Grid Impedance Measurement in Low-Voltage Network

Gaurav Trivedi, Rahul Sharma and Awnish Kumar Tripathi

Abstract The performance of the power system can be affected by the variation in grid impedance. Hence, continuous monitoring of the grid impedance is very essential. This paper presents a method for the measurement of grid impedance variation in low-voltage network. The estimation method is computationally very simple, and it is dependent on the variance in voltage of the grid at two successive time sampling instants. A quadratic equation is formed using grid voltage. The proposed method is modeled in MATLAB Simulink to measure the grid impedance. Simulation results obtained in MATLAB Simulink are showing or demonstrating the efficacy of the measurement technique for discerning the impedance in low-voltage network.

Keywords Impedance measurement · Grid voltage · Point of common coupling · Harmonic distortion · Quadratic equation

1 Introduction

It is very important to know about the impedance of the network at the time of controlling and modeling of the system. Without knowing the structure of the power system network and the impedance values that is alone used for the arrangement, it is inconceivable to mitigate the harmonic components of the network. This information is necessary for maintaining power quality under variation in load to a network or upgradation of the system. If the line impedance of the network is known, then it is

---

G. Trivedi (✉) · A. K. Tripathi
Department of Physics, National Institute of Technology Kurukshetra, Kurukshetra 136119, India
e-mail: gauravtrivedi687@gmail.com

A. K. Tripathi
e-mail: awnish1982@gmail.com

R. Sharma
Department of Electrical Engineering, National Institute of Technology Kurukshetra, Kurukshetra 136119, India
e-mail: rahulsharmaknit.2006@gmail.com

R. Bera et al. (eds.), *Advances in Communication, Devices and Networking*,
Lecture Notes in Electrical Engineering 537,
https://doi.org/10.1007/978-981-13-3450-4_8

possible to reduce the voltage disturbance in a network by rearranging the sensitive loads at the place of low harmonic distortion [1]. Hence, the line impedance of the network, in particular, is of the interest.

Transmission line impedance variation is very common, and it happens because of various reasons such as environmental abnormalities, transmission cables of very long distance, or the harmonics associated with the variable loads connected to the grid, such as distributed generation systems. The discrepancy in supply impedance too influences the ripples on the measured voltage at the point of common coupling. The control performance of the system connected to the point of common coupling can be affected by a mismatched impedance value alongside a distorted PCC voltage. Therefore, it is very important that the disparity in supply impedance should be considered for the proper control implementation. Also, it would be significantly advantageous, if a better online method for the estimation of the supply impedance Z_s is provided. It is used to keep posted the overall value of the impedance on the ac side for the control scheme. The line impedance measurement is widely needed for proper decoupling between the active and or/ reactive power, accurate power distribution, and proper grid synchronization and to improve the system stability. The existing line impedance estimation methods are completely based on harmonic or impulse injections and can measure impedance value mostly but the existing methods are very complex and add high computational burden on the inverter control algorithm. However, both inductive and resistive parts of the line impedance cannot be estimated separately and/or accurately.

There are a number of methods suggested in the literature with both offline and online implementations for the assessment of the supply impedance. The grid impedance measurement technique proposed in [2] is a steady-state technique in which a non-characteristic harmonic current is injected into the power plant network and the measurement of the change in voltage response is done. Fourier analysis of the particular injected harmonic current is done further for the processing of the results. In [3], fast Fourier transform is being applied to estimate the distinct harmonic impedances. A voltage transient is injected at the point of common coupling which results in a transient deviation in the voltage and current values at the point of common coupling. Nevertheless, a high computational effort is requisite for the application of an online FFT. Also, there are few more methods for the evaluation of grid impedance which requires variation of real and reactive powers [4]. In this method, some form of disruption is inserted onto the energized network for the measurement. Response to this inserted signal is used to estimate the impedance value. The impedance is estimated in [5] by inserting a small amount of sinusoidal current signal at various frequencies and then evaluating the phase and amplitude of the voltage and current at the insertion point. Another active method as suggested in [6] involves the insertion of a small current spike into the network. It is important that the current spike signal should have adequate spectral content for the suitable frequency range. Inserted current as well as voltage response transients is being measured for the estimation of the impedance in the frequency domain. Virtual-flux-based control method was also proposed to estimate impedance in [7]. In [8], the author has proposed a technique in which the grid impedance is calculated with the help of existed

PV-inverter sensors and logic control. An analytical approach for the calculation of the coupling impedance in DPC of active rectifiers is also suggested in [9, 10].

