



Nonlinear regression applied for power quality disturbances characterization in grids with wind generators

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Abstract. The impact of wind generation on the electrical system should be assessed to figure out potential hazards to system operation and deterioration of power quality indicia. In this paper signal processing algorithms has been applied to analyze switching transients within wind generation units. Nonlinear regression method and Prony model were applied to determine transients' parameters for various operation modes of the wind generator. Both methods delivered quite satisfactory results, but the regression method was prone to local minima.

Key words

wind generation, transients, nonlinear regression, Prony method

1. Introduction

Besides distinctive merits, the connection of wind generators leads to many disturbances, such as: voltage fluctuation, flickers, harmonics, instability, blind power regulation problems, and transients [1]. Those disturbances affect power quality. Power quality issues connected with wind generation are not only important because of technical aspects, they are also crucial on the free energy market.

There are at least three main wind generators structures, which can be pointed out. The simplest one, but certainly not advanced technologically, is the squirrel-cage induction generator connected directly to the grid.

Many of the wind energy converters installed today still have a squirrel-cage induction machine connected directly to the grid.

That type of installation is cost saving (repowering), and therefore widely used, but from the system analysis point of view it can be considered as a potential source of disturbances [2].

During the switching of capacitors transients occur, which are devastating for sensitive equipment, protection relays and insulation. The impact of transients on power quality indices cannot be neglected [1].

Transient overvoltages can theoretically reach peak values up to 2.0 pu. High current transients can reach values up to ten times the nominal capacitor current with duration of several milliseconds.

The purpose of this paper is the assessment of transients in electrical system with asynchronous wind generator. The analysis was carried out for real measured signals and for different operation conditions of the wind converter simulated in Matlab in SimPowerSystem Toolbox [3].

Presented below, the nonlinear regression method and the Prony method were considered as appropriate tools for parameters estimation of transients. Further, the simulation model and analyses of simulated and measured signals are presented.

2. Nonlinear Regression

Nonlinear regression is a general technique to fit a curve through data [4]. It fits data to any equation that defines Y as a function of X and one or more parameters. It finds the values of those parameters that generate the curve that comes closest to the data (minimizes the sum of the squares of the vertical distances between data points and curve). That technique requires a model of the analyzed signal. In the case of capacitor bank switching, the signal model of transient component can be defined as

$$x(t) = A_1 \sin(\omega_1 t + \varphi_1) + A_2 e^{-\alpha t} \sin(\omega_2 t + \varphi_2) \quad (1)$$

where A- amplitudes, α - damping factor and ω - angular velocities are unknown and should be estimated. Practically, the signal is observed (or measured) during a finite duration of time and N samples of this signal are available. The measured discrete time signal $y(nT_p)$ can be specified as

$$\begin{aligned} y(nT_p) = & A_1 \sin(\omega_1 nT_p + \varphi_1) + \\ & + A_2 e^{(-\alpha nT_p)} \sin(\omega_2 nT_p + \varphi_2) + e(nT_p) = \\ & x(nT_p) + e(nT_p) \end{aligned} \quad (2)$$

for $n=1,2,3,\dots,N$.

T_p - is the sampling period, N - the number of samples and e the estimation error correlated with each sample, which includes random noise and other distortions.

The problem of nonlinear regression can be formulated as an optimization problem, where the goal is to minimize the difference between the physical observation and the prediction from the mathematical model. More precisely, the goal is to determine the best values of the unknown parameters $A, \alpha, \omega, \varphi$ in order to minimize the squared errors between the measured values of the signal and the computed ones.

Thus, the optimization problem can be formulated as follows:

Find a vector $\mathbf{w} = [A_1, A_2, \alpha, \omega_1, \omega_2, \varphi_1, \varphi_2]^T$ which minimizes the objective function

$$E(\mathbf{w}) = \sum_{n=1}^N e^2(nT_p) = \sum_{n=1}^N [y(nT_p) - x(nT_p)]^2 \quad (3)$$

That is a well known standard least squares problem. To solve that problem, the Quasi-Newton method was applied [12]. At each iteration, the problem is to find a new iterate w_{k+1} of the form:

$$\mathbf{w}_{k+1} = \mathbf{w}_k + \tau \mathbf{d} \quad (4)$$

where τ is a scalar step length parameter and \mathbf{d} is the search direction. Using the quasi-Newton method, a line search is performed in the direction

$$\mathbf{d} = -\mathbf{H}_k^{-1} \cdot \nabla E(\mathbf{w}_k) \quad (5)$$

where \mathbf{H}^{-1} is an approximation of the inverse Hessian matrix.

