# Comparison of Different Methods for Line Impedance Estimation

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## Abstract

This paper surveys recent works in line impedance estimation. Inverters used in distribution system are often connected to the grid through LCL filter. Different methods are investigated for estimating the line impedance. Advantages and disadvantages with brief summary for each method are presented. Simulation results for a specified grid are shown for two main different methods and the results are compared with estimation error.

## 1. Introduction

The increase of energy demand in recent years and also the problems like black-out in USA and Europe make the research in estimating of line impedance important than before. So the need for power line impedance and its representation has been a great concern for both authorities and industrial consumers. Grid model shows the relationship between the current and voltage measured in PCC point, which considers the grid equivalent impedance in this point. The value of grid impedance is beneficial information for simulation and prediction of harmonic propagation into the power system. Because of continues connection and disconnection of loads in the networks, grid impedance become a vital factor in power system analysis. Information about grid impedance would be useful for detecting the grid faults and unbalance [1]. For increasing the stability of the current controller the parameters of controller can be adjusted with estimating the parameters by knowing more about impedance [2]. In order to eliminate the problems of harmonic elements in power system, it is important to measure the line impedance in a simple way. This paper investigates some practical methods for assessing the system impedance.

## 2. Measurement Methods

In general, the methods for grid impedance estimation can be classified in two groups, passive and active methods.

### 2.1 Passive methods

Passive methods use the non-characteristic signals like voltage and current which already present in the system. These methods are based on monitoring and measuring the distortions in grid, and the value of grid impedance is estimated based on the variations of these signals. Major drawback of these methods is that the estimation accuracy is low since the grid disturbance might not sometimes sufficiently large [3].

### 2.2 Active methods

Active methods produce a disturbance at the point of common coupling (PCC) and the impedance is calculated based on the grid response to distortion. The most common disturbances can be summarized as two methods which depended on the variation and injection in PCC point:

#### 2.2.1 Natural variation

A. *Voltage variation:* Additional impedance is used for voltage variation in impedance estimation.

B. *Power variation:* Active and reactive power produce grid voltage variations for impedance estimation [2].

Distributed generation connected to grid is illustrated in Fig 1.


Fig. 1. Distributed generation system.

The PCC voltage, $V_{Pcc}$, at two different operating points are represented as:

$$V_{Pcc2} = V_s + Z_g \cdot i_{Pcc2}$$
(1)

$$V_{Pcc2} = V_s + Z_g \cdot i_{Pcc2}$$
(2)

$$Z = \Delta V_{Pcc} / \Delta i_{Pcc}$$
(3)

where, $V_s$ is the source voltage and $Z_g$ is the impedance of grid and it is assumed that the grid impedance is linearly changed between these two adjacent points. The advantage and disadvantage of the variation methods are presented below:

Advantage: This method is fully non-invasive and can be applied everywhere.

Disadvantage: In the absence of predominant disturbing loads, it is difficult to obtain a high accuracy of estimation.

#### 2.2.2 Harmonic injection

Harmonic injection to the network gives the possibility of calculating the grid impedance in the injected frequency and by further processing the grid impedance at the fundamental frequency can be calculated [2], [4], [5]. Main drawback of the harmonic injection method is that sources already existing in the network produce harmonic voltage at the same frequency as the current injected. Harmonic injection methods can be categorized in several types, among which typical methods are described with advantages and disadvantages as follows:

A. *Nonlinear loads as unique harmonic current source*

Non-linear loads cause harmonic currents to flow into the power system and the harmonic impedance can be obtained by the division of voltage by current. Narrow frequency range is their advantage. Non-linear loads such as cycloconverters and arc furnaces usually produce inter-harmonics which exceed existing background level [5].

B. *Direct injection of inter-harmonic current*

In this method, injected current flows during the long duration and impedance can be estimated by one point calculation. Injection can be made by adding a harmonic signal to reference voltage of converter. Pre-existing harmonics must be taken into account [4, 5].

C. *Making use of pre-existing harmonic sources*

Background distortion is used as a positive input to system instead of being obstacle and the existed harmonics are used for estimating the line impedance. But results are important at frequencies which the sources exist [5].

*D. Use of inter-harmonic current generators*

Inter-harmonic current generators have been specially designed

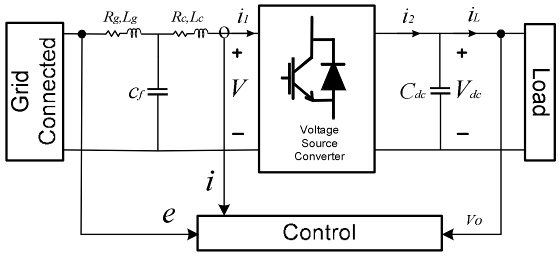



Fig. 2. Single-phase equivalent circuit of PWM rectifier with LCL filter

for measurement of harmonic impedance. These methods are successfully applied to LV, MV and HV networks. The currents injected by generators depend on the generator and sometimes have asymmetrical conditions [2], [5].

