Influence of Static VAR Compensator Application for Improving Power Quality in Distribution Lines Supplied Industry

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Abstract. The voltage drop in distribution line unavoidable but can be reduced until the allowable limit. The voltage drop occurred due to currents flow in impedance lines. Harmonics caused by non-linear loads that are often found in the industrial used electronics devices. This study is to discuss the application of static var compensator (SVC) to improve the power quality in distribution lines. Harmonics analysis of the loads industries are modelled as arc furnace and adjustable speed drive (ASD) using software ETAP simulation. The loads are connected to the IEEE 14 busses system. Fast decoupled method was used for investigating the voltage drop at each buss. Harmonics analysis was carried out to find harmonics level contents i.e., total harmonics distortion of voltage (THDV) and current (THDI). Values of THDV and THDI resulted are evaluated by state electrical company (PLN) standard. The load flow study result shows that there are some busses have voltage below the standard and harmonics analysis beyond the allowable limit but the voltage at Bus 14 is lowest, therefore SVC is connected to it. The results show all the voltage is fulfilling the standard. The SVC installation on this case is less significant it affects on mitigating harmonics.

1. Introduction

Currently, generally modern industry uses electrical equipment that is composed of electronic and power electronics-based by reason energy saving. This equipment is recognized as non-linear loads and produce harmonics. For example, non-linear loads in industries are variable speed (ASD), fluorescent lamp, arc furnaces, equipment with the saturation of ferromagnetic (example: induction motor, transformer. In industries, the ASD is used to control motor rotation, arc furnace is used to process iron melting whereas transformer as the step up or step down voltage in the electrical power system.

The equipment connected to industrial bus system produce out-put in sinusoidal waveform distorted. There are some effects if the harmonics waveform flow through the equipment leads to among others; the equipment over heat, the equipment can damage, system the load factor becomes
low. The low power factor results in economic loss in industry because penalty effect by the utility. The high currents the resulted voltage drops in distribution line. Both harmonics and voltage drop events are called power quality disturbance [1]. When the equipment subjected to voltage drop below the permitted limit, it can reduce the equipment performances even can switch off if the voltage drop is high.

Power quality matter is most frequently happens in distribution lines supply to industry sectors. Reactive power compensation is one of them becomes as the alternative to solve this power quality matter, commonly use fixed capacitor or fixed inductor can supply and absorb reactive power. Other way is to improve power quality using Static VAR Compensator (SVC) [2, 3]. The difference is the SVC uses component actively whereas the fixed capacitor and the fixed Inductor use compensation passively. Consequence the SVC has response is rapidly controllable reactive power compensation. The SVC can improve power quality because filter of the SVC can suppress harmonic, improvement power factor so voltage profile can to improve [4,5].

The values of the voltage, active power and reactive power for each bus are obtained through the load flow study. From this information can be determined SVC capacity is required. This study is to improve the power quality of distribution lines system that supplied industry loads includes increasing voltage and mitigating harmonics in simulation using ETAP. The distribution lines system used is the IEEE 14 busses system [6].

2. Methodology

2.1. Harmonics in power system

A harmonic frequency is components of the sinusoidal waveform which is a multiple of the fundamental frequency. For example, for basic frequency of 50 Hz, so second and third harmonics are 100 Hz and 150 Hz. Non-linear loads lead to the current varies is not proportional to voltage for each half cycles period so the current and the voltage distorted. Total harmonics distortion (THD) is as the indicator of harmonic content magnitude in a network [2]. For voltage and current are designated by equation eq. (1) and (2), respectively

\[ \text{THD}_v(\%) = \frac{\sqrt{\sum V_h^2}}{V_1} \times 100\% \]  
\[ \text{THD}_i(\%) = \frac{\sqrt{\sum I_h^2}}{I_1} \times 100\% \]

where \( V_h \) (volt) and \( I_h \) (amp) are total rms of voltage harmonic components and current, respectively. \( V_1 \) (volt) and \( I_1 \) (amp) are nominal voltage and fundamental current. According to the PLN standard [7] THD limitation for voltage and current in < 69 kV are 5% and 2.5%, for \( \text{THD}_v \) and \( \text{IHD}_v \) %, respectively. Current in rms is the function of current THD and rms of fundamental current is designated by a formula

\[ I = I_1\sqrt{1+\text{THD}_i^2} \]  

