Voltage Profile Analysis for IEEE 30 Bus System Incorporating with UPFC

Amit Debnath, Champa Nandi, Joseph Rualkima Rante

Abstract—This paper deals with Power flow, which is necessary for any power system solution and carry out a comprehensive study of the Newton- Raphson method of power flow analysis with and without UPFC. Controlling power flow in modern power systems can be made more flexible by the use of recent developments in power electronic and computing control technology. The Unified Power Flow Controller (UPFC) provides a promising means to control power flow in modern power systems. In this paper the Newton-Raphson is used to investigate its effect on voltage profile with and without UPFC in power system. Simulations have been implemented in MATUB and the IEEE 30-bus system has been used as a case study. Simulations investigate the effect of voltage magnitude with and without UPFC on the power flow of the system. This survey article will be very much useful to the researchers for finding out the relevant references in the field of Newton-Raphson power flow control with UPFC in power systems.

Index Terms — Newton-Raphson, Power flow control, Three phase fault, UPFC (Unified Power Flow Controller).

I. INTRODUCTION

In recent years, great electric power demands have been imposed upon high voltage transmission networks in the worldwide. Also, the construction of new generating Units and transmission circuits becomes more difficult because of economic and environmental reasons. One of the important issues of transmission lines is the controlling of the power flow and the other is reactive power compensation. A new technology concept known as Flexible Alternating Current Transmission Systems, FACTS technology was presented in the late of 1980s. FACTS technology consists of devices depended on using the reliable and high speed power electronic devices instead of mechanical controllers. Thus, the utilization of the existing power system comes into optimal condition and the controllability of the system is increased. Unified Power Flow Controller (UPFC) is the member of FACTS device that has emerged for the control and optimization of power flow in electrical power transmission systems. One of the most comprehensive FACTS devices is UPFC, which has been introduced by Gyugiy in 1991 It consists of a series converter namely Static Synchronous Series Compensator (SSSC), commercially known as Dynamic Voltage Restorer (DVR) injects a voltage in series with the system voltage provides the most cost effective solution to mitigate voltage sags by improving power quality Procedure for Paper Submission level that is required by customer and a shunt converter namely Static Synchronous Compensator (STATCOM) connected by a common DC link capacitor. It can simultaneously perform the function of transmission line real/reactive power flow control in addition to UPFC bus voltage/shunt reactive power control. This paper presents the performance evaluation of Newton-Raphson power flow analysis for IEEE-30 bus system with and without UPFC FACTS controller and verifies the voltage profile of a power system.

II. NEWTON-RAPHSON POWER FLOW

Newton-Raphson widely used for solving simultaneous nonlinear algebraic equation by successive approximation procedure based on an initial estimate of unknown variable. Now, considering one-dimensional equation given by (1)

$$f\,(x) = c \qquad (1)$$

The Newton iterations process is:

$$x_i^{(k+1)} = x_i^{(k)} + \Delta x_i^{(k)} \qquad (2)$$

$$\Delta x_i^{(k)} = \frac{\Delta c^{(k)}}{\left(\frac{df}{dx}\right)^{(k)}} \qquad (3)$$

Now the eq. (1-3) will be used to solve the power flow problem. The equation model for power flow are described as follow:

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (4)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \qquad (5)$$

The variables that need to optimize from (4) and (5) are d and |V| so the iterations (2) can be written as follows:

$$\delta^{(k+1)} = \delta^{(k)} + \Delta \delta_i^{(k)} \qquad (6)$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \qquad (7)$$

The eq. (3) can be written as (8-10)

$$\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad (8)$$

$$\Delta P_i^{(k)} = P_i^{sh} - P_i^{(k)} \qquad (9)$$

$$\Delta Q_i^{(k)} = Q_i^{sh} - Q_i^{(k)} \qquad (10)$$

The J1, J2, J3, and J4 actually are related to kind of buses, for PV-buses the variable need to optimize are □ □ and Q, and for

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PQ-buses the variable need to optimize are δ and $|V|$, so $J1, J2, J3,$ and $J4$ can be written as follows:

The equation of $J1$.

