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Research paper

Improvement of Power Quality with Induction Motor in Inertia-Free Stand-Alone Microgrid

Seung-Mook Baek[1], Hee-Jin Lee [2*]

[1] *Division of Electrical, Electronic and Control Engineering, Kongju National University,*
1223-24 Cheonan Dae-ro, Cheonan, Chungnam, South Korea
[2] *Department of Electronic Engineering, Kumoh National Institute of Technology,*
61 Daehak-ro, Gumi, Gyeongbuk, South Korea
**Corresponding author E-mail: jinlee@kumoh.ac.kr*

Abstract

This paper proposes a method of improving power quality in inertia-free stand-alone (IFSA) microgrid when induction motor connected. There are many converter based generators (CBGs) in the microgrid. The CBGs has harmonics which affect to induction motor. For smooth operation of induction motor, the input voltage of motor must be pure sinusoidal. The proposed filter design method can mitigate harmonic problem. To verify the proposed method, the IFSA microgrid system is implemented. The induction motor is modelled with dynamic approach to simulate.

Keywords: *Converter based generator, distributed generation, harmonic filter, inertia-free stand-alone, microgrid*

1. Introduction

Recently, electrical power systems are being designed toward maximum utilization of existing infrastructures with tight operating margins, due to economic, environmental, and political issues [1]-[3]. On the other hand, rapidly increasing load demands might be reached to the limited capacity of current power systems, and their upgrade is required [4]. The microgrid with distributed generation (DG) system has received a great attention worldwide as an effective solution for the above problems, because of its short construction time and quick response to peak load demands.

It is desirable that the renewable energy based DGs to mitigate environmental problem in the stand-alone microgrid. In general, the renewable resources based DG has many converters. For example, a photovoltaic (PV) or a fuel cell originally generates DC power. Then, it is converted to AC by a DC-to-AC converter (i.e. inverter). Also, AC output of type-4 wind turbine is converted synchronizing to the grid. A battery energy storage system (BESS) is connected to a grid with converters. These are converter based generators (CBGs).

Small islands become an inertia-free stand-alone (IFSA) microgrid to make carbon free. The IFSA microgrid is operated by only CBGs without any synchronous generators like diesel generator. The CBGs should be controlled to maintain the system voltage and frequency. The system is weak and have harmonics from converts inevitably. The harmonics may degrade the life of the induction motor which is used for water pump.

This paper proposes the filter design method to reduce the harmonics in IFSA microgrid system. To verify its performance, the system is implemented with the specific modelling method. Then, the case studies are carried out with harmonic analysis by using Fourier transform. The filter design method is evaluated by the power systems computer aided design/electromagnetic transients including DC (PSCAD/EMTDC®) based simulation. Section 2 is presented about inverter design, IFSA microgrid, and passive filter design, respectively. A case study is simulated in section 3.

2. System Design

2.1 Inverter Design

Voltage source converter (VSC) with pulse-width modulation (PWM) based renewable DGs has started to be used. Its specified model is shown in Figure 1.

The VSC is based on a modular design, for reducing the installation time and the footprint [5]. The PWM techniques have to be controlled the active power delivered to the microgrid and, at the same time, to control the reactive power as required for proper operation of the microgrid. The power can be controlled by the phase angle of the converter reference signal, whereas the reactive power can be controlled by changing the magnitude of the reference signal of the converter.

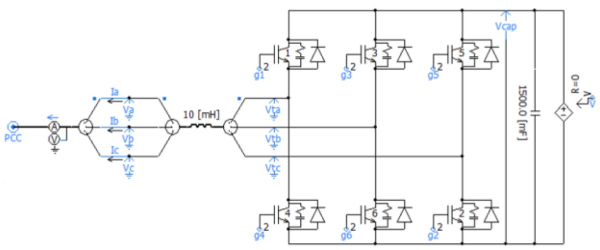

Figure 1: Three-phase inverter design.

As shown in Figure 2, some harmonics exist at the output voltage of PWM inverter.