Relationship load factor and THD can be expressed by a formula,

\[ \text{pf}_{\text{disp}} = \cos \theta \frac{1}{\sqrt{1+\text{THD}_i^2}} \]

Where \( \cos(\theta) \) is the displacement power factor \( (\text{pf}_{\text{disp}}) \) and \( \frac{1}{\sqrt{1+\text{THD}_i^2}} \) is distortion power factor \( (\text{pf}_{\text{dist}}) \).

Currents drawn by loads flow through distribution line impedance lead to drop voltage. Amount of drop voltage in the network can be calculated by an equation,
where \( I \) (A) is current flow in impedance, \( \cos \theta \) is load factor, \( X \) (\( \Omega \)) and \( R \) (\( \Omega \)) are reactance and resistance lines, respectively. According to the PLN voltage standard limitation is +5% and –10% from the nominal voltage [7].

2.2. Static VAR compensator

Static var compensator (SVC) is variable reactance connected shunt that produces and absorbs reactive power for controlling the voltage at point common coupling (PCC) [4, 5]. It is composed of the capacitor filter bank and reactor is series connected to the thyristor. One of the benefits of using SVC in distribution network is to keep system voltage stable. Schematic diagrams of the SVC such as in Figure 1.

![Figure 1. Static VAR compensator](image)

Location of SVC installing is at buses that have lowest voltage profile and below allowable standard voltage. Amount of reactive power (VAR) injected by SVC to network system can be calculated by an equation,

\[
Q_{SVC} = Q_1 - Q_2
\]

where, \( Q_1 \) and \( Q_2 \) are reactive power before and after installed SVC, respectively.

2.3. Research procedure

To investigate the SVC influence in distribution line on voltage profile and harmonics caused by industry loads. The voltage and harmonics levels on busses are investigated before and after the SVC installed. The step as following:

- Find out voltage at every buss using load flow study without the SVC
- Install SVC at the busses has voltage lower than standard and determine the SVC rated it uses equation (5)
- Check the bus voltage which has the biggest influence for installing the SVC at the bus
- Harmonics analysis are evaluated by State Electrical Company (PLN) of Indonesia Standard
- The voltage and harmonic analysis are carried out before and after installed SVC.

3. Result

3.1. Simulation result of load flow study

The load flow study used Fast decouple method result before and after the SVC installation such as in Table 1 and the simulation model in this study using ETAP such in Appendix.
### Table 1. Load flow result before and after the SVC installation

| Bus name | Nominal Voltage (kV) | Loading | Before the SVC installation (Voltage%) | After the SVC installation (Voltage%) |
|----------|----------------------|---------|----------------------------------------|--------------------------------------|
|          |                      | MW      | MVAR                                   |                                      |
| Bus 1    | 69                   | 0       | 0                                      | 100                                  |
| Bus 2    | 69                   | 21.7    | 12.7                                   | 100                                  |
| Bus 3    | 69                   | 94.2    | 19.0                                   | 100                                  |
| Bus 4    | 69                   | 39.8    | 39.8                                   | 91.2                                 |
| Bus 5    | 69                   | 7.3     | 1.5                                    | 98.2                                 |
| Bus 6    | 13.8                 | 11.2    | 7.5                                    | 100                                  |
| Bus 7    | 13.8                 | 0       | 0                                      | 91.5                                 |
| Bus 8    | 13.8                 | 23.9    | 1.9                                    | 88.0                                 |
| Bus 9    | 13.8                 | 7.3     | 4.7                                    | 90.0                                 |
| Bus 10   | 13.8                 | 2.9     | 1.5                                    | 90.7                                 |
| Bus 11   | 13.8                 | 5.7     | 1.5                                    | 95.5                                 |
| Bus 12   | 13.8                 | 12.2    | 5.2                                    | 93.9                                 |
| Bus 13   | 13.8                 | 11.9    | 4.0                                    | 87.2                                 |
| Bus 14   | 13.8                 |         |                                        | 90.1                                 |

