Voltage profile improvement analysis during the loss of transmission lines on 150kv subsystem using static synchronous compensator

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Abstract. A Flexible AC Transmission System (FACTS) device which is Static Synchronous Compensator (STATCOM) is commonly use to overcome voltage instability issue. However, the implementation of the STATCOM may cause a voltage increase within the allowable limits in all areas and maintaining the voltage stability of interconnected system. Therefore, this paper proposes an optimum placement of STATCOM to maintain the voltage profile of 150 kV subsystem during the loss of the transmission lines. The proposed methodology is verified by using a 150 kV interconnected system where the loss of two 150 kV transmission lines may lead to a voltage instability in the entire interconnected subsystem. The results show that the proposed method can maintain the voltage stability in the subsystem within the allowable limits in all period.

1. Introduction
Nowadays, instability of voltage poses a serious threat to safety and reliability of electrical power system. Voltage stability can be interpreted as power system ability that enables it to remain stable or to maintain operating condition of equilibrium after being a target to disturbances or severe contingencies from initial operating condition [1]. Power system can be defined unstable when voltage decreases uncontrollably because of loss of equipment, the loss of transmission lines, and sudden increment in load. [2]

Voltage stability is a local problem, but the consequences of the instability of voltage have big impact on power system. The impact may lead voltage collapse and also a blackout. For reliable operation of the power system, reactive power control must be done properly to make the voltage at all buses within acceptable limits. [2]

The voltage instability has big impact on power system. It can be caused by a disturbance on transmission lines which leads the loss of transmission lines [3]. Moreover, the loss of the transmission lines may also affect the voltage instability in the entire interconnected system.

In order to overcome the issue, A Flexible AC Transmission System (FACTS) device that is Static Synchronous Compensator (STATCOM) is installed. However, installation of STATCOM may cause a voltage increase within the allowable limits in other areas and maintaining voltage stability of the interconnected system. [4]
This paper proposes an optimum placement of STATCOM to maintain the voltage profile of the subsystem during the loss of the transmission lines. The proposed methodology is verified by using a 150 kV interconnected subsystem where the loss of two 150 kV transmission lines may lead to a voltage instability in the entire interconnected subsystem. For security reason, the identity of the 150 kV subsystem and its substations are adjusted.

This paper is organized as: Section 1 provides the research introduction, Section 2 proposes the configuration of the studied 150 kV subsystem and contingencies analysis in the subsystem, Section 3 proposes installation method of STATCOM on the subsystem, Section 4 presents the simulation and results, and Section 5 is the conclusion of this paper.

2. Subsystem Alpha and Contingencies Analysis on the Subsystem

2.1. Subsystem alpha

Figure 1 shows the configuration of Subsystem Alpha. The subsystem peak load is around 1.700 MW and also some customers of industrial are on this subsystem. Subsystem Alpha is supplied by 4x500 MVA Interbus Transformer (IBT), 3x280 MW Power Plants and 1x660 MW Power Plant with full capacity about 1.440 MW. Power Plants 01, 02 and 03 capacity is 3x280 MW and transmitted via 2 parallel transmission lines, those are lines 17-09 and lines 17-16. Those transmission lines are not burdened equally, electrical power from Power Plants 01, 02, and 03 tend to flow on lines 17-09 rather than lines 17-16.

![Figure 1. Configuration of subsystem alpha.](image-url)
2.2. Contingencies analysis on subsystem alpha

Contingency is an event caused by a failure or release of one or more generators or transmission lines. N-k contingency is a contingency that resulted from the release of a number k of system components [5]. Contingencies study in Subsystem Alpha have been done to assess some cases which may lead to voltage drop until exceeding the voltage limit standard used in this study, which is ±5% based on IEEE/ANSI C84.1 which can cause voltage instability of the subsystem [6].

| Case  | Transmission Contingencies                  |
|-------|---------------------------------------------|
| Case 1| Lines 17-09: two lines trip (N-2)           |
| Case 2| Lines 17-16: two lines trip (N-2)           |

Table 1. Cases of Transmission Lines Contingencies.

