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Power System Analysis for a Utility with Localized Wind Generation: Southern Negros Oriental Case

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Abstract:

Wind power and solar energy systems are among the green energy options that have been developed to a fairly large extent in many countries. Along with this development comes the concept of microgrids – localized grids that can disconnect from traditional grids to operate autonomously and distributed generation (DG) – an approach where renewable energy generators are located near consumption areas. In this paper, an electric utility in Negros Oriental is selected and wind power is considered. An optimization study conducted separately has identified that wind power generation is an optimal resource given the load profile and the location of the site. It is important to check the present system before determining the possible operational behavior of the system with an additional generator. The challenges in the planning, operation, maintenance, and control of a power system are partly solved and determined using computer-based power system analysis. Electrical Transient Analyzer Program (ETAP) is used in this study. Generation matches load. The existing distribution system for this electric utility has shown bus marginal undervoltages during the load flow. Some cables appear overloaded. Certain overcurrent protective devices in the substations will be in critical states whenever faults occur in the incoming buses. The behavior of the system with and without wind power generation is observed and evaluated. The wind turbines tend to increase the bus voltages, especially at the nearest bus. Transient stability simulations for the existing system exhibit stability while in the new system some parameters are not able to recover.

Keywords: microgrids, wind power, planning, ETAP, stability, renewable energy

INTRODUCTION

Power system analysis is essential in every power system and for every component of the power system: generation, transmission, and distribution. It determines the voltages at various buses and the currents that flow in the lines operating at different voltage levels. Planning, operation, and control of interconnected systems pose many challenges the solutions of which are partly solved by power system analysis.

With electricity demands continuing to soar and climate change threatening lives and economies, the need to shift to greener energy and increasing the efficiency of electric systems become more remarkable. Wind power and solar power systems are among the green energy sources that have been developed to a large extent in many countries. Along with this comes the concept of microgrids – localized grids that can disconnect from traditional grids to operate autonomously and distributed generation (DG) – an approach where renewable energy (RE) generators are located near consumption areas. Because of this, distribution systems are gaining new attention. Moreover, the electric grid has become more complex. Issues like power quality, blackouts, protection, and others also need regard. Before interconnections can happen, it is crucial to check if the existing system is even good enough to handle the current workings of the grid.

Wind and solar energy systems are among the most commonly used green energy resources [1]. Wind energy is one of the fastest-growing energy resources in the world and has many advantages such as being cost-effective and installations can be built on existing farms and ranches [2]. In a report by the Global Wind Energy Council, in 2016, more than 54 GW of wind power was installed globally, comprising more than 90 countries, including nine with more than 10,000 MW installations [3]. The same report highlighted that wind power penetration levels have increased. Denmark leads at 40%, followed by Uruguay. Portugal and Ireland have over 20%; Spain and Cyprus have around 20% and Germany has 16%. China, the US, and Canada have 4%, 5.5%, and 6% of their power needs met by wind energy, respectively. Along with this statistics are studies related to wind energy with various focus such as studies on power quality in distribution systems, integration challenges and power flow analysis, among others [4–9].

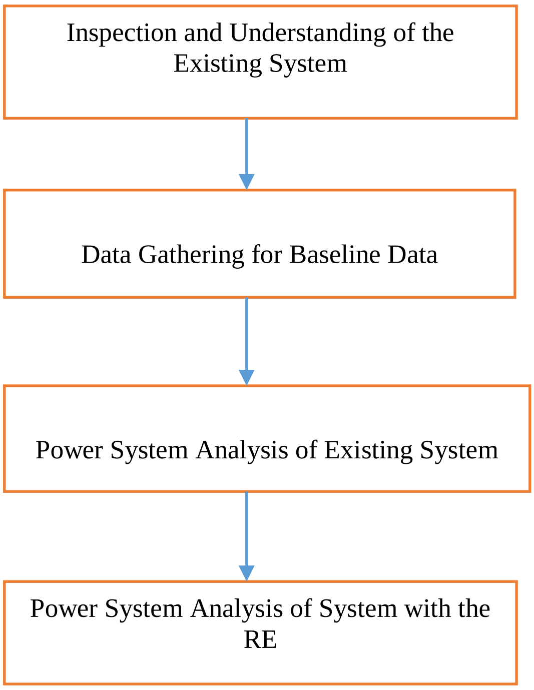
In this paper, an electric utility in Negros Oriental, Philippines is selected and wind power is considered. In one of the simulations of an optimization study conducted separately, wind power generation is optimal for the site based on the load profile, resource availability and associated costs. Only 12 MW is simulated though in anticipation of the large land area that would be required. Direct impact areas include wind turbine pads, access roads, substations, service buildings, and other infrastructures [10]. It is important to check the present system before determining the possible operational behavior of the system with an additional generator. The challenges in the planning, operation, maintenance, and control of a power system are partly solved and determined using computer-based power system analysis. Electrical Transient Analyzer Program (ETAP) is used in the simulations in this study. With the tool, a system model can be created and validated. Load flow analysis, a check on whether the network is within the necessary limits and tolerances in terms of the voltage profiles and loading of the components, is performed. Short-circuit analysis, which determines the magnitude of currents that flow during electrical faults and compare these against the ratings of the equipment, is done next. Transient stability analysis, an examination of the ability of the system to maintain synchronism when subjected to a severe fault or disturbance, is also performed in this investigation.

Power system studies using computer tools and simulators have become popular in recent years. They have become more intuitive and user-friendly. Electrical Transient Analyzer Program (ETAP) is one of the most comprehensive software packages for electrical power system modeling, design, analysis, optimization, control and automation [11]. This software is used for load flow, short-circuit and transient stability analyses of the existing distribution system. These are three of the most common analyses performed during the planning and in the investigation of electrical systems.

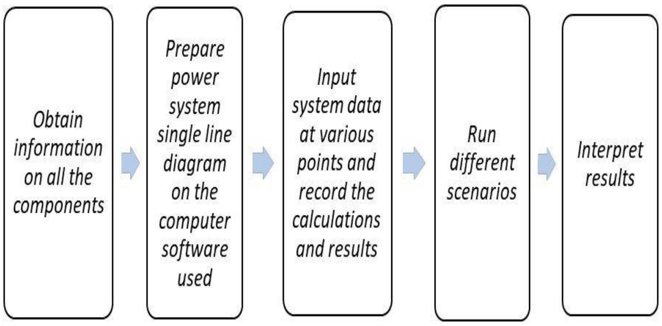
This paper is organized as follows: A brief introduction starts the paper; the methodology employed in the study is given after. In the succeeding section, load flow analysis for the existing system and for the system with wind power is presented. Short-circuit analysis and transient stability analysis follow. The last section contains the conclusions and some recommendations.

METHODOLOGY

The general methodology for this investigation is summarized below:



The steps in the power system analysis: load flow studies, short-circuit studies, and transient stability studies are as shown below.



LOAD FLOW ANALYSIS

Load flow analysis is an important part of electrical system design. It is a check on whether the network is within the necessary limits and tolerances in terms of the voltage profiles and loading of the components. Load flow studies and analysis are performed during the planning stages, when evaluating the operation and before changes to the existing system can be appropriately made. ETAP also features automatic device evaluation with a result analyzer and a summary of alarms or warnings [12].

Existing System

The existing distribution system is composed of 38 buses, 40 branches, 0 generators, 2 power grids and 17 loads. Load-MW is 42.239 (non-peak), Load-Mvar is 9.871 (non-peak). Generation matches load. Figure 1 shows the simplified system one-line view.

Table 1 shows five buses on marginal states. Marginal states specified are 95% for loading, 102% for overvoltage and 98% for undervoltage. Critical states specified are 100% for loading, 105% for overvoltage and 95% for undervoltage.

Figure 2 shows the portion of the system where the marginal states occur. They are in the Bayawan and Siaton substations. The cable appears to be in an overloaded state but this might need to be verified further.

System with Wind

Figure 2 illustrates the location of the wind farm. The wind turbines are connected to the RE Line for load flow purposes. Table 2 gives the load flow results of the buses when the wind farm is connected to the system. The marginal undervoltages in the existing system have gone normal but some other buses are now in marginal undervoltage and overvoltage.

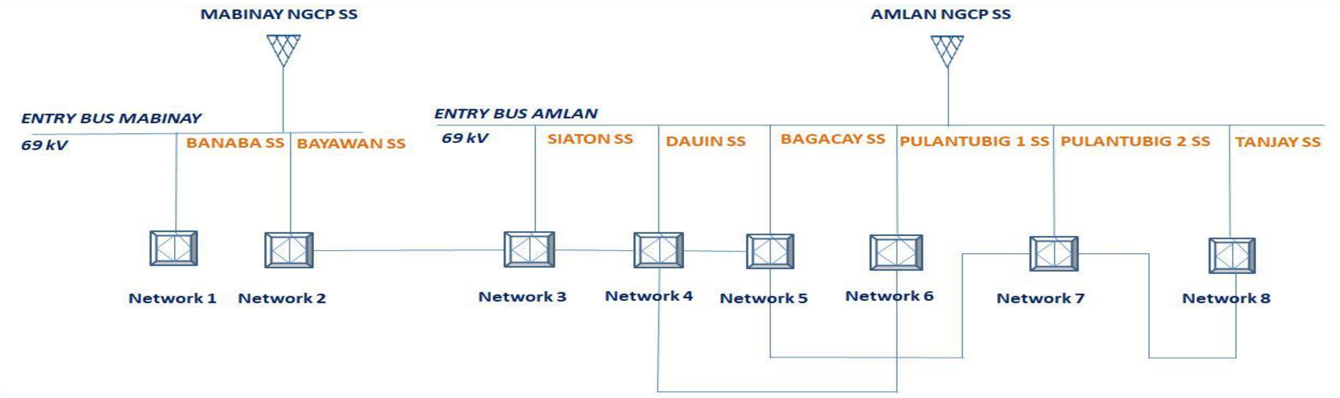


Figure 1. Simplified Distribution System One-Line View.