From Table 1 shows that there are some buses which the voltage less than 90% of it nominal (below PLN standard), some buses at rated voltage nominal and some buses in voltage critical (less than 95%). Most common the bus voltages that are far from source are smaller caused by voltage drop. From alternatively placement was obtained that Bus 14 is the best location for a 4.33 MVAR SVC. The load flow result for bus system voltage before and after application the SVC such as in Table 2. After the SVC installation, the voltages at bus 9 and bus 14 increases become more than 90%. So all the voltage busses system is meet to PLN standard for voltage.

#### 3.2. Simulation result of harmonic analysis

Simulation result of 14 busses system used ETAP package software caused by industry loads produce harmonic indexes for distortion of harmonic voltage total (THD\textsubscript{V}) and individual harmonic voltage (IHD\textsubscript{V}). In this discuss, industry loads used are pulse with modulation (PWM) of adjustable speed drive ASD (PWM ASD) and arc furnace.

**3.2.1. Simulation result caused by PWM ASD load.** Harmonic contribution of load type ASD is one model of group of harmonic sources of power electronic equipment. Spectrum of harmonic voltage resulted by the ASD is show in Figure 2. From voltage spectrum is obtained values of IHD\textsubscript{V} and THD\textsubscript{V} such as in Table 2. From Table 2 can be observed that IHD\textsubscript{V} values for harmonics of 5\textsuperscript{th}, 7\textsuperscript{th}, 11\textsuperscript{th} and 13\textsuperscript{th} are higher than PLN standard i.e., at busses 12, 13 and Bus 14. Whereas for other busses it values is below the standard. But THD\textsubscript{V} does not meet to the standard. The SVC installation is less significant to mitigate harmonics for this case.
Table 2. Values of IHD_\nu and THD_\nu caused by PWM ASD before and after the SVC installation

| Bus name | Harmonics order | IHD_\nu(\%) Before the SVC installation | IHD_\nu(\%) After the SVC installation | THD_\nu(\%) Before the SVC installation | THD_\nu(\%) After the SVC installation |
|----------|-----------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| 12       | 5               | 10,84                                  | 10,81                                  |                                         |                                        |
| 12       | 7               | 8,67                                   | 8,57                                   |                                         |                                        |
| 12       | 11              | 5,70                                   | 5,70                                   |                                         |                                        |
| 12       | 13              | 4,37                                   | 4,12                                   | 15,69                                  | 15,48                                  |
| 12       | 17              | 0,86                                   | 0,87                                   |                                         |                                        |
| 12       | 19              | 0,89                                   | 0,96                                   |                                         |                                        |
| 12       | 23              | 0,35                                   | 0,37                                   |                                         |                                        |
| 13       | 5               | 13,41                                  | 13,40                                  |                                         |                                        |
| 13       | 11              | 9,74                                   | 9,55                                   |                                         |                                        |
| 13       | 13              | 9,05                                   | 8,84                                   |                                         |                                        |
| 13       | 17              | 2,94                                   | 2,84                                   | 22,61                                  | 22,38                                  |
| 13       | 19              | 0,43                                   | 0,42                                   |                                         |                                        |
| 13       | 23              | 0,35                                   | 0,37                                   |                                         |                                        |
| 14       | 5               | 13,41                                  | 13,40                                  |                                         |                                        |
| 14       | 7               | 11,87                                  | 11,79                                  |                                         |                                        |
| 14       | 11              | 9,74                                   | 9,55                                   |                                         |                                        |
| 14       | 13              | 9,05                                   | 8,84                                   | 39,93                                  | 37,68                                  |
| 14       | 17              | 2,94                                   | 2,84                                   |                                         |                                        |
| 14       | 19              | 2,09                                   | 2,02                                   |                                         |                                        |
| 14       | 23              | 0,43                                   | 0,40                                   |                                         |                                        |

