ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 6, June 2014

Performance Analysis of Multi-Machine System Using UPFC

Dr. P.R. Sharma, Dr. Rajesh Kr. Ahuja, Shakti Vashisth

Department of Electrical Engineering, YMCAUST, Faridabad, India.

ABSTRACT: In this paper best location of UPFC placement is identified on the basis of maximum loadability of a system. Simulation is done by using standard data of IEEE-14 bus system. Load reactance is increased by 5 %, 10 %, 15%, 20%, 25%, 30%, 35%, and 40%. Voltage stability index namely L-INDEX and FVSI is calculated at each percentage change in reactive load. Weakest line, the line at which voltage stability index has highest value and lower value of voltage, is measured using voltage stability index. UPFC is placed onthe most critical line which improves the voltage stability and minimizes the losses in the transmission system.

KEYWORD: CPF, FACTS, FVSI, L- Index, PSAT,Stability,UPFC.

I.INTRODUCTION

The demand of efficient and high quality power is increasing in the world of electricity. Today's power systems are highly complex and require suitable design of new effective and reliable devices in deregulated electric power industry for flexible power flow control. In the late 1980s, the Electric Power Research Institute (EPRI) introduces a new approach to solve the problem of designing, controlling and operating power systems: the proposed concept is known as Flexible AC Transmission Systems (FACTS) [1]. A FACT is a system composed of static equipment used for the AC transmission of electrical energy. It is mean to enhance the controllability and increase power transfer capability of network. It is generally power electronics based device.

FACTS are defined by the IEEE as "a power electronic based system and other static equipment that provides control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability. [2]Its first concept was introduced by N.G. Hingorani in April 19, 1988. And first installation was done at the J.C. Slatt Substation in the Northern region. This is a 500 KV, 3- phase 60 HZ substation and was developed by EPRI,the Bonneville Power Administration and General Electric company .[3] different kind of FACTS controllers have been introduced.

- Static Var Compensators (SVCs) - voltage controlled device.
- Static Synchronous Compensators (STATCOMs) –Voltage controlled device.
- Thyristor Controlled Series Compensators (TCSCs) - Impedance controlled device.
- Static Synchronous Series Compensators (SSSCs) – Voltage Impedance, & Angle controlled device.
- Unified Power Flow Controllers (UPFCs) - Voltage, Impedance,& Angle controlled device.
- Inter –phase Power Flow Controller (IPFC) - voltage,impedance & Angle controlled device.
- Convertible series compensation (CSC)- Voltage, impedance& Angle Controlled device.
- Thyristor Controlled Phase Shifting Transformer (TCPST) – Angle controlled device.

Among them UPFC is the most versatile and efficient device which was introduced in 1991.Unified Power Flow Controller (UPFC) is the most promising version of FACTS devices as it serves to control simultaneously all three parameters (voltage, impedance and phase angle) at the same time. Therefore it is chosen as the focus of investigation. For the last few years, the focus of research in the FACTS area is mainly on UPFC. Many researchers have proposed different approaches of installing UPFC in the transmission line [4][5]. TheMathematical models of UPFChave been developed to study steady state characteristics without considering the effects of converters and the dynamics of generator [6]. The performance of UPFC has been reported by designing a series converter with conventional controller's device [7].UPFC is represented by an equivalent circuit with a shunt current source and a series voltage source [8]. Different algorithms have been proposed to increase the power flow control with UPFC in power transmission systems [9]. Baskaret. al. proposes a technique to control the real andreactive power in the transmission line by the two leg three phase converters based on UPFC. Some results of network with and without UPFC are also been compared in terms of active and reactive power flows in the line and reactive power flow at the bus to compare the performance of UPFC. Simulation results have compared when UPFC is connected between different buses in a specified transmission system. Ch. Chengaiahet. al. found that a system performs better when the UPFC is connected to a bus which has low voltage profile [10]. Based on IEEE- 14bus test system a simulation study of UPFC is carried out in this paper. The performance of UPFC in controlling power flow over the transmission line is investigated. We also propose a model which can improve and control the active as well as reactive power by placing UPFC at midpoint of a standard IEEE 14-bus system. However, to achieve the good performance of UPFC, proper placement of UPFC is a very important task. There are several methods for finding the locations of UPFC in vertically integrated systems but little attention has been devoted to the two fold task of increasing the loadability and reducing the losses [4]. In this paper, the selection of the best possible location for installation of an UPFC is carried out with an objective of reducing the losses and increasing the loadability of the bus thereby improving their voltage profiles and 14-bus systems using PSAT (Power System Analysis Toolbox) software by using different analysis techniques such as Small Signal Stability (SSS), Time Domain Analysis.

