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Steady State Simulation of 33 kV Power Grid

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Abstract

An example is presented in this paper relating to power problems in Sandakan power network. Sandakan is a suburb in east coast of Sabah state of Malaysia. The problems were reported with power flow and N-1 contingency in terms of blackout after main grid supply outages with overload and high fault current on distribution system. This paper focuses on analysis of steady state stability of 33 kV power grid using load flow, contingency analysis and voltage stability (P-V Curve). The analysis is done by using industrial grade power software called Power System Simulation for Engineers (PSS/E). The power flow result showed that there are three generators generating out of limits. Contingency results showed that three transformer branches and three distribution branches are affected. There are nine weakest buses that violate contingency voltage deviation criterion and cannot withstand more load power when N-1-1 case in the branch of bus 8 to bus 28 is under outage.

Keywords

Load Flow, Contingency Analysis, PV Curve, Voltage Stability, Overload, Voltage Deviation Violation

1. Introduction

In Sabah grid, the power demand is increasing annually but the generated capacities is less than the power demand, especially in the east coast [1]. The current equipments in transmission system such as electricity cable are getting old and are found operated closer to their limits of stability and cannot withstand with increased power supply [2]. Due to these, the grid system is exposed to disturbances or contingencies which can cause system collapse and blackout. Sabah faced two major serious blackouts [1]. The most severe blackout happened in 2014 for 10 hours of state-wide blackout. The collapse is triggered by flashover which is from conductor of 132 KV transmission line. Another one is blackout in the whole east coast due to outage of 275 KV transmission line.

As stated in Sabah grid Code [3], most of transmission lines, distribution and transformers fulfil N-1 contingency requirement, but in fact studies showed that there is no N-1 contingency in aging existing transformer and existing line configuration [2]. Therefore, when N-1 contingency happens, overload conditions occur on those transformers, distribution and transmission lines.

Contingency analysis has been developed by [4] using sensitivity factors to approximate power flow on branches whereas voltage performance index is used by [5] to approximate the contingency voltage on a certain bus in a power system. For voltage stability part, [6] reviewed four commonly used voltage stability analysis tools which are PV/QV curve analysis, L index, Modal analysis and V/Vo index. Authors have done comparison of accuracy results on IEEE bus power system.

This paper focuses on steady state stability for distribution level of power grid. Thus, 33 KV Sandakan network of Sabah Grid System is chosen to simulate steady state stability which consists of load flow simulation, contingency simulation and P-V curve. Contingency scenarios are created to test its overall steady state stability of the grid in terms of contingency voltage deviation violation and percentage overload. Moreover, P-V analysis is performed to determine the weakest buses in the network. The process of analysing the stability can be daunting and challenging if the power network is highly complex, large size and non-linear. The process takes a lot of time in the calculations to access all the power variables and contingencies [7]. Therefore, a Power System Simulation for Engineers (PSS/E) software is utilized to perform all power flow computations in this steady state analysis.

2. Existing N-1 Network

The existing model of power system network shown in **Figure 1** is modelled by using (PSS/E).This network is disconnected from the main grid power supply, especially the supply from 275 KV transmission line. Therefore, in that case, the network itself is assumed as N-1 under outages of main grid and is considered as external N-1 condition. Date of bus names, Transformers, generators, loads and branches regarding powers and impedances are given in the tables at the **Appendix**.

The grid system has the following major components:

1) Buses: 34 (27 of them are connected)

2) Loads: 24 (22 of them are in service)

3) Branches: 40 (29 out of 32 distribution branches and 8 transformer branches are in service)

4) Fixed shunts: 6 (5 of them are in service)

5) Generators (machines): 8 (6 of them are in service)

3. Load Flow Analysis

Load flow analysis is used to calculate voltage, current flows, active and reactive

