Proceeding Series of the Brazilian Society of Computational and Applied Mathematics, v. 11, n. 1, 2025.

Trabalho apresentado no XLIII CNMAC, Centro de Convenções do Armação Resort - Porto de Galinhas - PE, 2024

Proceeding Series of the Brazilian Society of Computational and Applied Mathematics

Nodal Current Analysis for Consumption-Injection Limits under PV Distributed Generator

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The fluctuating demand on a power grid can alter its profile voltage and reach the current grid's limits. Moreover, adding distributed generators, such as photovoltaic (PV) microgeneration, can speedup this process due the resistive-inductive properties of grid cables (Fig. 1) and the change in the current flow, sometimes consumed, sometimes injected. As a result, it becomes challenging to online predict the maximum allowable power generation for each PV system on the grid without exceeding voltage [1] and current limit.

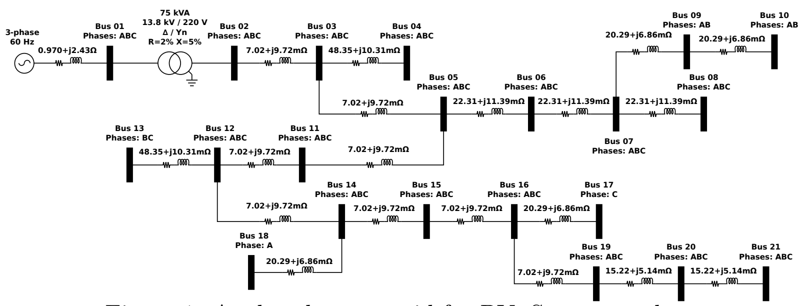

Figure 1: Analyzed power grid for PV. Source: authors.

On the flip side, it is straightforward to equate the maximum load or current injection at each bus (I_{bus}) without current in the other ones. For example, by assuming a typical 0.850 lagged power factor (PF) [2] for the maximum load (max I_{bus}) and an unity power factor for PV injection (min I_{bus}) to every single bus (Eq. (1)). In which V_{bus} is the RMS voltage value and Z_{bus} the Thévenin complex impedance seen by the analyzed bus. The $^{\bullet}$ and $\angle$ symbols represent phasors and their angles, respectively.

$$\begin{cases} \text{max } \texttt{or} \text{ min} & I_{bus} = |\dot{I}_{bus}| = |I_{bus_{real}} + j \cdot I_{bus_{imag}}| = |\dot{V}_{bus}/Z_{bus}| \\ \text{s.t.} & 116\,\text{V} \leq V_{bus} \leq 133\,\text{V} \\ & \text{PF} = 0.850 \left(\left(\angle\dot{V}_{bus} - \angle\dot{I}_{bus} \right) > 0 \right) \texttt{ or } 1.000 \left(\left(\angle\dot{V}_{bus} - \angle\dot{I}_{bus} \right) = 0 \right) \end{cases} \quad (1)$$

Even with the simplified conditions analyzed, the problem can not be solved with linear algorithms (Simplex) due the complex variables involved create a nonlinear correlation. The numerical solution in Table 1 resulted from the use of the `libreoffice-nlpsolver` package of `LibreOffice Calc` to solve Eq. (1), which internally implements the differential evolution [3]. Alternatively, if it is considered equal load/generation across all buses, loads of 7.2 A and PV injections of 3.9 A will reach the bus 21 voltage limit (the farthest bus from source), ranging from (116 V) to a maximum of 1.1 pu (133 V) [4, 5].

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Table 1: Maximum load with 0.850 inductive power factor & maximum active current injection.

Bus	Phases	Max. Load (A)	Max. PV gen. (A)
02	ABC	377.3	557.3
03	ABC	273.0	338.1
04	ABC	127.7	88.8
05	ABC	213.9	244.4
06	ABC	144.6	126.4
07	ABC	109.0	85.8
08	ABC	87.5	65.1
09	AB	90.4	66.4
10	AB	77.2	54.2
11	ABC	175.7	191.7
12	ABC	149.2	157.8
13	BC	92.0	68.4
14	ABC	129.5	134.1
15	ABC	114.5	116.6
16	ABC	102.6	103.2
17	C	86.1	75.8
18	A	104.3	91.3
19	ABC	92.9	92.5
20	ABC	82.2	74.4
21	ABC	73.7	62.4
All buses equal current		7.2	3.9

Table 1 results confirmed that the further away busses first reach the voltage limits [1] with lover load / injected currents. additionally, these findings do not offer a complete picture of the impact on the grid under distributed generation, and further analysis, such as temporal simulations and phase unbalance analysis is needed.

Acknowledgment

The authors thank the Research Foundation of the State of São Paulo (FAPESP) for supporting this research through grants #2016/08645-9 and #2021/11380-5.

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