This work proposes the simplified mathematical approach to estimate the line resistance and inductance separately and/or accurately. To estimate the line impedance, the proposed method required only local information and the designed mathematical equations. Any harmonic injection and complex computational burden are not required. The proposed method is implemented on the low-voltage islanded microgrid network. The proposed approach works on the principle of assumption that the magnitude of grid voltage does not change between two consecutive sampling time instants [10, 11]. The simulation results of the estimation compared to the actual line impedance are shown in different conditions to validate the proposed mathematical approach.

2 Proposed Method

In this paper, the total inductance is estimated by the given proposed method which is fed to the model-based predictive controller. By considering the value of total estimated inductance, the deviation in the supply inductance L_s can be easily observed and we can also calculate the grid voltage using the estimated value inside the controller (Figs. 1 and 2).

Herong et al. [12] shows that rise in frequency value leads to the decrement in the magnitude of voltage harmonics, as a result of which high-frequency harmonics has restricted effects on the grid impedance. In addition to this, the high-frequency values of grid impedance do not show any appreciable effects on the predictive control. Hence, a low-frequency grid impedance model is adopted here. The esti-

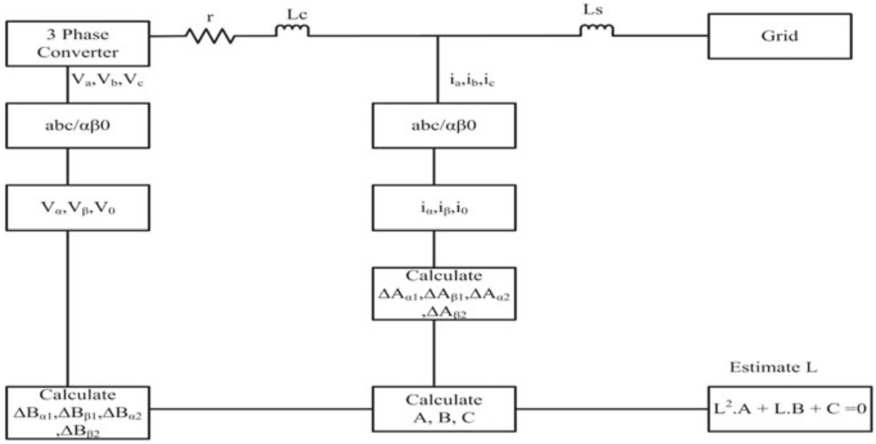

Fig. 1 Block diagram of Simulink model

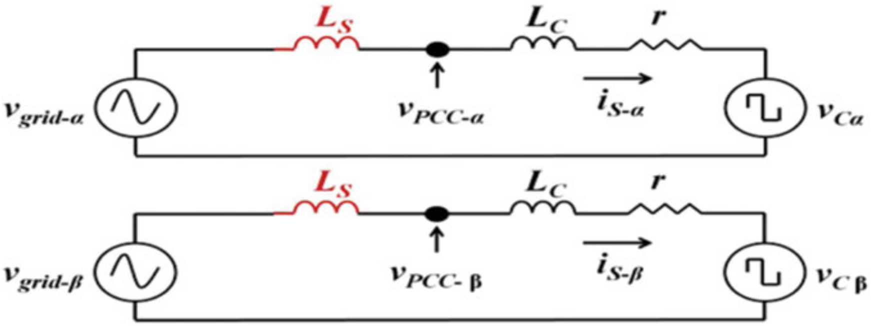

Fig. 2 α and β reference frames model

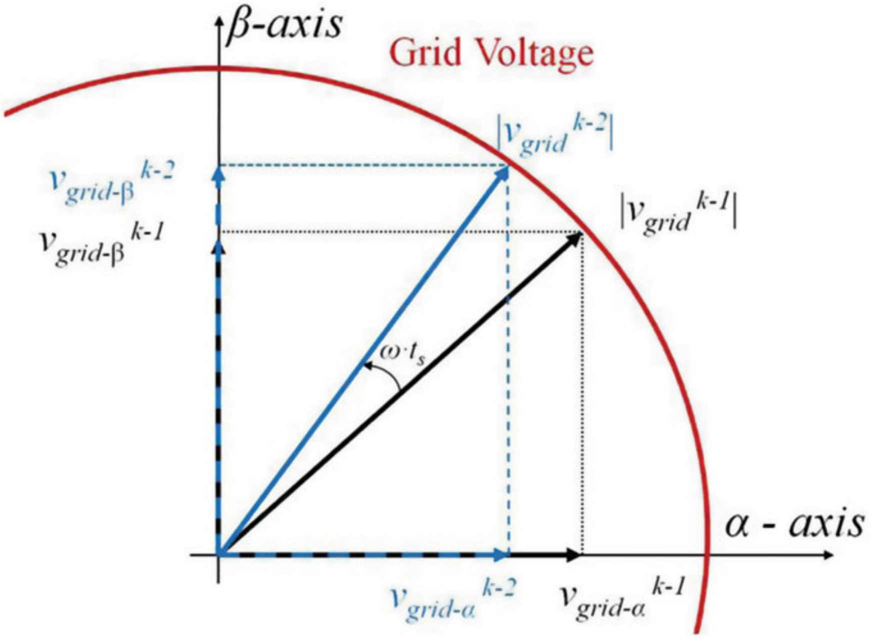

Fig. 3 Representation of grid voltage in $\alpha - \beta$ reference frame

mation method is based on the assumption that the magnitude of grid voltage does not change between two consecutive sampling time but a phase shift of "$\omega \cdot t_s$" is observed. However, the grid voltage vector will not change significantly which can be seen in Fig. 3.

