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Study Impact of Unified Power Flow Controller (UPFC) on a Transmission Line Performance under Different Loading Conditions

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ABSTRACT

Now-a-days the Flexible AC Transmission Systems (FACTS) technology is very effective in improving the power flow along the transmission lines and makes the power system more flexible and controllable. This paper deals with the most robust type of FACTS devices; it's a Unified Power Flow Controller (UPFC). Many cases have been taken to study how the system behaves in the presence and absence of the UPFC under normal and contingency conditions. The UPFC is a device that can be used to improve the bus voltage, increasing the loadability of the line and reduce the active and reactive power losses in the transmission lines, through controlling the flow of real and reactive power. Both the magnitude and the phase angle of the voltage can be varied independently. The steady state model of UPFC has been adopted on IEEE-30 bus test system and simulated using MATLAB programming language. Newton Raphson (NR) numerical analysis method has been used for solving the load flow of the system. The practical part has been solved through Power System Simulation for Engineers (PSS\E) software Version 32.0. The Comparative results between the experimental and practical parts obtained from adopting the UPFC where too close and almost the same under different loading conditions, which are (5%, 10%, 15% and 20%) of the total load.

Keywords: UPFC, PSS\E، MATLAB coding, load flow controller

دراسة تأثير وحدة التحكم في تدفق الطاقة الموحدة على أداء خط النقل في ظل ظروف تحميل مختلفة

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الخلاصة

في هذه الايام، اصبحت أنظمة نقل التيار المتردد المرنة (FACTS) تكنولوجيا فعالة جدا في تحسين تدفق الطاقة على طول خطوط النقل ويجعل نظام الطاقة أكثر مرونة ويمكن السيطرة عليها. يتناول هذا البحث أقوى أنواع أجهزة الـFACT استخداما؛ إنها قوة موحدة تحكم التدفق (**UPFC**). تم أخذ العديد من الحالات لدراسة كيفية سلوك نظام القدرة في حالة وجود وغياب**UPFC** في ظل الوضع الطبيعي وفي حالة حدوث الطارئ.UPFC هو جهاز يمكن استخدامه لتحسين الفولتية ، وزيادة قدرة تحميل الخط وتقليل خسائر الطاقة النشطة والمتفاعلة في خطوط النقل ،من خلال التحكم في تدفق القوة

الحقيقية والتفاعلية. كل من قيمة وزاوية الجهد يمكن أن يتم التحكم بها وتغيرها بشكل مستقل. نموذج حالة مستقرة الذي سيتم تطبيق UPFC على نظام اختبار **IEEE-30** الذي يمكن تمثيله باستخدام محاكاة لغة البرمجة MATLAB، واستخدام طريقة (NR) Newton Raphson لحل تدفق الحمل في النظام. الجزء العملي يتمثل في استخدام برنامج المحاكاة software **(PSS\E)** .Version 32.0 النتائج المقارنة بين الأجزاء التجريبية والعملية التي تم الحصول عليها من اعتماد ال UPFC حيث تكون قريبة جدًا ومتماثلة تقريبًا في ظل ظروف تحميل مختلفة التي هي

(5% ,10%,15%,20%)

الكلمات الرئيسية:UPFC ، PSS\E , MATLAB coding,سيطرة تدفق الحمل

1. INTRODUCTION

In recent years, as our modern life evolves, this will lead to an increase in the rate of electricity demand. In contrast to the absence of sufficient generation and reliable transmission lines, this has become the operation of the power system under high stress conditions, loss of security and reduction of supply quality. **(Christa & Venkatesh, 2006), (Spana Khanchil, 2013), and (Salman, 2015)**

Traditional solutions of all these problem like building new power plant or expend new transmission line became more difficult and complex because it has a lot of challenges like it requires a lot of time and capitals, environmental constraint also limit in energy resource. Therefore, optimal power flow (OPF)-based power flow redistribution methods are more preferable in solving line overload issues using flexible ac transmission systems (FACTS) devices **(Pengcheng Song, 2017)**

(Tuaimah & et, 2011)implemented number of reactive power controller compensators like SVC. STATCOM and others on Iraqi power networks.

FACT (Flexible Alternating Current Transmission) technology became use to make power system more flexible and controllable without need to build new transmission line. FACT device also it has a lot of advantages like can use as: **(Gaurav Singh Yadav, 2015)**

1. power flow control,
2. maximum transmission capability
3. voltage regulation
4. reactive power compensation, stability improvement
5. Power quality improvement
6. Power conditioning.

