ADBU-Journal of Engineering Technology

Study of Power Flow Control Using FACTS Devices

Lari Kupar Lyngdoh[1], Jesif Ahmed[2]

[1,2]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati - 781017, Assam, INDIA.
*[1]larikuparlyngdoh@gmail.com, [2]jesif.ahmed@dbuniversity.ac.in**

Abstract: ***With most of the countries on the threshold of industrialization the demand for electrical power also continues to increase steadily and is predominantly strong. Moreover, because the transmission systems are operated near to their thermal and stability limits, the chief challenge for the power industry is to supply electrical power to match the demands of the consumers with the minimum amount of losses while maintaining adequate power quality level. For various reasons, newly installed transmission lines are unable to cope up with the growing power generation. This paper presents the ideas of using FACTS devices for enhanced operation and more effective usage and control of the existing transmission network framework. Comparison has been done using MATLAB Simulink for power flows of IEEE 9 bus system without and with FACTS devices. The development of Flexible AC Transmission Systems, or FACTS based on high power electronics, offers a powerful means of meeting the challenges.***

Keywords: Power Flow, FACTS devices, SSSC, UPFC, IEEE-9 bus system, MATLAB Simulink.

(Article history: Received: 21 September 2017 and accepted: April 21 2018)

1. Introduction

In a three phase ac power system active and reactive power flows from the generating station, through different networks buses and branches and then to the load. The flow of active and reactive power is called power flow or load flow. Power flow studies give a systematic mathematical approach for determination of various bus voltages, their phase angles, active and reactive power flows through different network branches, generations and demands under steady state condition. It is used to evaluate the steady-state operating condition of a power system. Therefore, in a power distribution system power flow analysis is important and widely used during the planning and operation of the system.

The power flow study is done to obtain complete information about voltage magnitude and its associated angle for every bus in a power system for specified real power and voltage conditions of load and generator. Once this information is available, real and reactive power flowing on each branch, as well as generator output can be analytically determined.

In general, a large scale power system possesses multiple objectives to be achieved. The ideal power system operation is achieved when various objectives likes, cost of generation, transmission loss, environmental pollution, etc. are simultaneously attained with minimum values. Since these operations are conflicting in nature, it is impossible to achieve the ideal power system operation. These objectives cannot be handled by single objective optimization. Here formulation of multi-objective optimal power flow problem is given.

Since the equations describing the power system are inherently non-linear in nature, it is only through non-linear programming techniques that the economic dispatch aspect of the system can be studied accurately.

The reactive power service is required for transmission of active power, control of voltage, a normal and secure operation of a power system. As a result of this, the reactive power support service is identified as one of the key services in the amount of power being used, or dissipated, in a circuit is called true or real power. Reactive loads such as inductors and capacitors consume zero power, yet with their presence, there is a drop in the voltage and they draw current giving the deceptive impression that they actually dissipated power. The reactive power flows between the source and the reactor or capacitor at a particular frequency which is equal to twice the rated value. The power consumed by a load is referred to as true power whereas the power only absorbed and returned in load because of its reactive properties is termed as reactive power. Anyhow, in practice, most of the loads are inductive loads in nature, absorbs reactive power and thereby resulting in low lagging power factor.

2. FACTS devices for Power Flow Control

2.1 Static Synchronous Series Compensator (SSSC):

It is a member of FACTS family which is connected in series with a power system. SSSC is one of the most crucial and well known FACTS controller and it is a voltage-sourced converter-based series compensator which is used for series compensation of power. SSSC controllers are the third generation FACTS controller devices. It is a solid state voltage source inverter or voltage source converter, which injects a variable magnitude sinusoidal voltage, in series with the transmission line. The basic SSSC diagram is shown in figure 1. The capacitor connected in series as shown, balances the inductive reactance of the transmission line. The line current is in quadrature with the SSSC output voltage. The voltage drop across the series capacitor is –

jX_CI (where X_C is the capacitive reactance of the series capacitor) and voltage drop across line inductance (X_L) is + jX_LI which cancels each other out thus reducing the effect of line inductance. Due to this, power transfer capability is increased .The basic configuration of SSSC with voltage source converter is shown in figure 2. The SSSC works as a series inductor and controllable series capacitor. It is also necessary to know that SSSC's injected voltage has no relation with the line intensity and can be managed independently. For this feature, SSSC operates satisfactorily with low loads as well as high loads. The SSSC has several advantages over the SVC and STATCOM that are as follows[12]:

- It has improved technical characteristics.
- It has symmetrical capability in both capacitive and inductive operating mode.
- It offers possibility of connecting an energy source on the DC side to exchange real power with the AC network.