II.MODELLING OF UPFC

A Unified Power Flow Controller (or UPFC) is an electrical device for providing fast-acting Reactive power compensation on high – voltage electricity transmission networks. It uses a pair of three- phase controllable bridges to produce current that is injected into a transmission line using a series transformer .the controller can control active and reactive power flows in a transmission line. The UPFC uses solid state devices, which provide functional flexibility, generally not acceptable by conventional Thyristor controlled systems. The UPFC is a combination of a solid synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) coupled viaa common link .The UPFC concept was described in 1995 by L.Gyugyi of Westinghouse[5].

III.PRINCIPLE OF OPERATION OF UPFC

The UPFC is the most versatile FACTS controller developed so far, with all-encompassing capabilities of voltage regulation, series compensation, and phase shifting. It can independently and very rapidly control both real and reactive power flows in a transmission line. It is configured as shown in Fig1.and comprises of two VSC's coupled through a common DC terminal. One VSC- converter 1- is connected in shunt with the line through a coupling transformer; the other VSC – converter 2- is inserted in series with the transmission line through an interface transformer. The dc voltage for both converters is provided by a common capacitor bank. The series converter is controlled to inject a voltage phasor Vs, in series with the line, which can be varied from 0^o to 360^o. In this process, the series converter exchanges both real and reactive power with the transmission line. Although the reactive power is internally generated or absorbed by the series converter, the real-power generation or absorption is made feasible by the DC energy storage device-that is, the capacitor [11][12]. The shunt-connected converter 1 is mainly used to supply the real power demand of converter 2, which it derives from the transmission line itself. The shunt converter maintains constant voltage of the dc bus. Thus the net real power from the AC system is equal to the two converters and their coupling transformers. In addition, the shunt converter functions like a STATCOM and independently regulate the terminal voltage of the interconnected bus by generating or absorbing a requisite amount of reactive power.

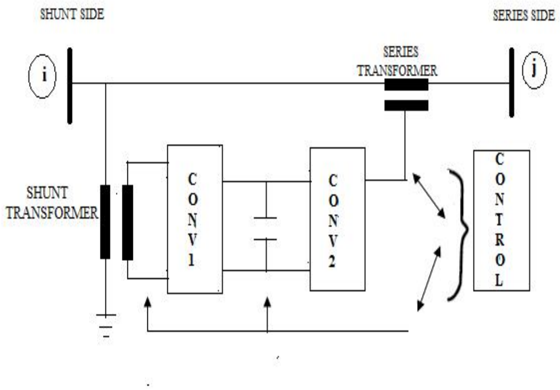

Fig .1: Block diagram of UPFC

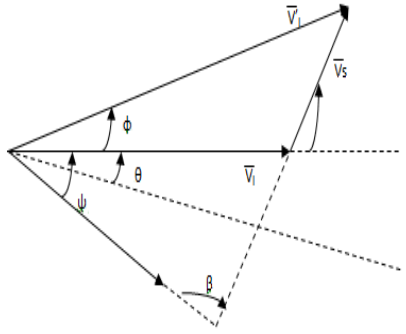

Fig .2: Phasor Diagram

Where,

$\overline{V_i'} = \overline{V_i} + \overline{V_s}$

r = $\frac{V_i}{V_i'}$ where r varies from $0 \le r \le r_{max}$

ϒ varies from $0 \le ϒ \le 2\pi$.

IV. MATHEMATICAL MODELING OF UPFC

In this model, we have considered the UPFC is placed at the center of a 300km transmission line. This model was derived with to study the relationship between electrical transmission system and UPFC in steady state conditions. The basic scheme is shown in fig.3. A UPFC can be represented by two voltage sources representing fundamental components of output voltage Wave forms of the two converters and impedances being leakage reactance of the two coupling transformers.

