The influence of Unified Power Flow Controller to increase the value of Available Transfer Capability on transmission system Java – Bali, Indonesia

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Abstract. Industrial growth and population in Indonesia led to an increase in demand for electricity. It needs a device that can perform a voltage correction profile online so that power will flow through transmission line. TJBTB (Transmisi Jawa Bagian Timur dan Bali) conditions before the installation of UPFC (Unified Power Flow Controller), the power supply received by the load is not 100% obtained from plants in the region, for example the Paiton power plant. In this research, the method used is with the help of MATLAB R2014a simulation by designing a 500 kV transmission system configuration and the placement of the UPFC found in regional IV namely East Java - Bali. From the simulation results, showing that there was a change in power flow when placing the UPFC. The right location is the West Surabaya - Gresik channel. On the Ngimbang bus there is a change in active power which before using UPFC by 1612 MW to 2208 MW after using UPFC, an increase in active power was 36.97%. The UPFC can fulfill all these functions and thereby meet multiple control objectives by adding the injected voltage with appropriate amplitude and phase angle, to the terminal voltage v.

1. Introduction

The growth in industry and population in Indonesia has led be increasing the demand for electricity energy [1,2]. This can indeed be fulfilled by adding a power plant and increasing the power transmission capacity [1,3,4]. To increase the capacity of electric power transmission is doing by building new transmission lines, it requires high investment costs and creates problem which difficult to get the solution [1]. In initial conditions, the whole system is in normal condition and the whole load is supplied by power through the transmission line [4-6]. But when the load situation has changes, the system will be imbalance so it makes the power supply to work.

The process of distributing power from the generator reaches the load before the installation of UPFC the power will flow from one substation to the other through transmission line [3,5]. The load requirements will be required by the power plant, but when there is an increase in load while there is get voltage collapse, the power supply will not flow fully the load and must taking the power from other plant but will get high losses [2,3].

Therefore, it needs a device that can perform a voltage correction profile on line so that power will flow through transmission line. So, the amount of power flow or power transferred to the load will be supplied properly without having to pass through other line.
The value of power which flow from the transmission line with total transfer capability less existing transmission commitment, less a transmission reliability margin is called **Available Transfer Capability** (ATC) [3]. By using this tool, voltage stability will be maintained and active power and reactive power can be adjusted so that the power supply to the load will be sufficient. This research is purpose to know about using UPFC on transmission system that make different analysis power of electricity.

2. Methods

2.1. Power flow calculation

Power flow calculation is a very important tool to determine the operating conditions of the system [5,7]. Power calculations at voltage, current, and power factor at various nodes of an electrical network are carried out under normal operating conditions [4,7,8]. The result of power flow calculation is used to make simulation the condition with big distraction, transient stability, as well as analysis of contingency, analysis with conditions where the half of component system disconnect to system. The network consists of several nodes/buses and branches whose impedance is expressed in per – unit (p.u) at the base Mega voltamper (MVA) [9,10]. There are four parameters that using on every bus, voltage, phase angle, active power, and reactive power. The use of UPFC on the transmission line can adjust the phase angle to get changes in the flow of active power and reactive power [4-6]. Basically, UPFC is a power flow controller device in transmission network system. Figure 1 shows a simple power system consisting of two terminals (bus). The system consists of voltage source ($E_s$), line impedance ($Z_{LN}$), and load impedance ($Z_{LD}$). It presents a radial system in the power system that transmits power from the generator to the load side through a conductor [10,11].

![Figure 1. Representation radial electric power system [11].](image)

The criteria that state the power system has voltage stability is that under certain operating conditions in the system, the voltage on a particular bus will get increasing in voltage when reactive power is injected on the same bus [11,12]. Meanwhile, the system voltage is unstable if at least one of the buses in the power system will get decreasing in voltage when applied reactive power to the same bus [8,13]. Thus, the electric power system has a proportional relationship between the reactive power (Q) and the bus voltage (V) when the system has voltage stability. The current (I) flowing in the system is formulated by the equation.

\[
\tilde{I} = \frac{\tilde{E}_s}{\tilde{Z}_{LN} + \tilde{Z}_{LD}} 
\]

With stating that,

\[
\tilde{Z}_{LN} = Z_{LN} \angle \theta \text{ and } \tilde{Z}_{LD} = Z_{LD} \angle \phi 
\]

