VOLTAGE STABILITY ANALYSIS IN AN IEEE 34 NODES TEST SYSTEM WITH THE PARTICIPATION OF PHOTOVOLTAIC GENERATION PLANTS

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ABSTRACT

This article describes a stability analysis in critical and generation nodes for an IEEE 34 topology that contains photovoltaic generation plants. The case studies the participation of photovoltaic plants is shown with 15% total generation of the system. The purpose of the case studies is to determine the range of stability that can be accepted in the proposed topology with the penetration of photovoltaic generation of the 15%, 25% and 50%, as well as to present the possible voltage variations, power drops and change in rotor angles in existing synchronous machines in the topology, in steady state as at the time of a failure.

KEYWORDS: DIGSILENT, Generation, Photovoltaic Plant

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1.INTRODUCTION

For the development of the analysis, the test topology 34 IEEE nodes is used (Figure 1).

Figure 1: IEEE 34 Node Test Topology [1]

When creating this configuration in the DIGSILENT software, adding virtual generation plants in some nodes and defining the nodes as bars with real impedance parameters and connection points, a much more voluminous scheme is obtained that is presented in figure 2, this it is attached in a legible format in the annexes to

this report.

All the elements of the proposed network were implemented in the DIGSILENT software, as an example shown in figure 3, the transformers between the bus 832-888 and the autotransformers between the bars 814-850.

Figure 3: Detail of elements in implemented topology (Created by the authors)

The line impedance parameters are shown in table 1, the impedance configuration in the lines is shown in table 2.

The voltage values in the different nodes are given by the system transformers, for the present case two voltages are presented, 24.9 kV and 4.16 kV, other parameters of these transformers are presented in table 3 and figure 4.

Table 1: Data line segments IEEE network 34

Node A	Node B	Length(ft.)	Config
800	802	2580	300
802	806	1730	300
806	808	32230	300
808	810	5804	303
808	812	37500	300
812	814	29730	300
814	850	10	301
816	818	1710	302
816	824	10210	301
818	820	48150	302
820	822	13740	302
824	826	3030	303
824	828	840	301
828	830	20440	301
830	854	520	301
832	858	4900	301
832	888	0	XFM-1
834	860	2020	301
834	842	280	301
836	840	860	301
836	862	280	301
842	844	1350	301
844	846	3640	301
846	848	530	301

850	816	310	301
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Table 2: Impedance settings for some of the implemented lines

Z & B Matrices before Changes					
Z (R + jX in ohms per mile)					
1.3368	1.3343	0.2101	0.5779	0.2130	0.5015
		1.3238	1.3569	0.2066	0.4591
				1.3294	1.3471
B in micro Siemens per mile					
5.3350		-1.5313		-0.9943	
		5.0979		-0.6212	
				4.8880	

Table 3: Transformers parameters

	kVA	kV-high	kV-low	R-%	X-%
Substation	2500	69-D	24.9 - Gr. W	1	8
XFM -1	500	24.9 – Gr. W	4.16 - Gr.W	1.9	4.08

2-Winding Transformer Type - Equipment Type Library\Trafo1.TypTr2

Basic Data

Name: Trafo1

Technology: Three Phase Transformer

Rated Power: 2.5 MVA

Nominal Frequency: 60 Hz

Rated Voltage:

HV-Side: 24.9 kV

LV-Side: 4.16 kV

Vector Group:

HV-Side: D

LV-Side: YN

Phase Shift: 0, *30deg

Name: Dyn0

Positive Sequence Impedance:

Short-Circuit Voltage uk: 3. %

Copper Losses: 10. kW

Zero Sequence Impedance:

Short-Circuit Voltage uk0: 3. %

SHC-Voltage (Re(uk0)) uk0r: 0. %

Figure 4: “Substation” transformer parameters in implemented scheme.