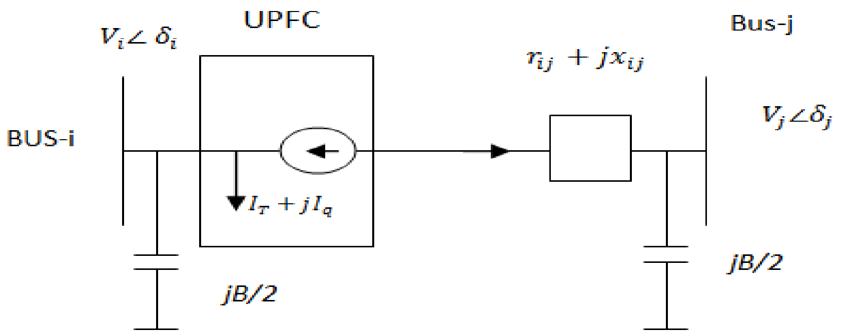

Fig.3: Block diagram

Based on the basic principle of UPFC and network theory, the active and reactive power flows in the line, from bus-i to bus-j, having UPFC can be written as,

$$P_{ij} = (V_i^2+V_T^2) + 2V_iV_Tg_{ij}\cos(\emptyset_T-\delta_j)-V_jV_T[g_{ij}\cos(\emptyset_T-\delta_j) + \quad b_{ij}\sin(\emptyset_T-\delta_j)-V_iV_j(g_{ij}\cos\delta_{ij}+b_{ij}\sin\delta_{ij})] \quad (1)$$

$$Q_{ij} = -V_iI - V_i^2\left(b_{ij}+\frac{B}{2}\right)-V_iV_T[g_{ij}\sin(\emptyset_T-\delta_i)+b_{ij}\cos(\emptyset_T-\delta_i)]-V_iV_j(g_{ij}\sin\delta_{ij}-b_{ij}\cos\delta_{ij})(2)$$

Where $g_{ij} + jb_{ij} = \frac{1}{r_{ij}+jx_{ij}}$ and I_q is the reactive current following in the shunt transformer to improve the voltage of the shunt connected bus of UPFC. Similarly, the active and reactive power flows in the line, from bus-j to bus-I, $having$ UPFC can be written as,

$$P_{ji} = v_j^2g_{ij} - V_jV_T[g_{ij}\cos(\emptyset_T-\delta_i)] - b_{ij}g\ sin(\emptyset_T-\delta_j)] - V_iV_j(g_{ij}\cos\delta_{ij}-b_{ij}\sin\delta_{ij}) \quad (3)$$

$$Q_{ji} = -V_j^2(b_{ij}+B/2) - V_jV_T[g_{ij}\sin(\emptyset_T-\delta_j) - b_{ij}\ cos(\emptyset_T-\delta_j))A = \pi r^2 + V_iV_j(g_{ij}\sin\delta_{ij}+b_{ij}\cos\delta_{ij}) \quad (4)$$

The real power and reactive power injections at bus-i with the system loading (λ) can be written as,

$$P_i = P_{Gi} - P_{Di}^0(1+\lambda) = \sum_{jeNa} P_{ij} \quad (5)$$
$$Q_i = Q_{Gi} - Q_{Di}^0(1+\lambda) = \sum_{jeNb} Q_{ij} \quad (6)$$

Where, P_{Di}^0 and $Q_{Di}^0$are the initial real and reactive power demands. $P_{Gi}$and$Q_{Gi}$are the real and reactive power generations at bus-i respectively. N_b is the number of system buses and λ is the sensitivity of system loading .In equation (5), uniform loading with the same power factor at all the load buses has been considered and the increase in the loading is assumed to be taken care by the slack bus whereas any sharing of generation amongst the generators can be easily incorporated in this model.

BEST LOCATION FOR UPFC:

Best location of (UPFC) FACT device is determined by finding out the maximum acceptable load on the bus. The most critical bus in the system is the bus which can accept maximum possible load. Line stability index method, Fast Voltage Stability Index (FVSI) and are some most important methods which are used to finding out the most sensitive line in the power system [13].

V. INDEX FORMULATIN

LSI and FVSI index formulation is discussed here in this subsection as following:

5.1.L-INDEX

Based on power transmission concept in a single line, Moghavvemi's derived a voltage stability index. To find out the overall system stability, an inter-connected system is reduced to a single line network. A typical single Transmission line having the following parameters in per unit is shown in fig 4.