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j\neq 1}|V_i||V_j||Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j) \qquad (11)$$

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j),\ j\neq i \qquad (12)$$

The equation of $J2$

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ij}|\cos\theta_{ij} + \sum_{j\neq 1}|V_j||Y_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j) \qquad (13)$$

$$\frac{\partial P_i}{\partial |V|_j} = -|V_i||V_{ij}||Y_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j),\ j\neq i \qquad (14)$$

The equation of J3

$$\frac{\partial Q_i}{\partial \delta_i} = \sum|V_i||V_j||Y_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j) \qquad (15)$$

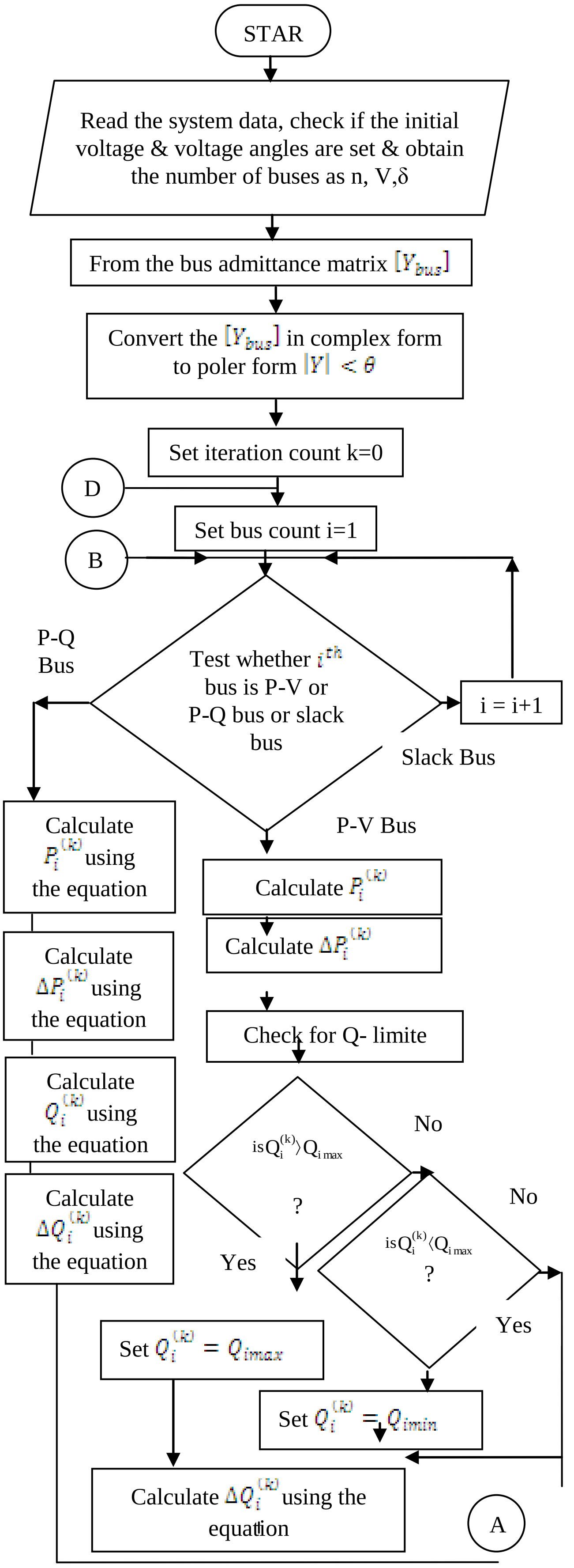
$$\frac{\partial Q_i}{\partial \delta_i} = -|V_i||Y_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j),\ j\neq i \qquad (16)$$

The equation of J4

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ij}|\sin\theta_{ij} - \sum_{j\neq 1}|V_j||Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j) \qquad (17)$$

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ij}|\sin\theta_{ij} - \sum_{j\neq 1}|V_j||Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j) \qquad (18)$$

Each iteration, the value of P and Q need to check within the limits or not. If the P is greater than P_{max} and Q is greater than Q_{max} so the P and Q are sets equal to P_{max} and Q_{max} respectively. If the P is less than P_{min} and Q is less than Q_{min} so the P and Q are sets equal to P_{min} and Q_{min} respectively. Fig.1. show the NR algorithm including checking the P-Q limits.



