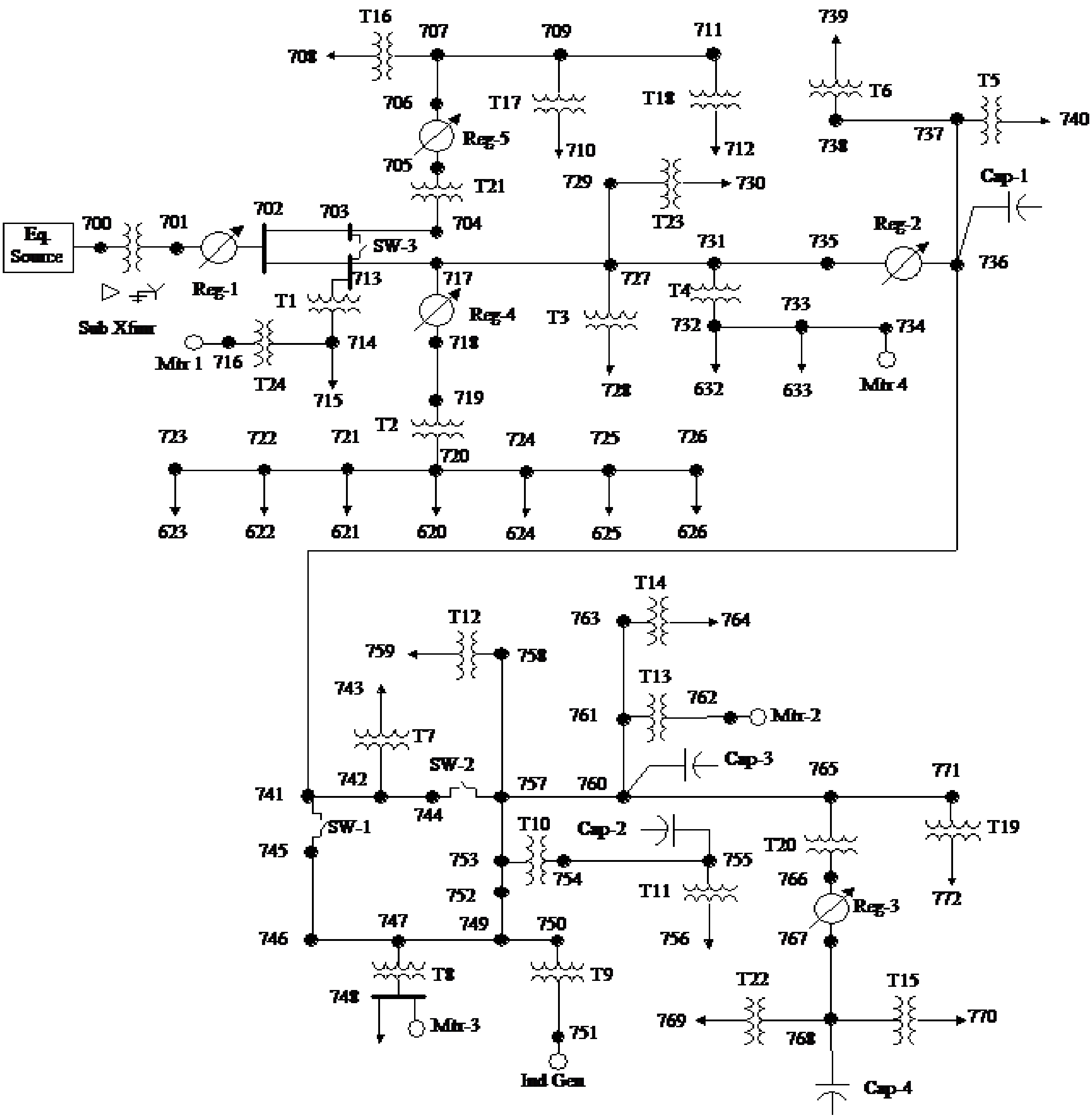

Fig.30.Single-line diagram of comprehensive system model.

C.3 8500 node test feeder: The 8500-node test feeder includes many elements that may be found on a North American MV distribution feeder: multiple feeder regulators, single-phase capacitor control, feeder secondaries, and service transformers. While the likely initial use of the test feeder is to simply solve the power flow for the defined loads, the test feeder was also selected for its potential for serving as the basis for future advanced test feeders. Two examples for which there is presently interest are

1. Distribution automations, including voltage and var control simulation, and
2. Daily and annual loading simulation for evaluating energy efficiency options, renewable generation, and electric vehicle impacts.

The 8500-node test system gives another benchmark by which Transactions reviewers can evaluate the claims of authors researching new methods for distribution system analysis. If the proposed method will perform well on this test feeder, it is more likely to perform well in actual practice.