Table 1 shows cases made to see the voltage stability of the subsystem with contingencies study. Case 1 shows the loss of two transmission lines 17-09 and Case 2 shows the loss of two transmission lines 17-16. Table 2 shows The contingency analysis simulation result.

| Substation | Voltage [pu] Normal | Voltage [pu] Case 1 | Voltage [pu] Case 2 | Substation | Voltage [pu] Normal | Voltage [pu] Case 1 | Voltage [pu] Case 2 |
|------------|---------------------|---------------------|---------------------|------------|---------------------|---------------------|---------------------|
| 01         | 1.011               | 0.977               | 0.991               | 09         | 0.974               | 0.925               | 0.938               |
| 02         | 0.988               | 0.945               | 0.960               | 10         | 0.969               | 0.920               | 0.933               |
| 03         | 0.982               | 0.938               | 0.952               | 11         | 0.970               | 0.921               | 0.933               |
| 04         | 0.979               | 0.934               | 0.947               | 12         | 1.022               | 0.982               | 1.012               |
| 05         | 0.979               | 0.920               | 0.947               | 13         | 1.002               | 0.920               | 0.972               |
| 06         | 0.977               | 0.931               | 0.944               | 14         | 1.002               | 0.911               | 0.965               |
| 07         | 0.977               | 0.931               | 0.944               | 15         | 1.004               | 0.910               | 0.958               |
| 08         | 0.976               | 0.930               | 0.943               | 16         | 1.011               | 0.938               | 0.951               |

Table 2. Voltage profile of subsystem alpha during normal condition, case 1 and case 2.

Simulation results indicate both Case 1 and Case 2 cause voltage instability on the subsystem. The drop voltage occurs in Subsystem Alpha until exceeding the voltage limit standard which is ±5% on those cases. Therefore, Static Synchronous Compensator (STATCOM) installation is needed in those cases to increase the voltage profile in the Subsystem Alpha so that voltage profile of all substations on the subsystem is in the standard set based on IEEE/ANSI C84.1 which is ±5% which may lead to voltage stability when transmission contingencies occur in the subsystem.

Installation of STATCOM can also aim to improve the reliability of electric power systems [7]. When there is some maintenance on some transmission lines on the system which can cause drop voltage in the subsystem if the load of system is not reduced, STATCOM can be a solution to maintain the voltage stability.

3. Installation Method of STATCOM in Subsystem Alpha

STATCOM is a device based on power electronics such as Gate Turn-Off Thyristor or Insulated-Gate Bipolar Transistor, to inject or compensate controllable reactive power into the power system network and therefore improving power system stability. STATCOM is one of Flexible AC Transmission System (FACTS) shunt controller devices. Synchronous from STATCOM means it can absorb and generate reactive power of power system on synchronization to improve voltage stability of power system network. [8]

STATCOM can be defined as static plant of Volt Ampere Reactive (VAR), with the output varies to maintain reactive impedances, using the arrangement of the sort of synchronous voltage source using
converter of switch power [9]. Figure 2 is showing STATCOM topology, consisting of DC capacitor converter and the transformer circuit.

\[
Q = \frac{(V_1(V_1-V_2))}{x} \quad (1)
\]

3.1. Work Principle of STATCOM

Figure 3 shows STATCOM principle of operation or work, showing the reactive and active power flow between sources V1 and V2. V2 defines system voltage that will be controlled and V1 defines the voltage generated by STATCOM [9].