2. PARAMETERS OF THE PHOTOVOLTAIC PLANT

The parameters of apparent nominal power, power factor, number of inverters, active and reactive power limits, internal resistance of the element, maximum current, minimum voltage disconnection, disconnection time, among others, are presented in table 4.

Table 4: Virtual power plant parameters

Technology	Three-phase active power source
Number of inverters in parallel	one
Nominal apparent power	100 kVA (Variable in stability tests)
Power factor	0.8 (Inductive)
Active power upper and lower limits	0-9999 kW
Short circuit model	Dynamic Voltage
Investor internal losses	0.8%
Internal control model	Voltage level (+ or-) 10%

The generation curves are those presented in [1], shown in table 5, figure 5 and figure 6.

Table 5: Model proposed for photovoltaics for 24 hours (taken from proposed article [1]).

Hour	Power on FV
0:00	0
1:00	0
2:00	0
3:00	0
4:00	0
5:00	0
6:00	10
7:00	40
8:00	60
9:00	80
10:00	90
11:00	95
12:00	100
13:00	100
14:00	98
15:00	95
16:00	75
17:00	50
18:00	30
19:00	10
20:00	0
21:00	0
22:00	0
23:00	0

Figure 5: Model curve proposed for photovoltaics for 24 hours (taken from proposed article [1]).

Figure 6: Generation curve in DigSilent interface. (Own elaboration of the authors)

2.1 Demand Data

For the generation of the load vectors for each hour of a day, a random of 34 values of consumed power is made, one for each node, which meet the condition that their sum must be the total power available in that hour given all the generators and all the PHOTOVOLTAIC PLANT, their condition is given by the following function.

$$\frac{\text{Random for current node}}{(\text{add 34 random} * \text{maximum allowable load value in that hour})}$$

This calculation is made for each node and for each hour, resulting in a matrix of 24 * 34 values, which are shown in table 6.

Table 6: Representation of vector matrix generated per hour

Hour	Loading Vector	Node 800	Node 801	Node 802	Node 803	Node 804	Node 805	Node BB
00:00	700	31.23160748	10.5944433	16.20221696	39.9404844	21.8221115	37.8175748	15.9502471
01:00	802	35.78249886	12.13820504	18.56311143	45.76038356	25.0019049	43.3281357	18.2744259
02:00	670	29.89311002	10.14039573	15.50783623	38.22874935	20.8868781	36.1968216	15.266665
03:00	730	32.57010494	11.04849087	16.89659769	41.65221945	22.7573448	39.438328	16.6338291
04:00	650	29.00077837	9.837697351	15.04491575	37.08759266	20.2633892	35.1163194	14.8109437
05:00	850	37.9240948	12.86468115	19.67412059	48.49915963	26.4982782	45.9213408	19.3681571

06:00	900	40.1549239	13.6214271	20.83142181	51.35205137	28.0570005	48.6225961	20.5074605
07:00	910	40.60108972	13.77277629	21.06288205	51.92262972	28.3687449	49.1628472	20.7353212
08:00	870	38.81642644	13.16737953	20.13704108	49.64031633	27.1217671	47.0018429	19.8238785
09:00	950	42.38575301	14.37817305	21.98872302	54.20494312	29.6157227	51.3238515	21.6467639
10:00	1100	49.07824033	16.6484109	25.46062665	62.76361834	34.2918895	59.4276175	25.064674
11:00	1110	49.52440615	16.79976009	25.69208689	63.33419669	34.6036339	59.9678685	25.2925346
12:00	920	41.00472556	13.92412548	21.29434229	52.49320807	28.6804894	49.7030983	20.9631819
13:00	810	36.13943151	12.25928439	18.74827962	46.21684623	25.2513004	43.7603365	18.4567145
14:00	850	37.9240948	12.86468115	19.67412059	48.49915963	26.4982782	45.9213408	19.3681571
15:00	930	41.49342137	14.07547467	21.52580253	53.06378642	28.9922338	50.2433493	21.1910425

Table 7 shows the values on which the load vector matrix depends.