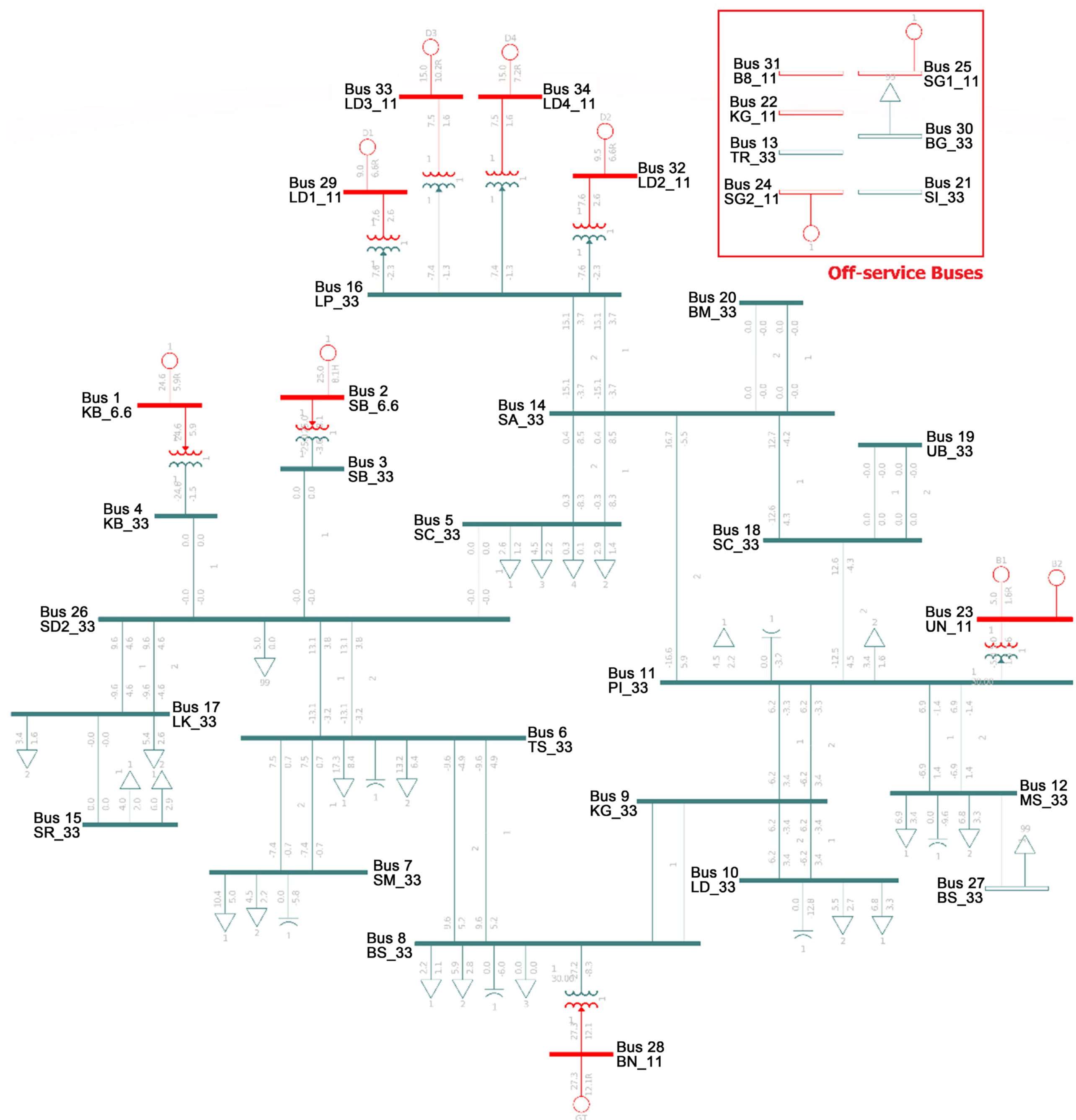

Figure 1. Existing power network drawn in PSS/E.

powers, power losses for generators, load and generator buses, distribution and transformer branches, and loads in the Power network. There are two types of solutions in PSS/E: Newton Raphson and Gauss Seidel load flows. Due to complexity and large number of buses in N-1 power network, Newton Raphson is chosen due to faster converging rate and repetitive complicated computation of Jacobian matrix and its minimal sensitivity. For contingency cases, Fixed Slope Decoupled load flow which is part of Newton Raphson created by Siemens Company is chosen as it performs better in difficult and complicated cases compared to other types of methods.

There are four power elements that load flow used to calculate. These are:

1) Generators (swing buses): generated active and reactive power flows

2) Distribution and transformer branches: current flows, active and reactive power flows, percentage voltage drop, power factor, and power losses.

3) Buses (load buses and generator buses): bus voltage, active and reactive power flows, and current flows.

4) Loads: active and reactive power flows, current flows, and percentage loading.

Table 1 shows the power flow results of generated active power and reactive power for each in-service generating unit which act as swing bus. P_{max} and P_{min} are the maximum and minimum generated capacity for each generator. Same goes to Q_{min} and Q_{max} which represent reactive power capacity. With respect to PGen, all generators generated within their active power and reactive power limits except for generators named KB_6.6, SB_6.6, and BN_11.

Table 2 shows the total generated power by all generators before and after the

Table 1. Generators results.

Bus No.	Bus Name	Base kV	PGen (MW)	P_{max} (MW)	P_{min} (MW)	QGen (MVAr)	Q_{max} (MVAr)	Q_{min} (MVAr)
1	KB_6.6	6.6000	24.6	10.0	0.0	5.9	7.3	0.5
2	SB_6.6	6.6000	25.0	10.0	0.0	8.1	7.3	0.5
23	GN_11	11.000	5.0	37.0	20.0	1.6	24.8	−14.7
28	BN_11	11.000	27.3	20.0	0.0	12.1	21.2	−15.2
29	LD1_11	11.000	7.6	15.0	8.0	2.6	11.4	−8.5
32	LD2_11	11.000	7.6	15.0	8.0	2.6	11.4	−8.5
33	LD3_11	11.000	7.5	15.0	8.0	1.6	11.4	−8.5
34	LD4_11	11.000	7.5	15.0	8.0	1.6	11.4	−8.5

Table 2. Total generated power in sandakan before and after N-1 outage.

Bus No.	Bus Name	Base kV	PGen (MW) (After Outage)	PGen (MW) (Before Outage)	Active Power Capacity (MW)
1	KB_6.6	6.6000	24.6	10.00	10.0
2	SB_6.6	6.6000	25.0	10.00	10.0
23	GN_11	11.000	5.0	14.76	37.0
28	BN_11	11.000	27.3	15.00	20.0
29	LD1_11	11.000	7.6	9.50	15.0
32	LD2_11	11.000	7.6	9.50	15.0
33	LD3_11	11.000	7.5	15.00	15.0
34	LD4_11	11.000	7.5	15.00	15.0
	TOTAL		112.10	98.76	137.00

main supply outage from 275 KV transmission line with respect to the total generated capacity. The table shows that the power demand increase by 13.34 MW from 98.76 MW after the outage, but they are within the total generated capacity.

Table 3 shows the load flow results for all in-service branches (transformer and distribution). Note: DB is distribution branch, TB is transformer branch. Transformer branches are found higher active and reactive power losses, higher percent of voltage drop, higher current flows and higher active and reactive power flows than that in distribution branches. Only transformer branches have higher loadings problem compared to distribution branches. For distribution branches, DB10_1 is recorded with highest power losses. For transformer branches, TB3 is recorded with highest reactive power loss and TB5 and TB6 share the highest active power losses. TB2 is recorded with highest percent of voltage drop among all branches, followed by DB2_1 and DB2_2. DB14_1, DB14_2, DB17_1 and DB17_2 are recorded with zero among all variables.

