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Impact of Wind Generation on Transmission Voltage Support during Weak Grid

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Impact of Wind Generation on Transmission Voltage Support during Weak Grid Conditions

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Honors Thesis Advisor

Abstract

Today, there are concerns about the effects of high wind penetration on electric power system operations. This is due to the more distributed nature of wind turbine generation and the corresponding multi-path power flows on the electric power transmission grid. In particular, the higher line impendences associated with inverter-based wind generation results in larger voltage fluctuation under varying load. This may results in conditions where even after a fault condition has been cleared, the transmission system voltages may not recover. Therefore, this paper concentrates on the impact of weak grid condition for voltage instability. To approach it, a 6-bus system is created in Matlab/Simulink application, and voltage stability of each fault line is simulated. Through the computer-based experiments, voltage instability can be observed. Results show the impact on voltage stability and recovery in terms of the presence of wind generation levels.

Acknowledgment:

I would first like to thank my adviser Dr. McCann for all help to complete my theses project and paper. He taught and supported me to proceed in transmission line simulation. Your appropriate advice pushed me to help my thinking and brought me to work at a higher level.

Finally, I would like to thank my family to support me to achieve my academic goal.

Table of Contents

List of Figures

List of Tables

I. INTRODUCTION

The growing production of electricity from inverter-based generation such as wind turbines and solar photovoltaic is also creating challenges for operating electric power networks. This is due to the presence of multiple power flows and higher impednaces associated with inverter-based generation. The increased source impedance of inverter-based generation results in reduced fault currents. This is referred to as a “weak grid” condition [1] and results in larger voltage fluctuations under both normal electrical load conditions and especially during fault conditions. Under some conditions, this can result in unstable voltages and a collapse such that power may now be restored after a fault is cleared. This research investigates the effect of renewable energy and inverter-based generation on voltage stability.

To create to analytical framework for the research, this thesis was implemented based on the power transmission system given in “Novel Back-to-Back Converter Configuration for Hybrid AC Transmission with Multi-Terminal DC Operation” [1] and “Method of Assessing Voltage Response of Inverter-Based Generation Due to System Faults” [2]. These projects focused on a power electronic circuit configuration that enables hybrid ac and dc transmission operations with improved reliability compared to existing methods. To approach the purpose of this research, a hybrid ac and dc transmission system is utilized since integrating dc power sources from renewable energy through multi-terminal configurations has potentially many advantages for meeting future electricity demands that include large amounts of inverter-based generation.

A. Renewable Energy

Initially, novel hybrid Back-to-Back (B2B) configuration is presented and Figure 1 shows this configuration. It suggests using a circuit breaker at the HVAC (High Voltage

Alternating Current) side to maximize the advantageous connection of PV plants and BESS (Battery Energy Storage System) into HVDC (High Voltage Direct Current). Basically, it has two modes, Control mode and Power injection mode. Control mode enables bi-directional power to flow control of transmission lines by serving as a series line compensator when needed for grid stability. The other mode, Power injection mode, enables the operation of a PV plant and BESS to inject active power to the grid.

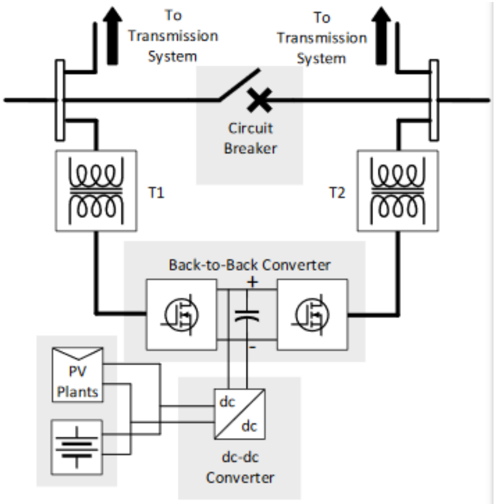

Figure. 1. Proposed novel hybrid back-to-back configuration [1].

Although there have been many publications which a concerned with multi-terminal HVDC systems, the project implement a new approach that provides a higher degree of grid stability and make sure reliable and continued operation of utility-scale power systems which containing increasingly large amounts of inverter-based generation. However, it also has potential risk that total expenses for devices and components may be higher than traditional technologies.

B. 6-Bus Diagram Model

6-bus diagram was simulated based on the results given in [2]. These days, published research of high wind penetration have provided needed results and recommendations for industry planners and government regulators. The Inverter Based Generator Integration Study (IBIS) examined the existence, the cause, and the impact of inverter control interactions based on grid weakness and high levels of IBR on system stability within the SPP operational area [3], [4]. These papers concluded that inverter instability will occur under various conditions. Also, insufficient reactive power produced by inverter-based generation contributes to load voltage instability. The system in [2] was derived from operational data and system models of the transmission grid characteristics observed in the south-central US. The overall dynamics are reduced to an equivalent six bus system. Fig. 1 shows the six bus one-line diagram and is designated by the 138 kV transmission terminals. There are additional busses at 34.5 kV and 69 kV that provide the interconnections for the inverter-based renewable energy. The diagram was developed using Siemens PTI's PSS®E version 33.10 software.

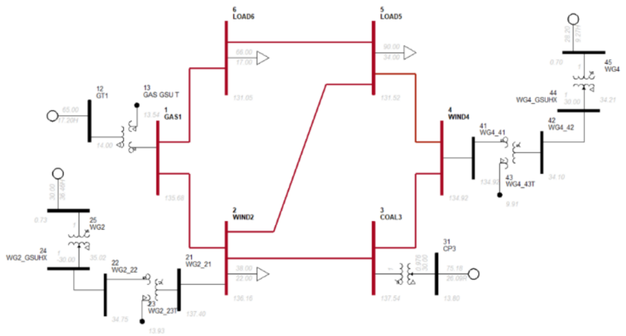

Figure. 2. Six bus system one-line diagram [2].

C. Three Phase Power

In this section, analysis of three-phase power is provided. Figures 3 and 4 show a delta connected three-phase and Y connected three-phase sources.

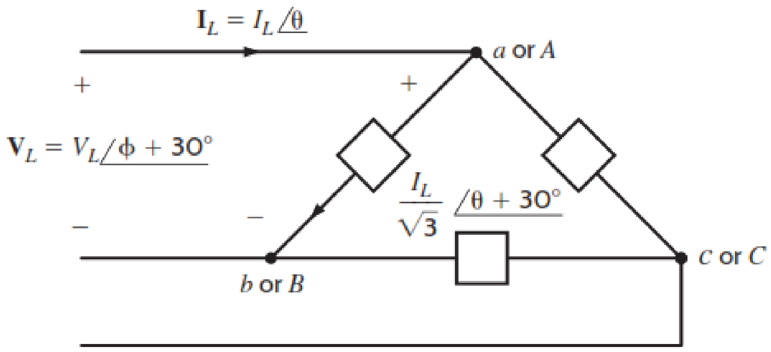

Figure. 3. Delta connected three-phase [5].

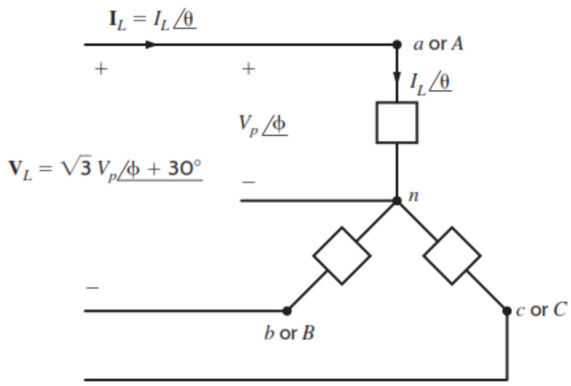

Figure. 4. Y connected three-phase [5].

$$S_{total} = 3 \times V_{lime} \times I_{\Delta} = \sqrt{3} V_{line} \times I_{line}, \tag{1}$$

$$S_{total} = 3 \times V_{phase} \times I_{phase} = \sqrt{3} V_{line} \times I_{line}. \tag{2}$$

Active and reactive power are calculated by following equations:

$$P_{total} = \sqrt{3} |V_{line}| |I_{line}| cos\theta_f, \tag{3}$$

$$Q_{total} = \sqrt{3} |V_{line}| |I_{line}| sinc\theta_f. \tag{4}$$

The angle θ_f is determined by following figure 7:

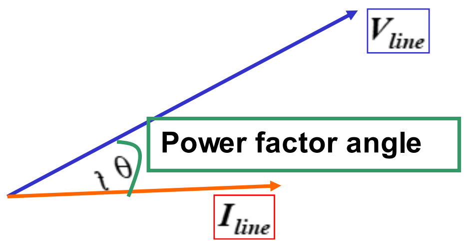

Figure. 5. Power factor angle.

This paper provides results of verification of the six bus system with Matlab/Simulink. Part II provides how to set up and proceed the computer-based experiments and data of base systems is provided. Part III. provides the results of the experiment and responses for fault conditions. Then, the simulation results are summarized in Part IV.

II. APPROACH AND METHODS

Testing was performed in 6-bus model diagram is focused on. The 138 kV six bus system shown in Fig. 6 was developed by Matlab R2020b and Simulink. Simulink makes it possible to build and simulate a wide range of circuit designs, and Matlab can implement complex calculations and graphing results. Therefore, they are used as one of the popular simulation software in Power Electronics research area. The base system was set up based on the model Fig 2. It has 30% inverter penetration and consists of 138 kV buses connected via seven 138 kV transmission lines of various lengths between loads (red), one conventional gas plant (yellow), one conventional coal plant (gray), two DFIG inverter plants (blue), and four loads.

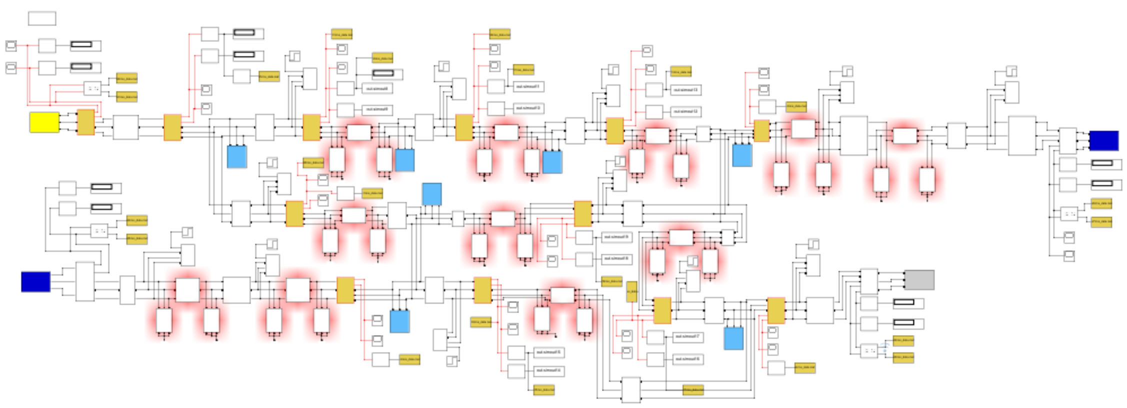

Figure. 6. Whole diagram of six bus system.

A. Simulation Model and Parameter Values

The parameters for the transmission lines are taken from the actual power flow data in Southwest Power Pools (SPP) models [2] to proceed with a valid simulation of the various line lengths and impedances of a real system. The system loads are taken from SPP models as well to get a fair representation of actual bus MVA loads and are shown in Fig 6. The generator step up transformers, collector systems, three-winding substation transformers, and interconnection lines were included for the inverter for completeness to get a true depiction. The power flow data of buses are shown in Table I. This includes the buses of generators and loads that are connected.

Load	**Base kV**	**Pgen MW**	**Pmax MW**	**Qgen MVar**	**Qmax MVar**	**Pload MW**	**Qload MVar**
2	138.0	----	----	----	----	38.0	22.0
5	138.0	----	----	----	----	90.0	34.0
6	138.0	----	----	----	----	66.0	17.0
Gas	13.8	65.0	83.44	17.20	17.20	----	----
Wind1	0.7	30.0	80.0	36.46	36.46	----	----
Coal	13.8	75.18	88.0	26.09	56.0	----	----
Wind2	0.7	28.20	100.0	9.27	9.27	----	----

Table 1. Base System Generator and Load Data

The Table II shows the impedance data of each base system branch. Values are given in per-unit based on the nominal voltage on the respective side of the neighboring transformer.