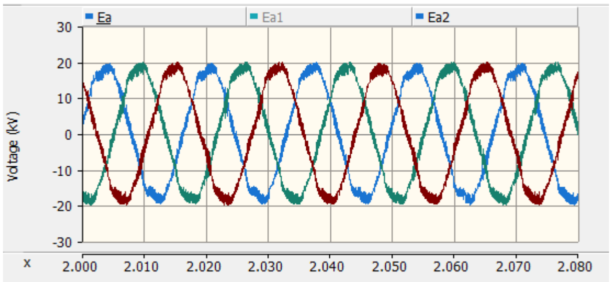

Figure 2: PWM inverter output voltage.

The harmonics in the output voltage is analysed by using Fourier transform method. The result spectrum is presented in Figure 3. The total harmonic distortion (THD) is about 4.9 % and maximum individual voltage distortion is 3 % at the fifth harmonic. The rated inverter output voltage is 22.9 kV. It meets the standard of IEEE 519 in Table 1.

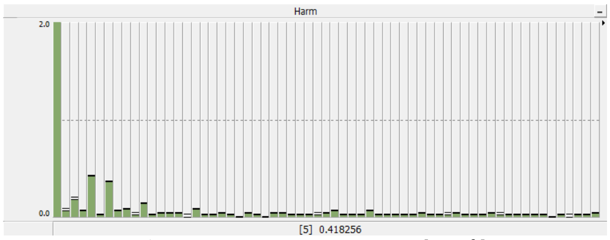

Figure 3: Harmonic spectrum without filter.

Table 1: The Voltage Distortion Limits Recommended by IEEE 519-1992

Bus voltage at PCC	Individual voltage distortion (%)	Total voltage distortion THD (%)
69 kV and below	3.0	5.0
69 kV to 161 kV	1.5	2.5
161 kV and above	1.0	1.5

2.2 Inertia-Free Stand-Alone Microgrid

The IFSA microgrid is operated by only CBGs without any synchronous generators. In general, the conventional CBGs control its output current to produce the real power generated from the primary source [6].

The IFSA microgrid satisfies IEEE standard 519. However, it still suffers from harmonics. To deal with this harmonics problem, a simple IFSA microgrid system in Figure 4 is considered.

In Figure 4, there are 7 buses, 3 CBGs, 3 constant loads, and one induction load. The inverters at bus 2 and 3 are operated with constant PQ mode. They generate 12 MW and 1.4 Mvar, 12 MW and 0.5 Mvar, respectively. The slack inverter at bus 1 generates real and reactive power to balance with all loads. The induction motor connected bus 7 consumes real and reactive power of 3 MW and 7.5 Mvar.

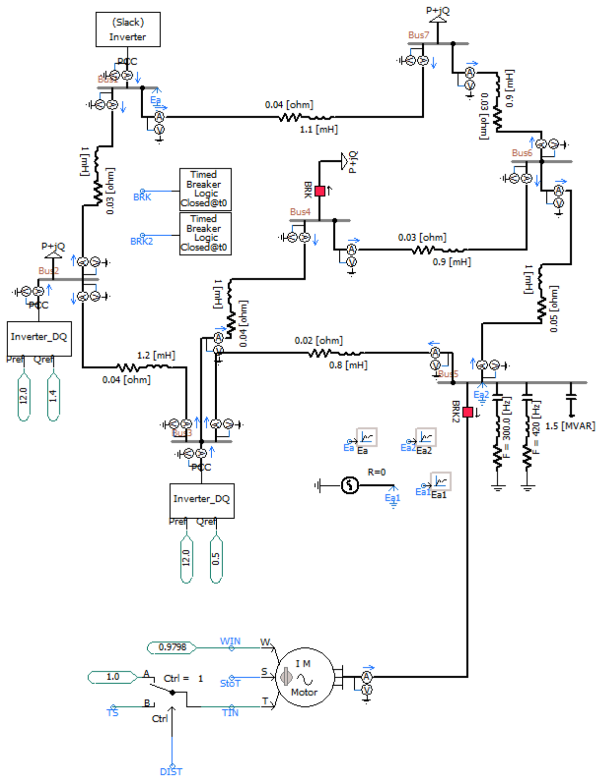

Figure 4: IFSA microgrid with induction load.