Table 4 and Table 5 show the load flow results for all in-service buses. Load buses are represented by bus code 1 while generator buses are represented by bus code 2. UB_33 and BM_33 are recoded zero in active and reactive power flows and current flows due to no loads connected to them. Generator buses are recorded higher current flows compared to load buses. All bus voltages are within contingency voltage range stated by Distribution Code of Energy Commission. The voltage range is from 0.9 pu to 1.1pu. That means all bus voltages are safe and secure under N-1 case which is disconnected from main grid supply.

This load flow analysis shows that all bus voltages are slightly higher than 100% and 2 load buses are overloaded as well as 3 generators generating out of limits.

4. Contingency Analysis

To compute the branch power flows after certain level of outage, contingency sensitivity factors are used to approximate the change in line flows and the changes in generation in a power system. It is one of fastest way to calculate possible overloads in a power system network. The main two sensitivity factors are Generation Shift Factors (GSF) and Line Outage Distribution Factors (LODF).

For GSF part, the generation factor is defined as changes in power flow in particular line when a change in power generation at reference bus occurs.

Generation shift factors,

$$\alpha_{li} = \frac{\Delta PF_l}{\Delta P_{Gi}} \tag{1}$$

where ΔPF_l = changes in power flow on l^{th} line

ΔP_{Gi} = changes in generation which takes place on i^{th} bus

For LODF, the line outage distribution factor is defined as the change in power flow on i^{th} line during pre-contingency line flow on l^{th} line.

Line outage distribution factors,

Table 3. Distribution and transformer branch results.

Branches	MW Flows	MVAr Flows	% Voltage Drop	kW Losses	kVAr Losses
DB1_1	13.606	3.741	0	0.002	0.196
DB1_2	13.3	1.644	0	0.002	0.176
DB2_1	12.004	6.544	2.25	30.998	557
DB2_2	12.004	6.544	2.25	30.998	557
DB3	13.752	7.036	0	0.002	0.234
DB4_1	7.457	0.646	0.22	13.641	36.767
DB4_2	7.457	0.646	0.22	13.641	36.767
DB5_1	9.328	4.194	0.95	11.233	195
DB5_2	9.328	4.194	0.95	11.233	195
DB6_1	13.406	1.646	0.75	35.109	632
DB6_2	13.406	1.646	0.75	35.109	632
DB7_1	6.187	−3.415	0.08	9.547	29.333
DB7_2	6.187	−3.415	0.08	9.547	29.333
DB8_1	6.225	−3.339	0.05	27.673	47.071
DB8_2	6.225	−3.339	0.05	27.673	47.071
DB9_1	6.907	−1.432	0.08	9.47	15.861
DB9_2	6.907	−1.432	0.08	9.47	15.861
DB10_1	12.132	−5.175	0.07	83.315	225
DB11_1	9.181	−3.916	0.04	30.672	82.668
DB12_1	22.751	2.229	0.09	16.57	34.142
DB12_2	22.751	2.229	0.09	16.57	34.142
DB13_1	9.212	−3.833	0.03	32.376	87.261
DB14_1	0	0	0	0	0
DB14_2	0	0	0	0	0
DB15_1	10.072	4.878	0	0.001	0.123
DB16_1	9.423	4.565	0.01	0.393	1.058
DB16_2	9.423	4.565	0.01	0.393	1.058
DB17_1	0	0	0	0	0
DB17_2	0	0	0	0	0
TB1	13.368	2.902	2.09	67.639	1258
TB2	13.68	5.136	3.59	74.983	1395
TB3	26.747	9.69	3.8	29.418	3530
TB4	12.879	1.094	0.76	49.758	925
TB5	11.549	2.247	1.65	81.776	629
TB6	11.549	2.247	1.65	81.776	629
TB7	11.361	1.21	1.15	77.846	599
TB8	11.361	1.21	1.15	77.846	599

Table 4. Load flows results for all in-service buses.

Buses	Bus Code	Bus Voltage (pu)	MW Loading	MVAr Loading	Amp Loading
BM_33	1	1.0316	0	0	0
BN_11	2	1.049	26.747	9.69	1423
BS_33	1	1.011	26.718	12.293	508.9
GN_11	2	1.04	12.879	1.094	652.3
KB_6.6	2	1.03	13.368	2.902	1162
KB_33	1	1.0091	13.3	1.644	232.4
KG_33	1	1.0329	12.394	6.772	239.2
LD1_11	2	1.049	11.549	2.247	588.7
LD2_11	2	1.049	11.549	2.247	588.7
LD3_11	2	1.044	11.361	1.21	574.4
LD4_11	2	1.044	11.361	1.21	574.4
LD_33	1	1.0337	12.375	12.823	301.6
LK_33	1	1.009	18.845	9.127	363.1
LP_33	1	1.0325	45.501	4.459	774.7
MS_33	1	1.0316	13.796	9.578	284.8
PI_33	1	1.0324	34.143	12.907	618.6
SA_33	1	1.0316	45.468	13.087	802.4
SB_3.3	1	1.0091	13.606	3.741	244.6
SB_6.6	2	1.045	13.68	5.136	1223
SC_33	1	1.032	9.212	3.833	169.2
SD2_33	1	1.0091	45.658	12.421	820.4
SD_33	1	1.0091	23.946	11.973	464.2
SM_33	1	0.9993	14.887	7.21	289.6
SR_33	1	1.009	10.072	4.878	194
TS_33	1	1.0016	45.375	16.043	840.7
UB_33	1	1.032	0	0	0

$$d_{li} = \frac{\Delta PF_l}{P_i^o} \tag{2}$$

where ΔPF_l = changes in power flow on l^{th} line

P_i^o = Power line flow on l^{th} line before contingency of i^{th} line

In PSS/E software, the process of performing contingency analysis is done automatically and comprehensively without manually tripping each line. Before carrying out N-1 contingency analysis, three types of files are created. They are *mon.file, *sub.file and *con.file. Each file is described in **Table 6**. **Figure 2** shows the process of creating these files.