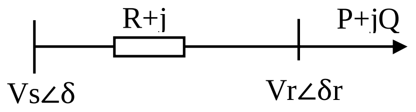

Fig.4: single line diagram of two bus system

Where,

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ISSN (Online): 2278 – 8875

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Vol. 3, Issue 6, June 2014

Vs - Sending end voltage,Vr - Receiving end voltage, Ps – sending end power Pr – receiving end power.
R - Line resistance,X - Line reactance,δ1 - Sending end voltage phase angle, δ2- Receiving end voltage phase angle.

Utilizing the concept of power flow in the line and analyzing with model representation, the power flow at the sending and receiving end can be expressed as:-

$$Sr = \frac{|V_S|\,|V_r|}{z}\angle(\theta - \delta 1 + \delta 2) - \frac{|V_r|}{z}\angle\theta \quad (7)$$

$$Ss = \frac{|V_S|}{z}\angle\theta - \frac{|V_S||V_r|}{z}\angle(\theta + \delta 1 - \delta 2) \quad (8)$$

From the above equation of power we can separate the real and reactive power,

$$Pr = \frac{V_s V_r}{Z}\cos(\theta - \delta 1 + \delta 2) - \frac{V_r^2}{Z}\sin\theta \quad (9)$$

$$Qr = \frac{V_s V_r}{Z}\sin(\theta - \delta 1 + \delta 2 - \frac{V_r^2}{Z}\cos\theta \quad (10)$$

Now putting (δ1-δ2) = δ into equation and solving it for Vr,

$$Vr = \frac{V_s \sin(\theta - \delta) \pm \{[V_s \sin(\theta - \delta)]^2 - 4ZQr\sin\theta\}^{0.5}}{2\sin\theta} \quad (11)$$

Where,

$Z = (R^2 + X^2)^{\frac{1}{2}} - \mathit{Line\ impedance}$
$\theta = \tan^{-1}(X/R)$

With Z= $\sin(\theta)\, X$, we can have

$$Vr = \frac{V_s \sin(\theta - \delta) \pm \{[V_s \sin(\theta - \delta)]^2 - 4XQr\}^{0.5}}{2\sin\theta}$$

(6)

In order to obtain real values of Vr in terms of Qr the equation derived above must have real roots. Thus the following condition can be used as stability criterion for voltage stability analysis.

$$[V_S \sin(\theta - \delta)]^2 - 4XQr \geq 0$$

$$\frac{4XQr}{[Vs\ \sin(\theta - \delta)]^2} = Lmn \geq 1.0 \quad (12)$$

Where, Lmn is termed as stability index of that line.
For voltage stability, this line stability index should be less than 1.
When this index exceeds the value 1, system loses its stability and voltage instability occurs. The equation (7) is used to calculate the stability index of single line connected between two buses. By using the above approach the line stability index of each line can be estimated for any inter-connected power system network.

5.2. FVSI

The line stability index FVSI is also based on the concept of power flow through a single line. For a typical transmission line, the stability index FVSI is calculated by equation given below:
Where,
Z = line impedance
X = line reactance

Qj = the reactive power flow at the receiving end
Vi = sending end voltage.

$$\text{FVSI} = \frac{4Z^2Q_r}{V_s^2X_r} \qquad (13)$$

The line that exhibits FVSI close to 1.00 implies that it is approaching the instability point. If FVSI goes beyond 1, one of the buses connected to the line experiences a sudden voltage drop leading to system collapse.

VI.STUDY SYSTEM

IEEE- 14 bus system:-

For this project an IEEE 14 bus system is taken and analyzed with both constant and voltage dependent load models. The simulations are carried out in PSAT software is shown in fig.5.It consist of 11 static loads and 4 transformers and 14 transmission lines .Base MVA is taken as 100 and base system voltage is 69 KV.

