

A Comprehensive Review on Power Flow Controller Devices in Transmission Line

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Abstract—This paper will review about power flow controller which is one of the Flexible AC Transmission System (FACTS) devices. FACTS devices is being used to increase the power transfer capability of transmission system and to regulate power flow over transmission line. Besides that, FACTS devices also being used in minimizing power losses in transmission system. The power flow controller devices being used in controlling power flow in a transmission system, to increase the transmission capacity, regulating the voltage and optimizing the stability of the transmission system. By using the power flow controller devices, it will prevent from a transmission line to be overloaded. There are a few types of power flow controllers being used nowadays such as Unified Power Flow Controller, Interline Power Flow Controller, SMART Power Flow Controller, Dynamic Unified Power Flow Controller, and last but not least which is a hybrid type of power flow controller is Interline Unified Power Flow Controller which is a combination of unified and interline design of power flow controller. For this paper, the content will focus on two types of power flow controller which are Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) because these two controllers are being widely used in the transmission system. The reasons of choosing UPFC and IPFC are because of the simplest connection yet most efficient devices to use among FACTS devices to improve the power system stability in the transmission system. As transmission system has a single line or multi-line system, these both controllers will play their role in controlling each system. For UPFC, it will control the single line system. If there is a multi-line system, it is inefficient to use UPFC as the devices need to be placed on each line and it will increase the costing. Therefore, IPFC can be used as the function is to control multi-line transmission system. This paper will review these two controllers in terms of their functions, operations and advantages for using the controllers in transmission system.

Index Terms—Flexible AC Transmission System (FACTS); Unified Power Flow Controller (UPFC); Interline Power Flow Controller (IPFC); Voltage Source Converter (VSC); Static Synchronous Compensator (SSSC); Static Compensator (STATCOM); Interline Unified Power Flow Controller (IUPFC).

I. INTRODUCTION

In future, the growth of power system demand will cause the transmission system to increase the capability of existing transmission system rather than building another transmission system as it is in economic and environmental view. FACTS devices can increase the capability of transmission line in order to improve power flow when there is increasing in the load demand. The advantage in using FACTS devices in

transmission system is because of it has independent control characteristics. Independent control of power flow as power flow controller offers leads to the reduction of reactive power flow in a transmission line. Power flow controller can compensate the reactive power flow and will supply more real power to the transmission line. It will also affecting the losses in generators, transformers and transmission lines, which all of these will increase the system efficiency. The concept of independent control of power also can allow the transmission lines to carry more active power by freeing up the generators, transformers and transmission lines. It also can prevent from any grid congestion by redirecting excess power flow from an overloaded line to under loaded lines, instead of tripping the overloaded line when power is needed the most [1]. This independent control in power flow will increase the capability and efficiency of one transmission system without have to construct another transmission line when there is increasing in load demand. If to construct a new power plants due to high demands, there are various reasons to explain the inconvenient of this option which are regulatory, environmental issues and public policies. And it is due to limited energy resources, deregulated electricity market, environmental constraints, time and capital required to build new transmission systems [2]. FACTS is being used to enhance the functionality of the AC transmission grid. The main objective of using power flow controller is to maintain balance of power flow in each transmission line so that every transmission lines will receive sufficient amount of power to be supply following the load demand. The basic power flow equations for the operations as stated below.

$$S_i^* = V_i^* I_i \quad (1)$$

where: S = Apparent Power
V = Voltage of a Particular Bus
I = Current in the Transmission Line

From Equation (1), the active and reactive power flow equations can be derived as below:

$$P_i = \sum_{j=1}^n V_i V_j Y_{ij} \cos(\delta_i - \delta_j + \theta_{ij}) \quad (2)$$

$$Q_i = \sum_{j=1}^n V_i V_j Y_{ij} \sin(\delta_i - \delta_j + \theta_{ij}) \quad (3)$$

where: $V_i = V_i e^{j\theta_i}$ = Voltage at bus i
 $V_j = V_j e^{j\theta_j}$ = Voltage at bus j
 $Y_{ij} = Y_{ij} e^{-j\theta_{ij}}$ = Admittance for the Transmission Line i-j

The basic power flow equations are applicable for each power flow controller as this is the basic equations that can be used in controlling power flow for each controller.

