Analysis of implementation UPFC for optimizing power flow & improving power system stability in Z power system

A A Nugroho¹, A Rahardjo², A Setiawan³, F H Jufri² and F Husnayain²
¹ Student, Department of Electrical Engineering Universitas Indonesia, Depok, Indonesia
² Lecturer, Department of Electrical Engineering Universitas Indonesia, Depok, Indonesia
³ Engineer, Operation System Department PT. PLN (Persero) P2B, Depok, Indonesia

*E-mail: faiz@eng.ui.ac.id

Abstract. In electric power systems, it will started from the generation phase until the distribution phase through transmission lines must take place well. The purpose of study is to analyze the implementation in optimizing the power flow and improving stability in Z Power System. Therefore, it is necessary to have sufficient electricity distribution so that the electricity sent can be as efficient as possible. In the Z electric power system, there are many problems in electric power transmission, namely loading on uneven channels and the threat of extinguishing in the event of a disturbance. Uneven load is caused by differences in impedance on the channel. Blackouts occur because the channel on the Z is a generator evacuation route where the area is crucial if a disturbance occurs. Therefore, a tool is needed to prevent it. One solution to this problem is to use a power electronics device called UPFC. The simulation results show an even distribution on the all transmission lines connected to substation of Generators will be decrease up more than 3% of the normal loading. In addition, the UPFC can also improve stability by compensating for the active power and reactive power needed by the system.

1. Introduction

Electrical energy is one of the most important needs for humans to live. In daily, humans need electricity exactly. In general, it can be said that electrical energy is one of the important parameters in human life and the development of human life requires an additional supply of electrical energy. People often state that economic growth will be directly proportional to the ability to provide electricity.

The electric power system consists of sources and loads that are located far apart and cover a very wide area. In power delivery, a transmission line is needed so that the power to be distributed can be sent to the load centers to be addressed. But a network transmission has a limited capacity. Operations that are out of bounds will cause the steady-state to be disturbed or will cause a reduction in poor electromechanical oscillation and the worst condition is the power system fails.

System instability can be defined as a system that allows the engine to move in a system to give its reaction to a disturbance under normal circumstances. To overcome this instability and to improve a large voltage drop a power electronic device is needed to be called a Flexible Alternating Current Transmission System (FACTS). One of them is the Unified Power Flow Controller (UPFC). This UPFC can regulate
power transfers by setting parameters in the power flow, namely voltage, channel impedance, and voltage angle [1].

For security reason, the identity of the 150 kV subsystem and its substations are adjusted. This paper is organized as: Section 1 presents the research introduction, Section 2 The Principle and Construction of UPFC, Section 3 provides the simulation and results, and Section 4 is conclusion of this paper.

2. The Principle and Construction of UPFC
The special ability of UPFC from the other devices is the capability to versatile. The versatile ability of UPFC can regulate active power flow and reactive power. Therefore, the UPFC has also been named a complicated device. UPFC consists of two converters which has many different functions. The first converter is arranged in series and is called SSSC (Static Synchronous Series Compensator). The second converter is arranged in parallel and is called SVC (Static VAR Compensator). Both converters carry out their respective functions. The series converter used for increasing the amount of angle controlled and phase voltage in series with the channel. The parallel converter used for supply reactive power to the ac system, besides, it will supply the dc power required for both inverters. The two converters are connected to a common dc capacitor [2]. At each converter branch, there is a transformer for step-up and step-down voltages and an electronic power converter. The key factor behind the features of UPFC is its ability to drain real power from both directions, maintain DC voltage so that it can be adjusted properly, and can work in all types of operating conditions [3, 4].

The core components of the UPFC are two voltage two inverter voltage sources in the UPFC are core components that play a role in providing general dc capacitor storage. The first VSI is connected to the shunt to the transmission system via a shunt transformer, on the other hand, the second VSI is connected in series through the transformer. The two VSCs are connected and create an active power exchange path between the converter at the DC terminal. Thus, the series convector provides active power to the channel through the shunt converter as shown in figure 1 [5]. For that reason, a different range of the control options is available matched to SVC or SSSC. The UPFC can be used to control the flow of active and reactive power through the transmission line and to control the total of reactive power distributed to the transmission line at the point of installation [6]. At UPFC, due to having the ability to survive in all conditions, the UPFC has many types of operating modes including VAR Control mode, Automatic Voltage Control Mode, Direct Voltage Injection Mode, Phase Angle Shift Emulation Mode [7, 8].