Table 1: Bus Results on Load Flow Analyzer (Existing).

BUS ID	Nominal kV	LOAD FLOW (Voltage)
BANABA13.2	13.2	99.57
Bus8-4	13.2	96.42
Bus8-23	13.2	99.18
Bus8-24	13.2	99.18
Bus8-26	13.2	99.18
Bus8-28	13.2	99.18
Bus8-30	13.2	99.18
Bus10-4	13.2	96.42
Bus10-27	13.2	99.18
Bus10-28	13.2	99.18
Bus10-30	13.2	99.18
Bus10-32	13.2	99.18
Bus10-34	13.2	99.18
Bus10-36	13.2	99.18
Bus10-38	13.2	99.18
Bus11-4	13.2	96.42
Bus11-26	13.2	96.42
Bus11-29	13.2	99.18
Bus11-30	13.2	99.18
Bus11-32	13.2	99.18
Bus11-36	13.2	99.18
Bus11-42	13.2	99.18
Bus11-43	13.2	99.18
Bus11-44	13.2	99.18
Bus11-48	13.2	99.18
Bus11-49	13.2	99.18
Bus11-50	13.2	99.18
Bus61	13.2	99.18
Bus87	13.2	96.42
SIATON13.2	13.2	98.37

Table 2: Bus Results on Load Flow Analyzer (With Wind).

BUS ID	Nominal kV	LOAD FLOW (Voltage)
BANABA13.2	13.2	99.57
Bus8-4	13.2	101.55
Bus8-23	13.2	97.53
Bus8-24	13.2	97.97
Bus8-26	13.2	98.26
Bus8-28	13.2	98.61
Bus8-30	13.2	98.11
Bus10-4	13.2	101.55
Bus10-27	13.2	97.53
Bus10-28	13.2	97.97
Bus10-30	13.2	98.26
Bus10-32	13.2	98.61
Bus10-34	13.2	98.11
Bus10-36	13.2	98.11
Bus10-38	13.2	97.97
Bus11-4	13.2	101.55
Bus11-26	13.2	101.55
Bus11-29	13.2	97.53
Bus11-30	13.2	97.53
Bus11-32	13.2	97.97
Bus11-36	13.2	98.26
Bus11-42	13.2	98.61
Bus11-43	13.2	98.61
Bus11-44	13.2	98.61
Bus11-48	13.2	98.11
Bus11-49	13.2	98.11
Bus11-50	13.2	98.11
Bus61	13.2	97.53
Bus87	13.2	101.55
SIATON13.2	13.2	98.24
RE Line	7.97	104.10%

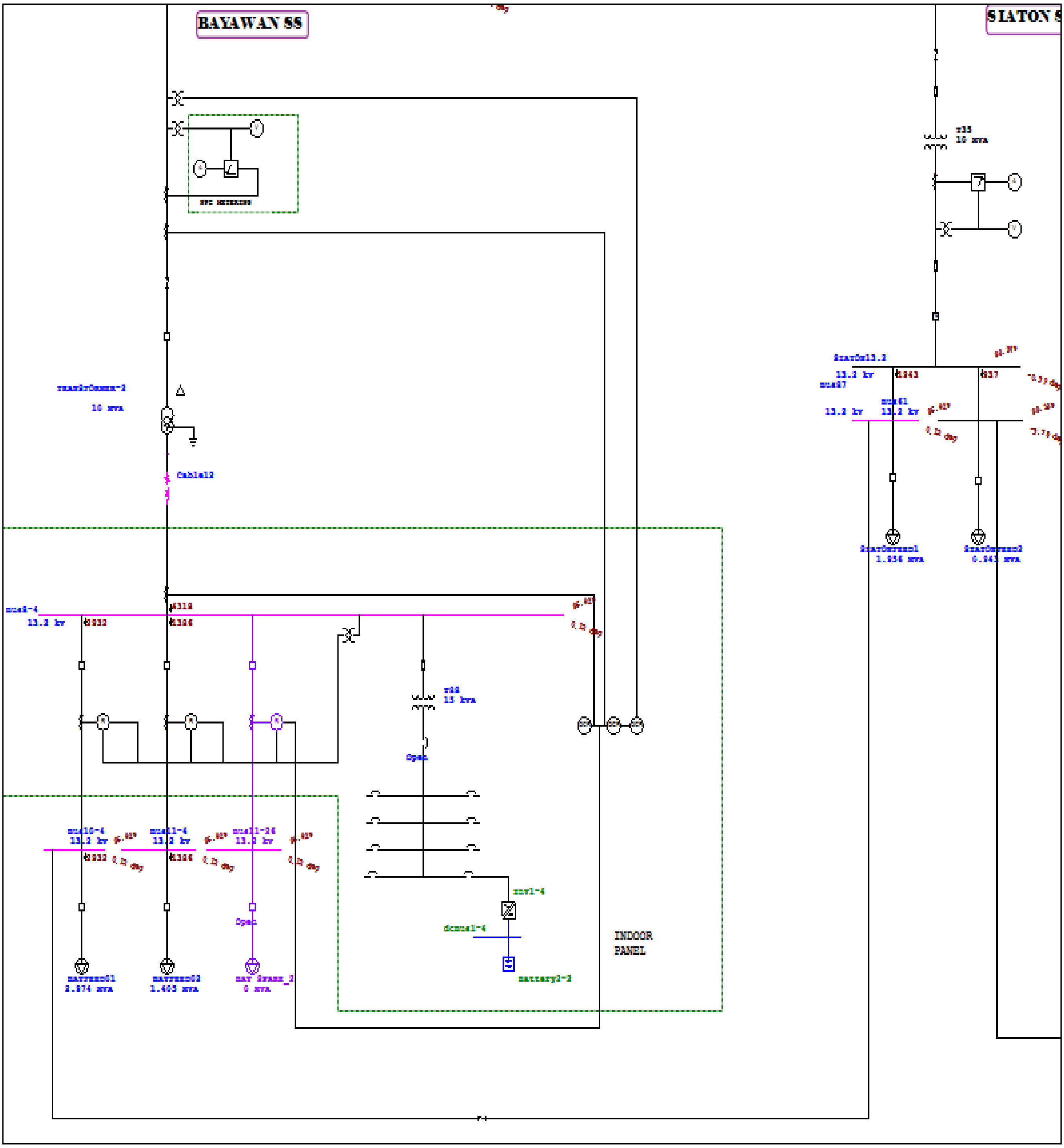


Figure 2: Portion of the System in Marginal States for Load Flow.

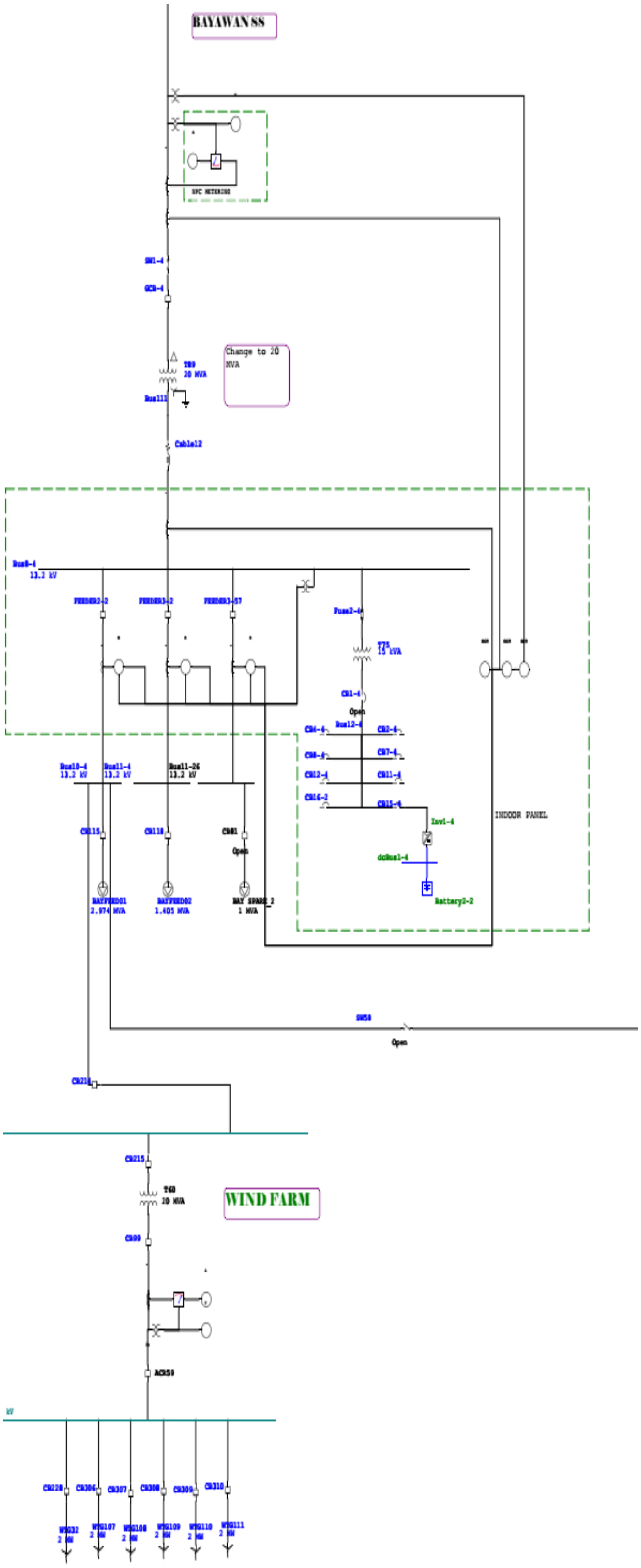


Figure 3. Location of the Wind Farm.