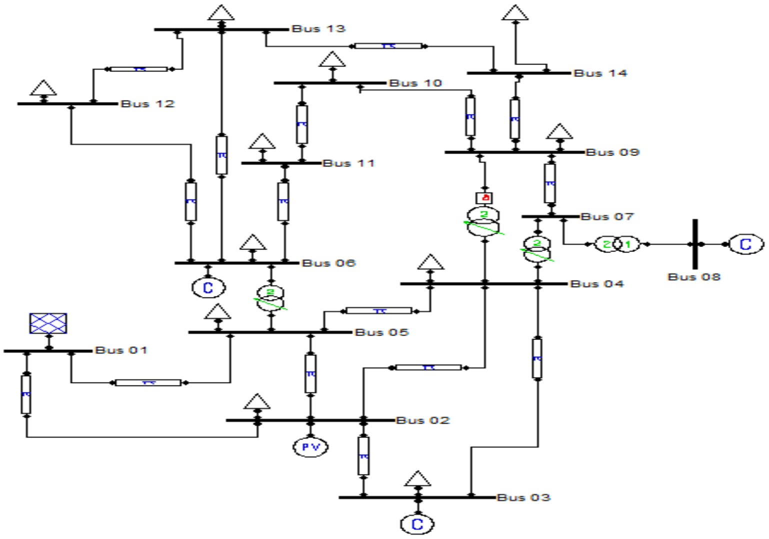


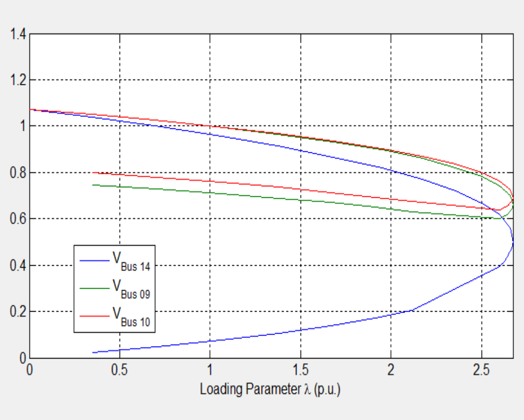
Fig .5: IEEE-14 Bus system

VII. RESULTS AND ANALYSIS

6.1STATIC VOLTAGE STABILITY

6.1.1 P-V curve

The variation of bus voltage with the loading factor λ is obtained for IEEE 14 bus system. Continuation Power Flow has been done in PSAT software and it is found that line (9-14) the most insecure line.by using L-INDEX and FVSI method. The figure 6 shows the P-V curve for the lowest three voltage buses without UPFC Fig 7.shows the P-V curve for three lowest voltage buses with UPFC at bus 14. It is clear that the laudability margin has been increased considerably.



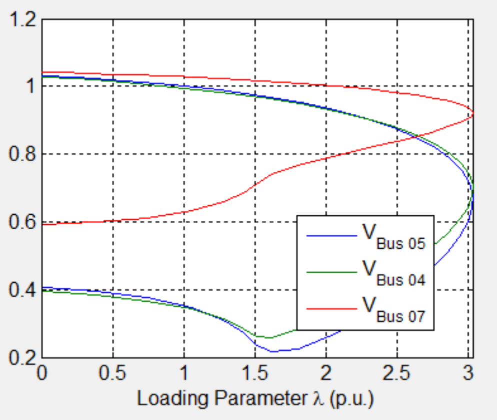


Fig .6: Three lower voltages without UPFC   Fig.7: Three lower voltages with UPFC

Bus no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Voltage without UPFC	1.06	1.045	0.996	1.001	1.01	1.07	1.029	1.09	1.001	1.0019	1.0301	1.0423	1.0289	0.9639
Voltage with UPFC	1.06	1.045	1.01	1.009	1.014	1.07	1.034	1.09	1	1.0018	1.0306	1.0439	1.0344	0.9851

Table -1 Bus Voltages With And Without UPFC

6.2. Determination of most critical line with referred to a bus using index

Step 1: Reactive load at a bus is gradually increased keeping all other loads keep constant.

Step 2: Load flow is done using PSAT to find out the active and reactive power transmitted at the receiving end for a particular load.

Step 3: Maximum Active and reactive power that can be transferred to a particular bus is calculated using the given formula.

Step 4: LSI and FVSI index is calculated at each load knowing power transmitted using load flow.

Step 5: This is repeated for each bus and indices are calculated for each line associated with bus.

Step 6: The line having maximum value of the stability indices at highest loadability point is the most critical line with respect to that bus.