In $\alpha - \beta$ frame of reference, the square of the magnitude of GV at any instant k can be represented as

$$\left|\upsilon_{grid}^{k}\right|^{2} = \left(\upsilon_{grid-\alpha}^{k}\right)^{2} + \left(\upsilon_{grid-\beta}^{k}\right)^{2} \tag{1}$$

From Figs. 1 and 2, the magnitude of GV at the time k is expressed taking the value of υ^k_{grid} obtained from the system model in $\alpha - \beta$ reference frame

$$\left(\upsilon^k_{grid-x}\right)^2 = \left(L \cdot \frac{di_{s-x}}{dt} + r \cdot i^k_{s-x} + \upsilon^k_{c-x}\right)^2 \tag{2}$$

Hence, the square of the magnitude of GV at time k can be represented as

$$\left|\upsilon^k_{grid}\right|^2 = \left(L \cdot \frac{di_{s\alpha}}{dt} + r \cdot i^k_{s\alpha} + \upsilon^k_{c\alpha}\right)^2 + \left(L \cdot \frac{di_{s\beta}}{dt} + r \cdot i^k_{s\beta} + \upsilon^k_{c\beta}\right)^2 \tag{3}$$

Similarly, the square of the magnitude of GV at the previous time instant $k - 1$ can be represented as

$$\left|\upsilon^{k-1}_{grid}\right|^2 = \left(L \cdot \frac{di_{s\alpha}}{dt} + r \cdot i^{k-1}_{s\alpha} + \upsilon^{k-1}_{c\alpha}\right)^2 + \left(L \cdot \frac{di_{s\beta}}{dt} + r \cdot i^{k-1}_{s\beta} + \upsilon^{k-1}_{c\beta}\right)^2 \tag{4}$$

$\upsilon_{c-\alpha}$ and $\upsilon_{c-\beta}$ in the above-mentioned equations are extracted from [11]. The total inductance L is calculated by equating Eqs. (3) and (4)

$$\left|\upsilon^k_{grid}\right|^2 - \left|\upsilon^{k-1}_{grid}\right|^2 = 0 \tag{5}$$

On solving Eq. (5), we can develop a quadratic Eq. (6), with the parameters *A, B, and C.*

$$L^2 \cdot A + L \cdot B + C = 0 \tag{6}$$

A, *B*, and *C* can be expressed as below:

$$A = (\Delta A_{\alpha 1})^2 + \left(\Delta A_{\beta 1}\right)^2 - (\Delta A_{\alpha 2})^2 - \left(\Delta A_{\beta 2}\right)^2 \tag{7}$$

$$B = 2 \cdot \left(\Delta B_{\alpha 1} \cdot \Delta A_{\alpha 1} + \Delta B_{\beta 1} \cdot \Delta A_{\beta 1} - \Delta B_{\alpha 2} \cdot \Delta A_{\alpha 2} - \Delta B_{\beta 1} \cdot \Delta A_{\beta 2}\right) \tag{8}$$

