A Comparative Study of Single-Tuned Filter and Detuned Reactor for Improve Power Quality in Microgrid

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Abstract. Propose of this study is to analyze the performance of the single-tuned filter and detuned reactor to improve power quality (voltage profile, power factor, and harmonic distortion) in a microgrid. Nowadays power quality becomes the focus of the electrical company as well as commercial customer and industry. The load consists of two types, linear load, and nonlinear load. Both of them cause a reduction of power quality as voltage drop, low power factor, and harmonic distortion. Those problems can make losses of electrical usage, broken on electrical devices and can stop the production process in the industry. Single-tuned filter and the detuned reactor is the type of harmonic filter that commonly used to mitigate harmonic distortion. The harmonic filter also has benefit to improve power factor and voltage profile on the system. All filters will be simulated on ETAP to get the performance of each filter on different condition. The most dominant load in this study is a 6-pulse battery charger.

Keywords: Harmonic distortion, Power factor, Voltage drop, Single-tuned filter, Detuned reactor

1. Introduction

A good assumption for most utilities in the world is that the sine-wave voltage generated in a central power station is very good. Because of that nowadays power quality became quite concerned with utility engineers. Power quality is about compatibility between the quality of the voltage supplied from the electric power system and the proper operation of end-use equipment. There are two categories of power quality that need to be considered steady state (continuous) power quality and disturbances. Steady-state power quality characteristics include voltage regulation, harmonic distortion, unbalance and flicker.

Drop voltage is phenomena defined as the amount of voltage loss that occurs through all or part of a circuit due to impedance. Drop voltage can cause low intensity in a lightning system, miss-operation in control system and decrease motor starting torque. Indonesian Electric Company recommends limiting the voltage drop for low-voltage 4 percent of the circuit voltage.

Power factor is important in the AC system like 3-phase or single-phase. Power factor is the ratio of the real power that is used to do work and the apparent power that is supplied to the circuit. The power factor can get values in the range from 0 to 1.

Harmonic distortion is caused by nonlinear devices in the power system. A nonlinear load device is one in which the current is not proportional to the applied voltage. The most commonly used standard of harmonic distortion is IEEE 519-2014.

The single-tuned filter is a passive filter which consists of inductance, capacitance and resistance element configured and tuned for a harmonic order. They are commonly used and are relatively inexpensive compared with other means for eliminating harmonic distortion.
The use of detuned reactors thus prevents harmonic resonance problems, avoid the risk of overloading capacitors and contributes to reducing harmonic distortion in the network. The tuning frequency can be expressed by the relative impedance of the reactor (in %), or by tuning order, or directly in Hz.

| Impedance (%) | Function                                                                 |
|---------------|--------------------------------------------------------------------------|
| 5.67%         | Is used where the dominant in 5th harmonic                               |
| 7.00%         | Is used where optimal protection to capacitor and harmonic reduction is achieved. |
| 14.00%        | Is to be used where system is rich in 3rd harmonics (3, 9, 15)           |

2. Methodology

2.1 Study Flowchart

The methodologies conducted in this are:
1) Problems identification and literature study: site survey and collect literature.
2) Data collecting: One-line diagram, Plant layout, harmonic spectrum and product catalogue.
3) Simulation and analysis: simulating system and analysis power quality from the simulation.
4) Power quality improvement: if power quality in a bus is low we should install harmonic filter on that bus to improve the power quality.
5) Conclusion and recommendation.

2.2 Study Case

Simulating the system on different study case to get filter design that can work in different condition. For this research selected 5 different condition.
Table 2. Study case.

| Condition | Io/Charger (A) | Vo/Charger (V) | P/Rectifier (kW) |
|-----------|---------------|---------------|------------------|
| 1         | 10.0          | 288           | 13               |
| 2         | 15.0          | 240           | 17               |
| 3         | 23.0          | 320           | 35               |
| 4         | 33.5          | 256           | 41               |
| 5         | 46.5          | 192           | 41               |

3. Power System Overview
This microgrid is a automotive battery manufacturer. Supplied by national electrical company with 3.465 kVA rated power as main power supply. Main distribution voltage from main transformers are 20kV step-down to 0.38 kV. The LV 0.38 kV distributed to others bus (LVMDP 1, LVMDP 2 and LVMDP 3). Existing capacitor bank capacity is 1,005 kVAR.

Figure 3. 6-pulse battery charger on the system.

Figure 4. Overall single line diagram.
4. Result and Discussion

4.1 Parameter Analysis

Software simulation using ETAP conducted in this study to find performance of single-tuned filter and detuned reactor to find the performance of both filter in 5 different load conditions.