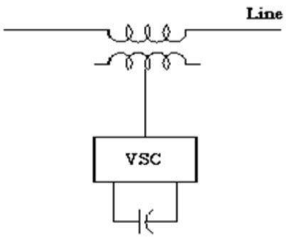

Fig. 1: Series Connected SSSC

SSSC has three basic components:

- VSC (Voltage Source Converter): This is the main component.
- Transformer: Coupled the transmission line and SSSC.
- Energy source: used for compensating device losses and providing a voltage across the dc capacitor.

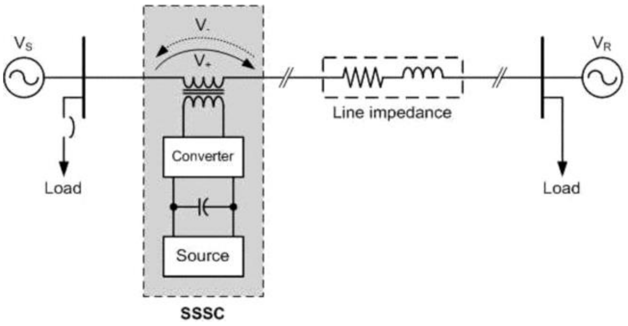

Fig. 2: Schematic Diagram of SSSC

2.2 Unified Power Flow Controller (UPFC):

It is an electrical device used for providing fast-acting reactive power compensation on high-voltage power transmission networks. It consists of a pair of three-phase voltage-sourced converters to produce a current which is injected into transmission line with the help of a series transformer. The converter can control active power which freely flows in either direction between the ac terminals of the two converters, and each converter can independently generate reactive power at its own ac output terminal. UPFC is a second generation FACTS device that can simultaneously control different power system parameters like transmission voltage, impedance and phase angle. The UPFC is composed of a pair of Voltage-Sourced Converters (VSC) one of which is connected in series which acts as Static synchronous series compensator (SSSC) and the other one in shunt which acts as Static synchronous compensator (STATCOM) with the transmission line. UPFC combines the unique features of these series and shunt compensation. The two inverters are coupled with a common DC link capacitor. The series inverter, acting as SSSC, controls the main functionality by injecting an AC voltage with controllable magnitude and phase. This injected voltage frequency is equal to that of the power line frequency. It serves as a synchronous voltage source. The complete single line diagram of a UPFC is shown in figure 3.

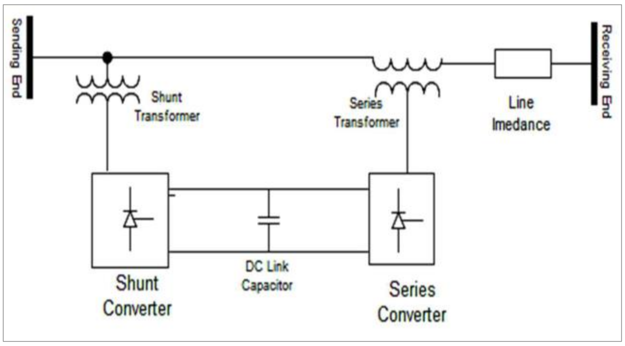

Fig 3: Single Line Diagram of Unified Power Flow Controller

2.2.1 Control Modes of UPFC

UPFC works with various operating modes. Both the voltage source inverters can operate independently with respect to one another by isolation of the dc part. The shunt converter working as STATCOM, injects a controllable current into the transmission line. The series converter, working as SSSC, injects a voltage of controllable amplitude and phase angle in series with the transmission line. Thereby the power flow through the transmission line is controlled.

The shunt inverter is driven by two operating modes[13]:

a) **Volt-Ampere Reactive Control Mode:**
Volt-Ampere Reactive (VAR) is a reference setting. The control samples set the converter gate to produce required current. Also DC feedback is required in this mode.

b) **Automatic Voltage Control Mode:**
The shunt reactive current is maintained automatically for regulating the transmission line voltages at a connection point to a preset quantity. Voltage feedback signal from the sending end bus to feeds the shunt transformer.