II. UNIFIED POWER FLOW CONTROLLER (UPFC)

A. Functions of UPFC

Unified Power Flow Controller (UPFC) is one of the FACTS devices that being widely used to control the power flow on a transmission line. UPFC has effectively increased the power flow capability in power system with the minimization of power losses [2] and also improving the bus voltage including the magnitude and angle. UPFC can enforce the unnatural power flows in a transmission system, to maximize the power flow while maintaining stability of the system. This device is only valid to control the power flow in the single transmission line as if it being used in a multi transmission line, it will increase the costing as the device has to be placed at each line in transmission system. As being used in Qatar Transmission System, UPFC role is to maintain balance of power flow between the networks or lines that supply to this weaker region of QTS. And in turn support network security should the demand in this region grows [3]. UPFC contribute to reactive power compensation in a transmission system. It offers in regulating the voltage, series and shunt compensation, regulating the phase angle and last but not least to control the real and reactive power independently at sending end and receiving end of a transmission line. In addition, UPFC can control the power flow between transmitted lines, increase transmission capacity and optimize the stability of the system. The stability that can be controlled by UPFC including the ability to maintain the machines connected to the system in synchronism as the disturbances always happen in a transmission system sudden reduction or removal of load, short circuits of lines and lighting [4]. UPFC as stated can reroute the power flow from overloaded line to under loaded line to prevent grid congestion from happen and can affect the stability of the system. Therefore, the other characteristic of UPFC is that UPFC can control power system networks parameters which are line impedance, phase angle and voltage magnitude. That is why when UPFC being used in transmission line, the power flow can be reroute as the power flow will choose the least impedance path. UPFC will control the line impedance and make the power flow being rerouted.

B. Basic Operation of UPFC

Unified Power Flow Controller (UPFC) can helps in improving the efficiency of the transmission system, improving the stability and can help rerouting the power flow from one transmission line to the other transmission line. When there is a power congestion in one transmission line, UPFC will act as the router to reroute the excess power flow from a transmission line to the other transmission line that has

less power. The power flow will choose a least impedance path in transmission line. There is a system applied in the UPFC. The systems are called classical parallel-filters that can control active and reactive power transmitted to the line. Parallel filters in the system can maintain the voltage value to be constant while series filters has to inject controllable voltage that comes with angle and magnitude and this way can control the power flow. Besides that, reviewing on the external system of UPFC which can complete the power flow controller system, there is an external control to the UPFC which describes the set points of the power system in aspect of steady state or dynamic state. The external control having two parts which are master middle control. Master control roles is handling the targets such as optimal power system set point, increase of transient stability, or sub-synchronous resonance dampening and delivers the middle control set points. Middle controls translates these master set points into set points for the series and shunt converter [5]. For the connection of UPFC, it is connected to the transmission system via coupling transformer. The connection of UPFC is shown in Figure 1. For the inner connection of the UPFC, it has two ac/dc converters which the ac sides being connected to shunt, the series connection connected directly to transmission line, the converters are connected back-to-back. Besides that, UPFC is built with the Voltage Source Converters (VSC) which has capacitor that acted as limited dc energy storage.

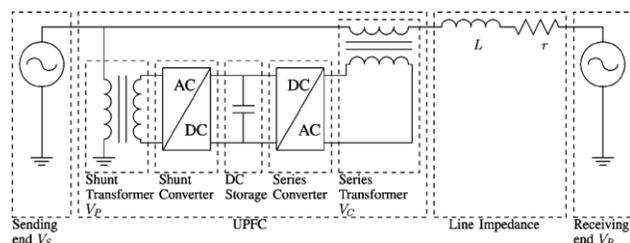


Figure 1: One-wire schematic of the transmission line with UPFC [5]