![Figure 5. Harmonic spectrum on charger.](image)

Figure 5 shows the harmonic spectrum based on measurement. The most dominant orde is 5th.

| Bus         | CM Limit <11th (%) | CM 3rd (%) | CM 5th (%) | CM 7th (%) | CM Limit >11th (%) | CM 11th (%) |
|-------------|---------------------|------------|------------|------------|--------------------|-------------|
| Charger 1-3 | 7                   | 1          | 30         | 3          | 3.5                | 7           |

Yellow = exceeding limit, CM = Current Magnitude

From table 3 and with IEEE 519-2014 standard about harmonics, harmonic on bus charger 1–3 which exceeding the limit are 5th harmonic and 11th harmonic.

Table 4. Bus with undervoltage condition.

| Bus          | % Voltage on Condition | Standard (%) |
|--------------|------------------------|--------------|
| Ball Mill    | 95.93                  | 95.78        | 95.72       | 96–104     |
| Grid Casting | 96.00                  | 95.85        | 95.79       | 96–104     |

Yellow = exceeding limit

From table 4 bus where happens undervoltage are Ball Mill and Grid Casting in condition 3, 4 and 5.

4.2 Filter Specification

Table 5. Single-tuned filter specification.

| Bus          | Condition | Orde | ΔQ (kVAR) | C (µf) | L (mH) |
|--------------|-----------|------|-----------|--------|--------|
| Charger 1-3  | 1         | 5    | 2.023     | 44.623 | 9.091  |
|              | 11        |      | 1.759     | 38.789 | 2.160  |
|              | 2         | 5    | 2.646     | 58.354 | 6.952  |
|              | 11        |      | 2.138     | 47.101 | 1.779  |
|              | 3         | 5    | 5.447     | 120.140| 1.060  |
|              | 11        |      | 4.397     | 96.973 | 0.271  |
|              | 4 and 5   | 5    | 7.529     | 166.050| 2.440  |
|              | 11        |      | 5.151     | 113.600| 0.737  |

Table 6. Detuned reactor specification.

| Qs Detuned Reactor (kVAR) | L (mH) | P (%) | Qs Kapasitor (kVAR) | Capacitor Rating (Volt) | Condition |
|---------------------------|--------|-------|---------------------|-------------------------|-----------|
| 50                        | 0.61   | 5.57  | 60                  | 415                     |           |
| 75                        | 0.41   | 5.57  | 85                  | 415                     |           |
| 100                       | 0.31   | 5.57  | 115                 | 415                     |           |
4.3 Case Studies

4.3.1 Case 1. The experiment, in this case, aims to identify the level of harmonics, voltage profile and power factor if charger set to condition 1.

Table 7. Current harmonic in condition 1.

| Bus Order | CM Limit (%) | CM Without Filter (%) | CM Installed Single-Tuned Filter (%) | CM Installed Detuned Reactor (%) |
|-----------|--------------|-----------------------|-------------------------------------|---------------------------------|
| Charger 1-3 | 7.0 | 0 | 2.15207 | 0.304147 |
| 3 | 7.0 | 2 | 5.92453 | 2.986630 |
| 5 | 7.0 | 30 | 3.21645 | 0.338990 |
| 7 | 7.0 | 3 | 1.90088 | 0.840195 |
| 11 | 3.5 | 7 | |

Figure 6. Current harmonics spectrum on condition 1.

Figure 7. Current waveform on condition 1.

Figure 6 shows the spectrum on each different filter. From the figure, it can be seen that the current harmonic decreased and all harmonic can meet IEEE 519-2014 standard (written on Table 7). Figure 7 shows the waveform on each different filter. Both of harmonic filter can maintain the current waveform to be pure sine wave. But on detuned reactor happen phase shifting 90°.

Table 8. Capacitor needed on condition 1.

| Filter | Power (kW) | Early PF (%) | Target PF (%) | Capacitor Needed (kVAR) |
|--------|------------|--------------|---------------|-------------------------|
| Without filter | 1381 | 74.0 | 95 | 816.347 |
| Single-Tuned Filter | 1381 | 74.0 | 95 | 816.347 |
| Detuned Reactor 50 kVAR | 1408 | 93.4 | 95 | 75.800 |

Table 8 shows the capacitor capacity needed for supplying reactive power on the system. If without the filter and using filter need 816.347 kVAR, but if using Detuned reactor only need 75.8 kVAR to gain 95% PF on the kVARH meter. Voltage profile and THDv still meet standard on condition 1.
4.3.2 Case 2. The experiment, in this case, aims to identify the level of harmonics, voltage profile and power factor if Charger set to condition 2.