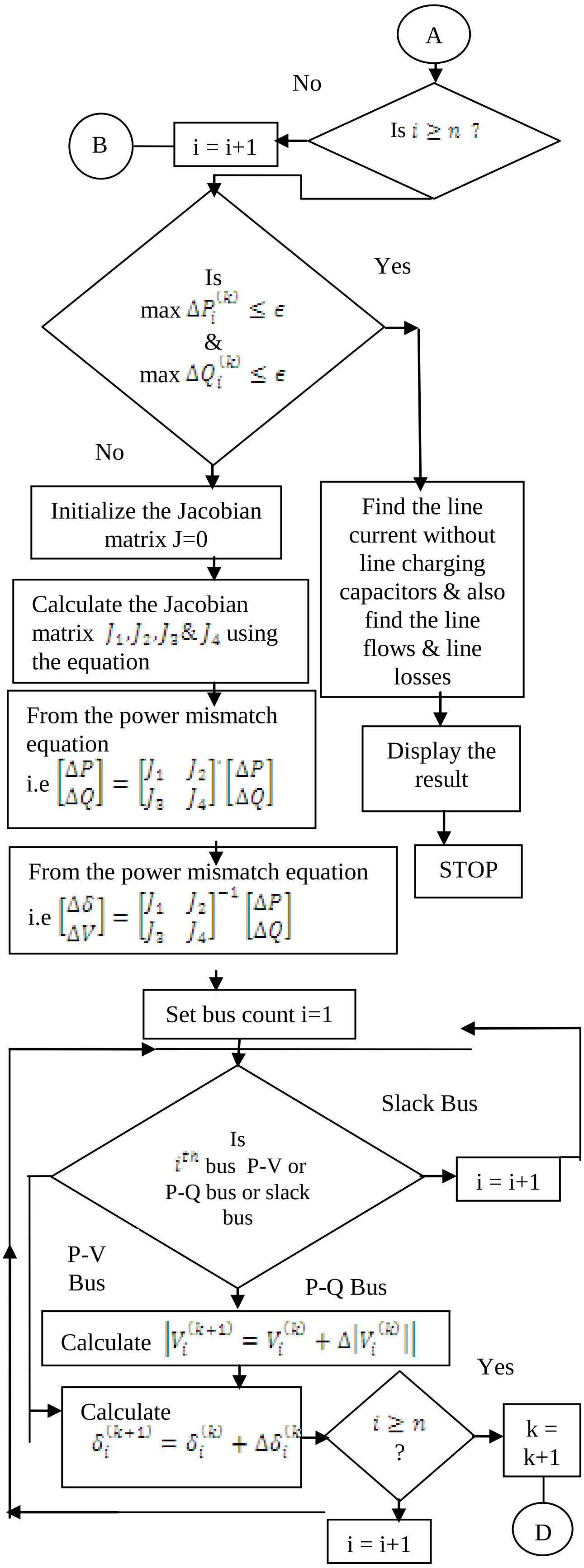


Fig.1: N-R Load flow Flowchart

III. POWER FLOW CONTROL

The power transmission line can be represented by a two-bus system ―k and ―m in ordinary form. The active power transmitted betweens bus nodes k and m is given by:

$$P = \frac{V_m V_k \sin(\delta_k - \delta_m)}{X} \tag{19}$$

Where V_m and V k are the voltages at the nodes, $(\delta_k - \delta_m)$ the angle between the voltages and X the line impedance. The power flow can be controlled by altering the voltages at a node, the impedance between the nodes and the angle between the end voltages [5]. The reactive power is given by:

$$P = \frac{V_k^2}{X} - \frac{V_m V_k \cos(\delta_k - \delta_m)}{X} \tag{20}$$

IV. OVERVIEW OF UPFC

A Unified Power Flow Controller (or UPFC) is an electrical device for providing fast-acting reactive power compensation on high-voltage transmission networks. The concept of UPFC makes it possible to handle practically all power flow control and transmission line compensation problems, using solid state controllers, which provide functional flexibility, generally not attainable by conventional thyristor controlled systems.