3. Methodology
Simulation is operated by using DigSilent 15.1 as software to operate the Z power system network. During operation, the electric power system is given a 3 phase short circuit interference to determine the system’s dynamic response. In this simulation, a comparison of the conditions before and after the UPFC was made. The variable as a parameter reference comparison is seen from the stability of the rotor angle and the stability of the active power flow. Due to the workings of the UPFC, it injects active power and reactive power into the system. So, the need for proper and accurate injection so that the results are optimal. The following is the formula for active power injection and reactive power from UPFC.

3.1. SVC (Static VAR Compensator)
The reactive power injection of a SVC connected to bus k is given by [9]

\[ Q_k = V_k^2 B_{SVC} \]  \hspace{1cm} (1)

\[ B_{SVC} = B_c - B_l \]  \hspace{1cm} (2)

The symbol and are the respective susceptances of the fixed capacitor and the thyristor controlled reactor. It also important that a SVC does not exchange real power with the system. Eq (1) and (2) mean that before
we were finally got the amount of reactive power injection, we should find the value of susceptance in SVC. The value is susceptance of capacitor minus susceptance of thyristor.

SSSC (Static Synchronous Series Compensator)
The active power injection of SSSC connected to bus m is given by [10]

\[ I_{SE} = \frac{V_{SE}}{Z_{KM}} \]  \hspace{1cm} (3)

\[ S_M = V_M(I_{SE}) \]  \hspace{1cm} (4)

Where

- \( Z_{KM} = \text{line impedance where UPFC series connected} \)
- \( V_M = \text{Bus voltage M where UPFC shunt connected} \)
- \( I_{SE} = I \text{ series where connected with } Z_{KM} \)
- \( V_{SE} = V \text{ series where connected with } Z_{KM} \)
- \( S_M = \text{power injection of UPFC series} \)

Eq (3-4) mean that before we were finally got the amount of active power injection by SSSC, we should find the value of \( I_{SE} \). After that, we can insert the value to the Eq.4.

### Table 1. UPFC Injection.

| Device | Injection Reactive Power | Injection Voltage Angle |
|--------|--------------------------|------------------------|
| SVC    | 315 MVAR                 | -                      |
| SSSC   | -                        | 2.8 p.u                |

4. Analysis and Simulation

In this simulation, the Z electric power system has been disturbed to find out how the system responds. The data obtained is divided into 2, namely the condition of the system before being paired with UPFC and the condition of the system after pairing UPFC. Under paired conditions, UPFC is varied in its placement to find the optimal installation location [11].

4.1 Without UPFC

![Figure 1](image-url)  

**Figure 1.** Active power of generators oscillation without UPFC.
System when one transmission line have been outages from the system. Active power and rotor angle didn’t reach equilibrium point after the system had a disturbance. Until the end of the simulation, the system can’t be solved. So we will install the UPFC to improve stability and increase the voltage of substation rapidly.

4.2 With UPFC

UPFC is installed in transmission lines in series and parallel. Installed in series with SSSC and installed in parallel with SVC [12]. The UPFC placement was carried out on the transmission lines A & B because it is the evacuation route that has the biggest impedance compared to the transmission lines C & D.
Figure 4. Active power and rotor angle of generators oscillation with UPFC.

Figure 5. Active power of transmission lines oscillation with UPFC.

Figure 6. Condition of voltage in z power system’s with UPFC.
In figure 4-5, we can see that many effects appear in the Z Power System when UPFC has been installed. First, the Oscillation of Active Power in Generator can be handled and more steady in 18s and 6s on Generator C & D and Generator A & B. That means the injection of UPFC successfully worked. Second, the Oscillation of Active Power in Transmission Lines can be handled too. It's not only stable but faster than the time needed for the oscillation of Active Power in Generators. Third, improvement stability can occur in the rotor angle. Both of generator can solve the instability on 16s and 15s in Generator A & B and Generator C & D. That means electrical torsion and mechanical torsion have more synchrony than before. The reduce of oscillation can give many benefits to the system. Especially to reduce power loss occurred on transmission lines.