Table 7: Values on which the charge vector matrix depends

34 IEEE Node Network	Maximum power available by VPP generators				
	Zone 1 ->	Generator 1	600	N/A	0
	Zone 2 ->	Generator 2	600	VPP1	75
	Zone 3 ->	Generator 3	600	VPP2 & VPP3	225

To exemplify in detail, figure 7 shows the power consumed by nodes in a 24-hour period.

Figure 7: Power consumed by reference nodes in 24 hours

3. PERMISSIBLE LIMITS OF VOLTAGE AND LOADABILITY OF THE NODES

Figure 8 shows the status of each node and each generator of the network according to the proposed limits. Although this graphic form is efficient to represent the conditions in which all the elements of the system are found, it does not allow to determine the variations and overloads that the generators present, therefore, it is necessary to generate a report of voltages, active and reactive power, current and load percentage of all bars for each hour, and analyze each generator independently for 24 hours.

Figure 8: Detail of permissible limits of voltage and chargeability in network nodes.

Figure 9 shows the demand vector taken as a reference for the respective analysis of the IEEE 34 node power system.

Figure 9: 24-hour demand vector.

In the simulation there are six generators distributed as follows: three conventional generators and three unconventional (PHOTOVOLTAIC PLANT), it is observed in the graph of figure 10 that the power generated by conventional generators (G1, G2, G3) and the non-conventional ones (photovoltaic plant1, photovoltaic plant2, photovoltaic plant3) correctly supply the energy demanded with small variations due to losses of transmission lines.

Figure 10: Based on this power flow and the generated demand curves, we have the highest and lowest demand hours, as well as the critical nodes of the system (Table 8).

Table 8: Maximum and minimum powers in 24 hours and critical node of the system

Power (kW) at peak time (12:00)	Power (kW) in hour of least demand (24:00)
1130	597
Critical node of the system at peak time	Node 890

Finally, it is determined that the stability analysis must be carried out at the critical node of the system (Node 890) since it is the furthest from the reference node (node 800), then a three-phase fault and stability analysis is performed at this point, varying the generation penetration of the PHOTOVOLTAIC PLANT by 15%.

4. STABILITY ANALYSIS WITH 15% PARTICIPATION OF PHOTOVOLTAIC PLANT

To perform the stability analysis in this case, the power that each generator node must have is determined, for a 15% share of the photovoltaic plants (Table 9).

Table 9: Power to be generated by each node in participation of 15% of the PHOTOVOLTAIC PLANT

Case 1 Photovoltaic plants with 15% participation	
Generator	Power (kW)
Gen 1	360
Gen 2	300
Gen 3	300

Vpp1	60
Vpp2	100
Vpp3	10
Total Power	1130

When a three-phase fault occurs, the voltage of the shorted node falls, while the voltages of the other nodes and generators also fall, but it recovers when the protections are activated, although not instantaneously, as illustrated in figure 11.

Figure 11: Voltage per unit in Fault Node (Green) Conventional plants (red) and PHOTOVOLTAIC PLANT (Blue)

The data obtained for the rotor angle of a synchronous generator (node 800 - Blue line) and the power factor of photovoltaic plants is described in figure 12, which shows how the rotor angle becomes unstable given the fault, and it tends to stabilize over time, while the power factor of photovoltaic plants recovers immediately when the switches are opened, to fall over time given the instability and overload of the system in it.

Figure 12. Node 800 generator rotor angle in radians and power factor of plants fotovoltaicas.

In the fault bus, the voltage and current per unit are calculated to check the estimated behavior, the voltage decreases and the current rises abruptly, until the time in which the protection trips, dissipating the fault, this is shown in the figure 13, the red line being the voltage, and the blue line being the current.

Figure 13: Current (blue line) and voltage (red line) at the fault node.