## 3. Simulation Results

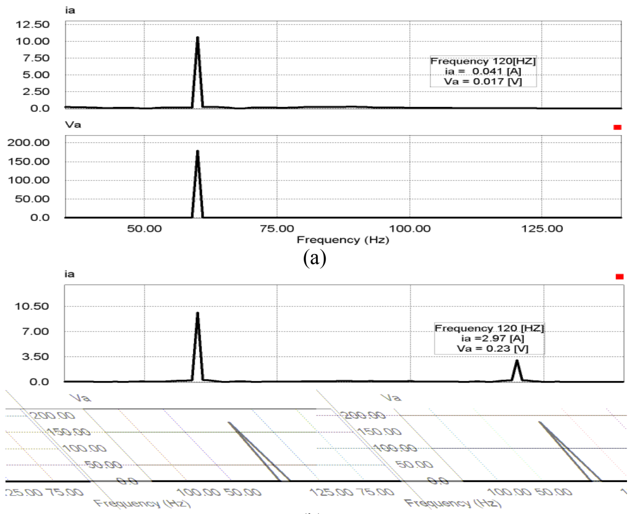
In this section, simulation results for different methods are presented. Fig.2 presents the single-phase equivalent circuit. Two main methods are presented in this section and the error between these two methods is specified and compared in comparison part. The system is tested in the following conditions: DC-voltage $V_d$ is $340[V]$, Grid voltage $V_s$ is $220[V]$ (rms). Inverter-side inductance $L_c = 5[mH]$, grid-side inductance $L_g = 1[mH]$ and capacitance for LCL filter $C_f = 20[\mu F]$ are specified respectively. Converter-side and grid-side resistance are $R_c = 0.1[\Omega]$ and zero. Dc-link capacitor size and constant load are $C_{dc} = 2500[\mu F]$ and $R_L = 40[\Omega]$, respectively. For simulation, it is assumed that grid impedance is $Z = 0.037[\Omega]$ with $R = 0.001[\Omega]$ and $L = 100[\mu H]$.

### 3.1 Natural variations

In natural variation method, variation of voltage at PCC point is made by the step change in impedance at this point. The resistance of $R = 0.1[\Omega]$ and inductance $L = 100[\mu H]$ are used for the variation for voltage and current in this point. Voltage and current at PCC before impedance step change are as $V_{Pcc1(rms)} = 127.013[V]$ and $i_{Pcc1(rms)} = 7.6879[A]$. After step change in impedance, $V_{Pcc2(rms)} = 127.014[V]$ and the current is $i_{Pcc2(rms)} = 7.662[A]$. So, the impedance is calculated as $Z = \frac{\Delta V_{Pcc}}{\Delta i_{Pcc}} = \frac{0.001}{0.0259} = 0.0386[\Omega]$.

### 3.2 Harmonic injection methods

In this method, harmonic injection is considered. The harmonic current is injected by adding a harmonic signal to voltage reference. This eliminates the need of a separate harmonic current generator. As known, one of the disadvantages of injection method is the pre-existing harmonics and the effect of that harmonics must be taken into account. The FFT spectrum for grid current and voltage in phase (a) with and without harmonic injection are illustrated in Fig. 3. The harmonic amplitude difference for voltage and current at 120Hz shows the exact injected-value of harmonic at 120HZ. Injected harmonic amplitudes for current and voltage are $I(120HZ) = 2.93[A]$ and $V(120HZ) = 0.213[V]$ respectively, so the impedance is calculated at this point $Z(120HZ) = 0.0726[\Omega]$. For finding the grid impedance at grid frequency (60HZ), $Z(60HZ) = R_g + j\omega_{60} \cdot L_g$ is used.




(a)

(b)

Fig. 3. FFT spectrum for voltage and current of phase a after injection. (a) Without injection. (b) With injection

Calculation is based on the effect of inductance since the inductance value is so larger than resistance.

### 3.3 Comparison of results

Comparison between the natural variation and harmonic injection methods are presented in Table 1. The injection method gives better accuracy than variation methods in simulation condition.

Table 1. Estimation of impedance with different methods

| Methods | Specified grid impedance [Ω] | Measurement grid impedance [Ω] | Measurement error [%] |
|---|---|---|---|
| Natural variations | 0.037 | 0.0386 | 4.3 % |
| Harmonic injection | 0.037 | 0.0363 | - 1.8 % |

## 4. Conclusions

Different methods for estimating line impedance, and advantages and disadvantages with brief summary for each method have been presented. Simulation results for one case of each category were prepared for specified system. Better performance in harmonic injection method comparing variation method is presented by simulation results.

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