From Bus	To Bus	To Bus	R (pu)	X (pu)	B (pu)	Line Length (miles)
1	2	----	0.010690	0.047000	0.013760	12.25
1	6	----	0.034230	0.074900	0.017090	17.28
2	3	----	0.008361	0.059166	0.016520	15.0
2	5	----	0.024660	0.140000	0.040260	36.0
3	4	----	0.020750	0.120290	0.032550	30.20
4	5	----	0.013800	0.080000	0.022180	20.28
5	6	----	0.023940	0.072480	0.018080	17.5
2	21	----	0.003225	0.023583	0.006790	6.13
4	41	----	0.000007	0.000040	0.000010	0.01
22	24	----	0.010850	0.013410	0.032900	19.6
42	44	----	0.007790	0.011190	0.009070	1.0
24	25	----	0.005820	0.065740	----	2WTxf
3	31	----	0.005300	0.106000	----	2WTxf
44	45	----	0.007500	0.060000	----	2WTxf
21	22	23	0.00161 0.00058 0.0023	0.08699 0.03129 0.12448	0.0008	3WTxf
42	41	43	198636.8 456336.6 370410.8	0.0881 0.147 0.0378	0.00075	3WTxf
12	1	13	109995 71241	0.1174 0.1107	0.00189	3WTxf

From Bus	To Bus	To Bus	R (pu)	X (pu)	B (pu)	Line Length (miles)
			98311.01	0.2014		

Table 2. Base System Branch Data

Note: 3WTxf data in p.u. or Watts

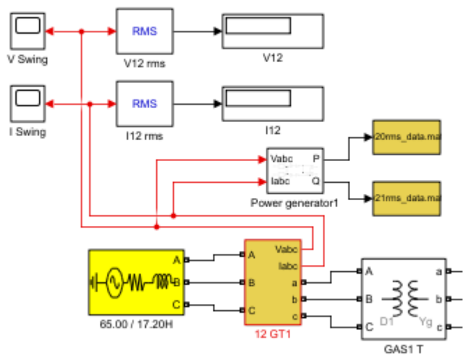

Figure. 7. Gas generator

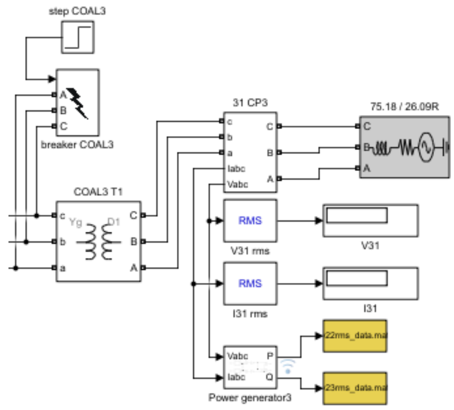

Figure. 8. Coal generator

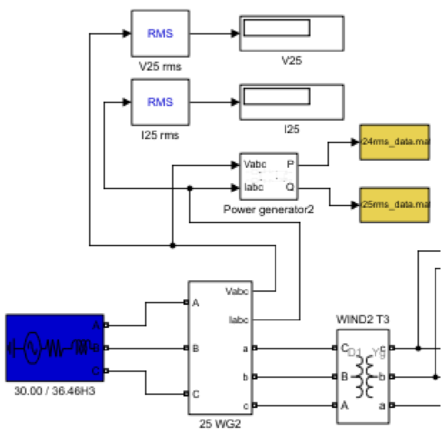

Figure. 9. Wind1 generator

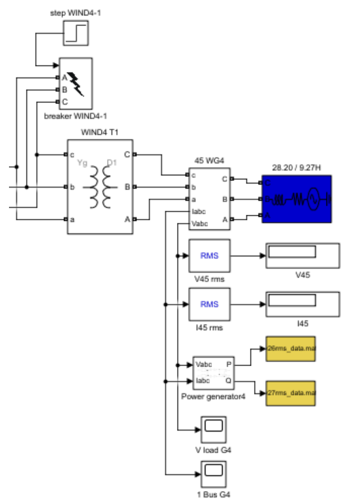

Figure. 10. Wind2 generator

B. Fault Condition

Fault conditions are described in Fig 11. A step-up component and circuit breaker are for opening the associated bus, and are closed again after the fault is cleared. This affects bus voltage stability, and the results are recorded. A fault location and circuit breaker operation (labelled ‘step load5’ and ‘breaker load5’) are logged for the voltage response. Then, both ends of the three-phase circuit breaker (Breaker 4-1 & Breaker 4-2) open after 6 electrical cycles. It makes possible to observe the voltage stability of loads due to specific line fault scenarios.

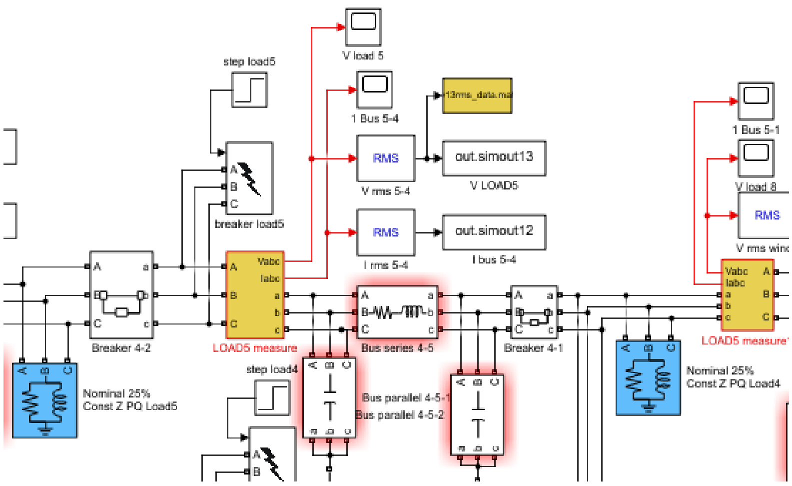

Figure. 11. Fault condition set up

C. Simulation Method

Fault condition simulations were performed in Matlab/Simulink to assess transient stability of the inverter plants due to system fault events. Three phase faults were applied to all 138 kV buses for all models with clearing times ranging from 4 cycles to 8 cycles by using the steps shown in the following example (referenced to 60 Hz system operation):

1) Set step up frequency to 2/60 to the specific fault line.
2) Set frequency of two both ends of line three-phase breaker to [6/60, 60/60] and initial condition to closed.

3) Set step up frequency to 0.2 to other fault lines
4) Set frequency of other three-phase breaker to [10/60, 15/60] and initial condition to closed.
5) Run the simulation for 0.2 seconds.
6) Take figures of three-phase voltage and rms voltage for Load1, 2, 3, and 6 and bus 1-2.
7) Take figures of active and reactive power of each generator loads.

Then, voltage stability of 138kV loads are observed, and the impact of fault line to voltage stability is figured out. In this simulation, there are several lines connected to each bus. Therefore, the fault is applied to only one bus in each simulation so that voltage stability can be observed influenced by fault condition.

III. RESULTS AND DISCUSSION

138 kV load voltages and generator side voltages of fault condition simulation are summarized in table. Also, 3-phase sinusoidal voltage wave and rms value plot of Load1, Load2, Load3, Load6, and Bus1-2 are shown. Finally, plots of active power and reactive power of gas, coal, and two wind generators.

According to table and figures, at the fault of bus 1-2, based on three-phase voltage and rms voltage, it can be observed that voltage stability is impacted during circuit breaker condition is changed.

A. Fault condition of Bus 1-2

At the fault of bus 1-2, voltage stability of load 2 and 6 is the most critical. Also, transient waves are observed in generator gas and coal.

	Initial(kV)	Fault(kV)	Final(kV)
Load1	126.1	0	113.0
Load2	74.5	39.4	68.8
Load3	73.3	37.8	67.7
Load4	127.3	64.0	117.8
Load5	126.9	42.8	116.4
Load6	126.2	21.5	114.6
Gas	126.1	0	113.2
Coal	73.2	38.0	67.7
Wind1(left)	74.5	39.3	68.8
Wind2(right)	127.3	64.1	95.9

Table 3. Voltages for fault condition of bus 1-2

Load1:

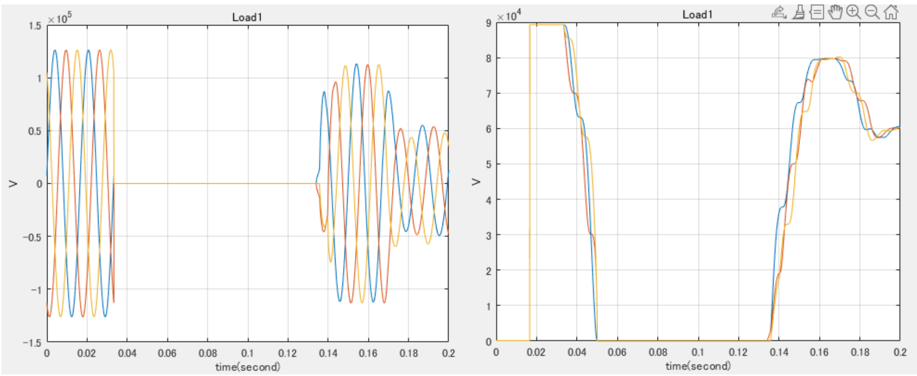

Figure. 12. Three-phase and rms voltage plot of Load1 for fault at bus 1-2

Load2:

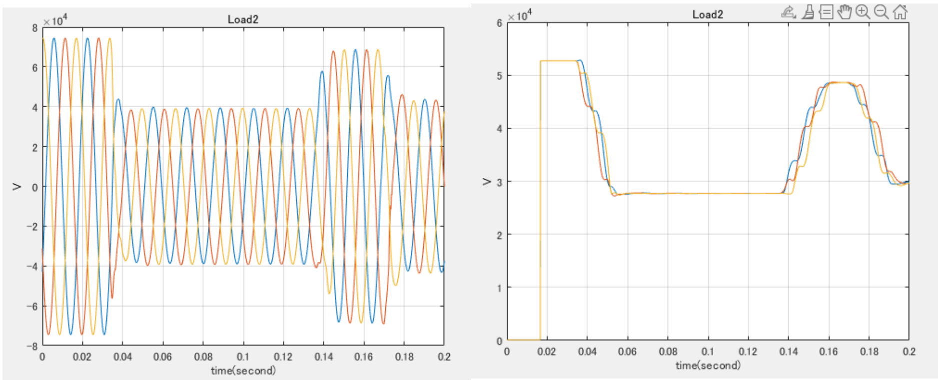

Figure. 13. Three-phase and rms voltage plot of Load2 for fault at bus 1-2

Load3:

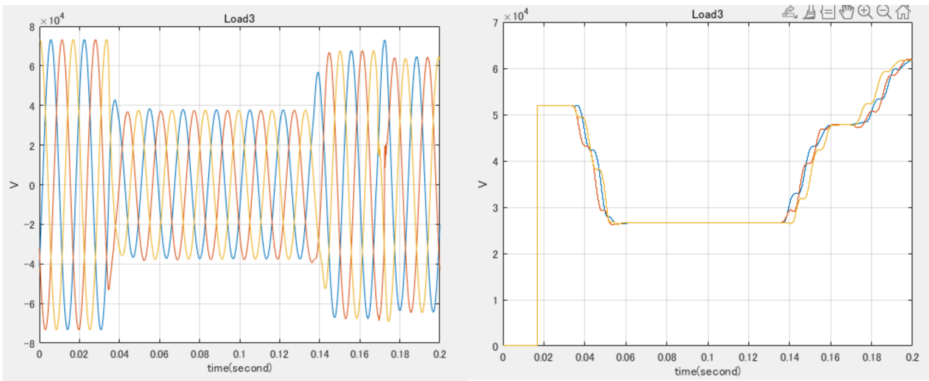

Figure. 14. Three-phase and rms voltage plot of Load3 for fault at bus 1-2

Load6:

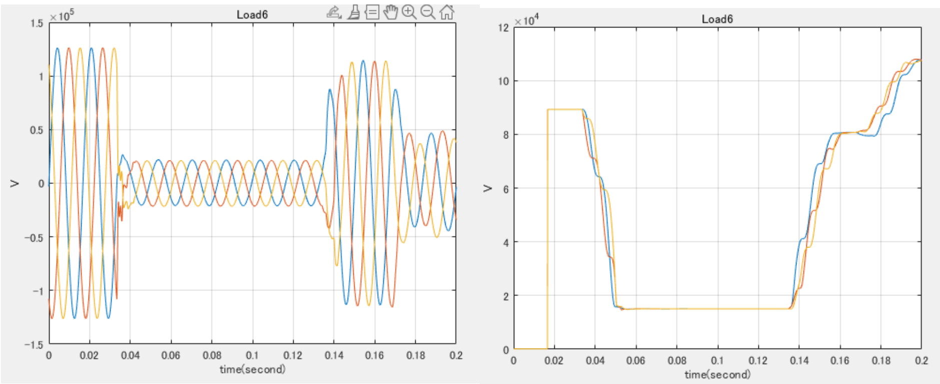

Figure. 15. Three-phase and rms voltage plot of Load6 for fault at bus 1-2

Bus1-2:

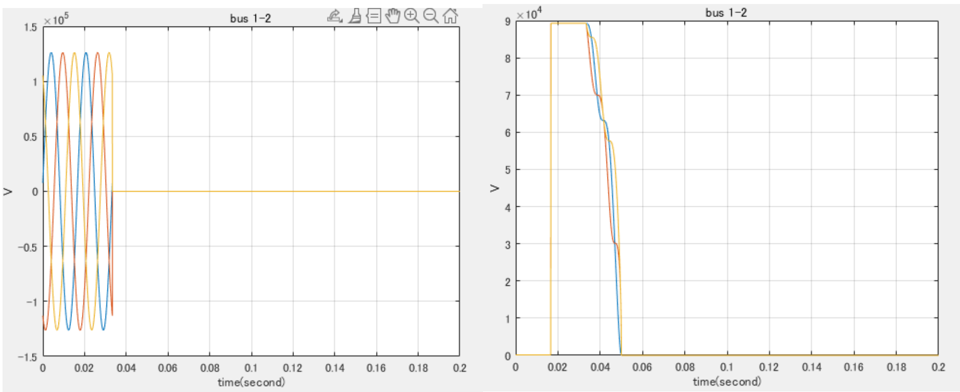

Figure. 16. Three-phase and rms voltage plot of Bus1-2 for fault at bus 1-2

Gas(P&Q):

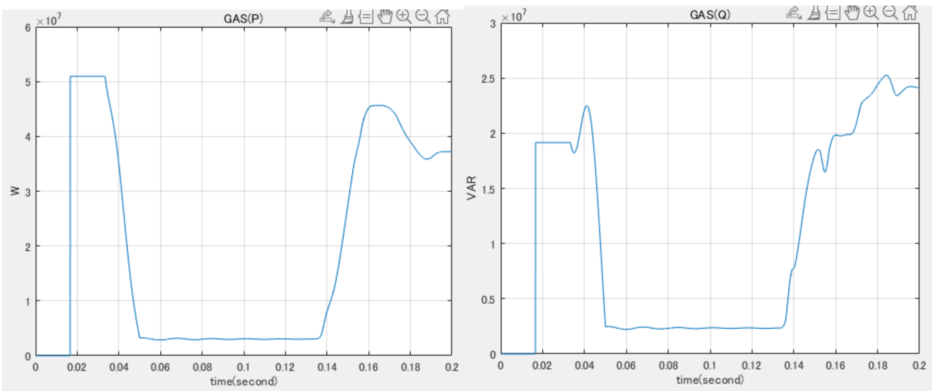

Figure. 17. Active and reactive power plot of gas generator for fault at bus 1-2

Coal(P&Q):

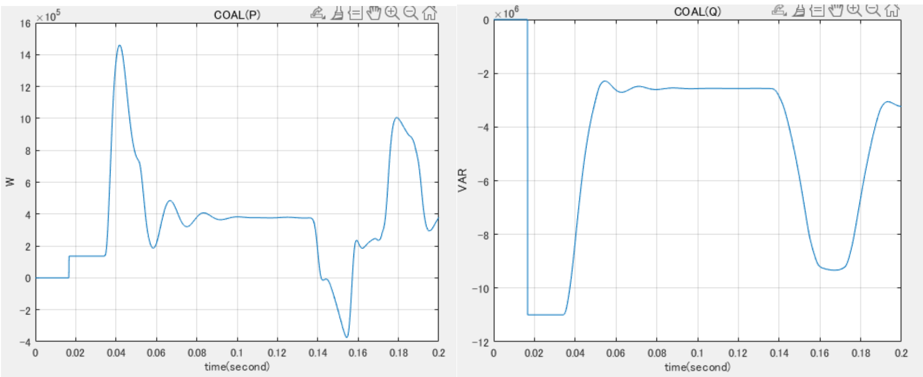

Figure. 18. Active and reactive power plot of coal generator for fault at bus 1-2

Wind1(P&Q):

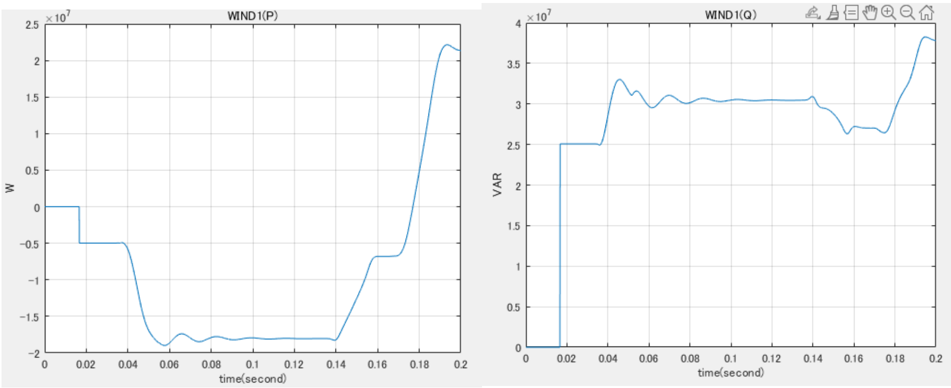

Figure. 19. Active and reactive power plot of wind1 generator for fault at bus 1-2

Wind2(P&Q):

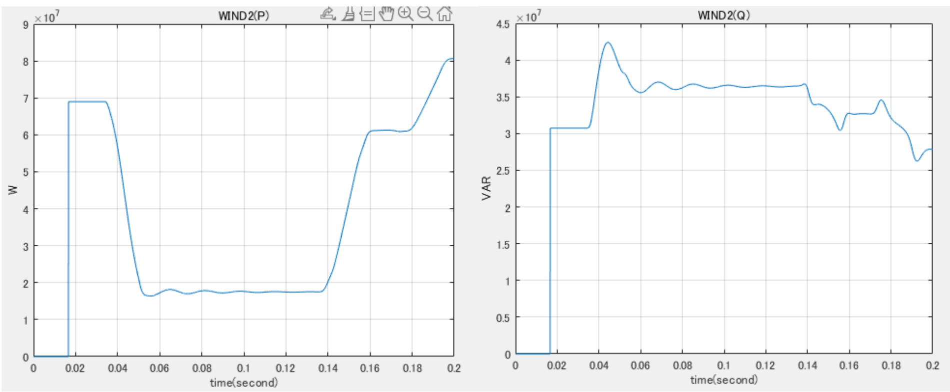

Figure. 20. Active and reactive power plot of wind2 generator for fault at bus 1-2

B. Fault condition of Bus 1-6

At the fault of bus 1-6, voltage stability of load 6 is the most critical.

	Initial(kV)	Fault(kV)	Final(kV)
Load1	126.2	0	0
Load2	74.5	39.4	67.4
Load3	73.3	37.8	66.0
Load4	127.3	64.5	114.4
Load5	127.1	42.9	114.4
Load6	126.1	21.8	114.3
Gas	126.1	0	143.8
Coal	73.2	38.0	65.9
Wind1(left)	74.5	39.3	67.4
Wind2(right)	38.9	36.8	41.8

Table 4. Voltages for fault condition bus 1-6

Load1:

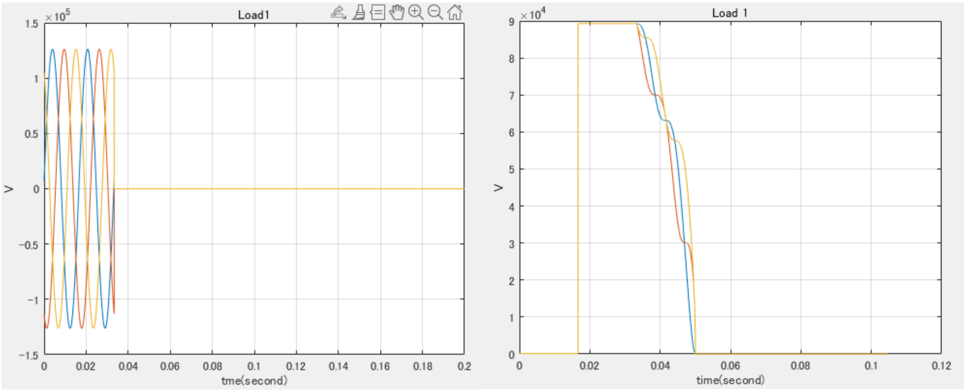

Figure. 21. Three-phase and rms voltage plot of Load1 for fault at bus 1-6

Load2:

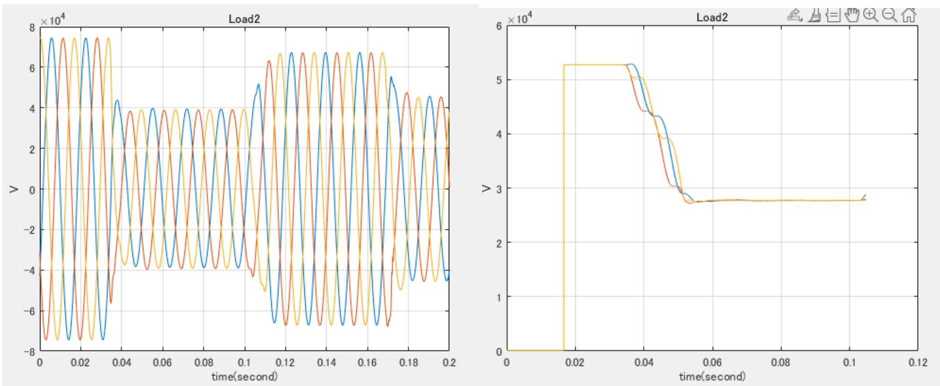

Figure. 22. Three-phase and rms voltage plot of Load2 for fault at bus 1-6

Load3:

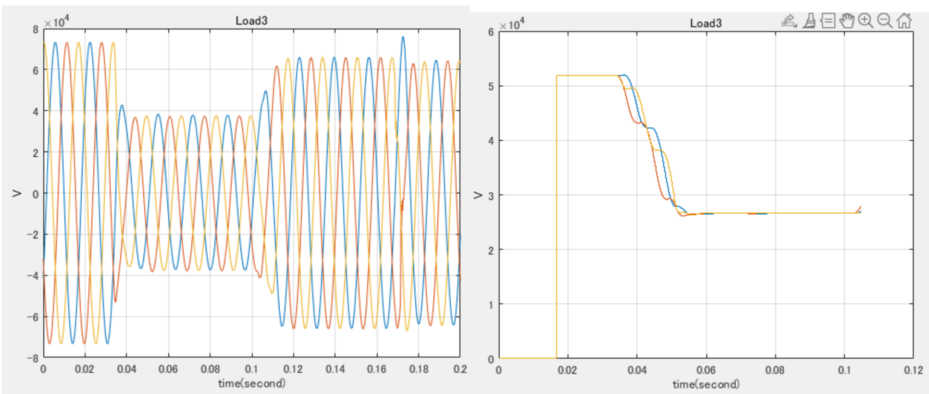

Figure. 23. Three-phase and rms voltage plot of Load3 for fault at bus 1-6

Load6:

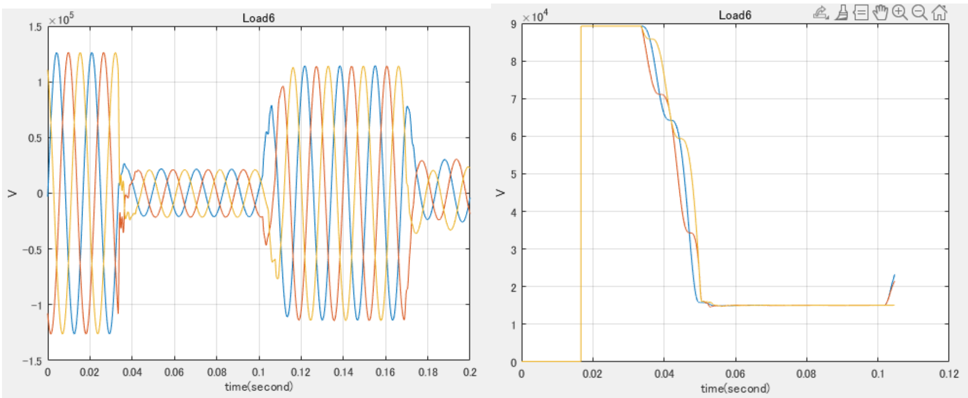

Figure. 24. Three-phase and rms voltage plot of Load6 for fault at bus 1-6

Bus1-2:

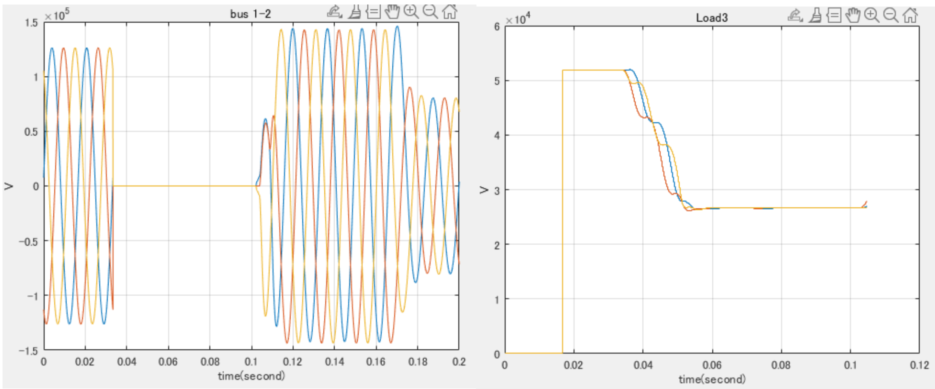

Figure. 25. Three-phase and rms voltage plot of Bus1-2 for fault at bus 1-6

C. Fault condition of Bus 2-3

At the fault of bus 2-3, voltage stability of load 6 and bus 1-2 is the most critical. Also, transient waves are observed especially when circuit breaker changes from closed to open.

	Initial(kV)	Fault(kV)	Final(kV)
Load1	126.0	56.6	112.1
Load2	74.5	0	0

Load3	73.3	46.5	62.6
Load4	127.3	15.9	111.0
Load5	126.9	29.7	111.4
Load6	126.2	43.2	111.5
Gas	126.1	56.8	112.4
Coal	73.2	4.65	62.6
Wind1(left)	74.5	0	68.2
Wind2(right)	0.34	0.59	0.39

Table 5. Voltages for fault condition bus 2-3

Load1:

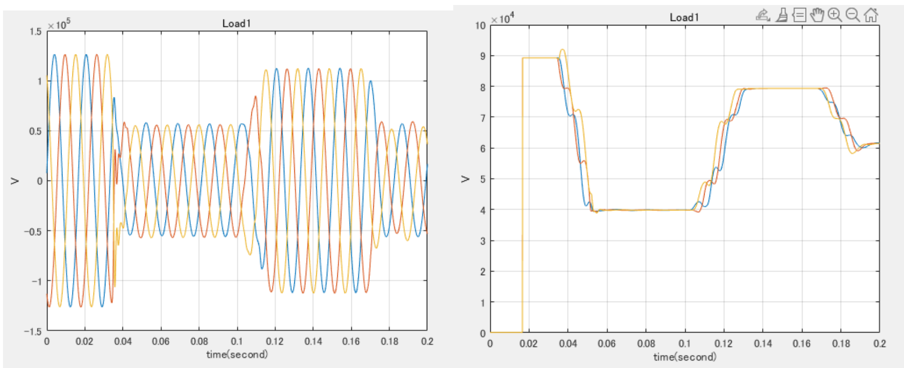

Figure. 26. Three-phase and rms voltage plot of Load1 for fault at bus 2-3

Load2:

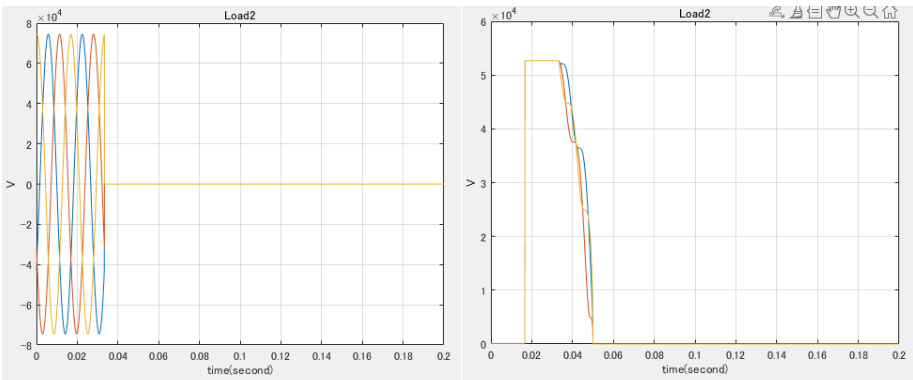

Figure. 27. Three-phase and rms voltage plot of Load2 for fault at bus 2-3

Load3:

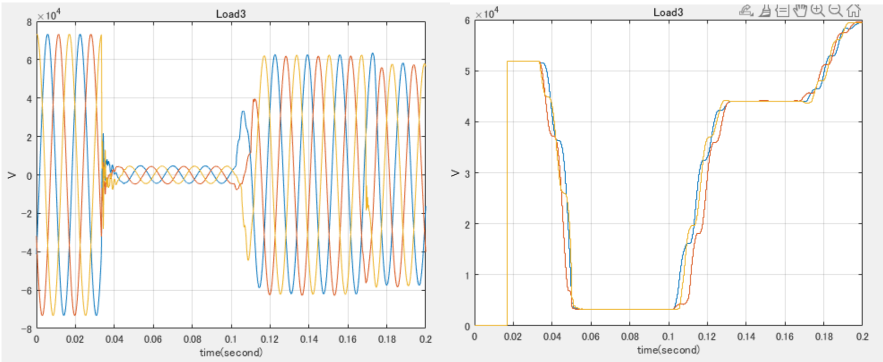

Figure. 28. Three-phase and rms voltage plot of Load3 for fault at bus 2-3

Load6:

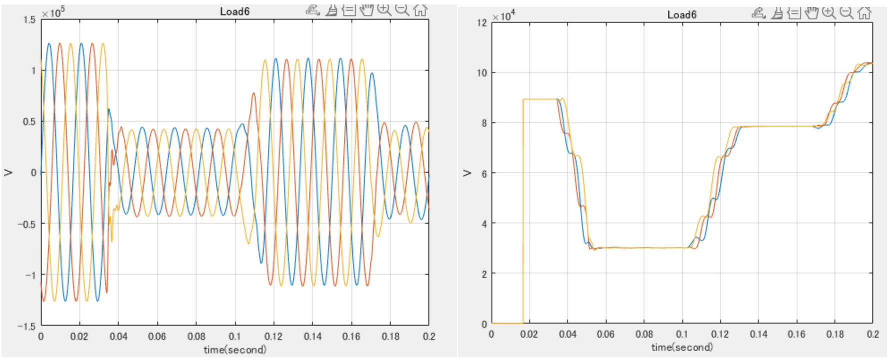

Figure. 29. Three-phase and rms voltage plot of Load6 for fault at bus 2-3

Bus1-2:

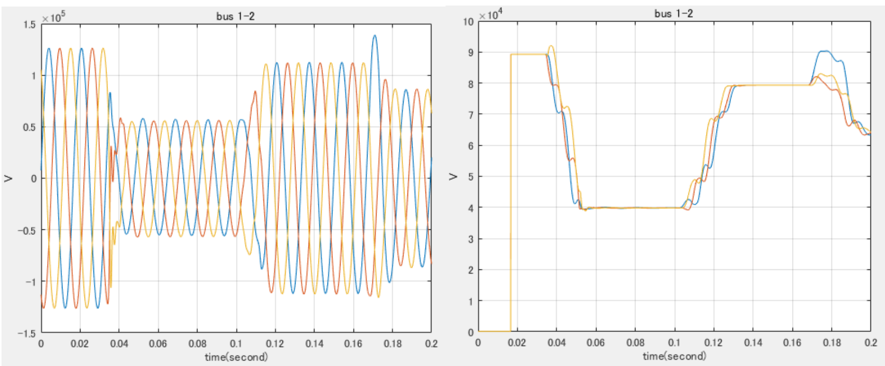

Figure. 30. Three-phase and rms voltage plot of Bus1-2 for fault at bus 2-3

Gas(P&Q):

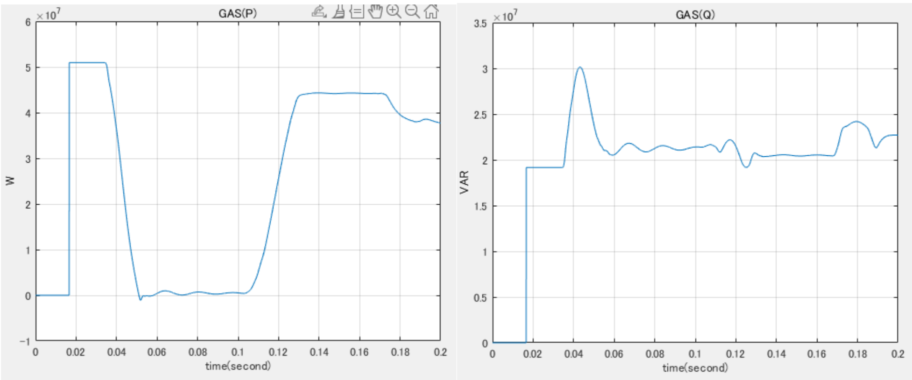

Figure. 31. Active and reactive power plot of gas generator for fault at bus 2-3

Coal(P&Q):

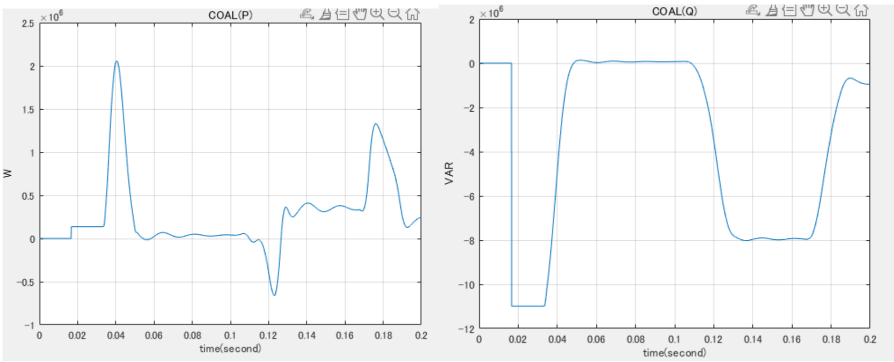

Figure. 32. Active and reactive power plot of coal generator for fault at bus 2-3

Wind1(P&Q):

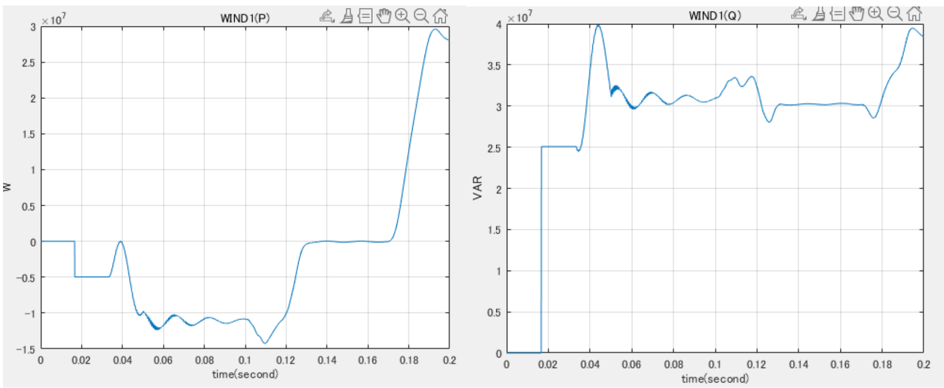

Figure. 33. Active and reactive power plot of wind1 generator for fault at bus 2-3

Wind2(P&Q):

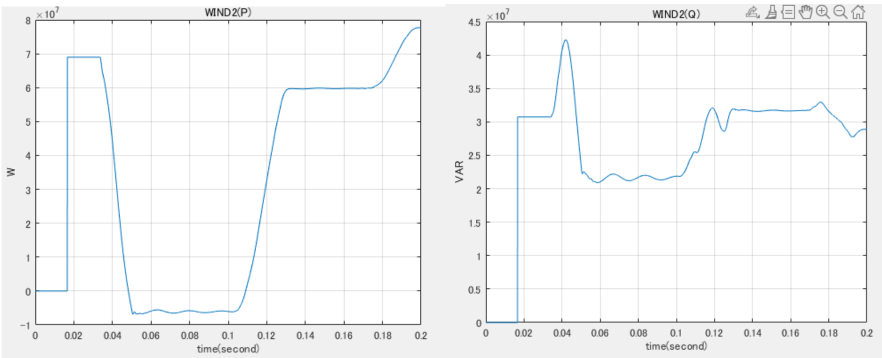

Figure. 34. Active and reactive power plot of wind2 generator for fault at bus 2-3

D. Fault condition of Bus 3-4

At the fault of bus 3-4, voltage stability of load 2 and bus 1-2 is the most critical. Also, transient waves are observed at generator loads during fault condition.