UPFC itself consists of two VSCs. One of the VSC is connected in shunt at one point in a line and the other VSC is being connected in series which both of them are link through back-to-back DC capacitor which is a DC Link. This connection can allow the real power to be circulated between the converters. To control the real and reactive power at the bus using series compensator, the magnitude and the phase angle of injected voltage has to be changed. Shunt VSC is considered as STATCOM and the series VSC is SSSC. Shunt converter function in the UPFC is by maintaining the line voltage at the reference value by providing or absorbing the real and reactive power in transmission line. Besides that, it will also control the UPFC bus voltage, shunt reactive power and DC link capacitor voltage [6]. On the other hand, for series converter, it can control the transmission line's real and reactive power flows by applying the series voltage which can adjust the magnitude and angle. The line current flows through the series compensator, resulting in an exchange of real and reactive power between the unified power flow controller and the transmission systems. The shunt controller supplies or absorbs the real power at DC link and simultaneously generates or absorbs the reactive power, and provide the

voltage control at the bus [7] also provide the dynamic reactive power support in the transmission system. In addition, the voltage that being injected by UPFC also providing the voltage regulation at the bus.

STATCOM as the shunt converter can be operated in two modes which are Volt-Ampere Reactive (VAR) Control and Automatic Voltage Control mode. The reactive current reference in the VAR control mode can be determined by the inductive or capacitive VAR demand. Besides that, in Automatic Voltage Control mode, the reactive current reference is determined by feedback voltage controller output. For the SSSC as the series converter, it can operate in power flow control (automatic mode) or else in manual voltage injection mode. This is when the real and reactive power errors can be identified by measuring the active and reactive power and compared with reference values. In automatic mode, the converter are being used while for manual mode, the converter are not used. In manual mode, the reference values of injected voltage is being used to replace the converter voltage. There are two conditions while operating the series and shunt converter in the UPFC which are steady state and transient state conditions. During under steady state conditions, shunt converter will supply the real power demand of series converter. On the other hand, when there is transient condition, the series converter real power demand is supplies by the dc link capacitor [6].

UPFC can control power system networks parameters which are line impedance, phase angle and voltage magnitude. That is why when UPFC being used in transmission line, the power flow can be reroute as the power flow will choose the least impedance path, UPFC will control the line impedance and make the power flow being rerouted. But, when using UPFC in a transmission line to give the efficient transmission line operation, there must be slightly error in the system or an overshoot will happen. Overshoot is when there is an extra power flow which sometimes can cause tripping in a system as it is consider as overloaded power flow which usually cause tripping and make the system unstable. Direct power control technique can be applied to benefit the UPFC in the fast dynamic control behaviour without overshoot. Direct power control is readily adaptable to other converter type so that it is an effective method that can be used with UPFC. Therefore, the overshoot problem can overcome to prevent the instability of the system. From most technical papers which reviewed about UPFC, this device can increase the real power flow in the transmission line and reactive power will experienced in decrement.

III. INTERLINE POWER FLOW CONTROLLER (IPFC)

A. Functions of IPFC

Interline Power Flow Controller (IPFC) is one of the FACTS devices that is being used widely in multilines or parallel transmission line. IPFC controls the power flow in the parallel and multi transmission lines within the same corridor of the transmission line [8]. Basically, IPFC and UPFC have the same function which are to maintain the stability of transmission system, increase the capability of the system to transfer power flow and to increase the efficiency of the power system in order to save the cost and environment. In this

paper, the basic operation of IPFC will be explained and the differences between IPFC and UPFC can be determined.

B. Basic Operation of IPFC

For IPFC, there are two or more than two of series compensator which is SSSC that combined together. In IPFC, there are two scheme being used in the operation principle. The schemes are Special Control Scheme and General Control Scheme. For Special Control Scheme, this scheme solve the power flow control in the transmission system that has two identical parallel lines. Besides that, for General Control Scheme, it will solve the problem involving multi line transmission system in the power flow control. As the FACTS devices function is to maximize the power transfer capability on transmission line, the IPFC device is one of the device that plays a role in this situation. The schemes is suitable to use in IPFC as IPFC can be used in parallel and multiline transmission system. As IPFC also using series and shunt converter that combined together, it has the capability to control both real and reactive power flow in transmission line. Real power flow on transmission line can be enhanced by compensating the reactive power on transmission line by using FACTS controller. Reactive power in a system should be reduced and the real power should be improved so that a power system will have a quality power flow to fulfil the load demand. Transfer capability of power flow in the transmission line can be increased or decreased by adjusting one of the transmission line parameters which are magnitude of voltage at the end of the lines, transmission line reactance and phase angle between bus voltage and currents.