So the current magnitude is,

\[
I = \frac{E_s}{\sqrt{(Z_{LN} \cos \theta + Z_{LD} \cos \phi)^2 + (Z_{LN} \sin \theta + Z_{LD} \sin \phi)^2}}
\]
or

\[ I = \frac{E_s}{\sqrt{F}} \frac{E_s}{Z_{LN}} \]  

(3)

Voltage magnitude on receiver side is,

\[ V_R = Z_{LD} I = \frac{1}{\sqrt{F}} \frac{Z_{LD}}{Z_{LN}} E_s \]  

(4)

Power who supplied to the load is,

\[ P_R = V_R I \cos \emptyset = \frac{Z_{LD}}{F} \left( \frac{E_s}{Z_{LN}} \right)^2 \cos \emptyset \]  

(5)

\[ Q_R = V_R I \sin \emptyset = \frac{Z_{LD}}{F} \left( \frac{E_s}{Z_{LN}} \right)^2 \sin \emptyset \]  

Where,

\[ F = 1 + \left( \frac{Z_{LD}}{Z_{LN}} \right)^2 + 2 \left( \frac{Z_{LD}}{Z_{LN}} \right) \cos(\theta - \emptyset) \]  

(6)

2.2. Unified Power Flow Controller (UPFC)

According to Gyugyi, the basic structure of the UPFC consists of Voltage Sourced Converters (VSC), which are connected to a common DC link via a DC storage capacitor [11]. Each converter is connected to the system via a coupling transformer. Converter 1 is connecting parallel with line transmission through shunt transformer (Boosting Transformer) and known as STATCOM. Meanwhile converter 2 is connected series with line transmission through series transformer (Exciting Transformer) and known as SSSC [4]. Figure 2 shows a schematic of the device UPFC who consists of converter 1, STATCOM and converter 2, SSSC and connecting by DC link capacitor [11-13].

![Figure 2. UPFC Circuit](image)

![Figure 3. UPFC working principal](image)
From figure 3, will get an equation that becomes the basic or working principle of the UPFC. Figure 3 is the basic principle of the UPFC before using UPFC the equation obtained is:

\[ P = \frac{V_1 \times V_3 \times \sin\delta}{X} \]  \hspace{1cm} (7)

\[ Q = \frac{V_1 \left(V_1 - V_3 \cos\delta\right)}{X} \]  \hspace{1cm} (8)

At the active power and reactive power above before the installation of UPFC, the Voltage \( V_1 \) is the terminal voltage or is a reference, seen in equations 7 and 8. Then when the UPFC is installed, there.

\[ V_2 = V_1 + \Delta V \] \hspace{1cm} (9)

\[ P = \frac{V_2 \times V_3 \times \sin\delta}{X} \] \hspace{1cm} (10)

\[ Q = \frac{V_2 \left(V_2 - V_3 \cos\delta\right)}{X} \] \hspace{1cm} (11)

### 3. Results and discussions

When running a usage simulation against UPFC, first simulate a system when not using UPFC. After doing simulation, the initial results of the simulation are obtained before using UPFC. The purpose of the power flow simulation is to find the power flow on each bus, because in the Java–Bali system there are 31 buses, it will show the flow of power on the 31 buses before the installation of UPFC.

#### Table 1. Power flow without UPFC on bus 1 until bus 9.

| No Bus | Bus Name       | Active Power (MW) | Reactive Power (Mvar) |
|--------|----------------|-------------------|-----------------------|
| 1      | Grati          | 43.84             | -1106                 |
| 2      | Gresik         | -1106             | -365.4                |
| 3      | Paiton         | -196.9            | 1461                  |
| 4      | Kediri         | 4171              | 4416                  |
| 5      | Surabaya Barat | 97.61             | 154.9                 |
| 6      | Ngimbang       | 1612              | 1617                  |
| 7      | Tanjung Jati   | -163.9            | -735.3                |
| 8      | Pedan          | 15.33             | -1251                 |
| 9      | Ungaran        | 89.21             | -235.8                |

Table 1 shows the power flow on each bus, where there is also a negative sign which indicates that the flow of power is returning to the plant, this happens because the power supply is also needed in order to operate the power plant. While the positive value of power indicates that 100 % of the power flows towards the electric load, meaning that all loads can be supplied with power properly.