	Initial(kV)	Fault(kV)	Final(kV)
Load1	126.0	53.9	114.6
Load2	74.5	4.32	65.3
Load3	73.3	0	0
Load4	127.3	11.62	113.5
Load5	126.9	25.9	113.9
Load6	126.2	39.9	113.9
Gas	126.1	53.9	114.8
Coal	73.2	0	64.2

Wind1(left)	74.5	4.328	65.7
Wind2(right)	0.39	0.61	0.38

Table 6. Voltages for fault condition bus 3-4

Load1:

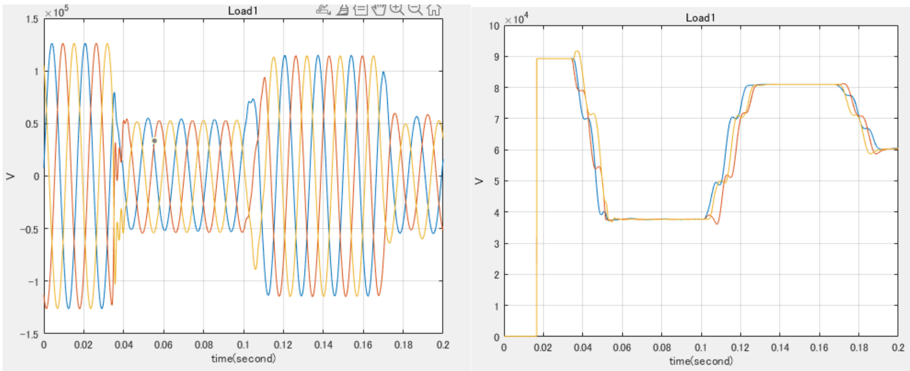

Figure. 35. Three-phase and rms voltage plot of Load1 for fault at bus 3-4

Load2:

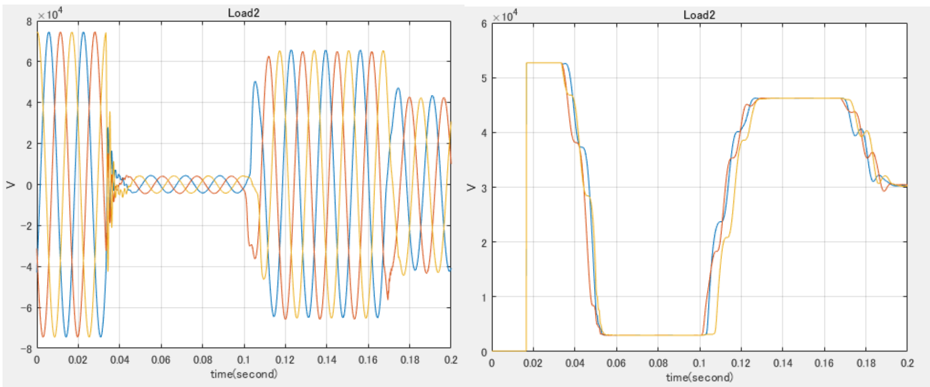

Figure. 36. Three-phase and rms voltage plot of Load2 for fault at bus 3-4

Load3:

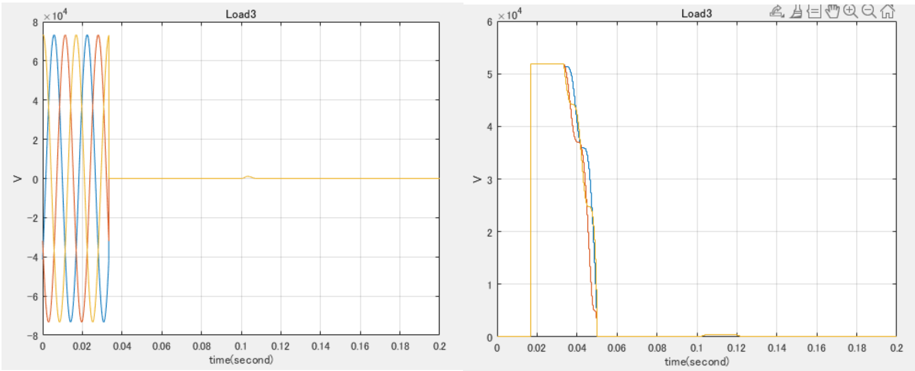

Figure. 37. Three-phase and rms voltage plot of Load3 for fault at bus 3-4

Load6:

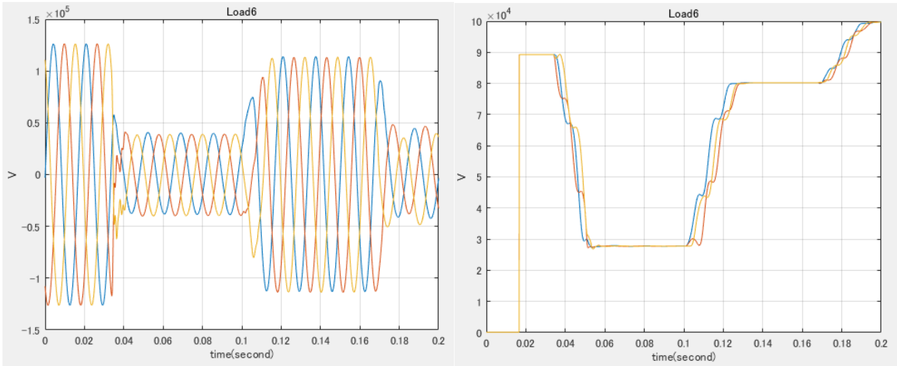

Figure. 38. Three-phase and rms voltage plot of Load6 for fault at bus 3-4

Bus1-2:

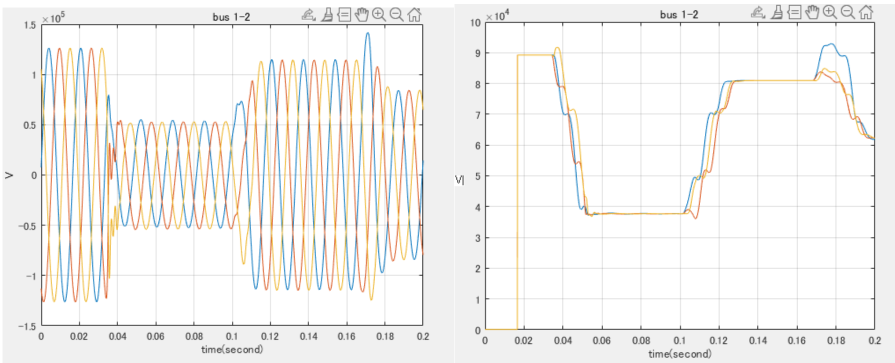

Figure. 39. Three-phase and rms voltage plot of Bus1-2 for fault at bus 3-4

Gas(P&Q):

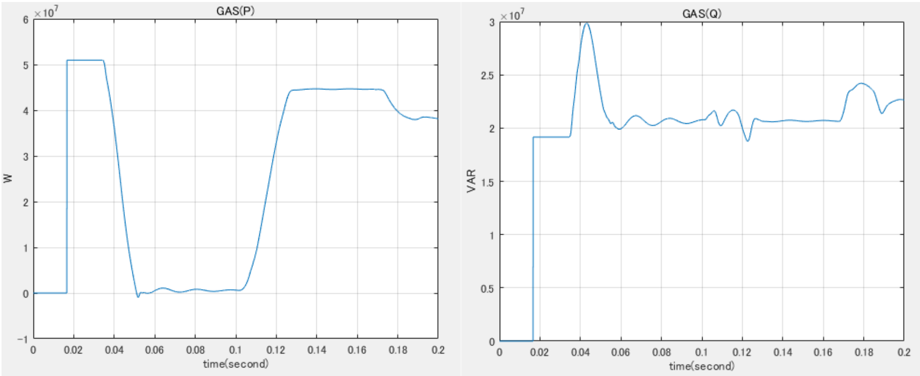

Figure. 40. Active and reactive power plot of gas generator for fault at bus 3-4

Coal(P&Q):

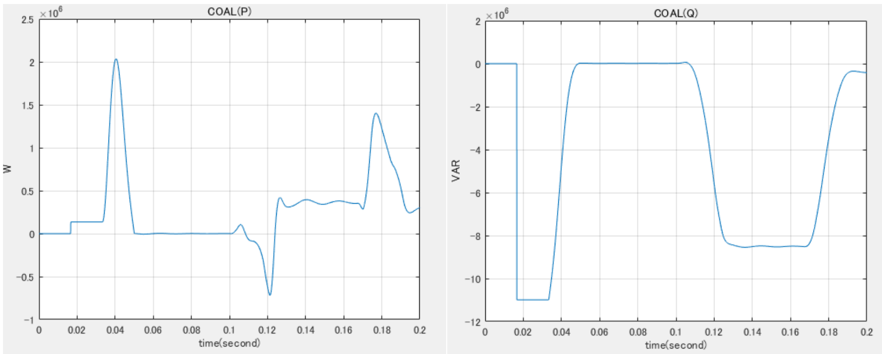

Figure. 41. Active and reactive power plot of coal generator for fault at bus 3-4

Wind1(P&Q):

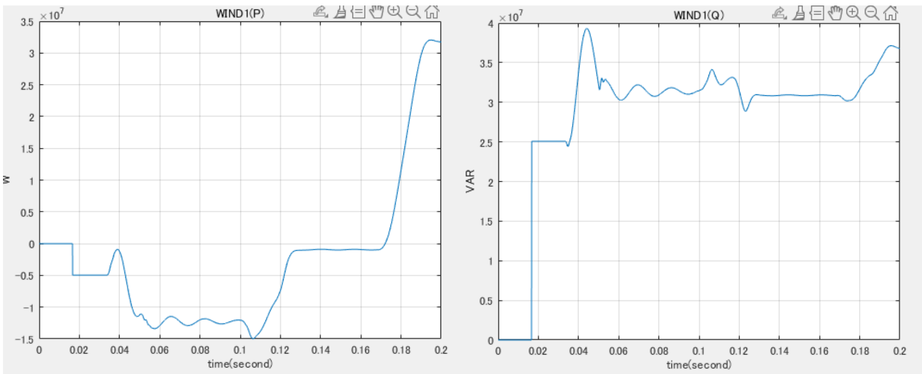

Figure. 42. Active and reactive power plot of wind1 generator for fault at bus 3-4

Wind2(P&Q):

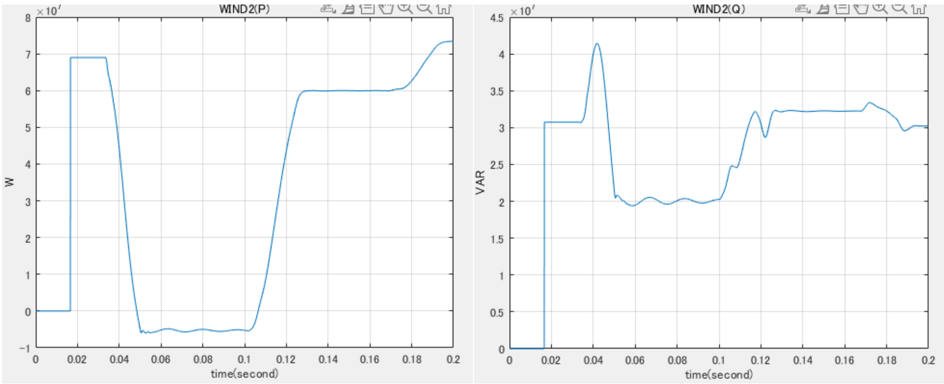

Figure. 43. Active and reactive power plot of wind2 generator for fault at bus 3-4

E. Fault condition of Bus 2-4

At the fault of bus 2-4, voltage stability of load 2 and 3 is the most critical. Also, transient waves are observed at gas, coal, and wind1 generator.