In term of increasement reactive power demand in the system network, the voltage generated by STATCOM (V1) is in phase with V2, which are zero therefore only reactive power will flow. If V2 is higher than V1, Q flows from V2 to V1 or STATCOM will absorb reactive power. And also, If V1 is higher than V2, Q flows from V2 to V1 or STATCOM will generate reactive power [9]. The amount of Q is found in expression in:

\[
Q = \frac{(V_1(V_1-V_2))}{x} \quad (1)
\]

3.2. Selection of STATCOM installation place

In this research, the selection of STATCOM installation place will be carried out by reviewing the weakest substation in Subsystem Alpha or the substation with the lowest voltage when contingencies occur.

Subsystem Alpha is divided into 2 areas, which are the area that is supplied by InterBus Transformer of Substation 500-12 and the area that is supplied by InterBus Transformer of Substation 500-12. In Case 1, voltage drop occurs on all areas so that STATCOM must be installed at 2 places, one at the substation that is supplied by InterBus Transformer of Substation 500-01 and the other one at the substation that is supplied by InterBus Transformer of Substation 500-12.

In case 2, voltage drop occurs only on area that supplied by InterBus Transformer of Substation 500-01 so that STATCOM will be installed at 1 place, which is at the substation on that area.

3.3. STATCOM modeling

In this paper, STATCOM will be modeled following the modeling obtained from the book “Power Factory Applications for Power System Analysis” [10], in the chapter “Programming of Simplified Models of FACTS Devices Using DigSILENT Simulation Language”. Figure 4 shows Installation Simulation of STATCOM on Subsystem Alpha.
4. Simulation Results and Discussion

In this study, there are 2 cases that need installation of Static Synchronous Compensator (STATCOM), which are Case 1 and Case 2. Installation of STATCOM aims to improve voltage profile of Subsystem Alpha therefore voltage stability can be maintained on Case 1 and Case 2 or when contingencies of transmission lines happen. The tool that is used to run the simulation is DIgSILENT Power Factory.

4.1. Simulation results at case 1

Table 3 shows voltage profile results at case 1 after installation of STATCOM in Substation 10 and Substation 15, with reactive power injection of 175 MVAr each.

Table 3. Voltage Profile in Subsystem Alpha after Installation of STATCOM at Substation 10 and Substation 15.

| Substation | Voltage [pu] Without STATCOM | Voltage [pu] With STATCOM | Substation | Voltage [pu] Without STATCOM | Voltage [pu] Without STATCOM |
|------------|-------------------------------|----------------------------|------------|-------------------------------|-------------------------------|
| 01         | 0.977                         | 1.012                      | 09         | 0.925                         | 0.986                         |
| 02         | 0.945                         | 0.992                      | 10         | 0.920                         | 1.018                         |
| 03         | 0.938                         | 0.988                      | 11         | 0.921                         | 0.982                         |
| 04         | 0.934                         | 0.987                      | 12         | 0.982                         | 1.003                         |
| 05         | 0.920                         | 0.986                      | 13         | 0.920                         | 0.973                         |
| 06         | 0.931                         | 0.986                      | 14         | 0.911                         | 0.977                         |
| 07         | 0.931                         | 0.986                      | 15         | 0.910                         | 0.990                         |
| 08         | 0.930                         | 0.986                      | 16         | 0.938                         | 0.992                         |
In Case 1 or N-2 contingencies (two transmission lines 17-09 trip), voltage drop occurs on Subsystem Alpha, as many as fourteen substations are below the standard set based on IEEE/ANSI C84.1 which is ±5%, those substations are Substation 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 13, 14, 15 and 16, with the lowest voltage is at Substation 15 with 0.910 pu.

Subsystem Alpha is divided into 2 areas, which are the area that is supplied by InterBus Transformer of Substation 500-12 and the area that is supplied by InterBus Transformer of Substation 500-01. In Case 1, voltage drop occurs on all areas so that STATCOM must be installed at 2 places, one at the substation that is supplied by InterBus Transformer of Substation 500-01 and the other one at the substation that is supplied by InterBus Transformer of Substation 500-12. Therefore the voltages on all substations in Subsystem Alpha can be improved.