The series inverter is driven by four operating modes:

a) **Direct Voltage Injection Mode:** The reference inputs are directly injected to magnitude of series voltage phase angle.
b) **Phase Angle Shifter Emulation Mode:** The reference input is phase displacement among sending and receiving end voltages.
c) **Line Impedance Emulation Mode:** An impedance preset value is set as the reference input by inserting in series with the line impedance.
d) **Automatic Power Flow Control Mode:** The preset values of active power and reactive power are the reference inputs for maintaining the parameters of transmission line irrespective of changes in system.

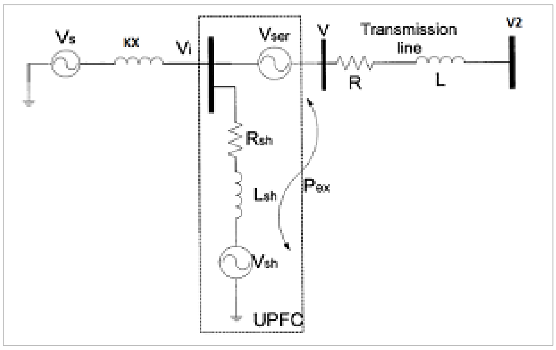

Fig. 4: A simple transmission system including UPFC

2.2.2 Control Strategy for UPFC

UPFC uses two types of strategies for voltage and power flow control, one at a time.

A. Shunt Converter Control Strategy

In this strategy, the shunt converter of the UPFC controls the UPFC bus voltage, shunt reactive power and the dc link capacitor voltage. In this case, the shunt converter voltage is decomposed into two components. One component is in quadrature and the other is in phase with the UPFC bus voltage. The de-coupled control system has been employed to achieve simultaneous control of the UPFC bus voltage and the dc link capacitor voltage.

B. Series Converter Control Strategy

In this second strategy, the series converter of the UPFC provides control of real and reactive power flow simultaneously in the transmission line. The series converter's injected voltage is decomposed into two components. One component of the series injected voltage is in phase and the other is in quadrature with the UPFC bus voltage. The quadrature injected component controls the real power flow in the transmission line. This strategy is similar to that of a phase shifter. The in-phase component controls the reactive power flow in the transmission line and is similar to that of a tap changer.

3. Power Flow through Transmission Line

The transmission line performance equation was always presented in the form of voltage and current relationships between sending-end and receiving-end. But loads are more often expressed in terms of real (watts/kW) and reactive (VARs/kVAR) power, hence it is convenient to deal with transmission line equation in the form of sending-end and receiving-end complex power and voltages. The complex power leaving the sending-end and entering the receiving-end of the transmission line can be expressed as:

$$S_S = P_S + j\,Q_S = V_S I_S^* \tag{1}$$

$$S_R = P_R + j\,Q_R = V_R I_R^* \tag{2}$$

Where,

$$P_S = \frac{|V_S|^2}{|Z|}\cos\theta - \frac{|V_S||V_R|}{|Z|}\cos(\theta+\delta) \tag{3}$$

$$Q_S = \frac{|V_S|^2}{|Z|}\sin\theta - \frac{|V_S||V_R|}{|Z|}\sin(\theta+\delta) \tag{4}$$

And,

$$P_R = \frac{|V_S||V_R|}{|Z|}\cos(\theta-\delta) - \frac{|V_R|^2}{|Z|}\cos\theta \tag{5}$$

$$Q_R = \frac{|V_S||V_R|}{|Z|}\sin(\theta-\delta) - \frac{|V_R|^2}{|Z|}\sin\theta \tag{6}$$

4. Methods for Power Flow Optimization

The optimal power flow solution methods are classified into two categories:

i. **Traditional Method:** Traditional methods are called conventional or deterministic optimization methods. The application of these methods provides an area of active research in the recent past. The conventional methods are based on mathematical programming approaches and used to solve different size of OPF problems. To meet the requirements of different objective functions, types of application and nature of constraints, the popular conventional methods are further subdivided into the following:
   1. Linear Programming
   2. Gradient methods
   3. Quadratic Programming
   4. Newton-Raphson
   5. Nonlinear Programming
   6. Interior Point

ii. **Artificial Intelligent (AI) Method:** The intelligent search has become a very important technique in searching the global or near-global optimal solution. It also called Non-deterministic or stochastic method. Major advantages of this method are:
   1. Able to handle various qualitative constraints.
   2. Can find multiple optimal solutions in single simulation run.
   3. Suitable for solving multi-objective optimization problems.
   4. Can find the global optimum solution.