SHORT-CIRCUIT ANALYSIS

Short-circuit analysis is a crucial investigation into a network's performance under fault conditions. A short-circuit happens when there is an unintended contact between two points of different potentials causing a diversion of current flow or an excessive current flow through the 'short'.

Existing System

Case 1: The short-circuit report (with 3-phase fault at Entry Bus Amlan) is shown in Figure 4, with the bus voltages and their current interruption operating values. This is only a sample scenario. There are other scenarios like when a 3-phase fault is at the Entry Bus Mabinay or in any of the remaining buses or any combination thereof.

A short-circuit alert view for the case is presented in Figure 5. It shows the kA ratings for the devices and their operating values during the short-circuit. SW32 is in the worst state operating at 39.755 kA with a momentary (bracing) short-circuit rating of only of 12 kA.

Case 2: The short-circuit analysis alert view for the case is presented in Figure 6, showing the kA ratings for the devices and their operating values. Fuse55 is in the worst state operating at 31.669 kA with a short-circuit rating of only of 3.35 kA only. SW 56's operating current is at 314.3% of its rating and is also in one serious state. Both devices are located in one of oldest substations in the system.

System with Wind

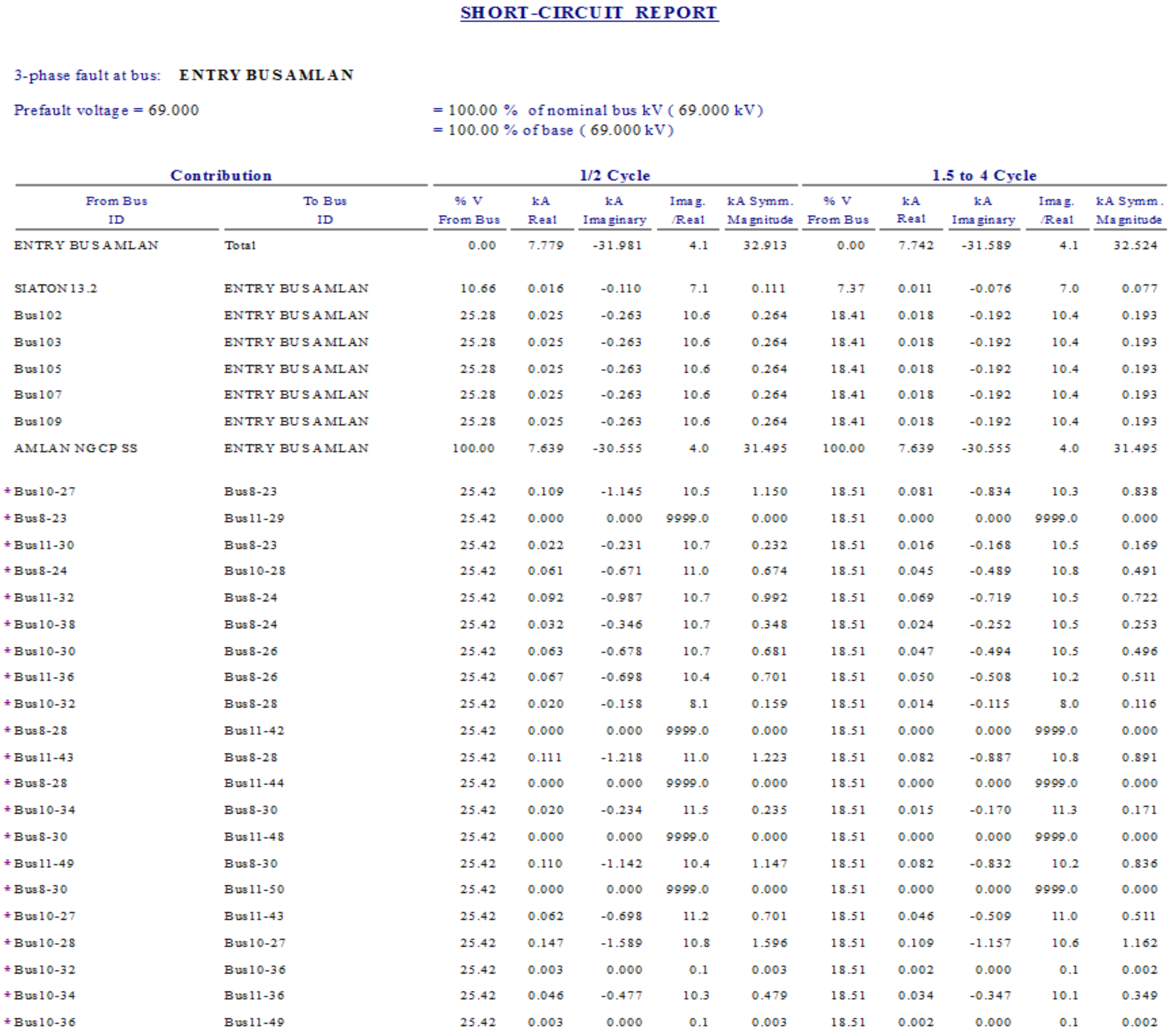
Case 1: The short-circuit analysis alert view when the system has wind generation (with 3-phase fault at Entry Bus Amlan) is shown in Figure 7. The alerts are the same as those without the RE resource.

Case 2: The short-circuit analysis alert view of the system (with 3-phase fault at Entry Bus Mabinay) is shown in Figure 8. The same devices as that of the current system have shown alerts, only that the operating values are a little bit higher this time.

As to 3-phase faults occurring at two other buses, the comparison of the existing system and the system with wind are:

- With 3-phase fault at Banaba13.2, the existing system has no alerts while the system with wind has a critical alert in FEEDER2-2 circuit breaker, operating at 105.4%.

- With 3-phase fault at Bus 8-4, the existing system has no alerts while the system with wind has a critical alert in FEEDER2-2, FEEDER3-2, and FEEDER3-57 circuit breakers; these operate at 105.4%.



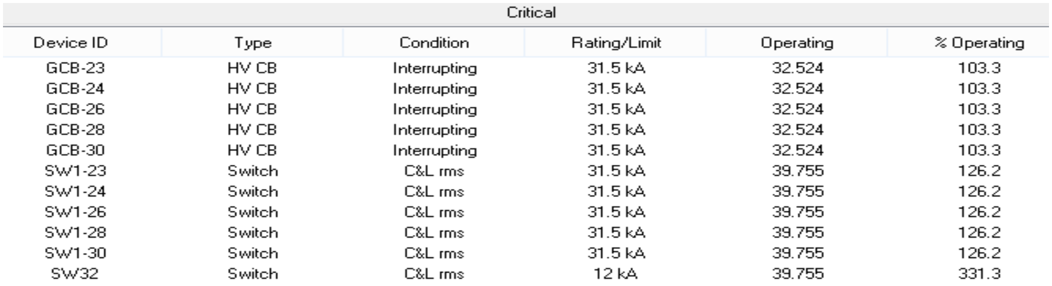
SHORT-CIRCUIT REPORT

3-phase fault at bus: **ENTRY BUSAMLAN**

Prefault voltage = 69.000 = 100.00 % of nominal bus kV (69.000 kV)
= 100.00 % of base (69.000 kV)