Table 9. Current harmonic in condition 2.

| Bus | Order | Limit (%) | CM Without Filter (%) | CM Installed Single-Tuned Filter (%) | CM Installed Detuned Reactor (%) |
|-----|-------|-----------|-----------------------|-------------------------------------|----------------------------------|
| Charger 1-3 | 1 | 7.0 | 0 | 0 | 0 |
| | 3 | 7.0 | 2 | 2.15340 | 0.531834 |
| | 5 | 7.0 | 30 | 4.70940 | 5.608200 |
| | 7 | 7.0 | 3 | 3.21850 | 0.626469 |
| | 11 | 3.5 | 7 | 1.46996 | 1.538540 |

Figure 8. Current harmonics spectrum on condition 2.

Figure 9. Current waveform on condition 2.

Figure 8 shown the spectrum on each different filter. From the figure can be seen that the current harmonic decreased and all harmonic can meet IEEE 519-2014 standard (written on Table 9). Figure 9 shown the waveform on each different filter. Both of harmonic filter can maintain the current waveform to be pure sine wave. But on detuned reactor happen phase shifting 90°.

Table 10. Capacitor needed on condition 2.

| Filter | Power (kW) | Early PF (%) | Target PF (%) | Capacitor Needed (kVAR) |
|--------|------------|--------------|---------------|-------------------------|
| Without filter | 1402 | 73.3 | 95 | 840.25 |
| Single-Tuned Filter | 1417 | 85.2 | 95 | 405.00 |
| Detuned Reactor 50 kVAR | 1530 | 88.5 | 95 | 302.30 |

Table 10 shown capacitor capacity needed for supplying reactive power on the system. If without filter 840 kVAR, if using Single-Tuned Reactor need 405 kVAR and if using Detuned reactor only need 302.3 kVAR to gain 95% PF on the kVARH meter. Voltage profile and THDv still meet standard on condition 2.
4.3.3 Case 3. The experiment, in this case, aims to identify the level of harmonics, voltage profile and power factor if charger set to condition 3.

**Table 11. Current harmonic in condition 3.**

| Bus Order | Limit (%) | CM Without Filter (%) | CM Installed Single-Tuned Filter (%) | CM Installed Detuned Reactor (%) |
|-----------|-----------|-----------------------|-------------------------------------|---------------------------------|
| Charger 1-3 | 7.0       | 0                     | 0                                   | 0                               |
| 3          | 7.0       | 2                     | 2.15                                | 0.700                           |
| 5          | 7.0       | 30                    | 4.14                                | 6.900                           |
| 7          | 7.0       | 3                     | 3.30                                | 0.810                           |
| 11         | 3.5       | 7                     | 0.17                                | 2.023                           |

**Figure 10.** Current harmonics spectrum on condition 3.

**Table 12. Capacitor needed on condition 3.**

| Filter               | Power (kW) | Early PF (%) | Target PF (%) | Capacitor Needed (kVAR) |
|----------------------|------------|--------------|---------------|-------------------------|
| Without filter       | 1505       | 74.4         | 95            | 857.0                   |
| Single-Tuned Filter  | 1506       | 75.8         | 95            | 800.0                   |
| Detuned Reactor 50 kVAR | 1531     | 93.9         | 95            | 57.5                    |

Table 12 shown capacitor capacity needed for supplying reactive power on the system. If without filter 857 kVAR, if using Single-Tuned Reactor need 800 kVAR and if using Detuned reactor only need 57.5 kVAR to gain 95% PF on the kVARH meter.
Table 13. Voltage profile on condition 3.

| Bus          | %V Without Filter | %V Installed Single-Tuned Filter | %V Installed Detuned Reactor 75kVAR |
|--------------|-------------------|---------------------------------|------------------------------------|
| Ball Mill    | 95.93             | 96.01                           | 96.06                              |
| G Casting    | 96.00             | 96.03                           | 96.08                              |

From table 13 shown voltage profile increased after installing harmonic filters. But detuned only detuned reactor can increase voltage profile to meet the standard. THDv still meets the standard IEEE 519-2014 on condition 3.

4.3.4 Case 4. The experiment, in this case, aims to identify the level of harmonics, voltage profile and power factor if charger set to condition 4.

Table 14. Current harmonic in condition 4.

| Bus          | Orde | Limit (%) | CM Without Filter (%) | CM Installed Single-Tuned Filter (%) | CM Installed Detuned Reactor (%) |
|--------------|------|-----------|-----------------------|-------------------------------------|--------------------------------|
| Charger 1-3  | 1    | 7.0       | 0                     | 0                                   | 0                              |
|              | 3    | 7.0       | 2                     | 2.160                               | 0.6500                         |
|              | 5    | 7.0       | 30                    | 2.020                               | 5.2300                         |
|              | 7    | 7.0       | 3                     | 3.266                               | 0.6234                         |
|              | 11   | 3.5       | 4                     | 0.420                               | 1.5700                         |

Figure 12. Current harmonics spectrum on condition 4.

Figure 13. Current waveform on condition 4.