Table 5. Load flow results for all in-service loads.

Load Buses	Id	MW Flows (kW)	MVAr Flows (kVAr)	Current Flows	% PF	% Loading
SD_33	1	2573	1246	49.57	90	99.1
SD_33	2	2879	1395	55.47	89.99	99.1
SD_33	3	4460	2160	85.92	90	99.1
SD_33	4	282	136	5.428	90.07	99.1
TS_33	1	17,289	8373	335.6	90	99.8
TS_33	2	13,172	6379	255.7	90	99.8
SM_33	1	10,415	5044	202.6	90	100.1
SM_33	2	4472	2166	86.99	90	100.1
BS_33	1	2181	1056	41.93	90	98.9
BS_33	2	5881	2848	113.1	90	98.9
LD_33	1	6849	3317	128.8	90	96.7
LD_33	2	5526	2676	103.9	90	96.7
PI_33	1	4497	2178	84.68	90	96.9
PI_33	2	3382	1638	63.68	90	96.9
MS_33	1	6947	3365	130.9	90	96.9
MS_33	2	6849	3317	129.1	90	96.9
SR_33	1	4031	1952	77.66	90	99.1
SR_33	2	6041	2926	116.4	90	99.1
LK_33	1	5416	2623	104.3	90	99.1
LK_33	2	3357	1626	64.68	90	99.1
SD2_33	1	−5000	0	86.69	100	99.1
TS_33	1	0	−6019	105.1	0	–
SM_33	1	0	−5992	104.9	0	–
BS_33	1	0	−6133	106.1	0	–
LD_33	1	0	−12823	217	0	–
PI_33	3	0	−3197	54.18	0	–
MS_33	3	0	−9578	162.4	0	–

Table 6. Three types of PSS/E files with descriptions.

File Type	Description
*mon.file	It informs load flow simulator the branches needed to be monitored when N-1 contingency happens. It also monitors and records the bus voltages within specific ranges or outside the range.
*sub.file	It tells load flow analysis to consider and perform at specific zone. It includes all involved power network elements in the case study.
*con.file	It is used to trip line or power elements to create contingency scenarios. Three types of contingencies: N-0 (system intact), N-1 (single power element outage) and N-2 (two power elements outage). In this case, N-1 is chosen.

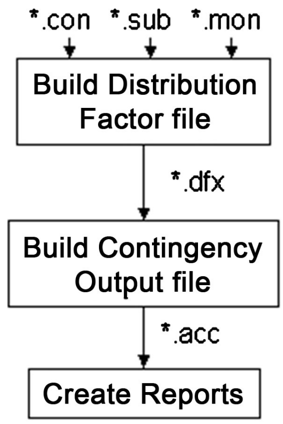

Figure 2. Process of creating these files.

Before doing any N-1 contingency analysis, it is compulsory to comply the contingency voltage range is set within ±10% of nominal voltage at steady state level for 33 kV distribution network. Since the nominal voltage is 1.0 pu, therefore the range is from 0.9 pu to 1.1pu. Besides, there are two types of contingency case analyzed as follows:

1) External contingency (N-1): is the power network cut off supply from main grid

2) Internal contingency (N-1-1): is another contingency happens after external contingency occurred

Branch flows and overload condition are determined for affected branches in every contingency case. Also, determines the buses that violate the contingency voltage deviation criterion which is the changes in voltage cannot rise more than 0.06 pu and drop more than 0.03 pu.

From **Table 7**, transformer branches which are marked in italic are recorded higher than that in distribution branches. The most severe overload cases happen on the transformer branches near to SB_6.6 and KB_6.6 generators. This is because the lost generation from incomer main grid is supplied by these two supplies, causing them to generate more power demand.

In the contingency analysis, all branches except six branches are considered safe and remained unaffected throughout all contingency cases (N-1-1 and N-1). **Table 8** shows that the list of 31 unaffected branches out of 37 branches involved in contingency analysis. The branches highlighted in italic are transformer branches and the rest are distribution branches.

There is no contingency voltage deviation violation report in all contingency cases except for case when outage of transformer branch bus 8 to bus 28. The bus that cannot withstand N-1 or N-1-1 is if they violate the voltage deviation criterion. The violation case can be shown visually in **Figure 3**. The affected buses highlighted in red are the buses that cannot withstand N-1. The transformer branch outage is highlighted in black. **Table 9** shows the affected buses during the contingency case named SINGLE 8-28 with their respective contingency voltage, initial voltage, and the voltage deviation limits.

Table 7. List of affected branches with respective total number of involved cases and overload percent.