In the operation of IPFC, SSSC provides the series compensation by injecting the voltage in series with transmission line. While for STATCOM in IPFC, it provides the shunt compensation by injecting the current in parallel with transmission line [9]. Shunt converter in IPFC controls the AC voltage at other transmission line and regulate the voltage at DC bus. The phase relationship that being used in the IPFC device, the converter can be operated in either inductive or capacitive mode. Inductive mode is when the current lags voltage while the capacitive mode is when current leads voltage. The differences between UPFC and IPFC is that in IPFC the active power demand of one series inverter is compensated by another series inverter while in UPFC the active power demand of the series converter was supplied by the shunt devices [8]. Figure 2 shows the model of IPFC. This shows that the inverter in IPFC can control the power supply to the common DC link from its own transmission line. From this configuration, the power flow can be controlled from overloaded to under loaded line, and there will be no more grid congestion in the system. Figure 2 shows the schematic diagram of IPFC. As shown in Figure 2, for IPFC there are two SSSC in the configuration. These two SSSC acted as different roles, one of the SSSC acted as master and the other one is slave. The master and slaved inverters are represented by voltage sources V_{s1} and V_{s2} respectively [10]. This diagram is the simplest IPFC which consist of two back-to-back DC to AC converter which is SSSC, where these two being connected in series through series coupling transformers. The two SSSC is being connected via common DC link. With this IPFC, in addition to providing series

reactive compensation, any converter can be controlled to supply real power to the common DC link from its own transmission line [10].

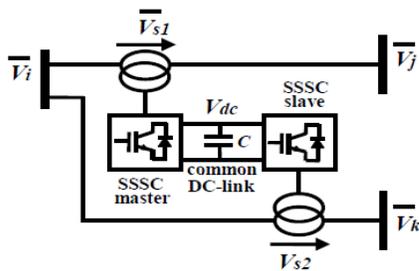


Figure 2: Schematic diagram of IPFC [10]

Besides IPFC, there is an improved device such as IUPFC which is to provide quality power supply. The benefits of IUPFC is to improve the power flow on a transmission line and regulate the bus voltage in the transmission line of power system. The advantage of using this power flow controller is because the controller does not need additional coupling transformer. The combination in using IUPFC with SSSC in the system is that they are capable of operating in capacitive and inductive mode. As the IUPFC required two or more than two SSSC in the system, therefore it is adaptive for them to work together in improving system efficiency and capability. In the IUPFC, SSSC will provide the reactive power compensation to the individual line where is connected and then it is capable to transfer the power from overloaded to under loaded power line. IUPFC is being able to control power flow in multi transmission line. IPFC also can increase the real power flow in the transmission line to provide the quality power flow in the transmission line, and causing the reactive power to have decrement.

IV. CONCLUSION

FACTS controller devices is important in improving the quality of power flow in the transmission system. As FACTS devices has been using widely in transmission system, a lot of improved models of power flow controller being invented day by day. The improved power flow controller will have a new improvement and will be doing it as future works. Based on the review done on many technical papers about power flow controller, it is proved that power flow controller such as UPFC and IPFC can improved the power quality of transmission system. Besides that, the problem to reroute the excess power on one transmission line had been solved by using the UPFC for single transmission line and IPFC for multi transmission line. FACTS controller can reroute the excess power flow from overloaded line to under loaded line whereas the power flow will choose the lease impedance path with some helps from converter in the power flow controller devices. This can improve the grid congestion that happened in transmission system and usually causing tripping and will

reduce the efficiency of power system.

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