The test feeder is provided with two versions of loads:

1. Balanced 120V secondary loads on the service transformers,
2. Unbalanced 120V secondary loads on the transformers.

The transformer former can be represented adequately with a simple transformer model while the latter requires a specific model of the ubiquitous 120/240V, centre-tapped residential service transformer. Detail system data can be found in ref []17.

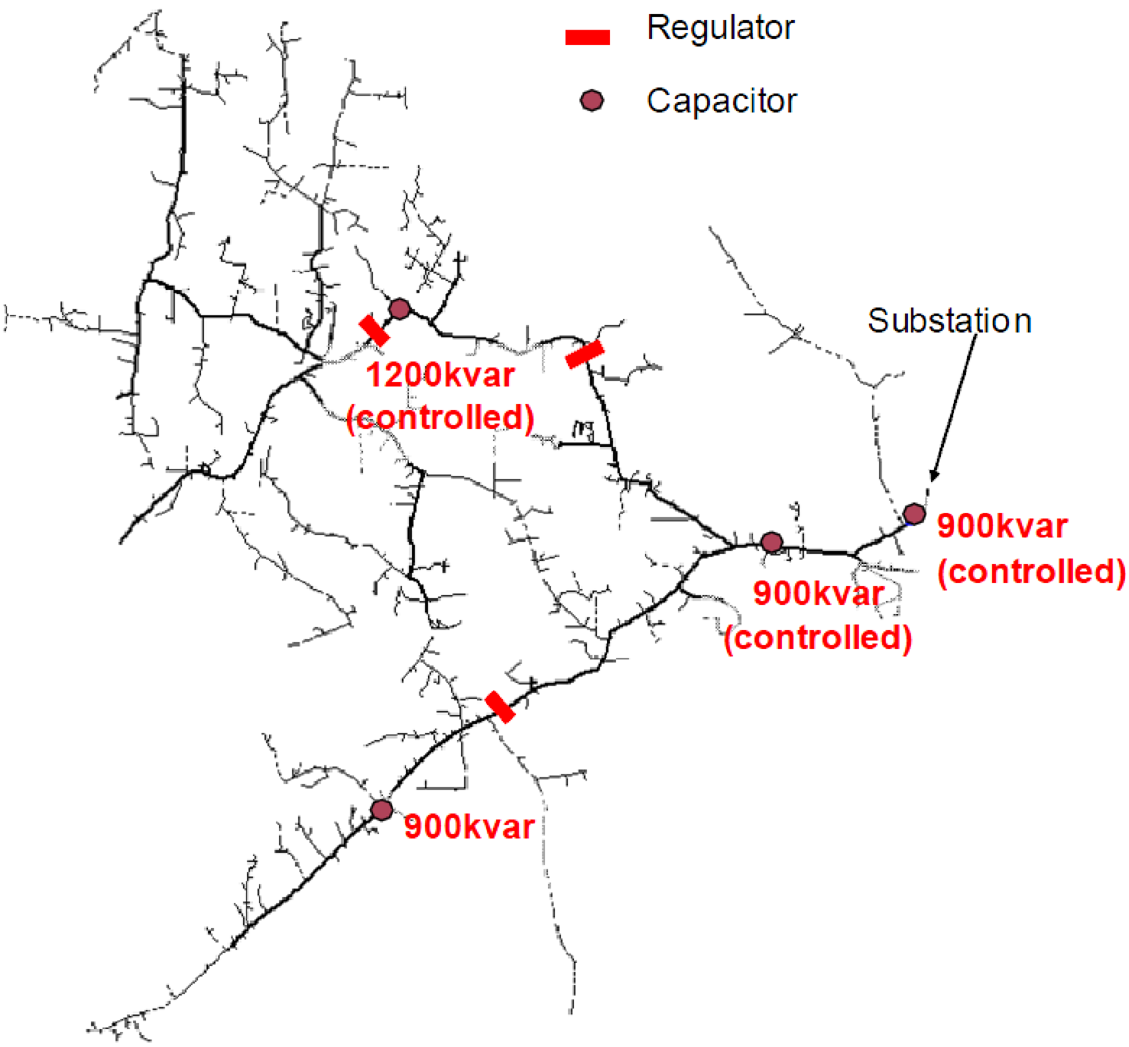

Fig.31. Single line diagram of 8500 node test system feeder.

