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On-line load sensitivity identification in LV distribution grids

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On-line load sensitivity identification in LV distribution grids

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Abstract—This letter proposes a new on-line load sensitivity identification by means of power electronics-based devices. Applying a voltage and frequency perturbation and measuring the consumed power of the loads, the proposed method computes in real time the voltage and frequency dependency of the load active and reactive power. In this work a Smart Transformer application has been proposed, but the method is general for any power electronics converter able to influence dynamically the voltage and frequency in the grid.

Index Terms—Load sensitivity, on-line identification, smart grid.

I. INTRODUCTION

IN recent years several applications have been proposed utilizing the controls of distributed resources in order to provide services to the main utility transmission grid. The regulation of load consumption by controlling the voltage magnitude is a relatively low-cost means for enhancing system stability, avoiding the need to resort to other, more stringent corrective actions, such as firm load shedding, in case of emergency conditions [1]. Similarly, in microgrids, or in Low-Voltage (LV) grids fed by Smart Transformer (ST), voltage control can be used as a means to modify the power consumption of the local loads, in order to achieve smooth operation [2], provided again that the load sensitivity is known, at least approximately. Load dependency on voltage can vary considerably from bus to bus due to the different nature of each connected load, and even in the same distribution feeder due to seasonable and time of day variations, different workday or weekend load patterns, etc. As a result it is important for any distribution system control to take into account the varying load sensitivity so as to avoid possible incorrect maneuvers during grid management [3]. To solve this problem, a method is proposed in this letter to measure the load sensitivity in real time, thus providing accurate information to system controls. The method proposed is based on applying an intentional small perturbation in voltage magnitude and frequency and subsequently measuring the load power variation. Since only a small variation is necessary (i.e. less than 1 %) the experiment can be repeated as often as deemed necessary, e.g. every hour or every 10 minutes, without affecting power quality. It is worth noticing that the voltage and frequency variations introduced are balanced, in order to not affect the three-phase loads

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connected in the grid (e.g. motors). In this paper we introduce the principle of the proposed method and demonstrate the proof-of-concept using simulation. The measurement method is general and does not depend on the load model simulated. In the simulation the on-line load sensitivity identification is applied by means of a Smart Transformer feeding a LV grid [4]. A three-phase identification is performed, i.e. the load on each phase is identified separately, so that the differences between phases, which are considerable in LV networks are correctly identified. The algorithm developed can be applied using any voltage control device, for instance a power electronics converter.

II. ON-LINE LOAD SENSITIVITY IDENTIFICATION

As explained in the Introduction, the sensitivity identification method is not dependent on the load model and is based on measurement. In the simulation used to demonstrate the concept an exponential load model (with respect to voltage dependence) is assumed of the form:

$$\begin{aligned} P &= P_0 (V/V_0)^{K_p} (1 + K_{fp}((f - f_0)/f_0)) \\ Q &= Q_0 (V/V_0)^{K_q} (1 + K_{fq}((f - f_0)/f_0)) \end{aligned} \quad (1)$$

where V and f are the rms voltage and frequency, V_0 and f_0 are the reference voltage and frequency respectively, and K_p , K_q , K_{fp} , K_{fq} are the sensitivity coefficients describing the dependency of active and reactive power on voltage and frequency. P_0 and Q_0 are the consumed load powers at reference conditions. The exponential load model has the following properties [5]:

- It is independent of initial voltage and does not require initialization.
- Only one parameter (exponent) is needed for active and one for reactive load.
- The exponent is equal to load sensitivity to voltage.

In the following only the active power sensitivity identification is described, as the reactive power case is identical.

1) *Voltage sensitivities*: The load power sensitivity to voltage is defined as:

$$\frac{dP/P_0}{dV/V_0} = K_p \quad (2)$$

In the case of exponential load the sensitivity is equal to the exponent K_p , while V_0 can be chosen arbitrarily because for any voltage V_1 and corresponding power P_1 it is easily shown that:

$$\frac{P_1}{V_1^{K_p}} = \frac{P_0}{V_0^{K_p}} \quad (3)$$

The identification method proposed is to introduce an intentional small voltage variation and approximate (2) at each time instant t_k as:

$$\frac{\frac{P(t_k) - P(t_{k-1})}{P(t_{k-1})}}{\frac{V(t_k) - V(t_{k-1})}{V(t_{k-1})}} = K_p \quad (4)$$

where t_{k-1} is the time of the previous measurement.

2) *Frequency sensitivities*: The sensitivity with respect to frequency is defined in a similar way.

$$\frac{dP/P_0}{df/f_0} = K_{fp} \quad (5)$$

Due to linearity of (5) P_0 can be again taken equal to the previous measurement. Discretizing equation (5) at time t_k , the frequency sensitivity of the active power can be algebraically calculated as follows:

$$\frac{\frac{P(t_k) - P(t_{k-1})}{P(t_{k-1})}}{\frac{f(t_k) - f(t_{k-1})}{f_0}} = K_{fp} \quad (6)$$