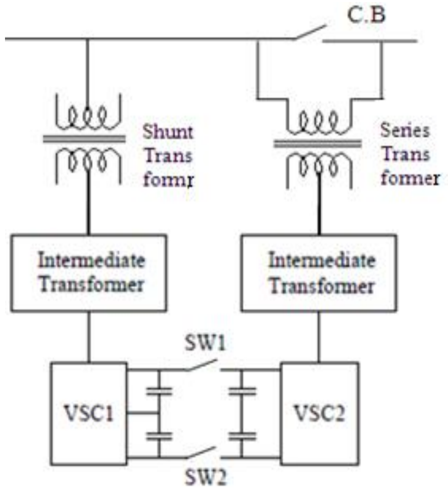


Fig.2 A UPFC Schematic Diagram

The UPFC is an advanced power systems device capable of providing simultaneous control of voltage magnitude and active and reactive power flows in an adaptive fashion. Owing to its instantaneous speed of response and unrivalled functionality, it is well placed to solve most issues relating to power flow control while enhancing considerably transient and dynamic stability.

V. POWER FLOW CONTROL WITH UPFC

The following are active and reactive power equations for the converter at bus k

$$P_{vR} = V_{vR}^2 G_{vR} + V_{vR} V_k \left[G_{vR} \cos(\delta_{vR} - \delta_k) + B_{vR} \sin(\delta_{vR} - \delta_k)\right] \tag{21}$$

$$Q_{vR} = -V_{vR}^2 B_{vR} + V_{vR} V_k \left[G_{vR} \sin(\delta_{vR} - \delta_k) - B_{vR} \cos(\delta_{vR} - \delta_k)\right] \tag{22}$$

$$P_k = V_k^2 G_{vR} + V_{vR} V_k \left[G_{vR} \cos(\delta_{vR} - \delta_k) + B_{vR} \sin(\delta_{vR} - \delta_k)\right]$$

(23)

$$Q_k = -V_{vR}^2 B_{vR} + V_{vR} V_k \left[G_{vR}\cos(\delta_{vR}-\delta_k) - B_{vR}\sin(\delta_{vR}-\delta_k)\right]$$

(24)

UPFC equivalent circuit consists of two coordinated synchronous voltage sources for the purpose of fundamental frequency steady state analysis. The UPFC voltage sources are:

$$E_{vR} = V_{vR}(\cos\delta_{vR} + j\sin\delta_{vR}) \qquad (25)$$

$$E_{cR} = V_{cR}(\cos\delta_{cR} + j\sin\delta_{cR}) \qquad (26)$$

Where, V_{vR} & δ_{vR} are the controllable magnitude $V_{vR\min} \le V_{vR} \le V_{vR\max}$ and phase angle $0 \le \delta_{vR} \le \delta_{2\pi}$ of the voltage source representing the shunt converter. The magnitude V_{cR} and phase angle δ_{cR} of the voltage source representing the series converter are controlled between limits $V_{vR\min} \le V_{vR} \le V_{vR\max}$ & $0 \le \delta_{vR} \le \delta_{2\pi}$ respectively. The phase angle of the series injected voltage determines the mode of power flow control. If δ_{cR} is in phase with the nodal voltage angle θ_k, the UPFC regulates the terminal voltage. If δ_{cR} is in quadrature with θ_k, it controls active power flow, acting as a phase shifter. If δ_{cR} is in quadrature with line current angle then it controls active power flow, acting as a variable series compensator, At any other value of δ_{cR}, the UPFC operates as a combination of voltage regulator, variable series compensator and phase shifter. The magnitude of the series injected voltage determines the amount of power flow to be controlled. Based on the equivalent circuit shown in Fig. the active & reactive power equations are:

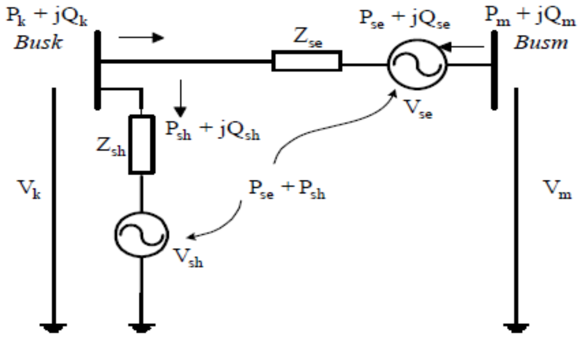


Fig.3 Unified Power Flow Controller Equivalent Circuit

At bus k:

$$P_K = V_{KK}^2 G_{KK} + V_K V_m\left[G_{Km}\cos(\theta_K-\theta_m) + B_{Km}\sin(\theta_K-\theta_m)\right] + V_K V_{cR}\left[G_{Km}\cos(\theta_K-\delta_{cR}) + B_{Km}\sin(\theta_K-\delta_{cR})\right] + V_K V_{vR}\left[G_{vR}\cos(\theta_K-\delta_{vR}) + B_{vR}\sin(\theta_K-\delta_{vR})\right]$$

(27)

$$Q_K = -V_K^2 B_{KK} + V_K V_m\left[G_{Km}\sin(\theta_K-\theta_m) - B_{Km}\cos(\theta_K-\theta_m)\right] + V_K V_{cR}\left[G_{Km}\sin(\theta_K-\delta_{cR}) - B_{Km}\cos(\theta_K-\delta_{cR})\right] + V_K V_{vR}\left[G_{vR}\sin(\theta_K-\delta_{vR}) - B_{Km}\sin(\theta_K-\delta_{vR})\right] \qquad (28)$$

At bus m:

$$P_m = V_m^2 G_{mm} + V_m V_K\left[G_{mK}\cos(\theta_m-\theta_K) + B_{mK}\sin(\theta_m-\theta_K)\right] + V_m V_{cR}\left[G_{mm}\cos(\theta_m-\delta_{cR}) + B_{mm}\sin(\theta_m-\delta_{cR})\right]$$

(29)

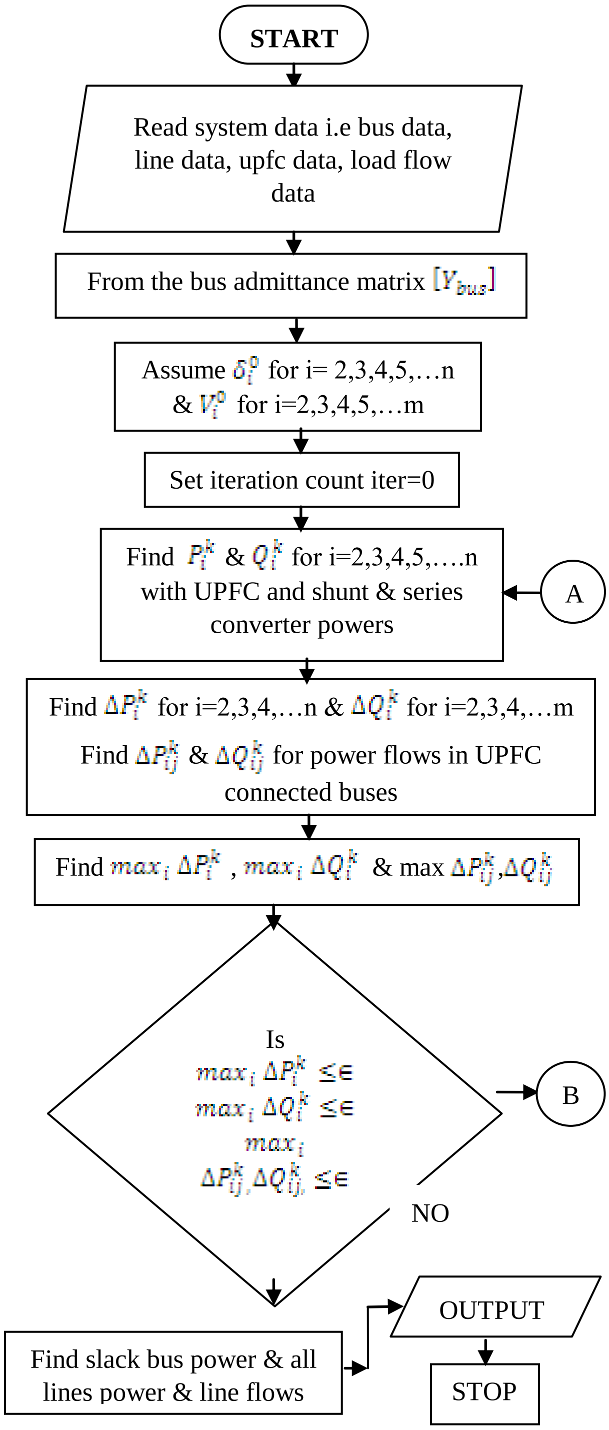
$$Q_m = -V_m^2 G_{mm} + V_m V_K\left[G_{mK}\sin(\theta_m-\theta_K) - B_{mK}\cos(\theta_m-\theta_K)\right] + V_m V_{cR}\left[G_{mm}\sin(\theta_m-\delta_{cR}) - B_{mm}\cos(\theta_m-\delta_{cR})\right]$$