	Initial(kV)	Fault(kV)	Final(kV)
Load1	126.0	45.8	111.9
Load2	73.3	4.76	64.5
Load3	73.3	2.39	63.2
Load4	127.3	0	0
Load5	126.9	15.4	110.3
Load6	126.2	30.6	110.4
Gas	126.1	45.6	112.1
Coal	73.2	2.36	63.1
Wind1(left)	74.5	4.77	64.5

Wind2(right)	0.29	0.37	-0.30

Table 7. Voltages for fault condition bus 2-4

Load1:

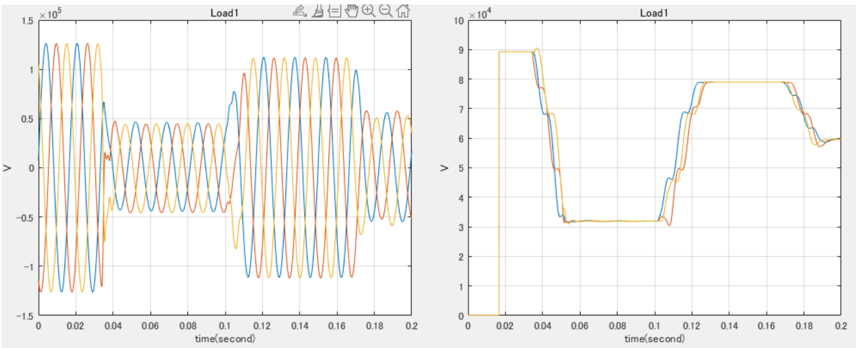

Figure. 44. Three-phase and rms voltage plot of Load1 for fault at bus 2-4

Load2:

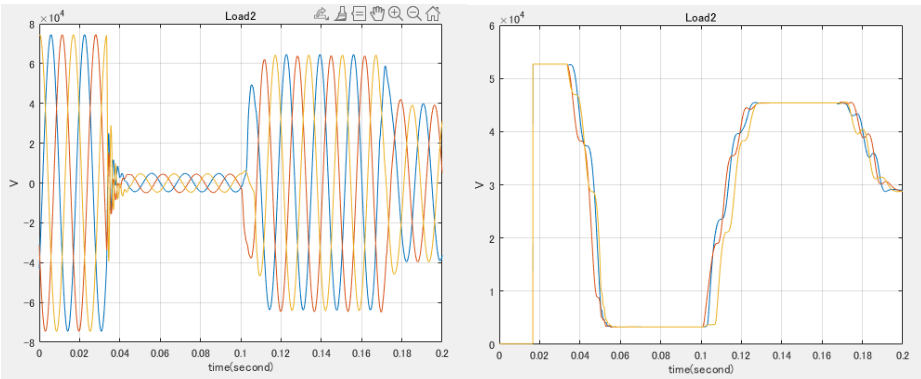

Figure. 45. Three-phase and rms voltage plot of Load2 for fault at bus 2-4

Load3:

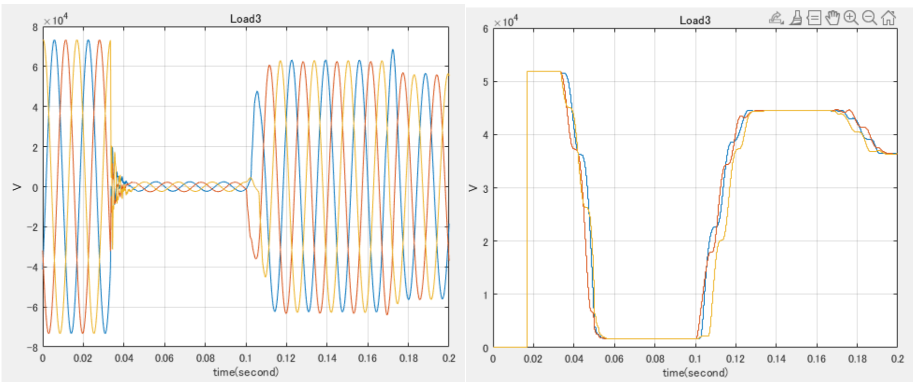

Figure. 46. Three-phase and rms voltage plot of Load3 for fault at bus 2-4

Load6:

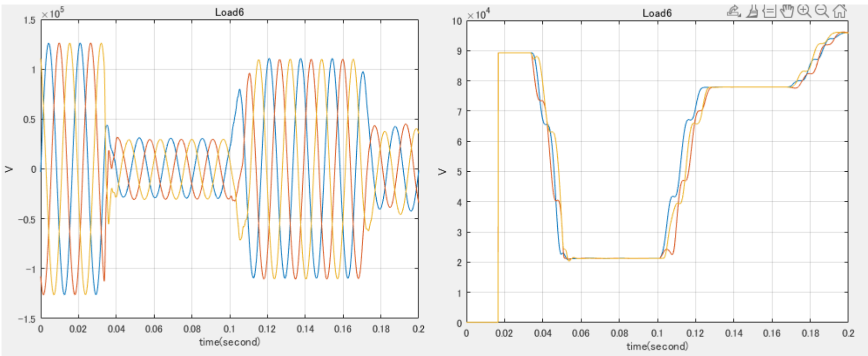

Figure. 47. Three-phase and rms voltage plot of Load6 for fault at bus 2-4

Bus1-2:

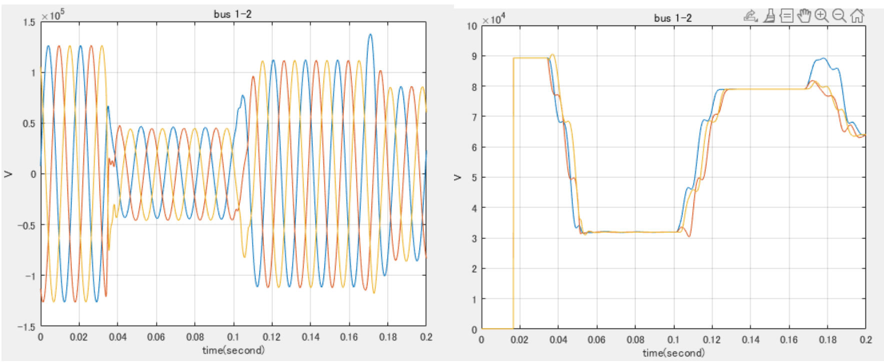

Figure. 48. Three-phase and rms voltage plot of Bus1-2 for fault at bus 2-4

Gas(P&Q):

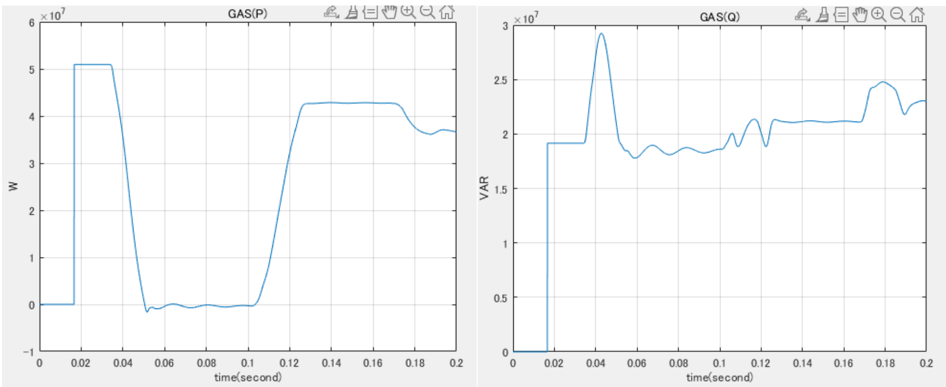

Figure. 49. Active and reactive power plot of gas generator for fault at bus 2-4

Coal(P&Q):

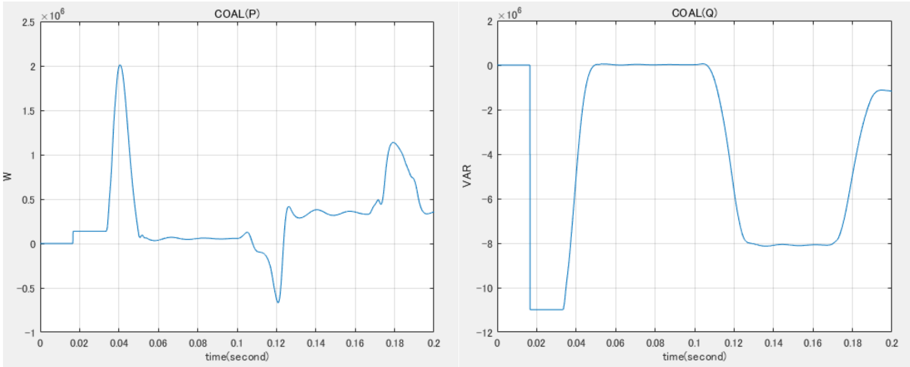

Figure. 50. Active and reactive power plot of coal generator for fault at bus 2-4

Wind1(P&Q):

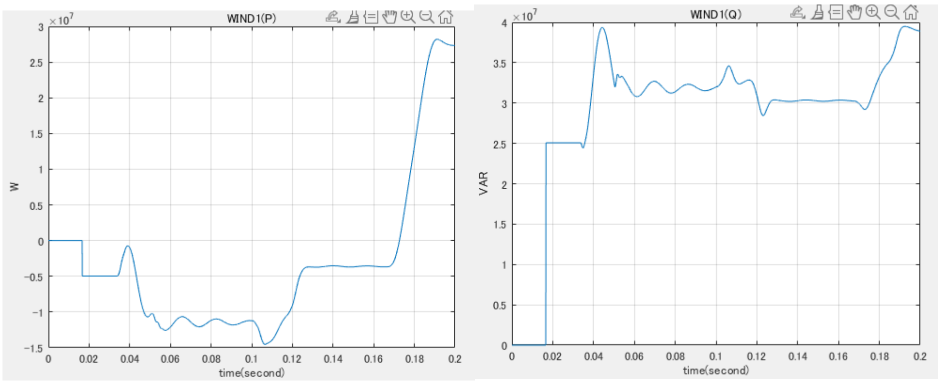

Figure. 51. Active and reactive power plot of wind1 generator for fault at bus 2-4

Wind2(P&Q):

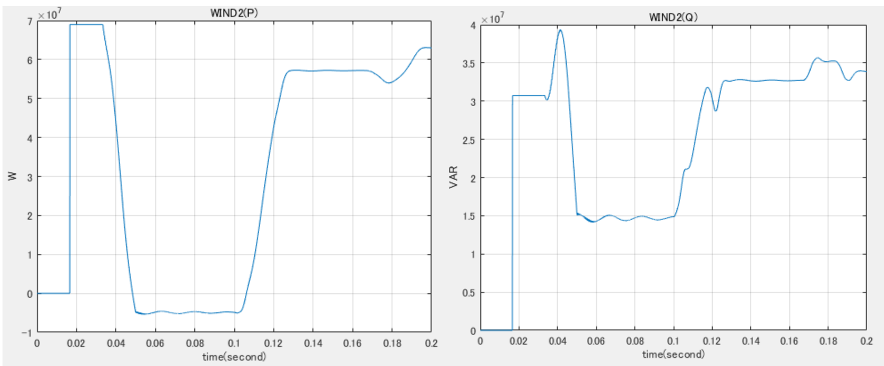

Figure. 52. Active and reactive power plot of wind2 generator for fault at bus 2-4

F. Fault condition of Bus 4-5

At the fault of bus 4-5, voltage stability of load 6 and bus 1-2 is the most critical. Also, transient waves are observed at power waves at generators gas, coal, and wind2.