The DFP formula was used for approximation of the inverse of Hessian matrix

$$\mathbf{H}_{k+1}^{-1} = \mathbf{H}_k^{-1} + \frac{\mathbf{s}^k (\mathbf{s}^k)^T}{(\mathbf{q}^k)^T \mathbf{s}^k} - \frac{(\mathbf{H}_k^{-1} \mathbf{q}^k) (\mathbf{H}_k^{-1} \mathbf{q}^k)^T}{(\mathbf{q}^k)^T \mathbf{H}_k^{-1} \mathbf{q}^k} \quad (6)$$

where $\mathbf{q}_k = \nabla E(\mathbf{w}_{k+1}) - \nabla E(\mathbf{w}_k)$ is gradient increment and $\mathbf{s}_k = \mathbf{w}_{k+1} - \mathbf{w}_k$ is variable increment.

3. Results

The wind generator with compensating capacitors is shown in Fig.1

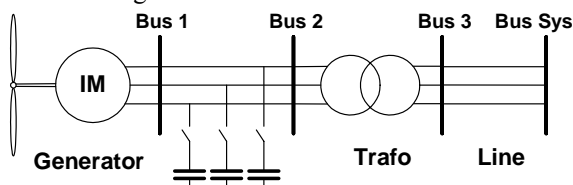


Fig. 1. Induction generator with compensating capacitors

Nonlinear regression and the Prony model were applied to estimate the parameters of the measured signals. The measurements were done on a real system. The wind park consisted of two 225 kW pitch-controlled wind turbines connected with cables to a 500 kVA transformer. In this practical case two-stage phase-compensating capacitors were connected at the wind turbines. One small ($C_1=0.5$ mF), for low rotor speed and both ($C_1+ C_2=1.7$ mF), when the wind turbines operated at higher rotor speed.

The current measured during the switching operation of both capacitors is shown in Fig. 2.

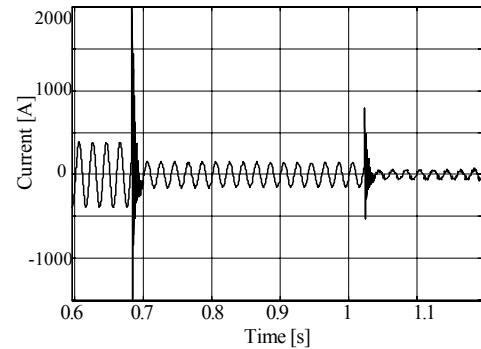


Fig. 2. Current waveform measured during switching of capacitors

TABLE I. - Transients' parameters computed for switching of two capacitors

SignalCom./ Method [No. -Mth.]	I [A]	τ [s]	f [Hz]	ψ [rd]
first capacitor switching				
1.-PRO	2225.2	0.0039	592.2	0.07
1.-NLR	2278.9	0.0037	592.2	0.07
2.-PRO	162.9		49.9	0.70
2.-NLR	155.8		49.8	0.71
second capacitor switching				
1.-PRO	831.0	0.0040	519.2	-0.34
1.-NLR	849.9	0.0039	508.4	-0.22
2.-PRO	51.2		50.9	0.83
2.-NLR	54.2		50.5	0.95

4. Conclusion

The research results show, that nonlinear regression and the Prony model are useful for transient estimation in systems with wind generators and compensating capacitors. These methods enabled accurate estimation of amplitude, time constant, phase and frequency of transients' components of simulated and measured signals (Table I). The current waveform and its parameters depend on system elements and its operating mode. These dependences could be observed during analysis and simulation of various cases.

References

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