$$C = (\Delta B_{\alpha 1}) + \left(\Delta B_{\beta 1}\right)^2 - (\Delta B_{\alpha 2})^2 - \left(\Delta B_{\beta 2}\right)^2 \tag{9}$$

where

$$\Delta A_{\alpha 1} = \frac{i^{k+1}_{s\alpha} - i^k_{s\alpha}}{Ts}, \Delta A_{\beta 1} = \frac{i^{k+1}_{s\beta} - i^k_{s\beta}}{Ts}$$

$$\Delta A_{\alpha 2} = \frac{i^k_{s\alpha} - i^{k-1}_{s\alpha}}{Ts}, \Delta A_{\beta 2} = \frac{i^k_{s\beta} - i^{k-1}_{s\beta}}{Ts}$$

Table 1 Simulation parameters

Grid line voltage (V, rms)	270
Frequency of grid (Hz)	50
Rating of grid (KVA)	500
Inductance, L_s (mH)	0.45
Filter capacitance, C_f (uF)	170

$$\Delta B_{\alpha 1} = r i_{s\alpha}^{k} + \upsilon_{c\alpha}^{k},\ \Delta B_{\beta 1} = r i_{s\beta}^{k} + \upsilon_{c\beta}^{k}$$

$$\Delta B_{\alpha 2} = r i_{s\alpha}^{k-1} + \upsilon_{c\alpha}^{k-1},\ \Delta B_{\beta 2} = r i_{s\beta}^{k-1} + \upsilon_{c\beta}^{k-1}$$

After substituting (7)–(9) in (6), the total inductance is evaluated as

$$L_{estimation} = \frac{1}{2} \cdot \frac{B}{A} \cdot \left[-1 + \sqrt{1 - \frac{4 \cdot C \cdot A}{B^2}} \right]$$

3 Results and Discussion

The system is modeled in MATLAB Simulink to validate the algorithm. The system data are shown in the Table 1.

Figure 4 represents the waveform of the power flow through the filter inductance and line inductance. The power waveform with impedance estimation shows lesser ripples and better dynamics as compared to the waveform without impedance estimation.

The current waveform also clearly reflects the improvement in power quality with the impedance estimation as compared to the current waveform without impedance estimation. This shows the effects of the line impedance (Fig. 5).

Similarly, voltage waveform shows the better result in terms of dynamics and ripple content with impedance estimation algorithm as compared to without estimation (Fig. 6).