Affected Branches					No. of Cases Involved from Total 38 contingency Cases	Overload Percent Ranges (%)
From Bus		To Bus		Id		
No	Name	No	Name			
1	*KB*_6.6	4	*KB*_33	1	38	174.0 - 228.1
2	*SB*_6.6	3	*SB*_33	1	38	173.4 - 238.3
6	TS_33	8	BS_33	2	1	110.2
8	*BS*_33	28	*BN*_11	1	38	110.5 - 142.0
14	SA_33	16	LP_33	1	8	101.8 - 165.0
14	SA_33	16	LP_33	2	8	101.8 - 165.0

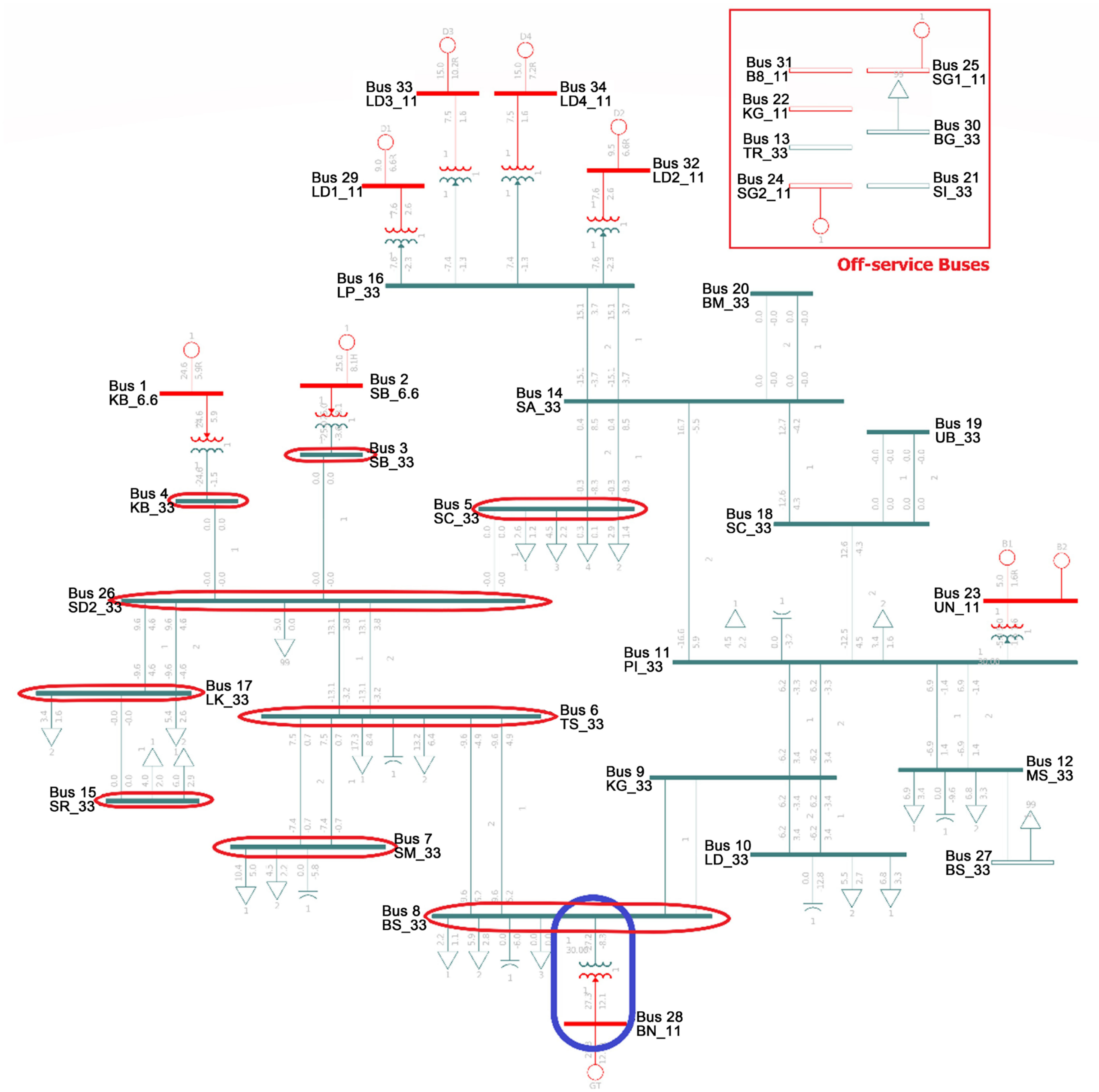

Figure 3. N-1-1 case with affected buses when outage of transformer branch from bus 8 to bus 28.

Table 8. List of unaffected branches throughout all contingency cases (N-1 and N-1-1 cases).

Unaffected Branches				
From Bus		To Bus		Id
No.	Name	No.	Name	
16	*LP*_33	29	*LD*1_11	1
16	*LP*_33	32	*LD*2_11	1
16	*LP*_33	33	*LD*3_11	1
16	*LP*_33	34	*LD*4_11	1
11	*PI*_33	23	*GN*_11	1
3	SB_33	26	SD2_33	1
4	KB_33	26	SD2_33	2
5	SD_33	14	SA_33	1
5	SD_33	14	SA_33	2
5	SD_33	26	SD2_33	1
6	TS_33	7	SM_33	1
6	TS_33	7	SM_33	2
6	TS_33	8	BS_33	1
6	TS_33	8	BS_33	2
6	TS_33	26	SD2_33	1
6	TS_33	26	SD2_33	2
9	KG_33	10	LD_33	1
9	KG_33	10	LD_33	2
9	KG_33	11	PI_33	1
9	KG_33	11	PI_33	2
11	PI_33	12	MS_33	1
11	PI_33	12	MS_33	2
11	PI_33	14	SA_33	1
11	PI_33	18	SC_33	1
14	SA_33	16	LP_33	1
14	SA_33	16	LP_33	2
14	SA_33	18	SC_33	1
14	SA_33	20	BM_33	1
14	SA_33	20	BM_33	2
15	SR_33	17	LK_33	1
17	LK_33	26	SD2_33	1
17	LK_33	26	SD2_33	2
18	SC_33	19	UB_33	1
18	SC_33	19	UB_33	2

Contingency results showed 3 transformer branches and 2 distribution branches are affected.