C.4 Neutral-to-earth voltage test case: The substation has a relatively large 3-winding transformer with a 0.3 ohm reactor in the neutral of the MV winding to limit fault current contributions. A 3-winding transformer is common in some areas where the transmission system might need additional ground strength. Four feeders leave the substation on the same poles for 5 pole spans (75 m each span). The four circuits share one neutral wire. However, there are also 4 telecom circuits on the same poles, each suspended from a grounded messenger wire. The messenger wires are assumed to have
similar electrical characteristics to #2 ACSR. The feeders split off at the 5th pole from the substation. Two of the feeders travel on the same poles for 6 more spans before splitting off separately. Most of the load on each feeder is modelled by lumping it at the end of each feeder with a 3-phase grounded-Y-Y connected equivalent. The low voltage side of these transformers is not of interest in this test case. The loads are unbalanced and are described by

1. kW demand.
2. Power factor (PF)
3. % 3rd harmonic current (%I3). All 3rd harmonic currents in the loads are assumed to be in phase with the Phase A-N voltage at each location.

Detail system data can be found in ref [17].

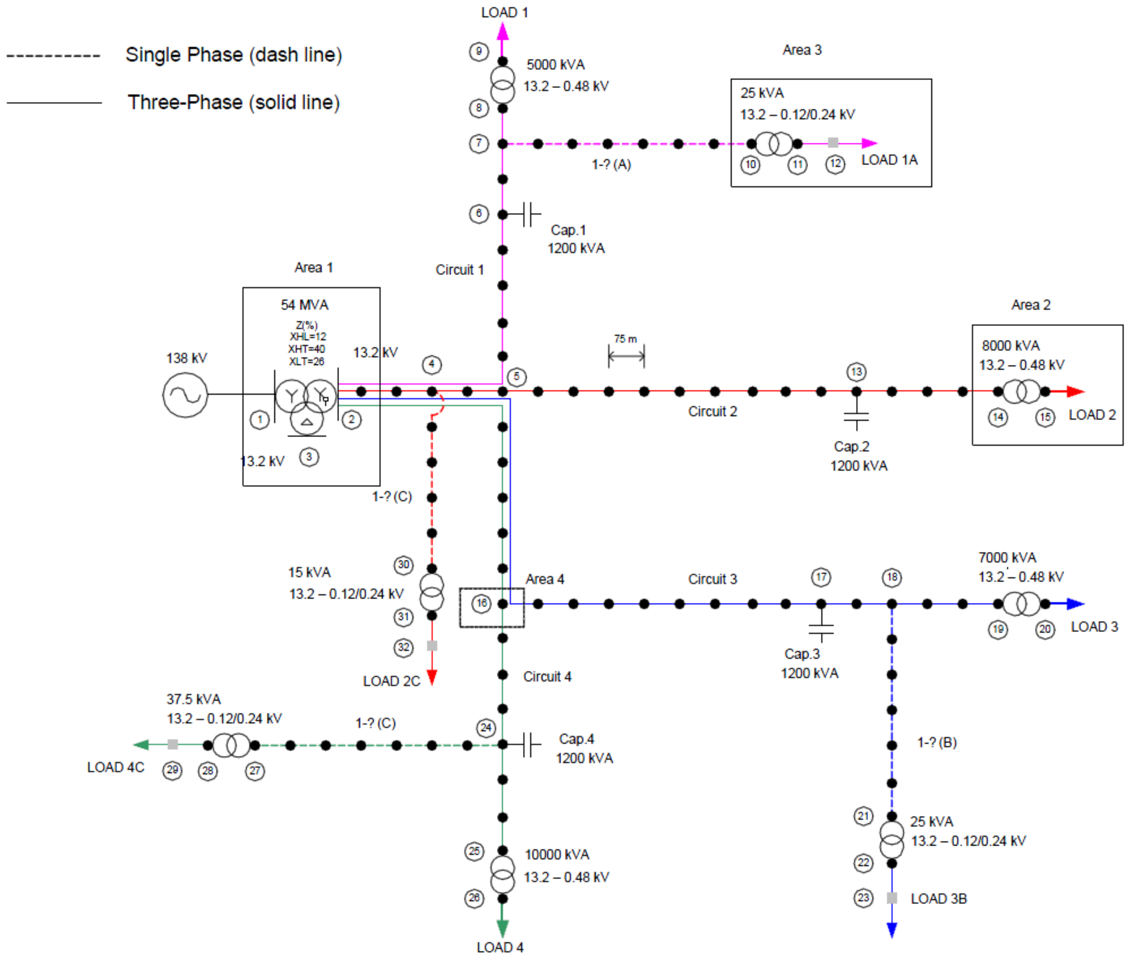

Fig. 32. Overall circuit diagram of neutral –to-earth voltage (NEV) test case.

V. Summary

This report has presented the most commonly used test power system for research and education purposes. The test cases presented here can be categorized as of transmission, distribution and unbalanced distribution systems. It is believed that this report can be useful for the researchers as well as new students in power engineering education.

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