	Initial(kV)	Fault(kV)	Final(kV)
Load1	125.9	34.4	98.4
Load2	74.5	22.1	68.9
Load3	73.3	20.2	67.6
Load4	127.3	32.6	117.5
Load5	126.9	0	0
Load6	126.1	17.3	95.4
Gas	126.1	34.3	98.1
Coal	73.2	20.4	67.3
Wind1(left)	74.5	22.0	68.9
Wind2(right)	0.39	0.53	0.38

Table 8. Voltages for fault condition bus 4-5

Load1:

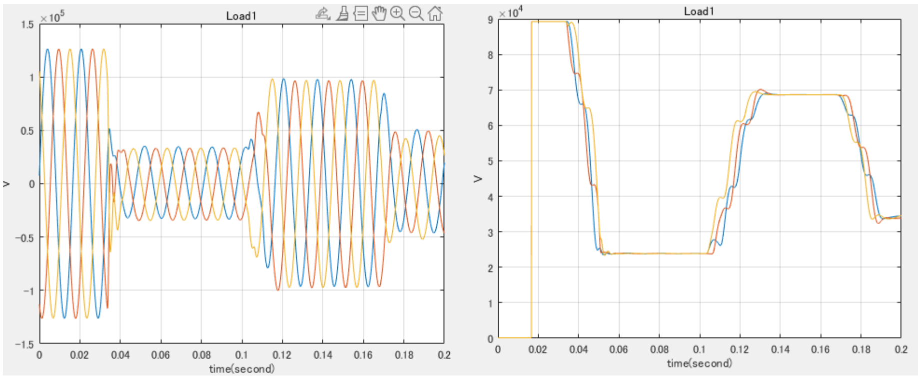

Figure. 53. Three-phase and rms voltage plot of Load1 for fault at bus 4-5

Load2:

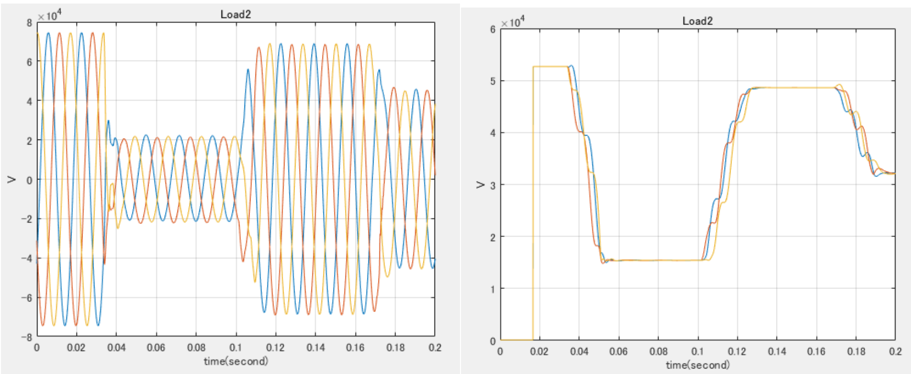

Figure. 54. Three-phase and rms voltage plot of Load2 for fault at bus 4-5

Load3:

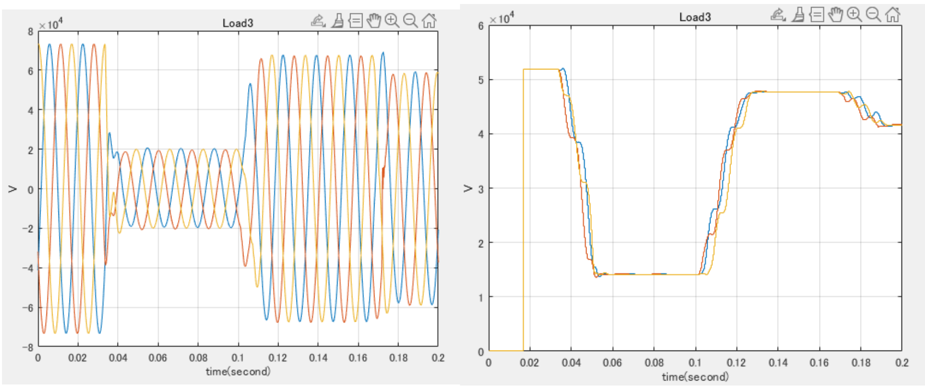

Figure. 55. Three-phase and rms voltage plot of Load3 for fault at bus 4-5

Load6:

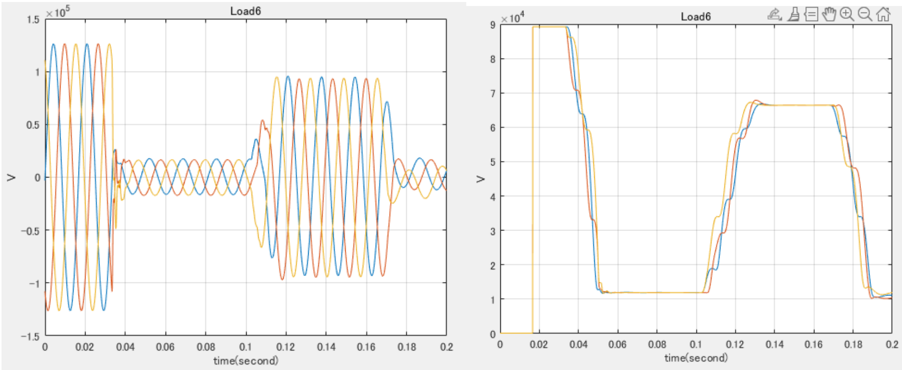

Figure. 56. Three-phase and rms voltage plot of Load6 for fault at bus 4-5

Bus1-2:

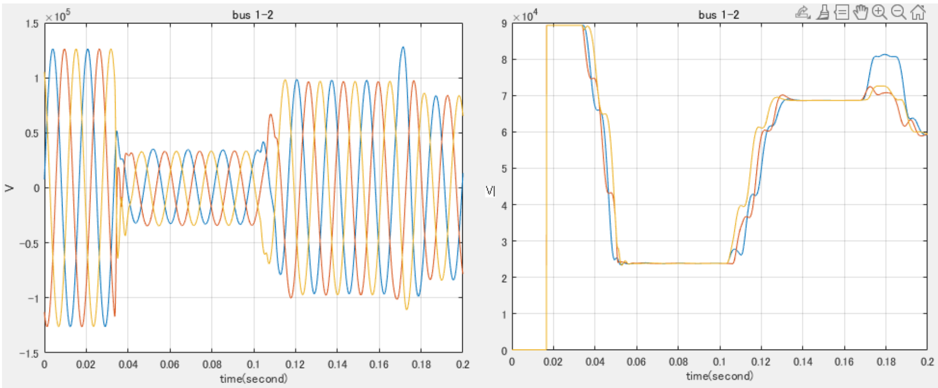

Figure. 57. Three-phase and rms voltage plot of Bus1-2 for fault at bus 4-5

Gas(P&Q):

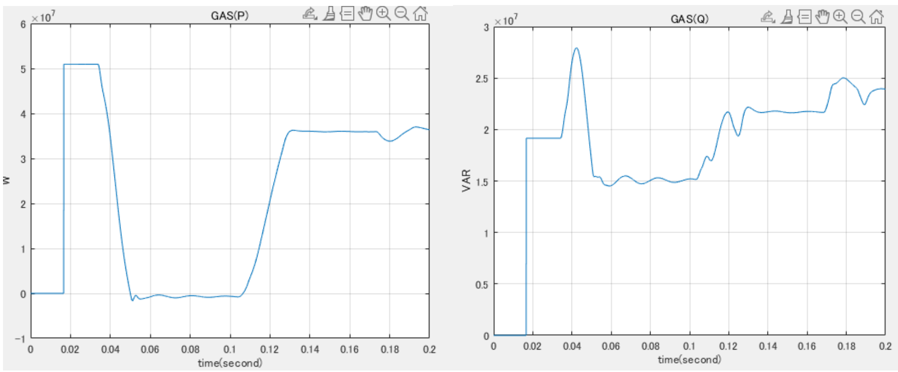

Figure. 58. Active and reactive power plot of gas generator for fault at bus 4-5

Coal(P&Q):

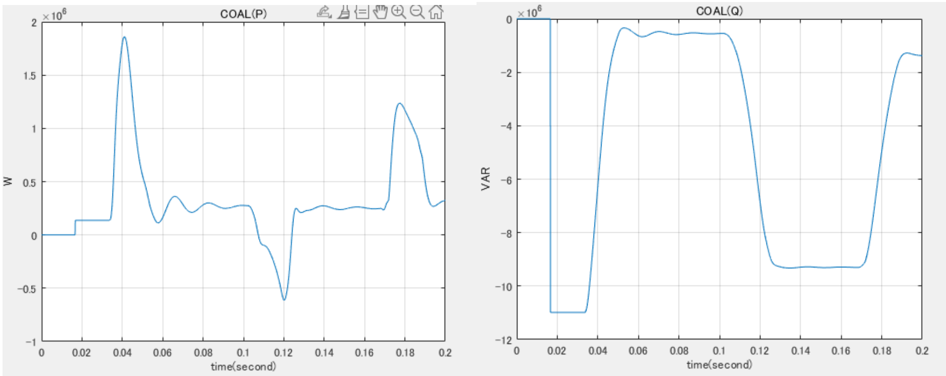

Figure. 59. Active and reactive power plot of coal generator for fault at bus 4-5

Wind1(P&Q):

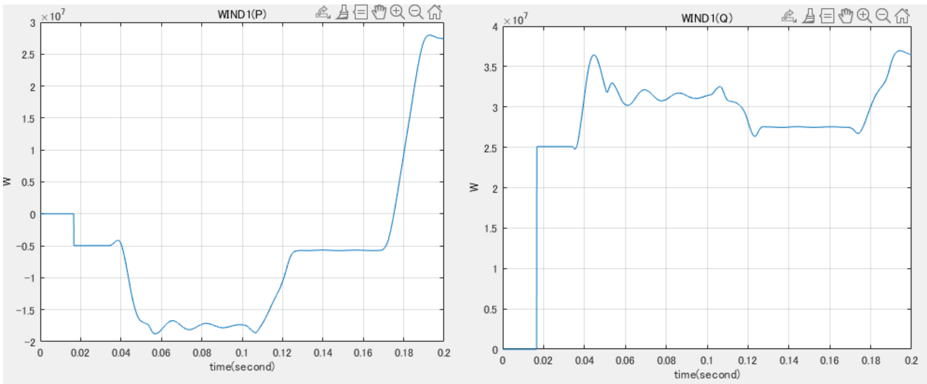

Figure. 60. Active and reactive power plot of wind1 generator for fault at bus 4-5

Wind2(P&Q):

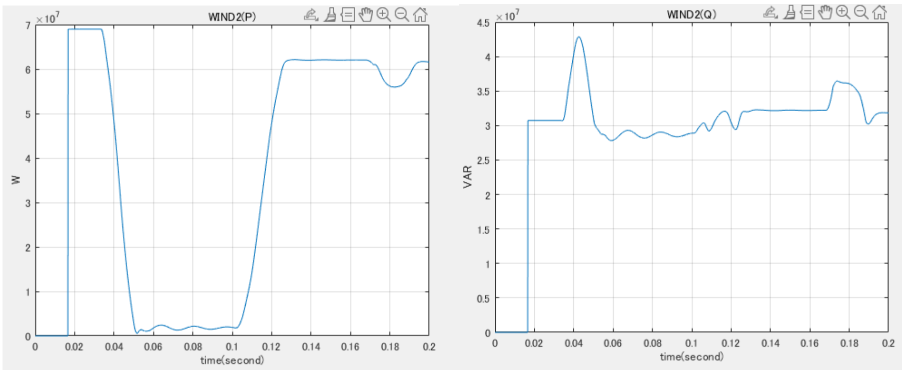

Figure. 61. Active and reactive power plot of wind2 generator for fault at bus 4-5

G. Fault condition of Bus 5-6

At the fault of bus 1-2, voltage stability of load 1 and bus 1-2 is the most critical. Also, transient waves are observed at power waves at generators gas, coal, and wind2.

