Investigation of voltage swell mitigation using STATCOM

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Abstract. STATCOM is one of the best applications of a self commutated FACTS device to control power quality problems in the distribution system. This project proposed a STATCOM model with voltage control mechanism. DQ transformation was implemented in the controller system to achieve better estimation. Then, the model was used to investigate and analyse voltage swell problem in distribution system. The simulation results show that voltage swell could contaminate distribution network with unwanted harmonic frequencies. Negative sequence frequencies give harmful effects to the network. System connected with proposed STATCOM model illustrates that it could mitigate this problems efficiently.

1. Introduction

Static Synchronous Compensator (STATCOM) is an influential controller device for electric transmission and distribution network. STATCOM is employed to provide voltage flicker compensation, voltage stability and power factor control thus increases power quality [1]. Applications of STATCOM also include fast supply of voltage to support the power system. Weak system gives instability to the system since disruption will caused unbalanced voltage. This results in severe damaging impact to both load and power system equipments.

This project aims to develop a STATCOM model with voltage control system using proportional integral, PI, controller using MATLAB Simulink software as described in reference [2]. Then the proposed model will be tested by studying impact of voltage swell in network in terms of total harmonic distortion, THD and harmonic contents.

2. Methodology

The overall test system setup is shown in Figure 1. The settings for the components are given in [2]. The difference between the STATCOM model in [2] and the STATCOM model in this paper was the power electronic device used in the voltage source converter, VSC. This paper used IGBT instead of ideal switch to represent practical implementation of STATCOM. The VSC control system has 4 inputs and 1 output with 2 control subsystems. The controllers are based on PI and DQ transformations.

The Re+jwL represents the transformer that isolates the network from the STATCOM. There are two loads in this test system, labelled as Line 1 (Re+jwL1) and Line 2 (Re+jwL2). The voltage swell was generated using a three phase programmable voltage source. The three phase programmable voltage source is placed beside Line 1. Two simulations were conducted. The first simulation will represent an ideal system with no fault, named as the Reference System. The other simulation, named as the Case Study System, was simulated with voltage swell injected in the test system.
2.1. PI controller
In this project, PI is used to tune and modify output of VSC in achieving the expected outcome. The control scheme operates in voltage control mode [3] as shown in Figure 2. The first PI will determine the amplitude modulation \((m)\) and the second PI will determine the angle modulation \((\alpha)\). Combination of outputs from magnitude and phase modulation control systems will produce, \(V_{\text{control}}\),

\[
V_{\text{control}}(\angle E) = \text{modulation} \cdot \cos(\omega t + \alpha + \theta)
\]  

2.2. DQ transformations
DQ transformation is mostly employed for three phase converters’ analysis and control design. The DQ controller provides superior transient response and low output voltage THD under nonlinear load operation [4]. In the amplitude modulation subsystem, the \(V_{\text{bus}}\) is converted into DQ components as follows,

\[
V_d = \frac{2}{3}(V_d \sin(\omega t) + V_b \sin(\omega t - 2\pi/3) + V_c \sin(\omega t + 2\pi/3)) \\
V_q = \frac{2}{3}(V_d \cos(\omega t) + V_c \cos(\omega t - 2\pi/3) + V_b \cos(\omega t + 2\pi/3)) \\
V_p = \frac{1}{3}(V_d + V_b + V_c)
\]

2.3. Analysis methods
Harmonic analysis was conducted to evaluate the effect of voltage swell on the network. The analysis was done by analyzing the bus voltage (\(V_1\)) and the bus current (\(I_0\)). The two analyses conducted were computation of THD and the harmonic contents of the signals. THD is given by
Harmonics frequencies can be grouped according to symmetrical system sequence which is positive sequence harmonic, negative sequence harmonic and zero sequence harmonic. The harmonic contents of a signal are determined as follows:

\[ THD_x = \sqrt{\sum_{h=1}^{\infty} \frac{x_h^2}{x_1^2}} \]  \hspace{1cm} (3)

Harmonics frequencies can be grouped according to symmetrical system sequence which is positive sequence harmonic, negative sequence harmonic and zero sequence harmonic. The harmonic contents of a signal are determined as follows:

\[ h = np \pm j \]  \hspace{1cm} (4)

where:

- \( h \) = order of harmonics,
- \( n \) = an integer 1, 2, 3…,
- \( p \) = number of current pulses per cycle

3. Results and Discussions

Table 1 lists the parameter settings for the simulation. Figure 3-4 show the THD and harmonic contents for V1 and Iac respectively. For the Reference System, the THD \( V_1 \) is at 0.31% and THD \( I_{ac} \) is at 0.43%. The THD for the Case Study System are very high, exceeding the 5% THD limit set by the IEEE [5], with THD \( V_1 \) at 54.9% and THD \( I_{ac} \) at 13.39%.

| Parameter               | Unit   |
|-------------------------|--------|
| Max Step Size           | 0.02   |
| Frequency               | 60 Hz  |
| Time offset Period      | 0.4 s  |
| Vrms phase              | 220 V  |
| Dicrete Time Power Gui  | 50e-006 s |

The Case Study System produced higher magnitude of harmonic frequencies. The fundamental frequency contributed the highest frequency component as expected. This is followed by the sidebands for the switching frequency of 900 Hz, the 13\textsuperscript{th} and the 17\textsuperscript{th} harmonic frequencies. The 13\textsuperscript{th} harmonic frequency is a positive sequence harmonic which can assist the torque production in the system. However, the 17\textsuperscript{th} harmonic frequency is a negative sequence harmonic that can cause inverse rotation of the three phase system resulting in torque pulsations. The results clearly show that the problem needs to be addressed to avoid power quality problem to the system.

4. Conclusion and Future Work

In this paper a STATCOM model with voltage control mechanism developed using Matlab Simulink has been presented. Simulations were carried out to verify the functionality of the proposed model with no fault and with fault presence in the system. The simulation results were analyzed in terms of THD and harmonic contents. The STATCOM model was shown to be able to mitigate the voltage swell problem. In future, similar study could be done with other power switching devices and with different filter configurations. The control system can be designed to have real (\( P \)) and reactive power (\( Q \)) as inputs in the control system.
5. References

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