Contribution		1/2 Cycle					1.5 to 4 Cycle				
From Bus ID	To Bus ID	% V From Bus	kA Real	kA Imaginary	Imag. /Real	kA Symm. Magnitude	% V From Bus	kA Real	kA Imaginary	Imag. /Real	kA Symm. Magnitude
ENTRY BUSAMLAN	Total	0.00	7.779	-31.981	4.1	32.913	0.00	7.742	-31.589	4.1	32.524
SIATON13.2	ENTRY BUSAMLAN	10.66	0.016	-0.110	7.1	0.111	7.37	0.011	-0.076	7.0	0.077
Bus102	ENTRY BUSAMLAN	25.28	0.025	-0.263	10.6	0.264	18.41	0.018	-0.192	10.4	0.193
Bus103	ENTRY BUSAMLAN	25.28	0.025	-0.263	10.6	0.264	18.41	0.018	-0.192	10.4	0.193
Bus105	ENTRY BUSAMLAN	25.28	0.025	-0.263	10.6	0.264	18.41	0.018	-0.192	10.4	0.193
Bus107	ENTRY BUSAMLAN	25.28	0.025	-0.263	10.6	0.264	18.41	0.018	-0.192	10.4	0.193
Bus109	ENTRY BUSAMLAN	25.28	0.025	-0.263	10.6	0.264	18.41	0.018	-0.192	10.4	0.193
AMLAN NGCP SS	ENTRY BUSAMLAN	100.00	7.639	-30.555	4.0	31.495	100.00	7.639	-30.555	4.0	31.495
*Bus10-27	Bus8-23	25.42	0.109	-1.145	10.5	1.150	18.51	0.081	-0.834	10.3	0.838
*Bus8-23	Bus11-29	25.42	0.000	0.000	9999.0	0.000	18.51	0.000	0.000	9999.0	0.000
*Bus11-30	Bus8-23	25.42	0.022	-0.231	10.7	0.232	18.51	0.016	-0.168	10.5	0.169
*Bus8-24	Bus10-28	25.42	0.061	-0.671	11.0	0.674	18.51	0.045	-0.489	10.8	0.491
*Bus11-32	Bus8-24	25.42	0.092	-0.987	10.7	0.992	18.51	0.069	-0.719	10.5	0.722
*Bus10-38	Bus8-24	25.42	0.032	-0.346	10.7	0.348	18.51	0.024	-0.252	10.5	0.253
*Bus10-30	Bus8-26	25.42	0.063	-0.678	10.7	0.681	18.51	0.047	-0.494	10.5	0.496
*Bus11-36	Bus8-26	25.42	0.067	-0.698	10.4	0.701	18.51	0.050	-0.508	10.2	0.511
*Bus10-32	Bus8-28	25.42	0.020	-0.158	8.1	0.159	18.51	0.014	-0.115	8.0	0.116
*Bus8-28	Bus11-42	25.42	0.000	0.000	9999.0	0.000	18.51	0.000	0.000	9999.0	0.000
*Bus11-43	Bus8-28	25.42	0.111	-1.218	11.0	1.223	18.51	0.082	-0.887	10.8	0.891
*Bus8-28	Bus11-44	25.42	0.000	0.000	9999.0	0.000	18.51	0.000	0.000	9999.0	0.000
*Bus10-34	Bus8-30	25.42	0.020	-0.234	11.5	0.235	18.51	0.015	-0.170	11.3	0.171
*Bus8-30	Bus11-48	25.42	0.000	0.000	9999.0	0.000	18.51	0.000	0.000	9999.0	0.000
*Bus11-49	Bus8-30	25.42	0.110	-1.142	10.4	1.147	18.51	0.082	-0.832	10.2	0.836
*Bus8-30	Bus11-50	25.42	0.000	0.000	9999.0	0.000	18.51	0.000	0.000	9999.0	0.000
*Bus10-27	Bus11-43	25.42	0.062	-0.698	11.2	0.701	18.51	0.046	-0.509	11.0	0.511
*Bus10-28	Bus10-27	25.42	0.147	-1.589	10.8	1.596	18.51	0.109	-1.157	10.6	1.162
*Bus10-32	Bus10-36	25.42	0.003	0.000	0.1	0.003	18.51	0.002	0.000	0.1	0.002
*Bus10-34	Bus11-36	25.42	0.046	-0.477	10.3	0.479	18.51	0.034	-0.347	10.1	0.349
*Bus10-36	Bus11-49	25.42	0.003	0.000	0.1	0.003	18.51	0.002	0.000	0.1	0.002

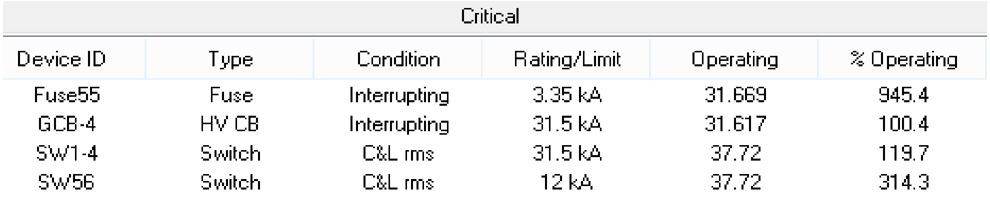
Figure 4: Short-Circuit Report_3-Phase Fault at Entry Bus Amlan.



Critical

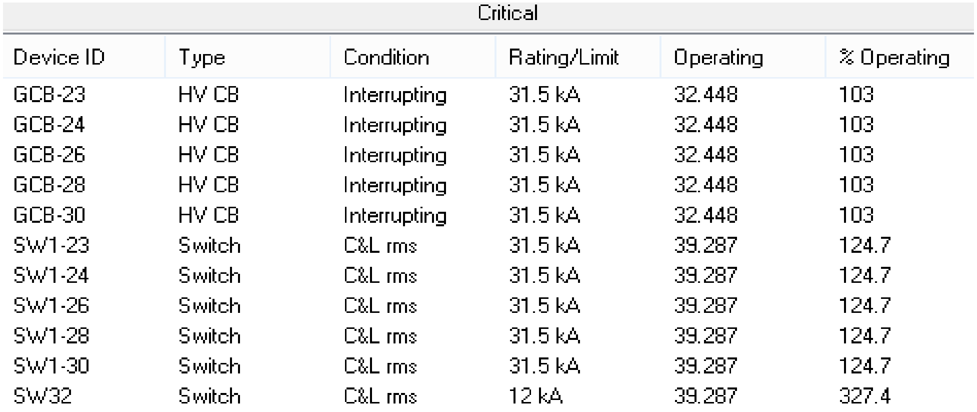
Device ID	Type	Condition	Rating/Limit	Operating	% Operating
GCB-23	HV CB	Interrupting	31.5 kA	32.524	103.3
GCB-24	HV CB	Interrupting	31.5 kA	32.524	103.3
GCB-26	HV CB	Interrupting	31.5 kA	32.524	103.3
GCB-28	HV CB	Interrupting	31.5 kA	32.524	103.3
GCB-30	HV CB	Interrupting	31.5 kA	32.524	103.3
SW1-23	Switch	C&L rms	31.5 kA	39.755	126.2
SW1-24	Switch	C&L rms	31.5 kA	39.755	126.2
SW1-26	Switch	C&L rms	31.5 kA	39.755	126.2
SW1-28	Switch	C&L rms	31.5 kA	39.755	126.2
SW1-30	Switch	C&L rms	31.5 kA	39.755	126.2
SW32	Switch	C&L rms	12 kA	39.755	331.3

Figure 5: Short-Circuit Analysis View_3-Phase Fault at Entry Bus Amlan.



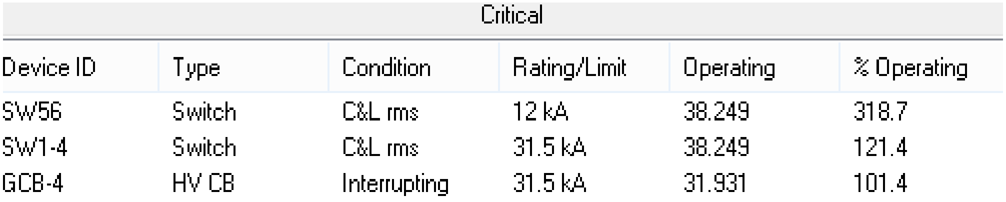
Critical					
Device ID	Type	Condition	Rating/Limit	Operating	% Operating
Fuse55	Fuse	Interrupting	3.35 kA	31.669	945.4
GCB-4	HV CB	Interrupting	31.5 kA	31.617	100.4
SW1-4	Switch	C&L rms	31.5 kA	37.72	119.7
SW56	Switch	C&L rms	12 kA	37.72	314.3

Figure 6: Short-Circuit Analysis View_3-Phase Fault at Entry Bus Mabinay.



Critical					
Device ID	Type	Condition	Rating/Limit	Operating	% Operating
GCB-23	HV CB	Interrupting	31.5 kA	32.448	103
GCB-24	HV CB	Interrupting	31.5 kA	32.448	103
GCB-26	HV CB	Interrupting	31.5 kA	32.448	103
GCB-28	HV CB	Interrupting	31.5 kA	32.448	103
GCB-30	HV CB	Interrupting	31.5 kA	32.448	103
SW1-23	Switch	C&L rms	31.5 kA	39.287	124.7
SW1-24	Switch	C&L rms	31.5 kA	39.287	124.7
SW1-26	Switch	C&L rms	31.5 kA	39.287	124.7
SW1-28	Switch	C&L rms	31.5 kA	39.287	124.7
SW1-30	Switch	C&L rms	31.5 kA	39.287	124.7
SW32	Switch	C&L rms	12 kA	39.287	327.4

Figure 7: Short-Circuit Analysis View_3-Phase Fault at Entry Bus Amlan (With Wind).



Critical					
Device ID	Type	Condition	Rating/Limit	Operating	% Operating
SW56	Switch	C&L rms	12 kA	38.249	318.7
SW1-4	Switch	C&L rms	31.5 kA	38.249	121.4
GCB-4	HV CB	Interrupting	31.5 kA	31.931	101.4

Figure 8: Short-Circuit Analysis View_3-Phase Fault at Entry Bus Mabinay.

TRANSIENT STABILITY ANALYSIS

Transients are momentary events preceding the steady-state condition during a sudden change of a circuit in a power system. These momentary bursts of energy are characterized by extremely high voltages that can drive very large amounts of currents into the system for a limited time. The stability of a system refers to the ability of a system to return back to its steady state when subjected to a disturbance. The transient stability analysis determines whether the components in the system returns to their steady state in a timely manner once the disturbance or fault is cleared.

The ETAP Transient Stability Analysis program can investigate the system dynamic responses and stability limits of a power system before, during, and after the occurrence of disturbances.

Existing System

Case 1: Figures 9-13 are plots obtained for the study case where there is a 3-phase fault at Entry Bus Amlan. The concern is to verify the response of the substation buses due to the disturbance. The fault is assumed to be cleared after 0.06 sec. The total simulation time was set to 0.5 sec, simulation time step (dt) to 0.001 and plot time step of 20 x dt.

Figure 9 reveals that all substation voltages return to their steady-state conditions after the fault is cleared. Their voltages go down to zero after the fault but rise up to their stable values in due time.

Figure 10 shows that all bus voltage angles return to their original angles after the clearing of the fault.

There is no problem with the buses' frequencies as shown in Figure 11.

Figures 12 and 13 show the bus real and reactive power loadings before, during and after the fault condition, respectively.. The loadings have returned to normal.