	Initial(kV)	Fault(kV)	Final(kV)
Load1	124.2	19.3	119.0
Load2	73.3	32.7	73.3
Load3	71.2	31.1	72.1
Load4	127.3	52.1	125.2
Load5	126.9	26.2	126.2
Load6	126.1	0	0
Gas	126.1	19.3	119.1
Coal	73.2	30.8	72.0
Wind1(left)	74.5	32.7	73.3
Wind2(right)	127.3	52.1	125.4

Table 9. Voltages for fault condition bus 5-6

Load1:

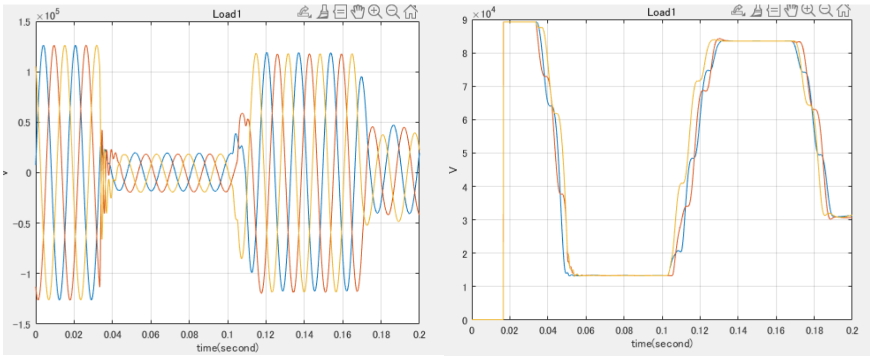

Figure. 62. Three-phase and rms voltage plot of Load1 for fault at bus 5-6

Load2:

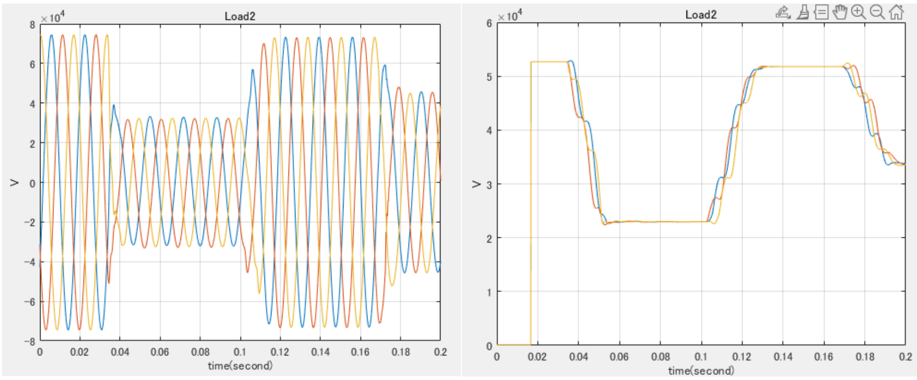

Figure. 63. Three-phase and rms voltage plot of Load2 for fault at bus 5-6

Load3:

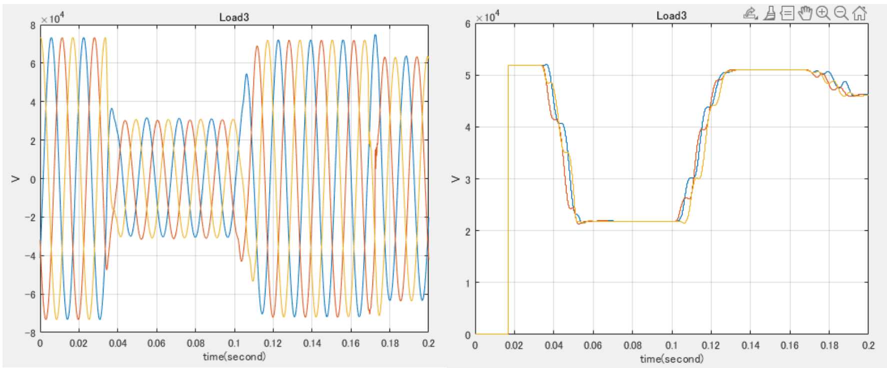

Figure. 64. Three-phase and rms voltage plot of Load3 for fault at bus 5-6

Load6:

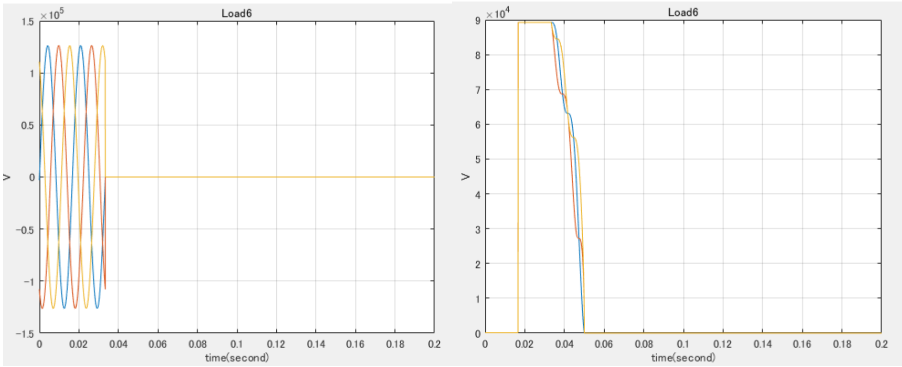

Figure. 65. Three-phase and rms voltage plot of Load6 for fault at bus 5-6

Bus1-2:

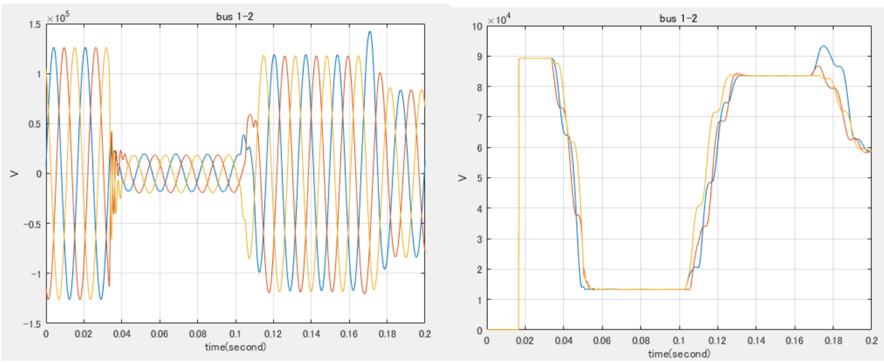

Figure. 66. Three-phase and rms voltage plot of Bus1-2 for fault at bus 5-6

Gas(P&Q):

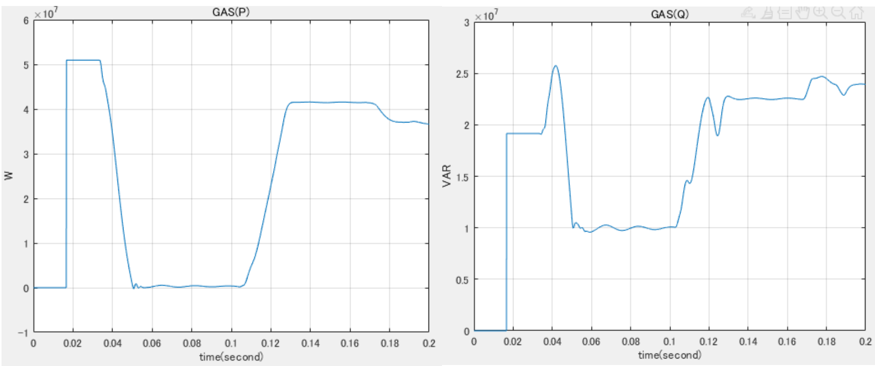

Figure. 67. Active and reactive power plot of gas generator for fault at bus 5-6

Coal(P&Q):

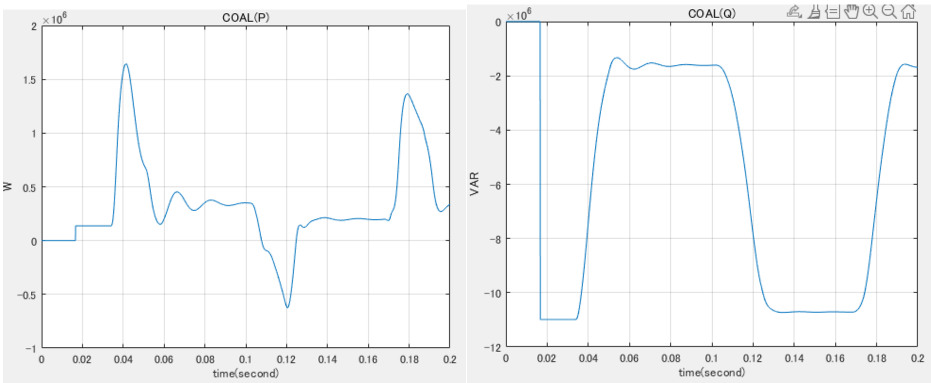

Figure. 68. Active and reactive power plot of coal generator for fault at bus 5-6

Wind1(P&Q):

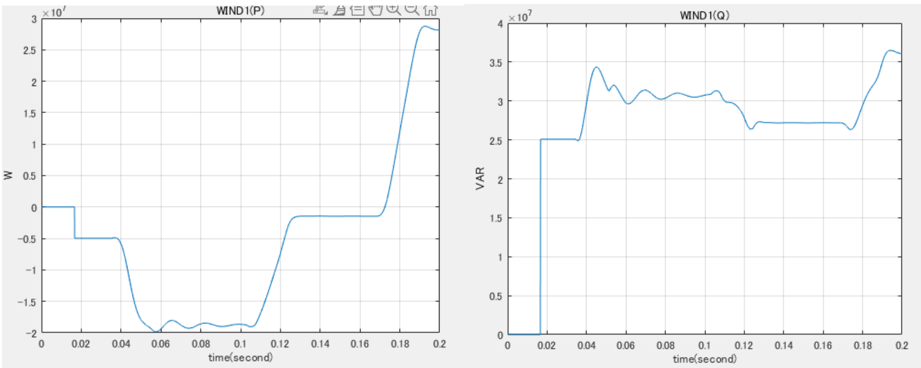

Figure. 69. Active and reactive power plot of wind1 generator for fault at bus 5-6

Wind2(P&Q):

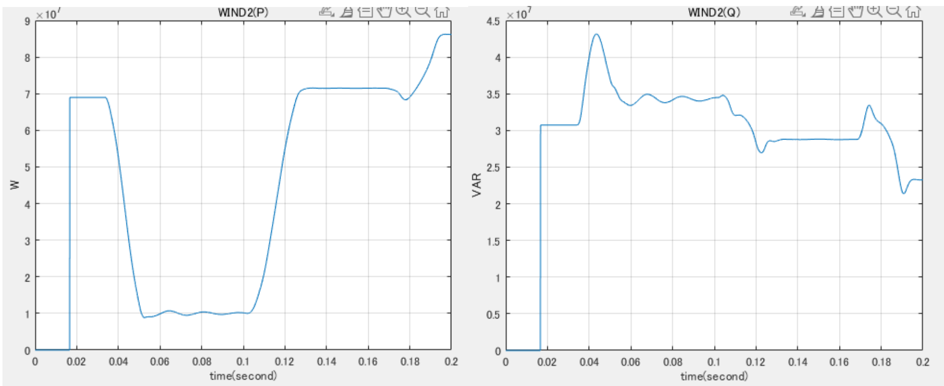

Figure. 70. Active and reactive power plot of wind2 generator for fault at bus 5-6

Based on the simulation results, it can be observed that voltage stability is affected because of weak grid transmission lines, especially at the beginning and at the end of fault events. According to the rms voltage plots, voltage variations can be observed during the initial fault occurrence and during the recovery phase after the fault has been cleared. It is observed the fault occurrence adjacent to inverter-based generation sources have degraded voltage stability and recovery characteristics compared to the stronger grid conditions seen in the vicinity if the tradition synchronous generators at turbo-driven generation stations. In addition to that, active and reactive power of most generator loads has a transient at the beginning and at the end of each fault condition. Thus, the increased reactive power delivery capability of conventional turbo-generators provides improved voltage stability in the presence of inverter-based resources with weak grid connections.

IV. CONCLUSION

Throughout the computer experiments, a voltage simulation that is representative of the central US was performed. The study included several transmission lines with additional components, such as circuit breakers and a mix of conventional synchronous machines (turbo-generators) along with inverter-based resources under weak grid conditions.

Through simulation of fault conditions, it is confirmed the impact on voltage instability based on fault events under weak grid conditions from inverter-based generation. Therefore, these results support the hypothesis that voltage stability cannot be guaranteed under weak-grid conditions that might exist due to inverter-based generation. This leads to the conclusion that improved voltage control and stabilization methods need to be developed in order to more fully utilize renewable energy resources.

V. REFERENCES

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