5. P-V (Load Power-Load Voltage) Curve Analysis

P-V curve is commonly used as voltage stability analysis tool to analyze maximum additional load power that a bus can sustain before its voltage collapses, after the load power exceeds its power limits. Figure 4 shows a simple P-V curve. When load power exceeds the power limit of a bus, the bus voltage will start to drop until reaching the critical point, which is voltage collapse point when the bus reaches the maximum additional power. PSS/E is able to simulate different P-V curve for different level of contingency. So, in this paper, P-V curve is simulated for external contingency and internal contingency cases for all 26 in-service buses. The maximum additional power transfer and voltage collapse point are recorded for each buses in every contingency cases.

All buses are simulated with P-V curves for every contingency case. Thus, 988 (38 contingency cases X 26 buses) P-V curves are simulated. Table 10 shows the list of number of contingency cases with the overall maximum additional power transfer among all buses. Among 38 contingency cases, 15 of them are recorded with the highest maximum additional power transfer with 312.50 MW, followed

Table 9. Contingency voltage deviation violation reports.

Contingency Label	Bus No.	Bus Name	V-Cont (pu)	V-Init (pu)	V-Rise (pu)	V-Drop (pu)
DEVIATION SINGLE 8-28	3	SB_33	0.97276	1.00406	0.06000	0.03000
DEVIATION SINGLE 8-28	4	KB_33	0.97276	1.00406	0.06000	0.03000
DEVIATION SINGLE 8-28	5	SD_33	0.97276	1.00406	0.06000	0.03000
DEVIATION SINGLE 8-28	6	TS_33	0.93054	0.98853	0.06000	0.03000
DEVIATION SINGLE 8-28	7	SM_33	0.92785	0.98622	0.06000	0.03000
DEVIATION SINGLE 8-28	8	BS_33	0.93149	1.00015	0.06000	0.03000
DEVIATION SINGLE 8-28	15	SR_33	0.97268	1.00398	0.06000	0.03000
DEVIATION SINGLE 8-28	17	LK_33	0.97268	1.00398	0.06000	0.03000
DEVIATION SINGLE 8-28	26	SD2_33	0.97276	1.00406	0.06000	0.03000

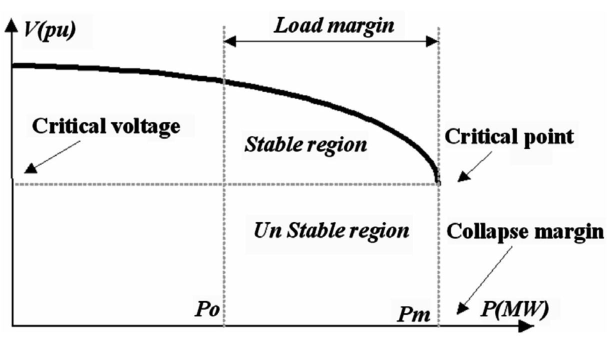

Figure 4. PV curve.

by 6 cases with 306.25 MW and 5 cases with 287.50 MW. The only one case with the lowest maximum additional power transfer (143.75 MW) happened when outage of transformer branch from bus 8 to bus 28. That means all buses can only withstand incremental power transfer up to 143.75 MW when this outage happens. That is why this case has only voltage violation cases, referring to Table 8. They cannot withstand higher power flows compared to other cases.

Among all P-V curves, almost all buses except generator buses have their voltage collapse point at below 0.9 pu. That is not reasonable that the steady state operating voltage is within 10% of the nominal voltage, from 0.9 pu to 1.1 pu. Since the weakest case is SINGLE 8-28 (1), in order to determine weakest buses, the maximum incremental power transfer at 0.9 pu of the nominal voltage is determined for each bus. Any voltage which is outside of the tolerance is not acceptable. Figure 5 shows the finding of maximum additional power transfer at

Table 10. List of number of contingency cases and the maximum additional power transfer.

No. of contingency cases	Maximum Additional Power Transfer (MW)
1	143.75
1	218.75
2	243.75
4	256.25
2	268.75
5	287.50
2	293.75
6	306.25
15	312.50

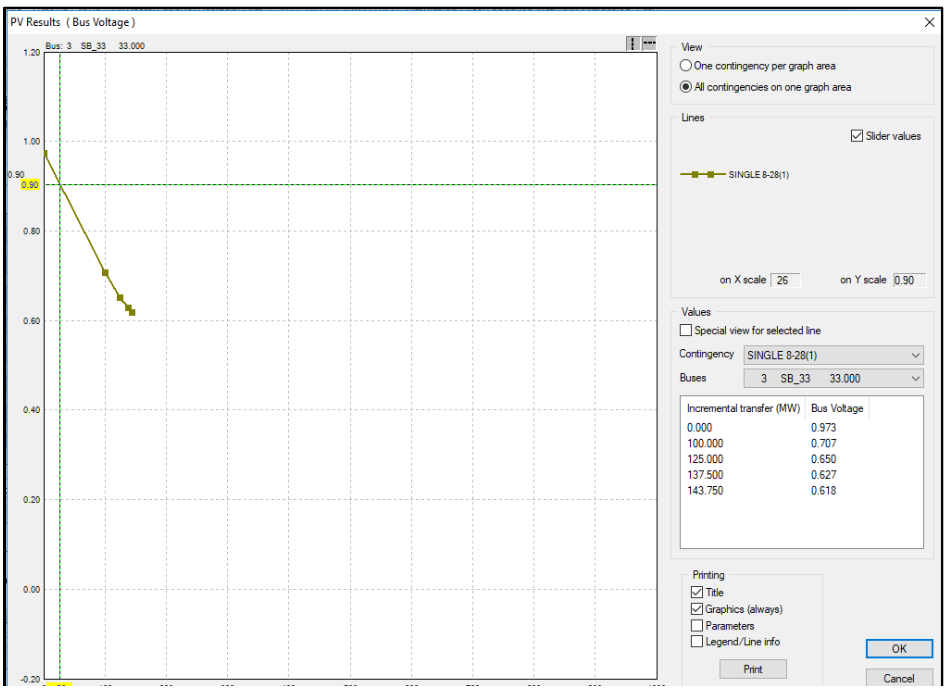

Figure 5. Maximum additional power transfer at 0.9 pu in PV curve.