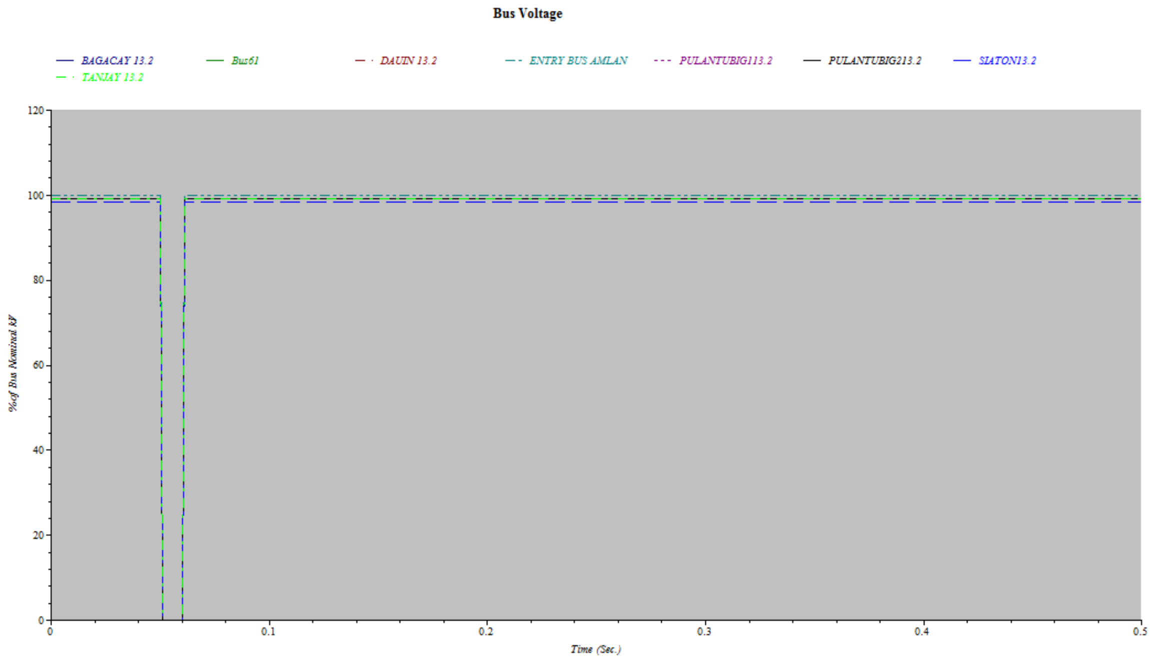


Figure 9: Bus Voltages at the Substations_3-Phase Fault at Entry Bus Amlan.

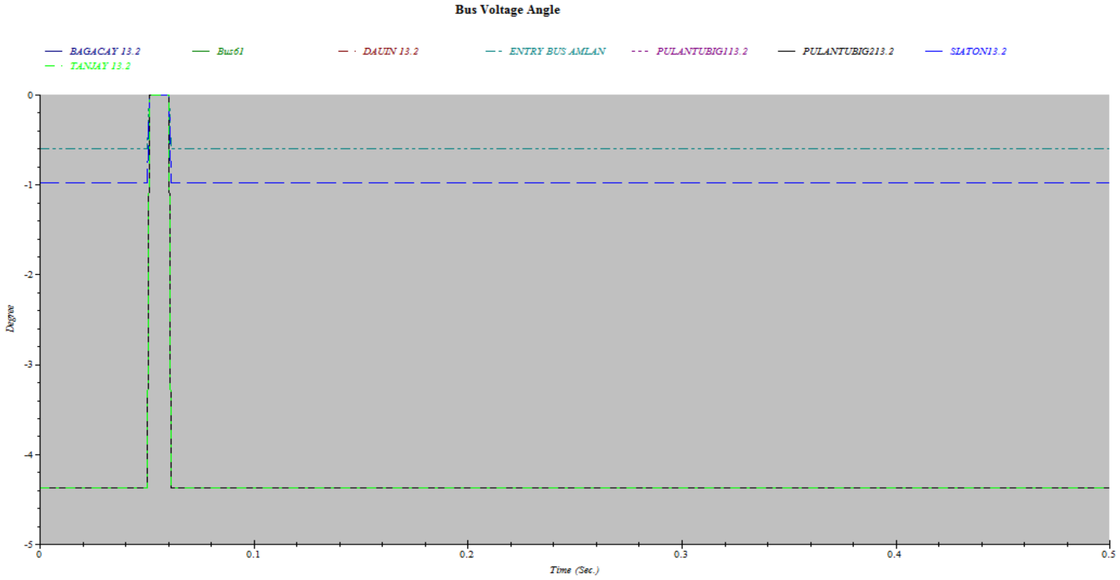


Figure 10: Bus Voltage Angles at the Substations _3-Phase Fault at Entry Bus Amlan.

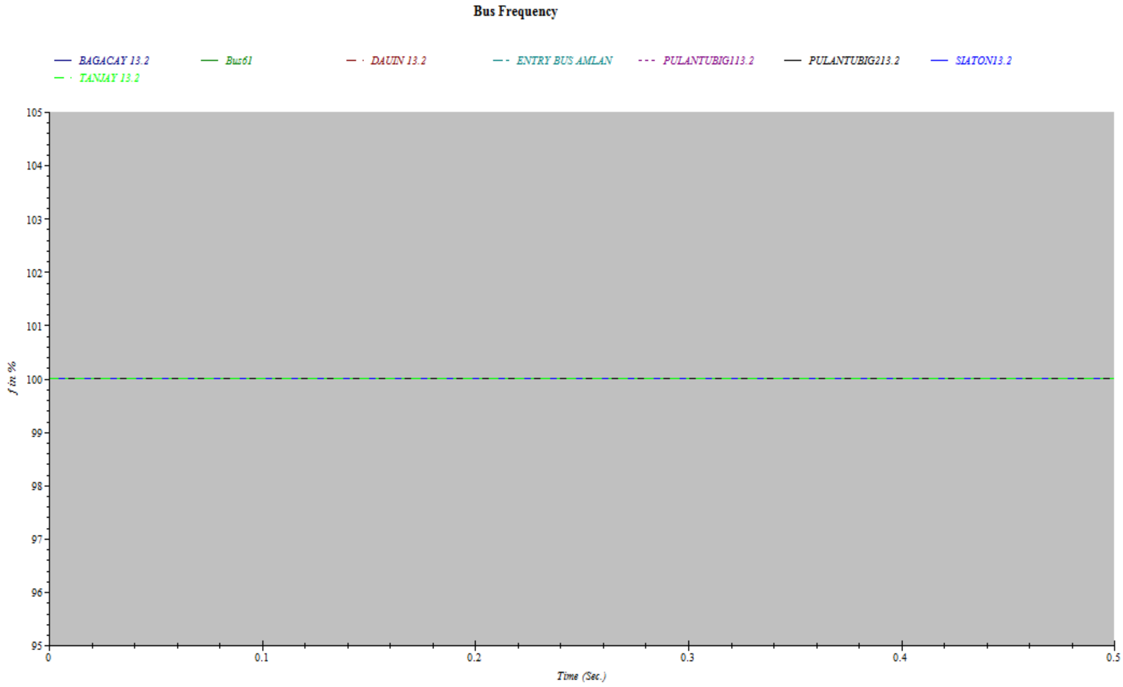


Figure 11: Bus Frequencies at the Substations _3-Phase Fault at Entry Bus Amlan.

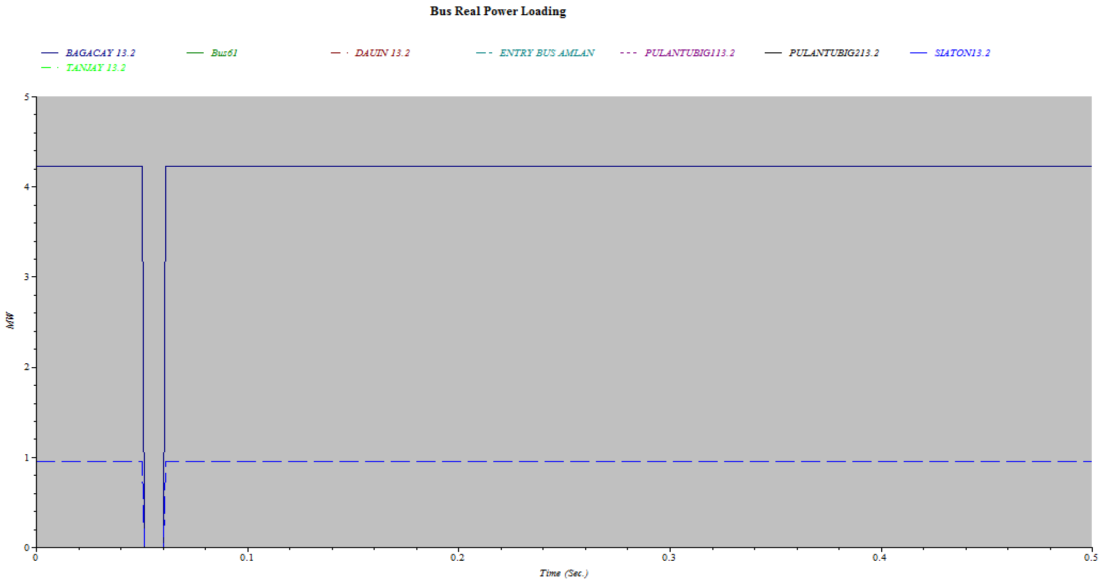


Figure 12: Bus Real Power Loading at the Substations_3-Phase Fault at Entry Bus Amlan.