5. Problem Formulation

The Load flow problem involves the determination of voltage magnitude and its phase angle at each bus and also the active-reactive line flows for specified terminal or bus conditions. Load flow studies are also used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. Conventional techniques for solving the load flow problem are iterative, using the Newton-Raphson or the Gauss Seidel method. Based on the quantities specified for the buses, the buses are classified into three types in load flow studies- load bus/P-Q bus, generator bus/voltage controlled bus/P-V Bus and slack bus/swing bus/reference bus.

Table 1: Type of bus and its variables

Type of bus	*Known Variable*	*Unknown Variable*
Load bus(P-Q)	P, Q	V, δ
Generator Bus (P-V)	P, V	Q, δ
Slack bus(V-δ)	V, δ	P, Q

As we can see from the table, two variables are known at each bus. In Load Bus, real power (P) and reactive power (Q) are known and are injected into the network and voltage magnitude (V) and voltage angle (δ) are unknown. Voltage magnitude and voltage angle are to be calculated in this. In Generator Bus, real power and voltage magnitude are specified. The reactive power and voltage angle are to be determined. Voltage magnitude is kept constant at a specified value by injection of reactive power. These buses are also known as Regulated Buses/ Voltage Controlled Buses. In Slack Bus, voltage magnitude and voltage angle are known and real power and reactive power are to be determined. This Bus makes up the difference between the scheduled load and generator power that are caused by losses in the network. This bus is also known as the Reference Bus. If slack bus is not specified then the generation bus with usually with a maximum active power P is taken as reference bus

6. Development of Load Flow Equation

The nodal current equations for an n-bus system are written below.

$$I_p = \sum_{q=1}^{n} Y_{pq} V_q \qquad (7)$$

$$I_p = Y_{pp} V_p + \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} V_q \qquad (8)$$

$$V_p = \frac{I_p}{Y_{pp}} - \frac{1}{Y_{pp}} \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} V_q \qquad (9)$$

$$V_p^* I_p = P_p - jQ_p \qquad (10)$$

$$I_p = \frac{P_p - jQ_p}{V_p^*} \qquad (11)$$

Substituting for I_p in equation,

$$V_p = \frac{1}{Y_{pp}} \left[\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} V_q \right] \text{, p=1,2,…n} \qquad (12)$$

I_p has been substituted by the real and reactive powers because normally in a power system these quantities are specified.

7. Different Iterative Methods

The equation (12) above is the load flow equation where bus voltages are the variables. It can be seen that the load flow equations are non-linear and they can be solved by an iterative method. The iterative methods are:

i. Gauss's method.
ii. Gauss-Siedel method.
iii. Newton-Raphson method.

8. Comparison of Solution Methods

Since the Gauss-Seidel is undoubtedly superior to Gauss method the comparison is restricted only between GS methods and Newton-Raphson method and that too when Y bus matrix is used for problem formulation. From the viewpoint of computer memory requirements polar coordinates are preferred for solutions based on NR method and rectangular coordinate for the GS method.

The time taken to perform one iteration the computation is relatively smaller in case of GS method as compared to NR method but the number of iterations required by GS method for a particular system are greater as compared to NR method and they increase with the increase in the size of the system .In case of NR method and the number of iteration is more or less independent of the size of the system and vary between 3 to 5 iteration.

The convergence characteristic of NR method are not affected by the selection of a particular bus may result in poor convergence. The main advantage of GS method as compared to NR method is its ease in programming and most efficient use of core memory. Nevertheless, for large power systems NR method is found to be more efficient and practical from the view point of computational time and convergence characteristics. Even though NR method can be solved most of the practical problems it may fail in respect of some ill-condition problems where other advanced mathematical programming techniques like non-linear programming techniques can be used.