Figure 12 shown the spectrum on each different filter. From the figure can be seen that the current harmonic decreased and all harmonic can meet IEEE 519-2014 standard (written on Table 14). Figure 13 shown the waveform on each different filter. Both of harmonic filter can maintain the current waveform to be pure sine wave. But on detuned reactor happen phase shifting 90°.

Table 15. Capacitor needed on condition 4.

| Filter                   | Power (kW) | Early PF (%) | Target PF (%) | Capacitor Needed (kVAR) |
|--------------------------|------------|--------------|---------------|-------------------------|
| Without filter           | 1631       | 75.5%        | 95%           | 880.5                   |
| Single-Tuned Filter      | 1632       | 77.2%        | 95%           | 807.3                   |
| Detuned Reactor 50 kVAR  | 1662       | 93.4%        | 95%           | 89.5                    |
Table 15 shown capacitor capacity needed for supplying reactive power on the system. If without filter 880.5 kVAR, if using Single-Tuned Reactor need 807 kVAR and if using Detuned reactor only need 89.5 kVAR to gain 95% PF on the kVARH meter.

**Table 16.** Voltage profile on condition 4.

| Bus        | %V Without Filter | %V Installed Single-Tuned Filter | %V Installed Detuned Reactor 75kVAR |
|------------|-------------------|---------------------------------|------------------------------------|
| Ball Mill  | 95.78             | 95.79                           | 96.01                              |
| G Casting  | 95.85             | 95.86                           | 96.08                              |

From table 16 shown voltage profile increased after installing harmonic filters. But detuned only detuned reactor can increase voltage profile to meet the standard. THDv still meets the standard IEEE 519-2014 on condition 4.

**4.3.5 Case 5.** The experiment, in this case, aims to identify the level of harmonics, voltage profile and power factor if charger set to condition 5.

**Table 17.** Current harmonic in condition 5.

| Bus        | Orde | Limit (%) | CM Without Filter (%) | CM Installed Single-Tuned Filter (%) | CM Installed Detuned Reactor 100 kVAR (%) |
|------------|------|-----------|-----------------------|-------------------------------------|----------------------------------------|
| Charger 1-3| 1    | 7.0       | 2                     | 2.160                               | 0.680                                  |
|            | 3    | 7.0       | 30                    | 2.015                               | 5.531                                  |
|            | 5    | 7.0       | 3                     | 3.260                               | 0.660                                  |
|            | 7    | 3.5       | 7                     | 0.400                               | 1.680                                  |

**Figure 14.** Current harmonics spectrum on condition 5.

**Figure 15.** Current waveform on condition 5.

Figure 14 shown the spectrum on each different filter. From the figure can be seen that the current harmonic decreased and all harmonic can meet IEEE 519-2014 standard (written on Table 17). Figure 15 shown the waveform on each different filter. Both of harmonic filter can maintain the current waveform to be pure sine wave. But on detuned reactor happen phase shifting 90°.
Table 18. Capacitor needed on condition 5.

| Filter                  | Power (kW) | Early PF (%) | Target PF (%) | Capacitor Needed (kVAR) (%) |
|-------------------------|------------|--------------|---------------|-----------------------------|
| Without filter          | 1546       | 74.8%        | 95%           | 863.6                       |
| Single-Tuned Filter     | 1548       | 76.6%        | 95%           | 790.3                       |
| Detuned Reactor 50 kVAR | 1585       | 98.4%        | -             | -                           |

Table 18 shown capacitor capacity needed for supplying reactive power on the system. If without filter 863.6 kVAR, if using Single-Tuned Reactor need 790.3 kVAR and if using Detuned reactor only do not need the capacitor to gain 95% PF on the kVARH meter. Because power factor on the system is up to > 95%.

Table 19. Voltage profile on condition 5.

| Bus          | % V Without Filter | % V Installed Single-Tuned Filter | % V Installed Detuned Reactor 75kVAR |
|--------------|--------------------|----------------------------------|-------------------------------------|
| Ball Mill    | 95.72              | 95.90                            | 96.49                               |
| G Casting    | 95.79              | 95.97                            | 96.55                               |

From table 19 shown voltage profile increased after installing harmonic filters. But detuned only detuned reactor can increase voltage profile to meet the standard. THDv still meets the standard IEEE 519-2014 on condition 5.

Conclusion

Based on the five study cases that have been done can be concluded:
1) Installation single-tuned filter and the detuned reactor can improve power quality on the system (voltage profile, capacitor load [PF] and harmonic distortion).
2) Electrical disturbances those happen on this microgrid is under voltage and current harmonic distortion. Voltage harmonic still meet IEEE 519 standard.
3) Installation detuned reactor needs autotransformer to maintain 90° leading condition effected by the detuned reactor.

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