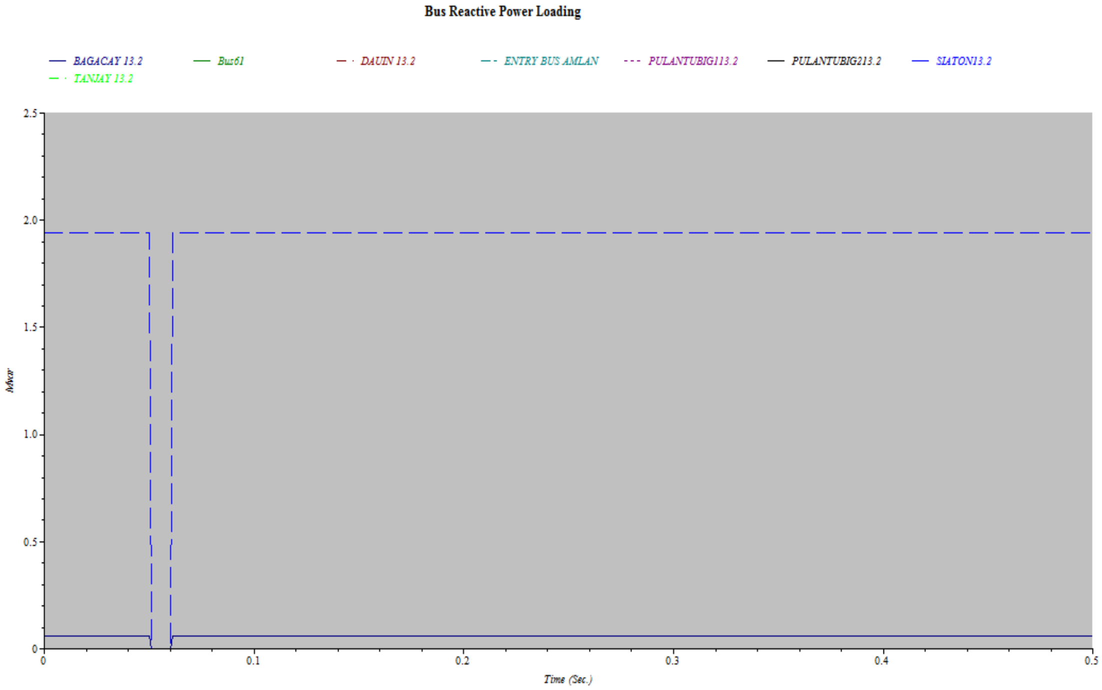


Figure 13: Bus Reactive Power Loading at the Substations_3-Phase Fault at Entry Bus Amlan.

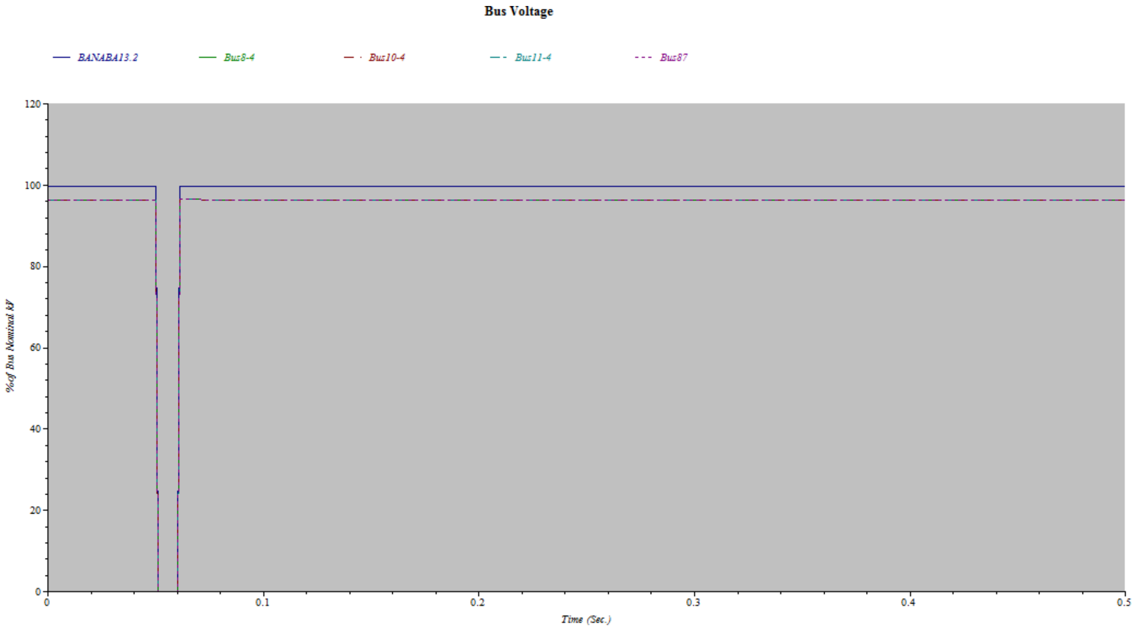


Figure 14: Bus Voltages at the Substations_3-Phase Fault at Entry Bus Mabinay.

Case 2: Figures 14-17 are plots obtained for the study case where there is a 3-phase fault at Entry Bus Mabinay. The response of the substation buses due to the disturbance is verified. The fault is still assumed to be cleared after 0.06 sec. The total simulation time was set to 0.5 sec, simulation time step (dt) to 0.001 and plot time step of 20 x dt.

Figure 14 reveals that all substation voltages return to their steady-state conditions after the fault is cleared. Their voltages go down to zero after the fault but also go up to their stable values in due time.

Figure 15 shows that Buses 8-4, 87, 10-4, and 11-4 do not go back to the same angle right away but do so after a negligible period of time.

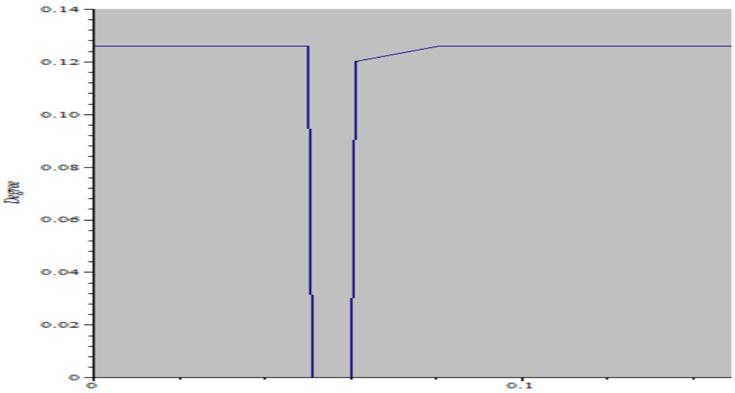


Figure 15: Bus Voltage Angle_3-Phase Fault at Entry Bus Mabinay.

There is no problem with the buses' frequencies as shown in Figure 16.

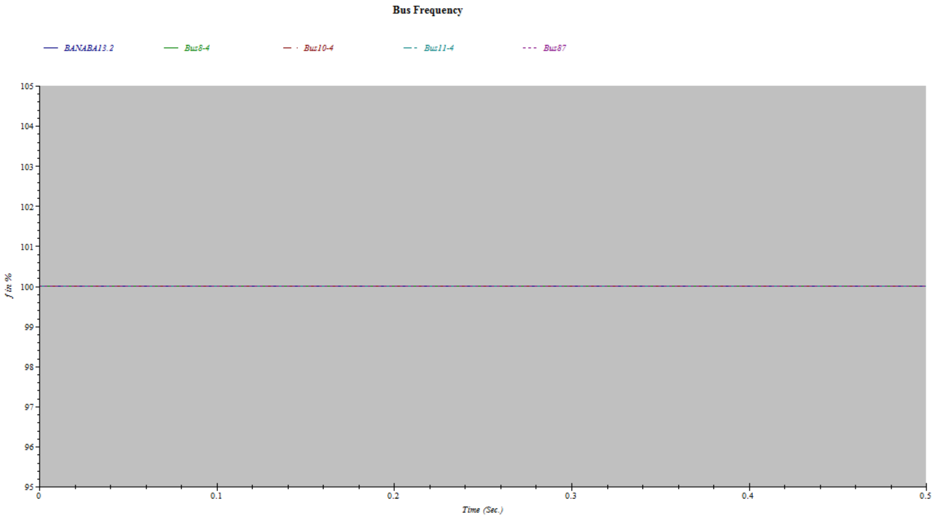


Figure 16: Bus Frequencies at the Substations _3-Phase Fault at Entry Bus Mabinay.