9. Newton-Raphson Method

The mathematical background of this method is explained as follows:

Let the unknown variables be (x_1, x_2, …, x_n) and the specified quantities y_1, y_2, …, y_n. These are related by the set of non-linear equation:

$$y_n = f_n(x_1, x_2, \dots, x_n) \qquad (13)$$

If all the equations are linearized and arrange in a matrix form, we have

$$\begin{bmatrix} y_1 - f_1(x_1^0, x_2^0, \dots, x_n^0) \\ \vdots \\ y_n - f_n(x_1^0, x_2^0, \dots, x_n^0) \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \vdots & \vdots & \vdots \\ \frac{\partial f_n}{\partial x_1} & \cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} \Delta x_1^0 \\ \vdots \\ \Delta x_n^0 \end{bmatrix} \qquad (14)$$

$$B = J\,.C \qquad (15)$$

Here J is the first derivative matrix known as the Jacobian matrix. The solution of the equations requires calculation of left hand vector B which is the difference of the specified quantities and calculated quantities at $(x_1^0, x_2^0, \dots., x_n^0)$. Similarly, J is calculated at this guess. Solution of the matrix equation gives $(\Delta x_1^0, \Delta x_2^0, \dots, \Delta x_n^0)$.

When referred to a power system problem (assuming there is only one generator bus which is taken as slack bus and all other buses are load buses), the above set of linearised equations become

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \vdots \\ \Delta P_n \\ \Delta Q_2 \\ \Delta Q_3 \\ \vdots \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial e_2} & \frac{\partial P_2}{\partial e_3} & \cdots & \frac{\partial P_2}{\partial e_n} & \frac{\partial P_2}{\partial f_2} & \frac{\partial P_2}{\partial f_3} & \cdots & \frac{\partial P_2}{\partial f_n} \\ \frac{\partial P_3}{\partial e_2} & \frac{\partial P_3}{\partial e_3} & \cdots & \frac{\partial P_3}{\partial e_n} & \frac{\partial P_3}{\partial f_2} & \frac{\partial P_3}{\partial f_3} & \cdots & \frac{\partial P_3}{\partial f_n} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ \frac{\partial P_n}{\partial e_2} & \frac{\partial P_n}{\partial e_3} & \cdots & \frac{\partial P_n}{\partial e_n} & \frac{\partial P_n}{\partial f_2} & \frac{\partial P_n}{\partial f_3} & \cdots & \frac{\partial P_n}{\partial f_n} \\ \frac{\partial Q_2}{\partial e_2} & \frac{\partial Q_2}{\partial e_3} & \cdots & \frac{\partial Q_2}{\partial e_n} & \frac{\partial Q_2}{\partial f_2} & \frac{\partial Q_2}{\partial f_3} & \cdots & \frac{\partial Q_2}{\partial f_n} \\ \frac{\partial Q_3}{\partial e_2} & \frac{\partial Q_3}{\partial e_3} & \cdots & \frac{\partial Q_3}{\partial e_n} & \frac{\partial Q_3}{\partial f_2} & \frac{\partial Q_3}{\partial f_3} & \cdots & \frac{\partial Q_3}{\partial f_n} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ \frac{\partial Q_n}{\partial e_2} & \frac{\partial Q_n}{\partial e_3} & \cdots & \frac{\partial Q_n}{\partial e_n} & \frac{\partial Q_n}{\partial f_2} & \frac{\partial Q_n}{\partial f_3} & \cdots & \frac{\partial Q_n}{\partial f_n} \end{bmatrix} \begin{bmatrix} \Delta e_2 \\ \Delta e_3 \\ \vdots \\ \Delta e_n \\ \Delta f_2 \\ \Delta f_3 \\ \vdots \\ \Delta f_n \end{bmatrix} \qquad (16)$$

The sequence of steps for the solution of load flow problem using Newton-Raphson method is explained as follows.

1. Assume a suitable solution for all the buses except the slack bus. Let $V_p=1+j0.0$ for p=1,2,…, n, p≠s, $V_s=\alpha+j0.0$.
2. Set convergence criterion = ε i.e., if the largest of absolute of the residues exceeds the process is repeated, otherwise it is terminated.
3. Set iteration count K=0
4. Set bus count p=1
5. Check if p is a slack bus. If yes go to step 10.
6. Calculate the active and reactive powers P_p and Q_p respectively using equations (4.12) and (4.13).
7. Evaluate $\Delta P_p^k + P_{sp} - P_p^k$
8. Check if the bus question is a generator bus. If yes, compare the Q_k^p with the limits. If it exceeds the limit, fix the reactive power generation to the corresponding limit and treat the bus as the load bus for that iteration and go to next step. If the lower limit is violate set $Q_{psp} = Q_{p\,min}$. If the limit is not violated evaluate the voltage residue.
   $$|V_p|^2 = \left|V_p\right|_{spec}^2 - \left|V_p^k\right|^2$$
   and go to step 10.
9. Evaluate $Q_p^k = Q_{ps} - Q_k^p$.
10. Advance the bus count by 1, i.e., p=p+1 and check if all the buses have been accounted. If not go to step 5.
11. Determine the largest of the absolute value of the residue.
12. If the largest of the absolute value of the residue is less than ε, go to step 17.
13. Evaluate elements for Jacobian matrix.
14. Calculate voltage increments $\Delta e_p^k$and Δf_p^k.
15. Calculate the new bus voltages $e_p^{k+1} = e_p^k + \Delta e_p^k$and $f_p^{k+1} = f_p^k + \Delta f_p^k$. Evaluate cosδ and sin δ of all voltages.
16. Advance iteration count K=K+1 and go to step 4.
17. Evaluate bus and line powers.