After installation simulation of STATCOM at the optimum placements, which are at Substation 10 and Substation 15 with reactive power injection of 175 MVAr each, voltage profile of all substations increases until reach the standard used in this study, which is ±5%. The most significant improvement is at Substation 15 where STATCOM is installed, with the improvement from 0.910 pu to 0.990 pu.

4.2. Simulation results at case 2
Table 4 shows voltage profile results at case 2 after installation of STATCOM in Substation 11, with reactive power injection of 150 MVAr.

| Substation | Voltage [pu] | Substation | Voltage [pu] |
|------------|--------------|------------|--------------|
|            | Without STATCOM | With STATCOM | Without STATCOM | With STATCOM |
| 01         | 0.991         | 1.016       | 09           | 0.938         | 0.985           |
| 02         | 0.960         | 0.995       | 10           | 0.933         | 0.981           |
| 03         | 0.952         | 0.990       | 11           | 0.933         | 0.994           |
| 04         | 0.947         | 0.998       | 12           | 1.012         | 1.017           |
| 05         | 0.947         | 0.998       | 13           | 0.972         | 0.975           |
| 06         | 0.944         | 0.987       | 14           | 0.965         | 0.967           |
| 07         | 0.944         | 0.987       | 15           | 0.958         | 0.961           |
| 08         | 0.943         | 0.986       | 16           | 0.951         | 0.954           |

In Case 2 or N-2 contingencies (two transmission lines 17-16 trip), voltage drop occurs on Subsystem Alpha, as many as eight substations are below the standard set based on IEEE/ANSI C84.1 which is ±5%, those substations are Substation 04, 05, 06, 07, 08, 09, 10, and 11, with the lowest voltage is 0.933 pu on Substations 10 and 11.

After installation simulation of STATCOM at the optimum placement, which is at Substation 11 with reactive power injection of 150 MVAr, voltage profile of all substations increases until reach the standard used in this study, which is ±5%. The most significant improvement is at Substation 11 where STATCOM is installed, with the improvement from 0.933 pu to 0.994 pu.

In Case 2, STATCOM is installed only at one substation because only substations that are supplied by InterBus Transformer of Substation 500-01 whose experienced voltage drop until exceeding the standard, so that STATCOM is installed at Substation 11 which is on that area. Substations those are supplied by InterBus Transformer of Substation 500-12, which are Substations 12, 13, 14, 15 and 16 also affected by the installation of STATCOM at Substation 11, but the voltages on those substations only improve slightly, the most significant improvement on that area is at Substation 12, which is from 1.012 pu to 1.017 pu.
5. Conclusion
Voltage profile in Subsystem Alpha in case 1 or N-2 contingencies (17-09 two lines trip), before using STATCOM drop significantly. 14 of 16 substations are under the standard set based on IEEE/ANSI C84.1 which is ±5%. After installation of STATCOM at Substation 10 and Substation 15 with reactive power injection of 175 MVAr each, voltage profile of all substations in Subsystem Alpha increased until all substations reach the standard.

In case 2 or N-2 contingencies (17-16 two lines trip), voltage profile in Subsystem Alpha drops, but not as bad as case 1. Only substations in area that is supplied by InterBus Transformer of Substation 500-01 drop until exceeded -5% voltage standard. So that STATCOM is installed only at the substation in that area, which is in Substation 11. After installation of STATCOM at Substation 11 with reactive power injection of 150 MVAr, voltage profile of substations in area that supplied by InterBus Transformer of Substation 500-12 improve slightly.

Voltage profile improvement using STATCOM can also improve the electrical power transfer capability of the power system. By using STATCOM, the issue of voltage drop that may lead to outage or black out of the system can be solved. Maintaining voltage profile of the subsystem by using STATCOM can also improve the Available Transfer Capability (ATC) of the subsystem. However, in this research, the increased value of ATC of the subsystem is not discussed.

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