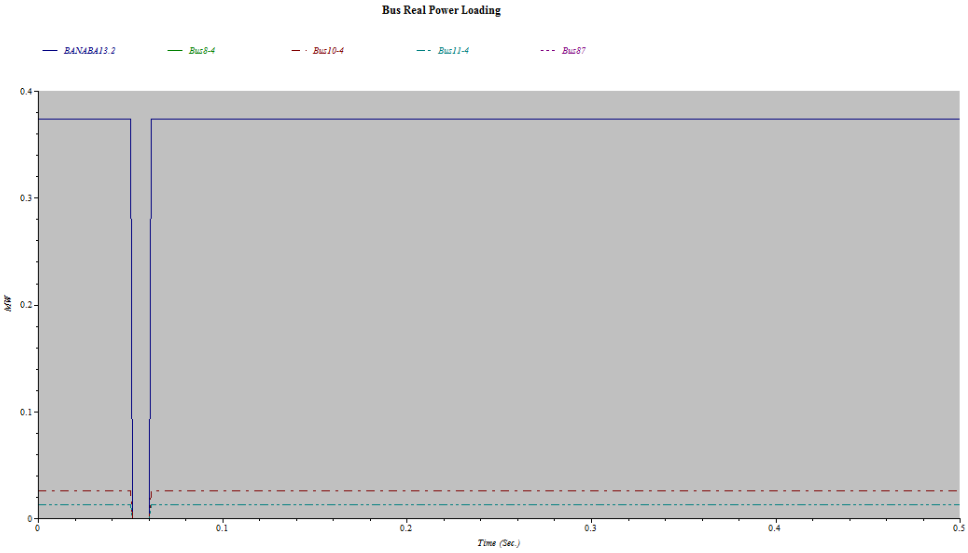


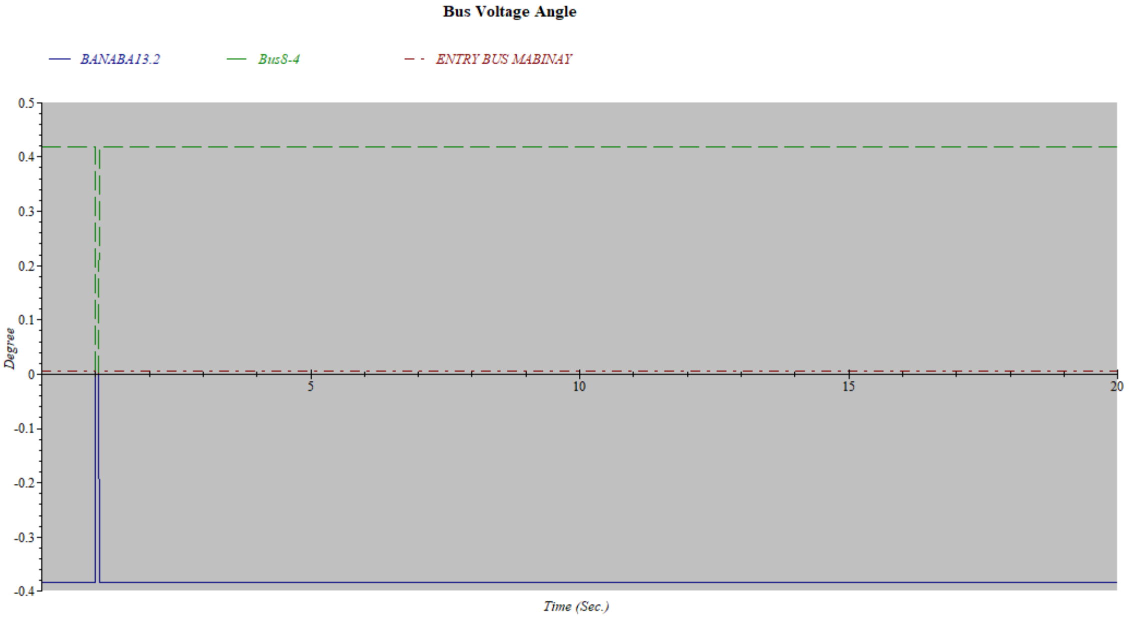
Figure 17: Bus Real Power Loading at the Substations_3-Phase Fault at Entry Bus Mabinay.

Figure 17 shows the real power loadings before, during and after the fault condition. The loadings have returned to normal.

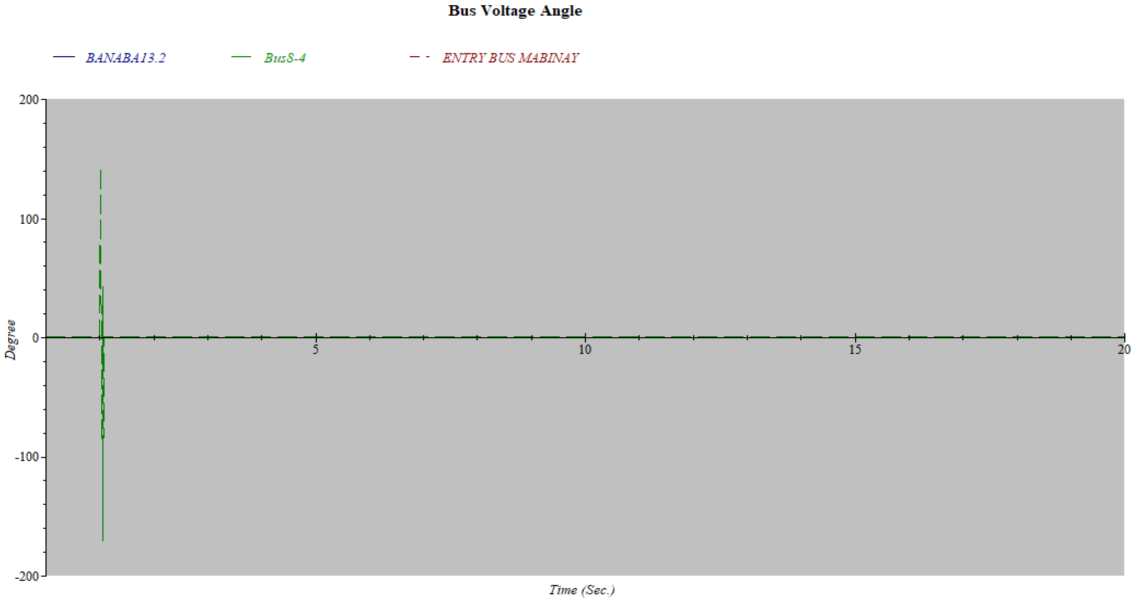
System with Wind

The transient stability study for the system with wind aims to verify the response of the system to disturbances when it has a localized wind generation system. A stable system must be able to go back to its original state or to a state of equilibrium after the clearing of faults. Figures 18-21 are sample stability plots obtained under the different study cases where the existing system and the system with wind show a particular difference in behavior

Figure 18 is for 3-Phase Fault at Entry Bus Amlan.



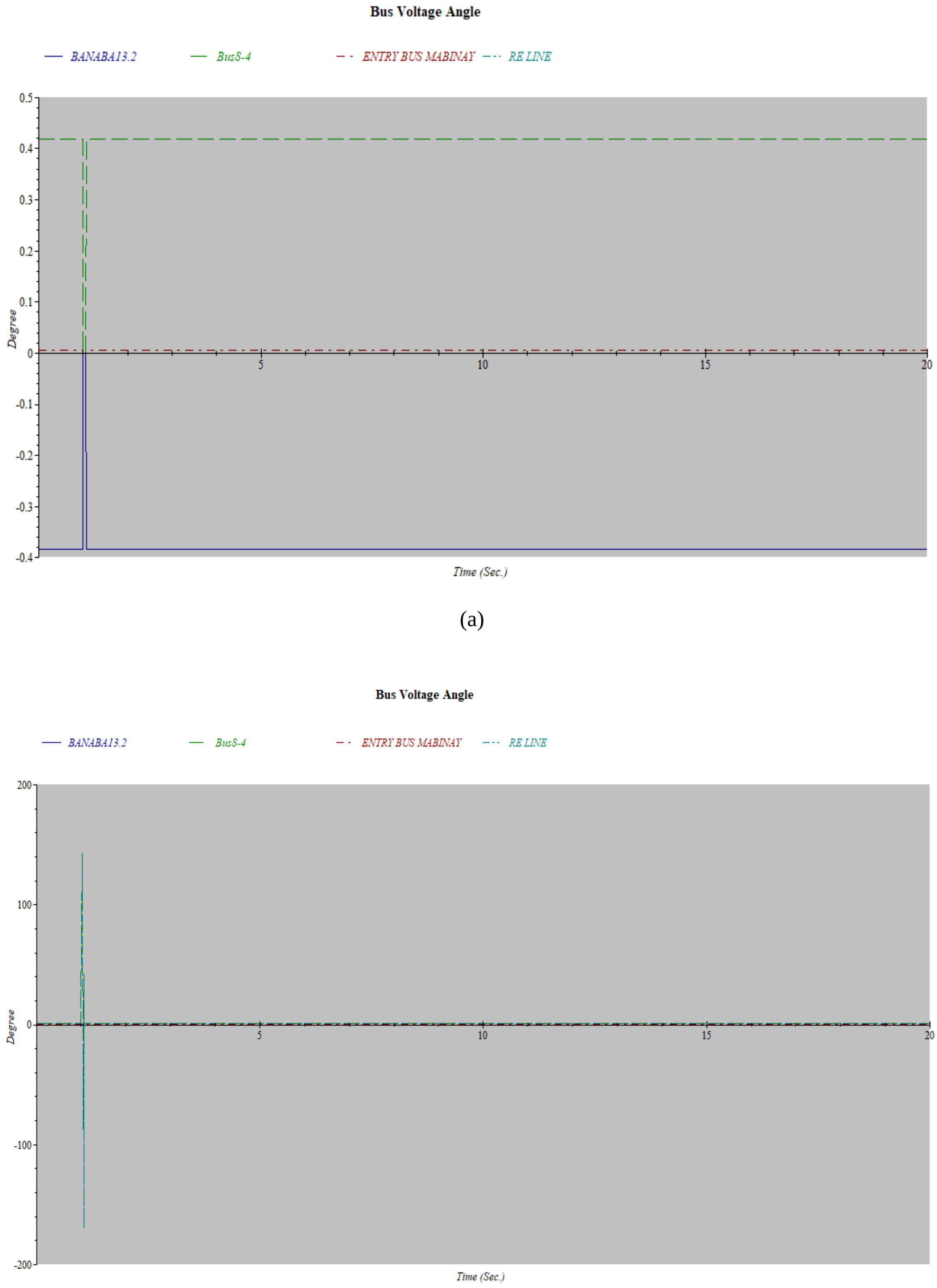
(a)



(b)

Figure 18: Bus Voltage Angle (a) Existing System. (b) System with Wind.