10. Optimal Location of FACTS Device using Sensitivity Index

The sizing and allocation of FACTS devices constitutes a milestone problem in power system. For this, various methods of location of FACTS controllers are given below. Generally, location of FACTS devices in the power system have obtained based on static and / or dynamic performances. Apart from these there are several methods for finding optimal location of FACTS devices in vertically integrated system as well as unbundled power system. The objective of the series device placement may be reduction in the real power loss of a particular line, reduction in the total system real power loss, reduction in the total system reactive power loss and maximum power transfer in the system. Sensitivity analysis is a widely used terminology to describe the analysis based on the evaluation of the rate of change of one group of variables in a system with respect to another group. There are many different ways to perform the analysis depending on the selected variables and methodologies used to calculate the sensitivities.

Loss sensitivity index is a method based on the sensitivity of total system active and reactive power loss with respect to control variable of the FACTS devices.

Loss sensitivity index with respect to real power is b_{ij} and with respect to reactive power is a_{ij}.

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}}$$

$$b_{ij} = \frac{\partial P_L}{\partial X_{ij}}$$

These factors can computed at a base load flow solution as given below. Consider a line connected between buses i and j and having a net series impedance of Xij and Qi is the net reactive power injected in the bus i. The bus sensitivity index with respect to Xij computed as,

Where,

$$\frac{\partial Q_L}{\partial X_{ij}} = \left[V_i^2 + V_j^2 - 2V_iV_j[\cos(\delta_i - \delta_j)]\right] \frac{r_{ij}^2 - X_{ij}^2}{\left(r_{ij}^2 - X_{ij}^2\right)^2} \tag{17}$$

And,

$$\frac{\partial P_L}{\partial X_{ij}} = \frac{V_iV_j \sin(\delta_i - \delta_j)\left({r_{ij}}^2 + {X_{ij}}^2\right) - 2V_i^2 r_{ij}X_{ij} + 2V_iV_j r_{ij}X_{ij}\cos(\delta_i - \delta_j)}{\left({r_{ij}}^2 + {X_{ij}}^2\right)^2} \tag{18}$$

Here, X_{ij} is the reactance of the line between buses ith and jth.

r_{ij} is the resistance of the line between buses ith and jth.

11. Simulation of IEEE 9 Bus System

An IEEE 9 bus system has been considered in MATLAB Simulink to show the power flow without and with FACTS device. The location of FACTS devices in this system is chosen based on the loss sensitivity index. The sensitivity index of the system is given in the table below.

Table 2: Sensitivity index for IEEE 9 bus

Line number	*From bus*	*To bus*	*Sensitivity Index*
1	1	4	-0.00553883
2	4	5	-0.016442602
3	5	7	0.056585789
4	2	7	-0.001916422
5	7	8	0.000373483
6	8	9	-0.004985141
7	3	9	1.058857031
8	6	9	-0.026916026
9	4	6	-0.054581984

As we can see from the table shown above the line 7 from bus 3 to bus 9 has the largest sensitivity index, so FACTS device has been connected between those buses.

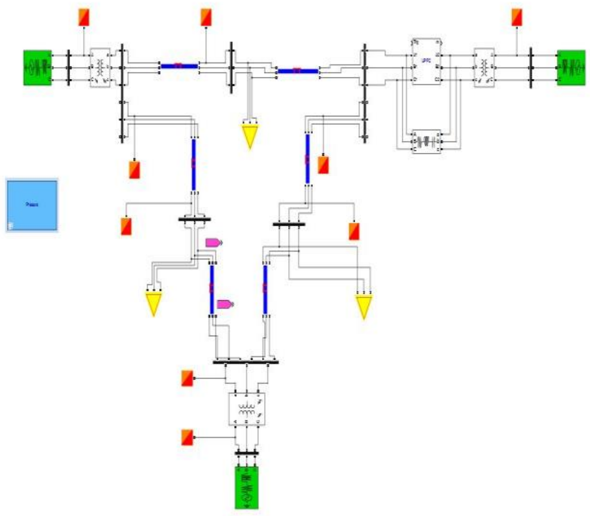

Fig. 5: MATLAB SIMULINK model of IEEE 9 bus system with UPFC.