(30)

Series converter:

$$P_{cR} = V_{cR}^2 G_{mm} + V_{cR} V_K\left[G_{Km}\cos(\theta_{cR}-\theta_K) + B_{Km}\sin(\theta_{cR}-\theta_K)\right] + V_{cR} V_m\left[G_{mm}\cos(\theta_{cR}-\delta_m) + B_{mm}\sin(\theta_{cR}-\delta_m)\right]$$

(31)



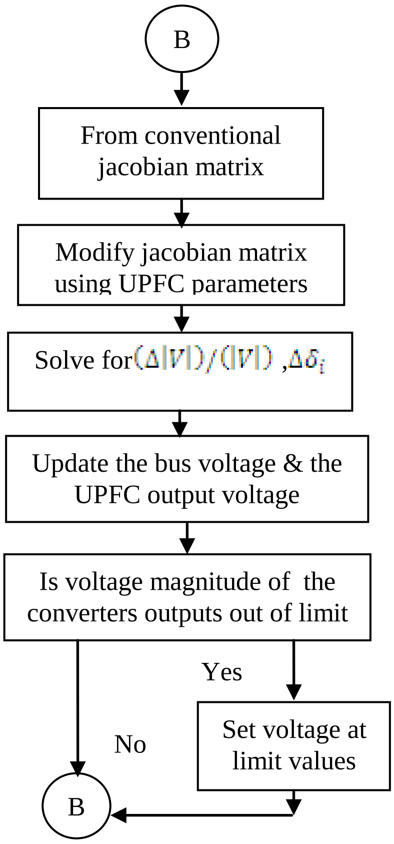


Fig.4 UPFC Flow-chart

$$Q_{cR} = -V_{cR}^2 G_{mm} + V_{cR} V_K \left[G_{Km}\sin(\theta_{cR}-\theta_K) - B_{Km}\cos(\theta_{cR}-\theta_K)\right] + V_{cR} V_m \left[G_{mm}\cos(\theta_{cR}-\delta_m) + B_{mm}\sin(\theta_{cR}-\delta_m)\right] \quad (32)$$

Shunt Converter:

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_K \left[G_{vK}\cos(\theta_{vR}-\theta_K) + B_{vR}\sin(\theta_{vR}-\theta_K)\right]$$
$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_K \left[G_{vR}\sin(\theta_{vR}-\theta_K) - B_{vR}\cos(\theta_{vR}-\theta_K)\right] \quad (33)$$