3.1. Placement Unified Power Flow Controller (UPFC)

After the simulation, the placement of UPFC on the West Surabaya – Gresik bus shows a very positive effect which is shown from the improvement in the stress profile on the West Surabaya – Gresik Bus. However, the placement of UPFC on this channel an also improve the voltage profile on other buses and also improve the active power that becomes the supply to the load.

The following shows the power flow where the UPFC is installed on the West Surabaya – Gresik channel and is injected with varying power, namely 0.5 pu, 1 pu, 2 pu.
Table 2. Data power flow Surabaya Barat – Gresik with UPFC installed 0.5 pu.

| No | Bus Name   | Active Power (MW) | Reactive Power (Mvar) |
|----|------------|-------------------|-----------------------|
| 1  | Grati      | -126              | -240                  |
| 2  | vrf        | -830.2            | 438.2                 |
| 3  | Paiton     | -232              | 2662                  |
| 4  | Kediri     | 6139              | -112                  |
| 5  | Surabaya Barat | -62.29          | 3110                  |
| 6  | Ngimbang   | 2208              | 115.8                 |
| 7  | Tanjung Jati | 169.6            | 858.5                 |
| 8  | Pedan      | 261.1             | -36.82                |
| 9  | Ungaran    | -261.3            | 2618                  |

From the simulations performed, the transformer voltage magnitude is 0.103 pu and the voltage phase angle is 135 deg. In the power flow, it can be seen in table 2 that there is a negative sign, it indicates that the flow of power is opposite, meaning that the substation bus release energy, for example on the Ungaran bus the amount of active power released is 62.29 MW. And the graph can be seen in Figure 4, the blue sign is the one that has used UPFC and the orange sign is before placing UPFC on the transmission line.

![Figure 4. Line active power Surabaya Barat – Gresik with and without UPFC installed 0.5 pu.](image)

From the simulation results carried out through 7 scenarios, it shows a change in power flow, namely the active power and reactive power on the bus. It means that the placement of UPFC has a very significant impact on the flow of power in the transmission network system, especially in region 4, namely East Java and Bali.

This research has been doing before. From Uninsula Electrical Engineering thesis conducted by Mukhtar Hadi under the title Influence of UPFC Placement on Stability of Semarang City 150 kV Transmission System with Matlab Simulation [14]. From research Electrical Engineering Dept. of Electrical & Electronics Engineering Scope College of Engineering Bhopal India conducted by Kunal Gupta, et al discussing "Available Transfer Capability Enhancement By UPFC" describes the placement of UPFC in 5 bus system and obtained by UPFC improves power flow so that ATC value also increased and losses - losses on transmission lines of low value [15].

Through simulation shows an increase and decrease in both active and reactive power on each bus. This happens due to the stress injection carried out by the UPFC on the line that is experiencing stress collapse. On the West Surabaya - Gresik channel, the active power increases from the resulting data. The results of the data obtained, on the Grati bus there was an increase from 43.84 MW to 162 MW,
here it is seen that there is a change in the flow of active power 100% and has increased, this indicates that the placement of UPFC on the channel has resulted in positive changes in UPFC.

There is also a bus. In addition, there is a change in active power, which before using UPFC is 1612 MW to 2208 MW after using UPFC, there is an increase in active power by 36.97%. So, in the end there is an increase in certain buses, if the voltage on the busbar increases, the reactive power also increases.

The definition of Available Transfer Capability is to measure the goodness of the interconnection system of a network, the reliability of a transmission system is an important parameter for increasing ATC. In this study, there is a change in power flow where the active power and reactive power increase so that it can be said that ATC also increases when installing UPFC. This research has a different something than the other research which doing before. Because the bus who using in installed UPFC is many buses than other research. So, we can get a good value or percentage of the power flow after installed UPFC.

4. Conclusion
Placement of the UPFC in the 500 KV transmission line system in the eastern part of Java – Bali, which is rightly placed on the West Surabaya – Gresik Line and The Ngimbang bus increases to 2208 MW from 1612 MW without UPFC, meaning an increase of 36.97%. It means that the operation of the Unified Power Flow Controller from the standpoint of conventional power transmission based on reactive shunt compensation, series compensation, and phase shifting, the UPFC can fulfill all these functions and thereby meet multiple control objectives by adding the injected voltage with appropriate amplitude and phase angle, to the terminal voltage v.

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