Figure 19 is for 3-Phase Fault at Entry Bus Mabinay.

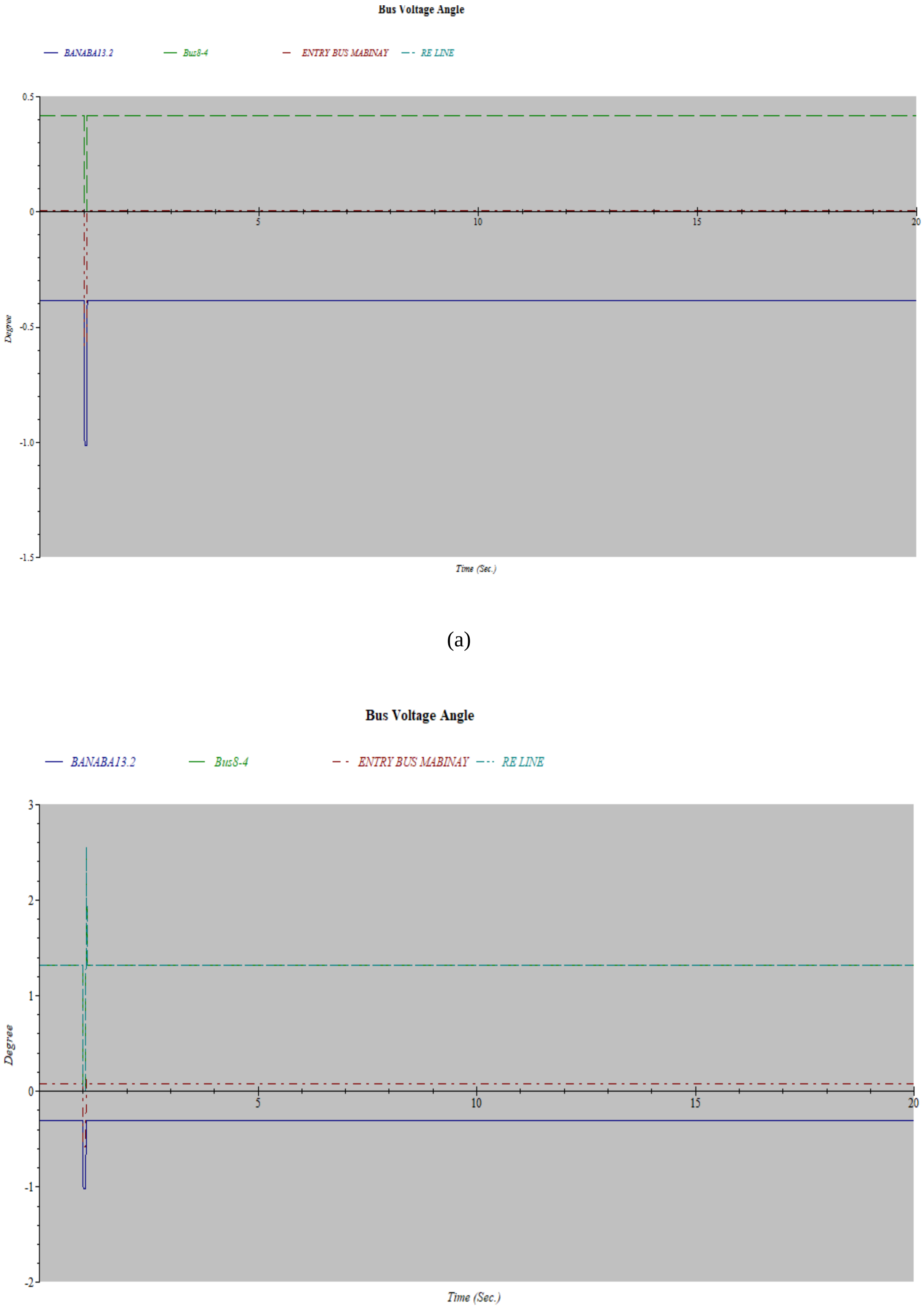


(a)

(b)

Figure 19: Bus Voltage Angle (a) Existing System. (b) System with Wind.

Figure 20 is for 3-Phase Fault at Bus8-4.

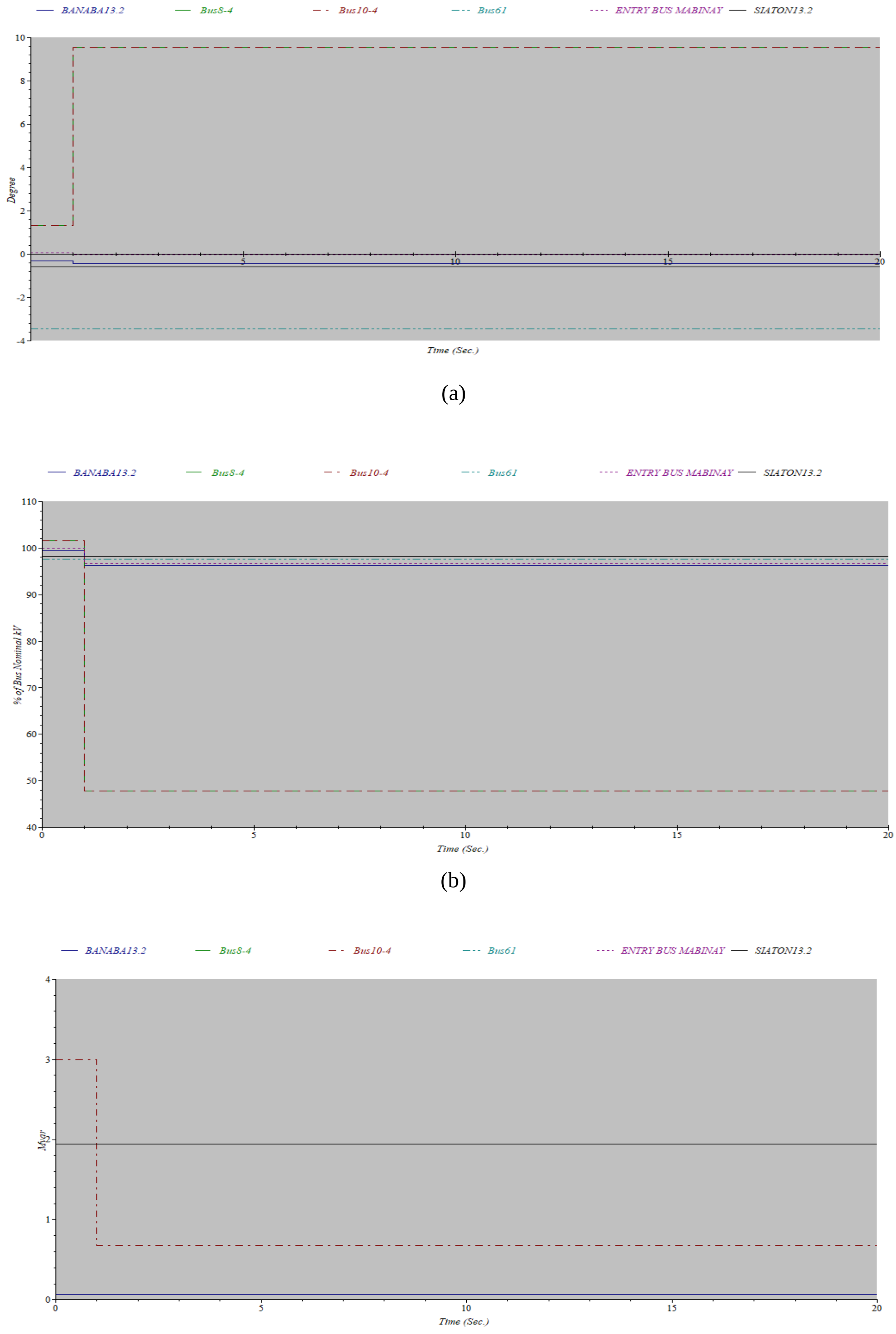


(a)

(b)

Figure 20: Bus Voltage Angle (a) Existing System. (b) System with Wind.

Lastly, Figure 21 is for 3-Phase Fault at the bus where the wind farm connects to. Bus10-4 is not able to recover; voltage is reduced to around 50% only after the clearing of the fault.



(a)

(b)

(c)

Figure 21: (a) Bus Voltage Angle. (b) Bus Voltage. (c) Bus Reactive Power Loading.

CONCLUSIONS AND RECOMMENDATIONS

This investigation of the distribution system for the local utility has shown some marginal undervoltages during the load flow. The coming in of wind power generation can put buses to overvoltage and such has happened as manifested by a marginal overvoltage seen. Some cables appear overloaded. The single line diagrams from the utility indicated the size that was used in the simulations but the cable specifications need to be verified further. Some overcurrent protective devices can be in critical states during short-circuits and faults. Transient stability simulations for both the existing and new system with RE have generally shown buses and parameters returning to their original states after the fault is cleared, but not when the fault occurred at the bus where the RE connects to; Bus10-4 parameters are not able to go back to original values. This scenario can escalate when the substations are in an interconnected mode. Additional simulations are recommended.

As some assumptions, despite being reasonable, are used in this investigation, using the precise specifications for all the devices used and intended for use in the system will help yield better results. Further investigation of the specific behaviors of the wind turbine generators is recommended, too. Simulation and analysis employing additional devices, equipment, and modifications to improve the systems considered here would be an interesting separate piece of work.

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