Table 2. Comparison between before and after UPFC attached.

| Substation | Fault Condition (pu) | After FACTs (pu) | Increase (%)
|------------|----------------------|-----------------|------------|
| A          | 0.9                  | 0.96673         | 0.08       |
| B          | 0.6                  | 0.91693         | 0.48       |
| C          | 0.9                  | 0.96             | 0.09      |
| D          | 0.4                  | 0.9082          | 1.17       |
| E          | 0.2                  | 0.47046         | 1.31       |
| F          | 0.4                  | 0.9218          | 1.30       |
| G          | 0.9                  | 0.9542          | 0.08       |

Table 3. Comparison between loading before and after UPFC attached.

| Transmission Lines | Fault Condition | Fault Condition |
|-------------------|----------------|-----------------|
| A                 | 8.53           | 8.53            |
| B                 | 8.53           | 8.53            |
| C                 | 0 (Outage)     | 0 (Outage)    |
| D                 | 93.19          | 61.73           |

The results show an improvement in performance after connected the UPFC to the system. It can be seen:
- There is an increase in voltage on each bus in the Z power system so that the problem of buses that have Under voltage without UPFC can be handled.
- There is a decrease in loading on the generator evacuation channel. The decrease was up to 31.46% on the transmission line D and a decrease of up to 3% on the transmission lines of A & B.
- The stability response of the active power of the generator, transmission line, and generator rotor angle is getting better. This can be proven by the occurrence of oscillation reduction when the UPFC is installed into the system.
5. Conclusion
Based on the simulation conducted, there are some point that feasibly address as the result. The UPFC is capable to injects reactive power and p.u. voltage to improve stability in a system affected by interference. Furthermore, the study show that it could reduce generator power oscillations, transmission line power oscillations, and generator rotor angles before simulation ended. The other advantage is the UPFC can increase the voltage on the bus that has under voltage (7 buses) so that the bus returns to normal. As the result, it can flatten the load on the transmission line up to 30% lower than without UPFC so that overload loading can be prevented. Regarding the optimum UPFC placement, the UPFC circuit is recommended to be installed on the transmission line C & D.

Acknowledgment
This research is funded by research grant of HIBAH PITTA B 2019 No. NKB-0729/UN2.R3.1/HKP.05 .00/2019 from Universitas Indonesia

References
[1] Kundur P 1994 EPRI Power System Engineering Series in Power System Stability and Control (New York: Mc-Graw Hill)
[2] Xu L and Agelidis V G Flying Capacitor Multilevel PWM Converter Based UPFC IEE Proc. of Electronic Power Application 149 No. 4, July 2003 pp. 304-310.
[3] Mubeen S E, Nema R K and Agnihotri G 2008 World academy of science, Engineering and Technology 2 2507-2511
[4] G.Hingorani G and Gyugyi L 1999 Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems (New York: Wiley-IEEE Press)
[5] Noroozian M, Anguist L, Ghandhari M and Andersson G 1997 IEEE Trans. on Power Delivery 17 1629–1634
[6] Bhowmik A R Int. J. Comp. Tech Appl. 2 1889-1896
[7] B.Gopinath B, Kumar S S and Mohanapriya S 2013 International Journal of Scientific and Research Publications 3 1–6
[8] Bhowmick, S Das B and Kumar N 2008 IEEE Transactions on Power Delivery 23 2079-2088
[9] Zhang X P, Rehtanz C and Pal B Flexible AC Transmission Systems: Modelling and Control
[10] Kalyani S T and Das G T 2008 Simulation of Real and Reactive Power Flow Control with PFC Connected to a Transmission Line Journal of Theoretical and Applied Information Technology
[11] Kumar B V and Srikanth N V 2014 “Optimal location and sizing of Unified Power Flow Controller (UPFC) to improve dynamic stability: A hybrid technique”. IJAREEIE
[12] Kale V S, Patil P R and Khatri R 2010 Unified Power for Controller for Power System Improvement, IJESE.