When the induction motor operates rated power with 1 pu of mechanical load, the motor draws electrical power shakily as shown in Figure 5. Because the bus voltage has harmonics as shown in Figure 2 and 3. This oscillatory operation of motor may reduce its durability and life.

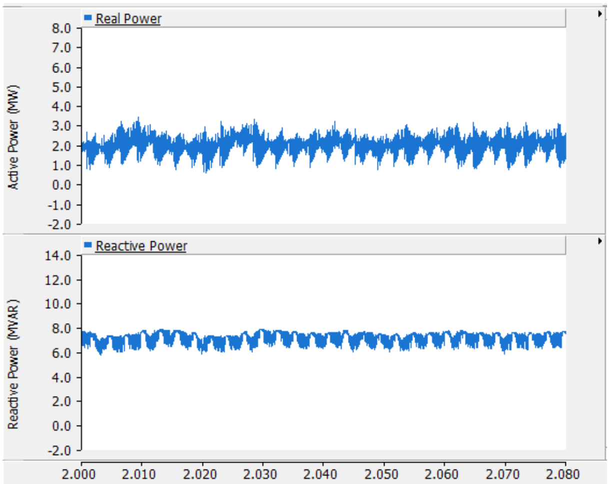

Figure 5: Power of induction motor without filter.

2.3 Filter design

The passive harmonics filters are composed of passive elements: resistor (R), inductor (L) and capacitor (C). The common types of passive harmonic filter include single-tuned, double-tuned filters, and C-type filter. The double-tuned filter is equivalent to two single-tuned filters connected in parallel with each other, so that only single-tuned filter and other three types of damped filters are presented here. The ideal circuits of the presented three types of filters are shown in Figure 6.

Single-tuned resonant filter only comprises LC components, its investment cost and power loss are lower than that of damped filters with same capacity, and easily to design. However, its performance of with frequency is slightly higher than the resonant frequency of filter. At high frequency, the single-tuned filter is inefficient [7].

As shown in Figure 3, the inverter has various harmonic spectrum. The double-tuned filter may worsen the harmonic characteristics of IFSA microgrid.

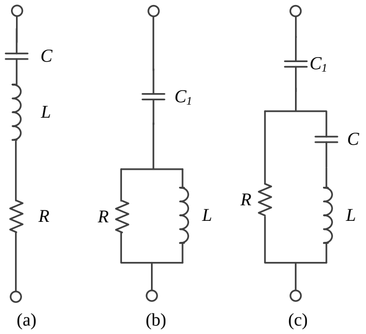

Figure 6: Typical passive harmonic filters (a) single-tuned damped filter (b) second-order damped filter (c) C-type damped filter.

To plan a single-tuned harmonic filter, we must characterize its frequency response of impedance. To this work, two parameters namely characteristic harmonic order, h0 and damped time constant ratio m are defined as follows for single-tuned and damped filters, respectively:

$$h_0 \equiv \sqrt{\frac{X_C}{X_L}} = \frac{1}{f_b}\frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

For damped filters,

$$h_0 \equiv \frac{X_C}{R} = \frac{1}{2\pi f_b RC} \qquad (2)$$

$$m \equiv \frac{L}{R^2 C} = \frac{X_C X_L}{R^2} = h_0 \frac{X_L}{R} \qquad (3)$$

The impedance $Z_f(h)$ of harmonic filter with respect to harmonic order h can be derived.

$$Z_f(h) = j\left(hX_L - \frac{X_C}{h}\right) \qquad (4)$$

3. Case Study

To extend life of motor, the voltage waveform should be pure sinusoidal. The filters are designed to reduce the harmonics in Figure 2 and 3. As shown in Figure 3, the fifth and seventh harmonics are larger than the others. However, the high order harmonics have also some values, they cannot be ignored.