LINE	L-index	FVSI
14-9	.11675	.1152
14-13	.2234	.22332
13-12	.02602	.05332
13-6	.113909	.11309
12-6	.06494	.064921
10-9	.009822	.0096617
10-11	.0947	.0947024
4-5	.05178	.05178
4-2	.04397	.04390
4-3	.15725	.1507
5-2	.05558	.055528
5-1	.08968	.0897
2-3	.010925	.010907
1-2	.08904	.088902

Table -2: Line Stability Indices

Table- 2.shows the indices value for most stressed lines without UPFC and the results show that the line 13-14 is the most critical line with respect to bus 14. Line (13-14) has the highest value of L-index.

CHANGE IN LOAD	FVSI(13-14) WITHOUT UPFC	FVSI(9-14) WITHOUT UPFC
0	.2234	0.11675
5	.2322004	0.1248
10	.241173	0.133091
15	.2501994	0.14136
20	.25929	0.1497
25	.268393	0.1581
30	.2775965	0.16656
35	.28686	0.17508
40	.296214	0.18366

Table -3: FVSI without any FACT Device

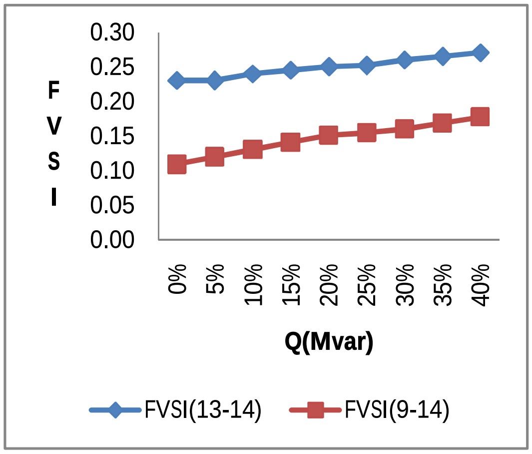


Fig .12: FVSI Vs load variation

LOAD CHANGES	FVSI (13-14) WITH UPFC	FVSI (9-14) WITH UPFC
0 %	.23075	.109433
5 %	.230576	.120011
10 %	.24074	.13062
15%	.2457	.14127
20%	.25078	.1491
25%	.2524	.1555
30%	.26094	.1604
35%	.26601	.1690
40%	.27111	.17768

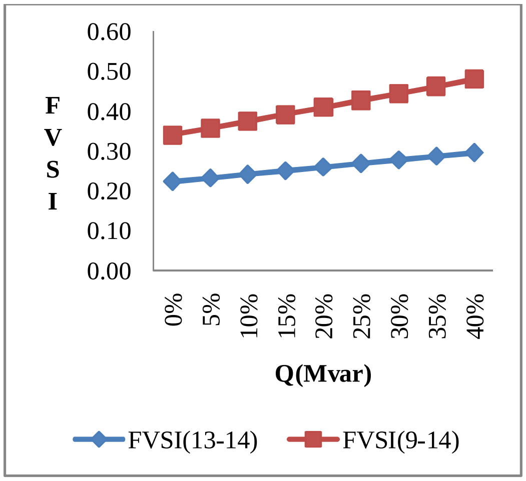


Table – 4: FVSI with UPFCFig .13: FVSI Vs load variation

Table-3 and Table -4 shows that the value of FVSI increases with the increment in the reactive loading of the system which can be clearly understood by Fig .12 and Fig .13.

LOAD CHANGE AT LINE(9-14)	FVSI WITHOUT UPFC	FVSI WITH UPFC
0	0.11675	.109433
5	0.1248	.120011
10	0.133091	.13062
15	0.14136	.14127
20	0.1497	.1491
25	0.1581	.1555
30	0.16656	.1604
35	0.17508	.1690
40	0.18366	.17768

Table – 5: FVSI at line (9-14) UPFC

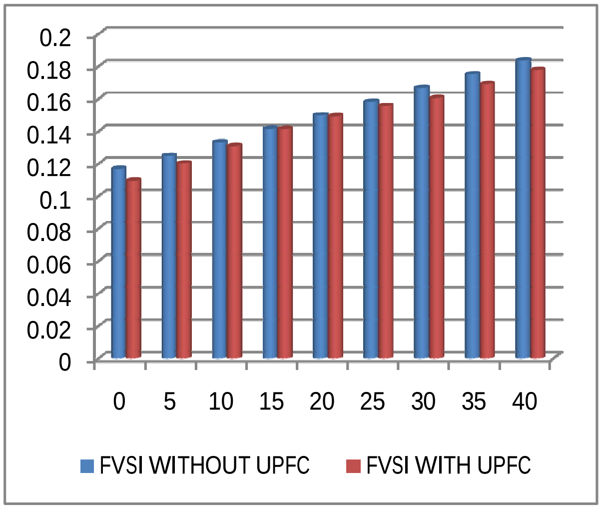


Fig .14: FVSI Vs load variation

(13-14)	FVSI WITHOUT UPFC	FVSIWITH UPFC
5	.2322004	.230576
10	.241173	.24074
15	.2501994	.2457
20	.25929	.25078
25	.268393	.2524
30	.2775965	.26094
35	.28686	.26601
40	.296214	.27111