12. Results

The section below shows the results of the simulation of IEEE-9 bus system without and with FACTS devices.

Table 3: Power flow of IEEE 9 bus system without FACTS device.

From bus	*Without UPFC*	
	Active (MW)	*Reactive (MVAR)*
1-4	71.97	26.58
4-5	41.12	31.92
7-5	84.13	-3.72
2-7	162.79	6.48
7-8	76.41	7.01
9-8	24.07	13.52
3-9	84.79	-10.99
9-6	59.32	-4.80
4-6	30.85	9.12

From the load flow of IEEE 9 bus without FACTS device the total power loss is P = 4.55 MW and Q = 48.06 MVAR.

Table 4: Power flow of IEEE 9 bus system without and with UPFC.

From bus	*With UPFC*		*Without UPFC*	
	Active (MW)	*Reactive (MVAR)*	*Active (MW)*	*Reactive (MVAR)*
1-4	72.00	26.08	71.97	26.58
4-5	41.19	31.52	41.12	31.92
7-5	84.07	-3.21	84.13	-3.72
2-7	162.79	9.69	162.79	6.48

7-8	76.45	6.38	76.41	7.01
9-8	24.02	14.18	24.07	13.52
3-9	84.79	-8.57	84.79	-10.99
9-6	59.35	-3.90	59.32	-4.80
4-6	30.81	8.32	30.85	9.12

From the load flow of IEEE 9 bus with UPFC the total power loss is P = 4.58 MW and Q = 52.74 MVAR.

Table 5: Power flow of IEEE 9 bus system without and with SSSC.

From bus	*Without SSSC*		*With SSSC*	
	Active (MW)	*Reactive (MVAR)*	*Active (MW)*	*Reactive (MVAR)*
1-4	71.97	26.58	72.00	26.08
4-5	41.12	31.92	41.19	31.52
7-5	84.13	-3.72	84.07	-3.21
2-7	162.79	6.48	162.79	9.69
7-8	76.41	7.01	76.45	6.38
8-9	-24.07	-13.52	-24.02	-14.18
3-9	84.79	-10.99	84.79	-8.57
9-6	59.32	-4.80	59.35	-3.90
4-6	30.85	9.12	30.81	8.32

From the load flow of IEEE 9 bus with SSSC the total power loss is P = 4.58 MW and Q = 52.74 MVAR.

13. Conclusion and future scope

At the end of the project we have implemented FACTS devices, UPFC and SSSC on transmission line in standard IEEE 9-bus system. The study of the basic principles of the UPFC and SSSC are carried out. A power flow model of UPFC and SSSC are attempted and it is seen that the modified load flow equations help the system in better performance. However, when the FACTS (i.e. UPFC and SSSC) devices are connected in transmission line in IEEE 9-bus system, the results are not as prominent as expected.

Therefore, firstly, the future scope of this project is to obtain the optimal configuration of the devices in those multi bus systems and try to get prominent results. Second, is to include the cost function, where the generation cost of total power has to be reduced as much as possible.

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AUTHOR PROFILE

Lari Kupar Lyngdoh is currently an M.Tech. second semester student in the Department of Electrical and Electronics Engineering, School Of Technology, Assam Don Bosco University, Guwahati, Assam, India. He received his B.Tech. Degree in Electrical and Electronics Engineering in 2017 from Assam Don Bosco University, India. His research intetest includes Power System Protection, Application of Power Electronics in Power Systems, FACTS.

Jesif Ahmed is working as an Assistant Professor in the Department of Electrical and Electronics Engineering, School Of Technology, Assam Don Bosco University, Guwahati, Assam, India. He is pursuing his Ph.D. from Gauhati University, Assam, India. He received his M.Tech. degree from N.I.T. Kurukshetra in 2011 and B.E. degree from Jorhat Engineering College, India in 2008. His research interest includes study of electricity market, Power systems optimization and transmission congestion management.