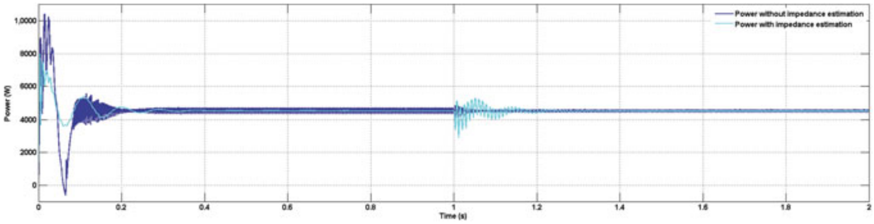

Fig. 4 Waveform of the power flow

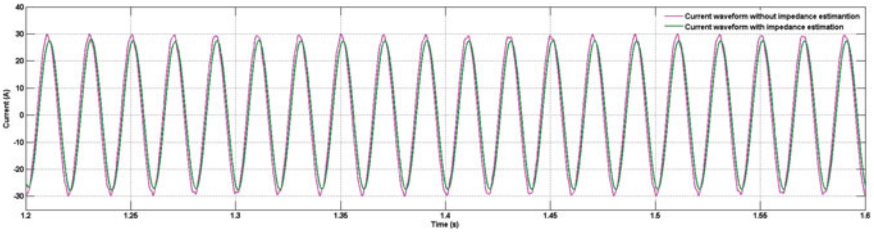

Fig. 5 Waveform of current

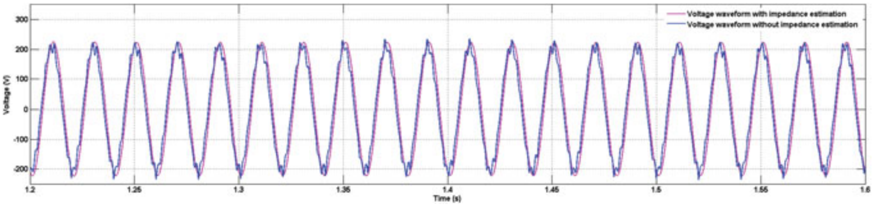

Fig. 6 Waveform of voltage

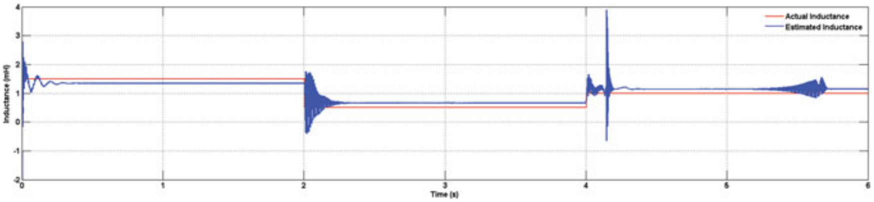

Fig. 7 Waveforms of actual and estimated inductance

Figure 7 shows the waveforms of the line inductance in actual and estimated with algorithm. The estimated algorithm is closely tracking the actual line inductance value. This shows the usefulness of the impedance estimation method.

4 Conclusions

The proposed method is designed to estimate the impedance of line in the network. The results have validated the usefulness of the estimation method. The waveforms have shown the improved power quality with the estimation method against the without estimation method results. The line impedances also affect the control method in the weak grid and microgrid connected system as concluded by the result analysis. Therefore, the line impedance estimation is a must for proper control and improves power quality of the low-voltage network. This proposed method may be applied in the distributed energy systems to improve the control schemes such as microgrid, weak grid, etc. Further, the dynamic and transient response of the line impedance estimation method may be improved as the scope of the future study.

References

1. Dugan RC, McGranaghan MF, Beaty HW (1996) Electrical power systems quality, 1st ed. McGraw Hill
2. Timbus A, Teodorescu R, Blaabjerg F, Borup U (2006) Online grid impedance measurement suitable for multiple PV inverters running in parallel. In: Proceedings of APEC'06, 19–23 March 2006, 5 pp
3. Sumner M, Palethorpe B, Thomas DWP, Zanchetta P, Piazza MC (2002) A technique for power supply harmonic impedance estimation using a controlled voltage disturbance. IEEE Trans Power Electron 17(2):207–215
4. Timbus AV, Rodriguez P, Teodorescu R, Ciobotaru M (2007) Line impedance estimation using active and reactive power variations. In: Proceedings of the IEEE power electronics specialists conference, Jun 2007, pp 1273–1279
5. Rhode JP, Kelley AW, Baran ME (1995) Line impedance measurement: a nondisruptive wide-band technique. In: Presented at IAS annual meeting, Orlando, Florida, USA
6. Palethro B, Summer M, Thomas D (2000) Power system impedance measurement using a power electronic converter. In: Proceedings of harmonics and quality of power, 2000, vol 1, Orlando, FL, pp 208–213
7. Antoniewicz P, Kazmeirkowski MP (2008) Virtual-flux-based predictive direct power control of AC/DC converters with online inductance estimation. IEEE Trans Ind Electron 55(12):4381–4390
8. Asiminoaei L, Teodorescu R, Blaabjerg F, Borup U (2004) A new method of on-line grid impedance estimation for PV inverters. In: Proceedings of APEC'04, vol 3, pp 1527–1533
9. Norniella JG et al (2011) Analytical and iterative algorithms for online estimation of coupling inductance in direct power control three-phase active rectifiers. IEEE Trans Power Electron 26(11):3298–3307
10. Norniella JG et al (2013) New strategies for estimating the coupling inductance in grid-connected direct power control-based three-phase active rectifiers. In: Proceedings of the IEEE PEC, July 2013, pp 1–5
11. Arif B, Tarisciotti L, Zanchetta P, Clare J, Degano M (2014) Integrated grid inductance estimation technique for finite set model predictive control in grid-connected converters. In: Proceedings of the IEEE ECCE, Sep 2014, pp 5797–5804
12. Herong G, Xiaoqiang G, Deyu W, Weiyang W (2012) Real-time grid impedance technique for grid-connected power converters. In: Proceedings of the IEEE ISIE, May 2012, pp 1621–1626