Table – 6: FVSI at line (9-14) UPFC

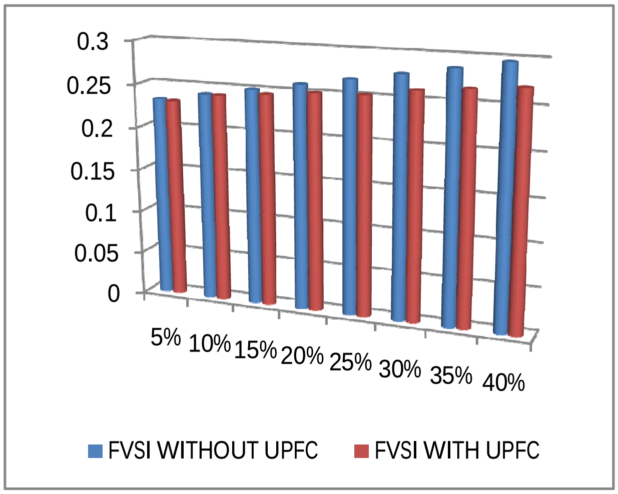


Fig .15: FVSI Vs load variation

Table – 5 and Table -6 Shows That Value of Voltage Stability Index Decreases at all the lines after Implementing UPFC at Most Critical Line (9-14). That's why line (9-14) is Suitable location for UPFC.

6.3. LOSSES- Real and Reactive losses plays animportant role in power system which involves the stability and coast factor both .that's why facts devices are implemented on that location where minimum losses can be possible .

Losses	Losses without any Fact device	Losses at line (9-14) with UPFC	Losses at line (13-14) with UPFC
Real losses	0.30192	0.18449	0.19767
Reactive losses	0.94172	0.43292	0.45828

Table – 7: Real and Reactive losses at most critical lines

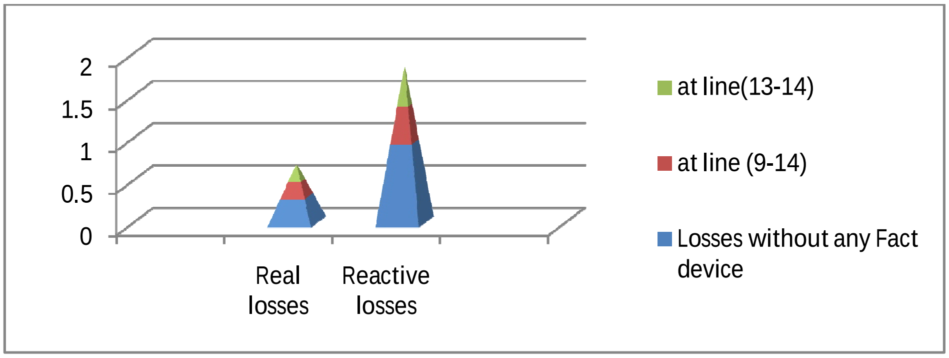


Fig.16: Losses Vs Line

VIII . CONCLUSION

It is found that best suitable location of UPFC is the bus-14. Simulation is carried out in PSAT software and critical line and weakest bus is determined using CPF, and voltage stability indexes L-INDEX and FVSI. From the above discussion it is cleared that FVSI and L-INDEX values has been reduced at all the buses and voltage profile is improved. Without using UPFC real and reactive losses are 0.30192 and 0.94172 respectively .after using UPFC at line (9-14) real and reactive losses become 0.18449 and 0.43292 respectively and if UPFC is connected on line (13-14) real and reactive losses becomes 0.19767 and 0.45828 respectively. It cleared that losses are more reduced if UPFC is connected at on line (13-14) and steady state stability is achieved by using UPFC.

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