Because the induction motor draws reactive power of 7.5 Mvar, total capacity of filter sets to 7.5 Mvar. The fifth harmonic filter is tuned at 300 Hz, 3 Mvar, and 100 of m factor. The seventh harmonic filter is tuned at 420 Hz, 3 Mvar, and 100 of *m* factor. A capacitor bank of 1.5 Mvar is installed to reduce higher order harmonics. The simulation results are shown in Figure 7, 8, and 9.

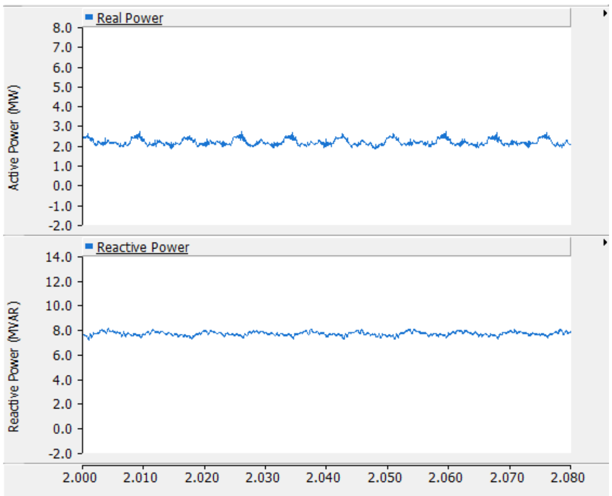

Figure 7: Power of induction motor with filter.

The input power of motor is more uniformly than before in Figure 5. The voltage waveform of bus 7 becomes sinusoidal as shown in Figure 8. The fifth and seventh harmonics are reduced to 0.08 and 0.03 from 0.42 and 0.35, respectively. The THD also is reduced to 3 % from 4.9 %. However, the third harmonic increase to 2.7 % as shown in Figure 9. It still meets the IEEE standard 519.

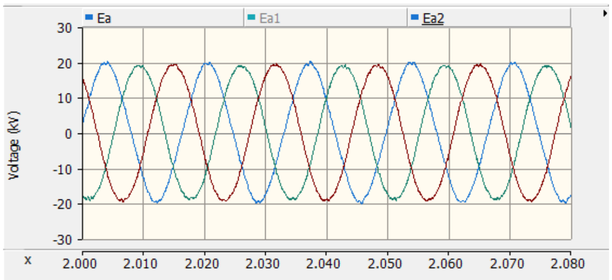

Figure 8: Voltage waveform of bus 7.

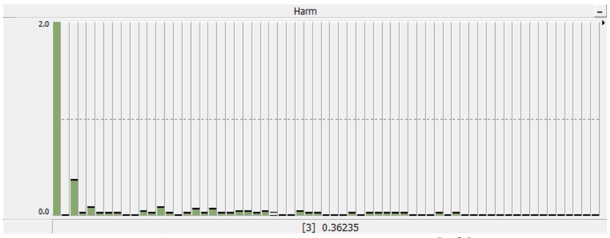

Figure 9: Harmonic spectrum with filter.

The simulation results show that the filters are appropriate to extend life of induction motor.

4. Conclusion

This paper proposes the filter design method to reduce the harmonics of IFSA microgrid system. The system is operated by only CBGs without any synchronous generators. The system is weak and have harmonics from converts inevitably. The harmonics may degrade the life of the induction motor which is used for water pump. To reduce harmonics, two single-tuned filters and a capacitor are used. To verify its performance, the ISFA microgrid system is implemented with the specific modelling method. The simulation results show that the filters are appropriately operated to reduce harmonic.

Acknowledgement

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Author profile

Seung-Mook Baek He received the Ph.D. degree in Electrical and Electronic Engineering from Yonsei University in 2011. He is currently the Associate Professor of Division of Electrical, Electronic and Control Engineering, Kongju National University.

Hee-Jin Lee He received the Ph.D. degree in Electrical and Electronic Engineering from Yonsei University in 2013. He is currently the Assistant Professor of the Department of Electronic Engineering, Kumoh National Institute of Technology.