The voltages in the generation nodes remain relatively stable at the time of failure, they decrease from their value 1 per unit to 0.2 per unit, to gradually stabilize after the opening of the protection contacts in a time of 0.2 seconds, sufficient to ensure the stability of the system.

Figure 14: Voltages in generating bars during failure.

The power delivered by the generating nodes grows 2.3 times at the moment of the failure, to fall when it dissipates, however, the time required to achieve coordination in generation is 0.5 seconds, considerable, although it does not present a risk for the physical components of these elements (figure 15).

Figure 15: Active power in generator nodes at failure time.

The power factor in the generating nodes varies enormously depending on their location in the topology, that is, how far away from the point of failure they are, in figure 16 we have the furthest node (ocher line - node 800) presents a slight variation of its power factor, while virtual plant 2 (celestial line - node 824) presents an enormous variation given its proximity and little resistance to failure (figure 16).

Figure 16: Power factor in system generation nodes

For a more detailed analysis of the condition of distance to failure, the variation of the rotor angle of the generators implemented in the topology is analyzed, for a long distance the impact on the machine is minimal, as evidenced by the yellow line in the following graph, while the blue and red lines represent synchronous machines close to the point of failure, showing greater disturbance in their torque and angle of rotation (figure 17).

Figure 17: Rotor angle during failure of synchronous generators of the system.

5. RESULTS

Results with case 1 - 15% partition of PHOTOVOLTAIC PLANT.

Voltage in Generators G1, G2, G3, Photovoltaic Plant1, Photovoltaic Plant2, Photovoltaic Plant3 with $t = 0.5s$ (figure 18).

Figure 18: Voltage in Generators G1, G2, G3, Photovoltaic Plant1, Photovoltaic Plant2, Photovoltaic Plant3 with $t = 0.5s$.

Active power in generators G1, G2, G3, PHOTOVOLTAIC PLANT1, PHOTOVOLTAIC PLANT2 AND PHOTOVOLTAIC PLANT3 with a $t = 0.6s$ (Figure 19).

Figure 19: Active power in generators G1, G2, G3, PHOTOVOLTAIC PLANT1, PHOTOVOLTAIC PLANT2 AND PHOTOVOLTAIC PLANT3 with a $t = 0.6s$.

Power factor in Generators G1, G2, G3, Photovoltaic Plant1, Photovoltaic Plant2, Photovoltaic Plant3 with $t = 0.6s$ (figure 20).

Figure 20: Power factor in Generators G1, G2, G3, Photovoltaic Plant1, Photovoltaic Plant2, Photovoltaic Plant3 with $t = 0.6s$.

Rotor angle in G2 and G3 generators at $t = 3s$ (figure 21).

Figure 21: Angle of the rotor in the G2 and G3 generators at $t = 3s$.

8. CONCLUSIONS

When performing the stability analysis in the three proposed scenarios, in which the generation of energy by means of photovoltaic plants is 15%, 25% and 50% of the total, it is defined that in normal operating scenarios of the system the photovoltaic plants They do not affect the voltage or affect the synchronous generators present in the topology, they generate their contribution to the required voltage assuming that the generation curve of these photovoltaic plants during the day is stable and does not show drops given atmospheric conditions such as cloudiness or low radiation, without However, when faced with failures, they have a great impact on critical nodes of the system as well as on the generation nodes, in the study cases of 15% and 25% it was found that the effect on the voltage level in the generation nodes is similar to that generated by conventional generators, however in the 50% case study it is found that the voltage drop is twice per unit, and its p factor Power goes from inductive to capacitive, this being unacceptable since it injects all its stored energy into the system, making it much more unstable and without the possibility of recovering quickly.

The distance (and in turn the reactance) that the generation plants present to the fault node also determines their affectation, the further away a synchronous machine is, the lower its variation in the rotor angle, however, its voltage drop remains indifferent to distance and its power factor is still dependent on the response of other elements such as capacitor banks or unconventional plants.

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