Where,

$$Y_{KK} = G_{KK} + jB_{KK} = Z_{se}^{-1} + Z_{sh}^{-1} \quad (34)$$
$$Y_{mm} = G_{mm} + jB_{mm} = Z_{se}^{-1} \quad (35)$$
$$Y_{Km} = Y_{mK} = G_{Km} + jB_{Km} = Z_{se}^{-1} \quad (36)$$
$$Y_{sh} = G_{sh} + jB_{sh} = Z_{sh}^{-1} \quad (37)$$

Assume losses converter values, the active power supplied to the shunt converter, P_{vR} equals the active power demanded by the series converter, P_{cR}

i.e $P_{cR} + P_{vR} = 0$ (38)

Furthermore, if the coupling transformers are assumed to contain no resistance then the active power at bus k matches the active power at bus m.

Accordingly,

$$P_{cR} + P_{vR} = P_K + P_m = 0 \quad (39)$$

The UPFC power equations linearised and combined with the equations of the AC transmission network. For the cases when the UPFC controls the following parameters:

1) Voltage magnitude at the shunt converter terminal
2) Active power flow from bus m to bus k
3) Reactive power injected at bus m, and taking bus m to be PQ bus.

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VI. SIMULATION AND RESULTS

A. IEEE-30 Bus Voltage Profile analysis by N-R Method

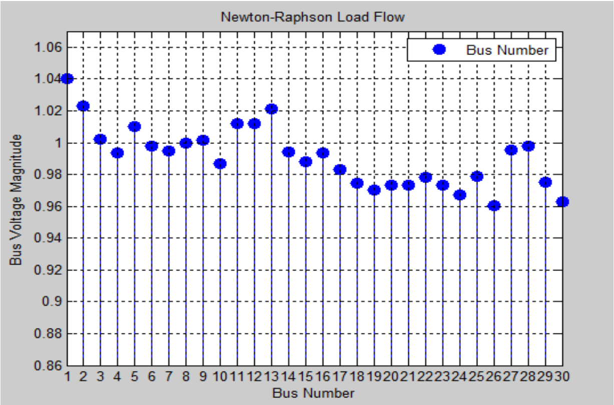

Fig.5 Voltage Magnitude of IEEE-30 bus System.

B. IEEE-30 Bus Voltage Profile analysis With UPFC by N-R method

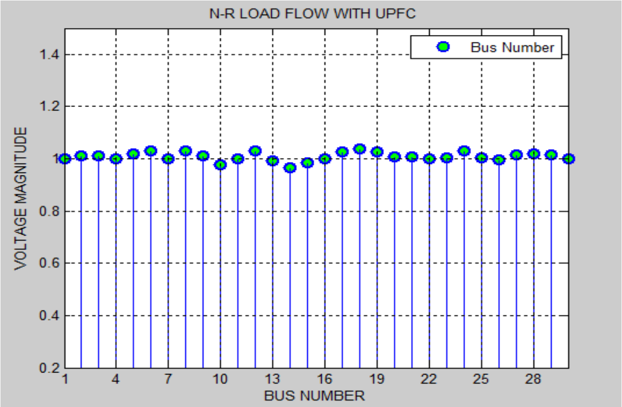

Fig.6 Voltage Magnitude of IEEE-30 bus System in the presence of UPFC.

Table-1 Voltage Magnitude With & Without UPFC

N-R Power Flow	Bus No.	Bus Voltage Magnitude (p.u)
Without UPFC	26	0.96
With UPFC	26	1.00

VII. CONCLUSION

This paper consists of various aspects, regarding Newton-Raphson power flow analysis for IEEE-30 bus system with and without UPFC has been presented and the importance to maintain voltage profile has been discussed. The UPFC modeling and analysis when connected to a bus no-26 and made it to maintain bus voltage profile of the full range of operation when there is a need. There by the reactive power compensation was successfully done in the particular transmission whenever it is required. The power flow and the voltage profile in various transmission lines along with and without the placement of UPFC in a specific transmission line is obtained in order to improve the system performance. Hence the themes of the paper to maintain voltage stability have been successfully achieved with the incorporation of UPFC.

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