0.9 pu. Table 11 shows the maximum additional power transfer at 0.9 pu for each bus with respective voltage collapse point at contingency case named SINGLE 8-28.

From Table 11, the generator buses (KB_6.6, SB_6.6, BN_11, GN_11, LD1_11, LD2_11, LD3_11 and LD4_11) have maintained constant bus voltage along all incremental power transfer. This is because no losses involved when the generators generate the output voltage to the nearest buses. The loss will be very small. Any bus that withstand below 50% of the 143.75 MW is considered as weakest buses. Therefore, the weakest buses are SB_33, KB_33, SD_33, TS_33,

Table 11. List of all buses with their respective maximum additional power transfer at 0.9 puin weakest contingency case (Single 8-28).

Bus No.	Bus Name	Maximum Incremental Power Flow (MW) at 0.9 pu	Voltage Collapse Point (pu)
1	KB_6.6	143.75	1.030
2	SB_6.6	143.75	1.045
9	KG_33	80	0.812
10	LD_33	80	0.807
11	PI_33	83	0.827
12	MS_33	86	0.821
14	SA_33	92	0.843
28	BN_11	143.75	1.049
29	LD1_11	143.75	1.049
32	LD2_11	143.75	1.049
33	LD3_11	143.75	1.044
34	LD4_11	143.75	1.044
18	SC_33	91	0.834
19	UB_33	91	0.834
20	BM_33	92	0.843
23	GN_11	143.75	1.040
16	LP_33	98	0.850
3	*SB*_33	26	0.618
4	*KB*_33	26	0.618
5	*SD*_33	26	0.618
6	*TS*_33	8	0.349
7	*SM*_33	6	0.334
8	*BS*_33	8	0.333
15	*SR*_33	29	0.618
17	*LK*_33	29	0.618
26	*SD2*_33	27	0.618

SM_33, BS_33, SR_33, LK_33, and SD2_33. The results from P-V actually correlate with the Contingency Voltage Violation results shown in Table 9.

6. Conclusions

Sandakan power network has serious overload condition on generating units compared to other distribution lines. This paper shows that 3 generators out of 8 are generating out of the limits. For all loads, a vast majority of loads are marginally overload. There are 9 weakest buses determined at weakest N-1-1 contingency case via P-V curve and Contingency analysis. The buses are found dropped out of the contingency voltage deviation criterion and can withstand smaller power transfer after the power exceeds their bus power limit.

Contingency analysis is a very important and useful tool in planning the unplanned electrical outages. It can predict the future power system conditions under outages. It evaluates how many those buses survive under outages and those didn't. In this case, PSS/E is able to perform contingency analysis within seconds and provide with accurate results. To improve its stability, two types of FACTS devices are recommended: UPFC and STATCOM. UPFC is used to compensate power flows to reduce overload condition whereas STATCOM is used to maintain bus voltage for better voltage profile.

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Appendix

Table A1. Buses Data Used in PSS/E.

Bus No.	Bus Name	Bus Code	Base kV	Voltage (pu)	Angle (deg)
1	KB_6.6	−2	6.6	1.0085	−15.28
2	SB_6.6	−2	6.6	1.0085	−15.28
3	SB_33	1	33.0	0.9594	−19.51
4	KB_33	1	33.0	0.9594	−19.51
5	SD_33	1	33.0	0.9594	−19.51
6	TS_33	1	33.0	0.9524	−23.99
7	SM_33	1	33.0	0.9499	−24.28
8	BS_33	1	33.0	0.9709	−23.60
9	KG_33	1	33.0	0.9543	−25.46
10	LD_33	1	33.0	0.9545	−25.73
11	PI_33	1	33.0	0.9549	−24.88
12	MS_33	1	33.0	0.9538	−25.07
13	TR_33	4	33.0	1.0000	0.00
14	SA_33	1	33.0	0.9615	−23.11
15	SR_33	1	33.0	0.9593	−19.52
16	LP_33	1	33.0	0.9615	−23.11
17	LK_33	1	33.0	0.9593	−19.52
18	SC_33	1	33.0	0.9580	−24.01
19	UB_33	1	33.0	0.9580	−24.01
20	BM_33	1	33.0	0.9615	−23.11
21	SI_33	4	33.0	1.0000	0.00
22	KG_11	4	11.0	1.0000	0.00
23	GN_11	2	11.0	0.9549	−54.88
24	SG2_11	4	11.0	1.0000	0.00
25	SG1_11	4	11.0	1.0000	0.00
26	SD2_33	1	33.0	0.9594	−19.51
27	BS_33	4	33.0	1.0000	0.00
28	BN_11	2	11.0	1.0490	10.42
29	LD1_11	2	11.0	0.9615	−23.11
30	BG_33	4	33.0	1.0000	0.00
31	B8_11	4	11.0	1.0000	0.00
32	LD2_11	2	11.0	0.9615	−23.11
33	LD3_11	2	11.0	0.9615	−23.11
34	LD4_11	2	11.0	0.9615	−23.11

Table A2. Transformer branch data used in PSS/E.

Transformer Branches				Id	Tap Positions	Winding MVA Base
From Bus		To Bus				
No	Name	No	Name			
1	KB_6.6	4	KB_33	1	8	14.0
2	SB_6.6	3	SB_33	1	8	14.0
8	BS_33	28	BN_11	1	5	25.0
11	PI_33	23	GN_11	1	13	20.0
16	LP_33	29	LD1_11	1	5	20.0
16	LP_33	32	LD2_11	1	5	20.0
16	LP_33	33	LD3_11	1	5	20.0
16	LP_33	34	LD4_11	1	5	20.0

Table A3. Machines data used in PSS/E.