III. SIMULATION RESULTS

The effectiveness of the method has been proved simulating in PSCAD/EMTDC™ the 230 V_{rms} LV grid shown in Fig. 1, for 20 s with a time-step of 50 μs. A ST has been chosen as MV/LV interface to apply direct voltage and frequency control in the LV grid. The single-phase aggregate loads of the grid are unbalanced and have different active and reactive power dependency on voltage and frequency as shown in Table I. In the simulation the voltage sensitivities are calculated starting from the 10th second, applying a perturbation of −2.3 V (−0.01 p.u.) simultaneously in all three phases lasting for 1 second, while the frequency coefficients at the 15th second, applying a variation of −0.1 Hz for 3 seconds, as shown in Fig. 2. Gaussian noises with standard deviation equal to 5 V and 5 A have been added respectively to the voltage and current measurements to simulate measurement noise. During the voltage and frequency ramp variations (0.2 s for the voltage and 0.5 s for the frequency), the coefficients are evaluated each time step and stored in memory. At the end of the time window

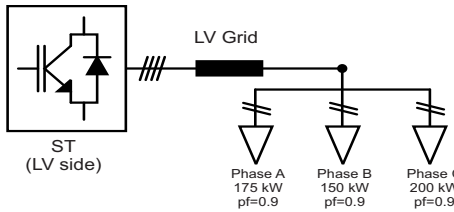


Fig. 1. Grid simulated in PSCAD/EMTDC™

TABLE I
COMPARISON BETWEEN THEORETICAL AND ESTIMATED VALUES

Phase		K_p	K_q	K_{fp}	K_{fq}
A	Theoretical	0.70	1.20	2.50	1.20
	Estimated	0.78	1.09	2.65	1.44
B	Theoretical	1.40	1.40	5.00	4.00
	Estimated	1.53	1.47	4.63	4.04
C	Theoretical	2.00	3.20	0.00	-2.50
	Estimated	1.95	3.14	0.19	-2.34

the estimated coefficients are computed averaging the stored values and are shown in Table I. As can be noticed, the load is correctly identified with negligible errors, caused by the load time constants, and the noise impact. Errors can be minimized by increasing the perturbation of the controlled variable, but this will have a stronger impact on grid power quality.

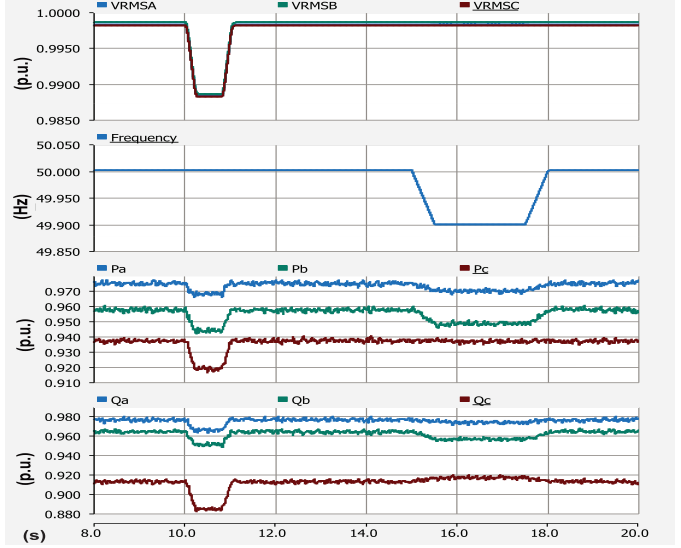


Fig. 2. (a) single-phase ST rms voltages, (b) grid frequency, (c) single-phase consumed active powers, (d) single-phase consumed reactive powers

IV. CONCLUSION

In this letter a new on-line load sensitivity identification method has been proposed using an intelligent power electronics-based device. It is noted that no fitting methods or a long data history are required for the sensitivity measurement. The sensitivity is identified in real time by means of voltage and frequency perturbations, followed by active and reactive power measurements. Load sensitivities to voltage and frequency are identified separately on each individual phase, even though the applied disturbance is a three-phase one to avoid added unbalance. Case studies with three-phase motors and other loads, as well as laboratory experiments will be part of future research. The method, here described for a Smart Transformer case, can be also applied using any power electronics-based device able to influence the voltage or frequency value in the grid.

REFERENCES

- [1] P. Aristidou, G. Valverde, and T. Van Cutsem, "Contribution of distribution network control to voltage stability: A case study," *IEEE Transactions on Smart Grid*, vol. PP, no. 99, pp. 1–1, 2015.
- [2] G. De Carne, G. Buticchi, M. Liserre, P. Marinakis, and C. Vournas, "Coordinated frequency and voltage overload control of smart transformers," in *IEEE PowerTech*, 2015.
- [3] J. Milanovic, K. Yamashita, S. Martinez Villanueva, S. Djokic, and L. Korunovic, "International industry practice on power system load modeling," *IEEE Transactions on Power Systems*, vol. 28, no. 3, pp. 3038–3046, Aug 2013.
- [4] R. Pena-Alzola, G. Gohil, L. Mathe, M. Liserre, and F. Blaabjerg, "Review of modular power converters solutions for smart transformer in distribution system," in *IEEE Energy Conversion Congress and Exposition (ECCE)*, Sept 2013, pp. 380–387.
- [5] T. Van Cutsem and C. Vournas, *Voltage Stability of Electric Power Systems*. Kluwer Academic Publishers, 1998.