3.2.2. Simulation result caused by arc furnace load. One of the harmonics source group models of arcing device equipment is arc furnace. This type of load is commonly found in metal smelting factories. The SVC was installed at Bus 14 which the harmonic voltage spectrum resulted before and after the SVC installation such as in Figure 3. Arc furnace load produces harmonic order 2\textsuperscript{nd}, 4\textsuperscript{th}, 5\textsuperscript{th}, 7\textsuperscript{th} and 8\textsuperscript{th}. The harmonics order produced by the arc furnace is different with resulted by the ASD, and fifth harmonic order is highest due to the ASD.
Effect of the SVC installation is observed on closest to Bus 14 viz. Bus 12 and Bus 13, because on these busses have effect largest. Limitations of IHD\textsubscript{V} and THD\textsubscript{V} are 3.0\% and 5.0\%, respectively. The simulation result of arc furnace load for harmonic analysis as shown in Table 3.

**Table 3.** Values of IHD\textsubscript{V} and THD\textsubscript{V} caused by arc furnace before and after the SVC installation

| Bus name | Harmonics order | IHD\textsubscript{V}(\%) Before the SVC installation | After the SVC installation | THD\textsubscript{V}(\%) Before the SVC installation | After the SVC installation |
|----------|-----------------|---------------------------------|-----------------------------|---------------------------------|-----------------------------|
| 12       | 2               | 1.37                            | 1.34                        |                                 |                             |
| 12       | 4               | 0.90                            | 0.88                        |                                 |                             |
| 12       | 5               | 3.85                            | 3.72                        | 4.64                            | 4.38                        |
| 12       | 7               | 2.15                            | 2.06                        |                                 |                             |
| 12       | 8               | 0.53                            | 0.51                        |                                 |                             |
| 13       | 2               | 1.88                            | 1.23                        |                                 |                             |
| 13       | 4               | 1.14                            | 0.97                        |                                 |                             |
| 13       | 5               | 4.87                            | 4.31                        | 6.08                            | 4.58                        |
| 13       | 7               | 2.77                            | 2.44                        |                                 |                             |
| 13       | 8               | 0.78                            | 0.55                        |                                 |                             |
| 14       | 2               | 4.26                            | 3.29                        |                                 |                             |
| 14       | 4               | 2.88                            | 2.12                        |                                 |                             |
| 14       | 5               | 12.77                           | 11.32                       | 15.76                           | 13.51                       |
| 14       | 7               | 7.46                            | 6.11                        |                                 |                             |
| 14       | 8               | 1.83                            | 1.32                        |                                 |                             |

From Table 3 can be observed that IHD\textsubscript{V} highest is at fifth order which the value exceeds the standard, but after SVC installed the value decrease and highest decrease is at bus 14 which the SVC installed whereas for busses 12 and 13 are slightly decrease. Harmonic order of fifth is higher and not fulfils the standard for 12, 13 and 14.

Figure 3 shows the result of harmonic voltage spectrum caused by arc furnace. Arc furnace load produces harmonic order 2\textsuperscript{nd}, 4\textsuperscript{th}, 5\textsuperscript{th}, 7\textsuperscript{th} and 8\textsuperscript{th} and harmonic order highest is at order-5. There is no significant effect on the SVC installation for mitigating harmonics. Harmonic content level highest is at Bus 14 which arc furnace installed.

**Figure 3.** Voltage spectrum of the arc furnace
4. Conclusion

Based on obtained results, the following can be concluded that the SVC installation can increase the bus voltage system so that finally the all bus system meets PLN standard. Harmonics order produced by the ASD is not similar to arc furnace. The harmonics considered significantly influenced caused by the ASD until order 23 whereas the harmonics caused by arc furnace until order 8. The harmonic resulted from the ASD is larger than the arc furnace. The SVC installation can reduce harmonics level caused by the arc furnace meanwhile harmonic caused by the ASD load is not significantly decrease. Therefore, to mitigate harmonic caused by the ASD it is needs especially harmonics filter.

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Appendix

Figure. IEEE 14 bus system used as a model