Bus No.	Bus Name	Bus Code	PGen (MW)	P_{Max} (MW)	P_{Min} (MW)	QGen (Mvar)	Q_{Max} (Mvar)	Q_{Min} (Mvar)
1	KB_6.6	2	10.00	10.0	0.0	7.31	7.31	0.50
2	SB_6.6	2	10.00	10.0	0.0	7.31	7.31	0.50
23	GN_11	2	14.76	19.0	10.0	12.39	12.39	−7.35
23	GN_11	2	15.00	18.0	10.0	8.56	12.39	−7.35
24	SG2_11	4	25.00	10.0	0.0	−3.003	7.00	−5.00
25	SG1_11	4	25.00	10.0	0.0	1.525	7.00	−5.00
28	BN_11	2	15.00	20.0	0.0	17.468	21.24	−5.22
29	LD1_11	2	9.00	15.0	8.0	6.648	11.40	−8.50
32	LD2_11	2	9.50	15.0	8.0	6.603	11.40	−8.50
33	LD3_11	2	15.00	15.0	8.0	10.185	11.40	−8.50
34	LD4_11	2	15.00	15.0	8.0	7.224	11.40	−8.50

Table A4. Load data used in PSS/E.

Bus No.	Bus Name	Id	P_{load} (MW)	Q_{load} (Mvar)
5	SD_33	1	2.5730	1.2460
5	SD_33	2	2.8790	1.3950
5	SD_33	3	4.4600	2.1600
5	SD_33	4	0.2820	0.1360
6	TS_33	1	17.2890	8.3730
6	TS_33	2	13.1720	6.3790
7	SM_33	1	10.4150	5.0440
7	SM_33	2	4.4720	2.1660
8	BS_33	1	2.1810	1.0560
8	BS_33	2	5.8810	2.8480
8	BS_33	3	0.0000	0.0000
10	LD_33	1	6.8490	3.3170
10	LD_33	2	5.5260	2.6760
11	PI_33	1	4.4970	2.1780
11	PI_33	2	3.3820	1.6380
12	MS_33	1	6.9470	3.3650
12	MS_33	2	6.8490	3.3170
15	SR_33	1	4.0310	1.9520
15	SR_33	2	6.0410	2.9260
17	LK_33	1	5.4160	2.6230
17	LK_33	2	3.3570	1.6260
26	SD2_33	99	-5.0000	0.0000
27	BS_33	99	-10.0000	0.0000
30	BG_33	99	-2.0000	0.0000

Table A5. Branch/distribution line data used in PSS/E.

Distribution Branches								
From Bus		To Bus		Id	RATE1 (MVA)	Length (mile)	Line R (pu)	Line X (pu)
No	Name	No	Name					
3	SB_33	26	SD2_33	1	36.0	36.0	0.000000	0.000100
4	KB_33	26	SD2_33	2	36.0	36.0	0.000000	0.000100
5	SD_33	14	SA_33	1	36.0	9.0	0.017631	0.333357
5	SD_33	14	SA_33	2	36.0	9.0	0.017631	0.333357
5	SD_33	26	SD2_33	1	36.0	36.0	0.000000	0.000100
6	TS_33	7	SM_33	1	35.5	6.7	0.024425	0.065831
6	TS_33	7	SM_33	2	35.5	6.7	0.024425	0.065831
6	TS_33	8	BS_33	1	18.0	5.6	0.010970	0.207422
6	TS_33	8	BS_33	2	18.0	5.6	0.010970	0.207422
6	TS_33	26	SD2_33	1	36.0	10.0	0.019590	0.370397
6	TS_33	26	SD2_33	2	36.0	10.0	0.019590	0.370397
8	BS_33	9	KG_33	1	32.6	0.7	0.005039	0.007713
8	BS_33	9	KG_33	2	32.6	0.7	0.005039	0.007713
9	KG_33	10	LD_33	1	43.7	6.7	0.020426	0.062755
9	KG_33	10	LD_33	2	43.7	6.7	0.020426	0.062755
9	KG_33	11	PI_33	1	18.0	3.5	0.059158	0.125699
9	KG_33	11	PI_33	2	18.0	3.5	0.059158	0.125699
11	PI_33	12	MS_33	1	18.0	1.2	0.020283	0.043097
11	PI_33	12	MS_33	2	18.0	1.2	0.020283	0.043097
11	PI_33	14	SA_33	1	35.5	14.0	0.051038	0.137557
11	PI_33	18	SC_33	1	35.5	9.0	0.032810	0.088430
12	MS_33	27	BS_33	1	0.0	36.0	0.000000	0.000100
14	SA_33	16	LP_33	1	18.0	0.2	0.003380	0.007183
14	SA_33	16	LP_33	2	18.0	0.2	0.003380	0.007183
14	SA_33	18	SC_33	1	35.5	9.5	0.034633	0.093343
14	SA_33	20	BM_33	1	35.5	9.0	0.032810	0.088430
14	SA_33	20	BM_33	2	35.5	9.0	0.032810	0.088430
15	SR_33	17	LK_33	1	36.0	0.0	0.000000	0.000100
17	LK_33	26	SD2_33	1	35.5	0.1	0.000365	0.000983
17	LK_33	26	SD2_33	2	35.5	0.1	0.000365	0.000983
18	SC_33	19	UB_33	1	35.5	0.0	0.000000	0.000100
18	SC_33	19	UB_33	2	35.5	0.0	0.000000	0.000100