 UPFC (Unified Power Flow Controller) is the most multilateral devise It can either simultaneously or selectively control the active and reactive power flow through the lines and also bus voltages. (Christa & Venkatesh, 2006)

 UPFC consist from two voltage source convertor.one connected in series with line (represent the static synchronous series compensator (SSSC)) through series transformer, and the other connected in shunt with line (represent the static synchronous compensator (STATCOM)) through shunt transformer. this two part is connected by dc link capacitor. with this arrangement can see that the VSC connected to the shunt transformer can perform the function of a variable reactive power source similar to that of shunt compensator. In addition, the VSC can charge the DC link capacitor. In other hand the VSC that connected to the series transformer can operate as series or phase angle compensation also can injecting a series voltage to the terminal bus. **(Nitin pawar, 2015)and (Gyugyi, 2000)**

In this paper UPFC set up to solve all problem resulting from overload in transmission line and improve from the performance of system by minimums line power losses, control the flow of real and reactive power by injection of a voltage in series with the transmission line**.**

By implement this project on IEEE30 bus on MATLAB **(Takkolu Kalyani and T. Ramesh Kumar, 2016)**And PSS\E (Chang, et al., 2005)can show the effect of UPFC device on load flow, line losses, rate of generation and compare the MATLAB result with practical result obtain from PSS\E under normal and contingency condition**.** To develop a novel UPFC-based line overload control in different load line, the remaining of the paper organized as follows. The basic operating principles of the UPFC are discussed in Section 2.in Section3, based on relationship between the line load of a transmission line and the active power setting of the UPFC, the control law of the line overload control is developed and represent in five section and explanation with the equations listed. In Section 4.the simulation results in MATLAB and PSS\E programs listed in two table with and without UPFC. Conclusions are presented in Section 5.

2. Unified Power Flow Controller (UPFC) Model

The basic principle of UPFC working that presence voltage source convertor (VSC) on sending and receiving end. **(Sarkar, 2013)**

The UPFC can limited the moment and the direction of active power flow in the lines by relation output voltage of VSC as magnitude and phase angle $V_{vR} \angle \boldsymbol{\delta_{vR}}$ with AC voltage supply $V_S \angle \mathbf{0}$ as shown in Eq. (1). **(Takkolu Kalyani and T. Ramesh Kumar, 2016)**

So is the case of reactive power also can be control by controlling of relation $V_{vR} \angle \boldsymbol{\delta_{vR}}$ of VCR with respect to $V_S \angle \mathbf{0}$ as shown in Eq. (2), where it can be generated Reactive power when $V_{vR} > V_S$, and can be consume when $V_{vR} < V_S$.

(Spana Khanchil, 2013)

$$P = \frac{V_S V_{vR}}{X_l} \sin \delta vR \tag{1}$$

$$Q = \frac{V_S^2}{X_l} - \frac{V_S V_{vR}}{X_l} \cos \delta vR \tag{2}$$

From schematic diagram of UPFC as illustrated in **Fig. 1** can notice. The Unified Power Flow Controller is consisting of two voltage sourced converters(VSC), labeled "series" and "shunt" convertor in the figure are operated with a common dc link provided by a dc storage capacitor.

The main function of operation shunt convertor is to supply or absorb the real power demanded by the series converter at the common dc link. The power of the dc link is converted back to ac and coupled to the transmission line through a shunt-connected transformer. Also shunt convertor can work as synchronous condenser, so it can generate reactive power to AC system.

On other hand the series convertor can injected voltage as controllable magnitude and phase angle in series with transmission line through series transformer, also can control of active power flow in transmission line and exchange reactive power with ac system which produced in series converter.

3.PROBLEM FORMULATION

The main purpose of this paper is to achieve the three main functions given below:

- Minimizing the real and reactive power loss.
- Preserve the bus voltage within the limit.
- Control of the power flow in overloaded lines.

To investigate all these function must be analysis the UPFC equivalent circuit and limit all basic equation. **(Gyugyi, 2000)**

3.1. Voltage Level:

Based on the equivalent circuit shown in **Fig. 2.** The two voltage equation that will produce in both series and shunt converter and constraint equation would be: **(Acha, 2004)**

$$Evr = Vvr\,(cos\,\delta vR + j\,sin\,\delta vR) \qquad (3)$$

$$Ecr = Vcr\,(cos\,\delta cR + j\,sin\,\delta cR\,) \qquad (4)$$

$$Re\{-E_{vR}\,I_{vR}^* + -E_{cR}\,I_{cR}^*\} = 0 \qquad (5)$$

transfer admittance equation can be written:

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} (Y_{cR} + Y_{vR}) & -Y_{cR} & -Y_{cR} & -Y_{vR} \\ -Y_{cR} & Y_{cR} & Y_{cR} & 0 \end{bmatrix} \begin{bmatrix} V_k \\ V_m \\ E_{cR} \\ E_{vR} \end{bmatrix} \qquad (6)$$

The equation of active and reactive power in sending and receiving bus (k, m) respectively; **(Takkolu Kalyani and T. Ramesh Kumar, 2016)**

At bus k:
$$P_k = V_k^2 G_{kk} + V_k V_m [G_{km}\,cos(\theta_k - \theta_m) + B_{km}\,sin(\theta_k - \theta_m)] + V_k V_{cR}[G_{km}\,cos(\theta_k - \delta_{cR}) +$$
$$B_{km}\,sin(\theta_k - \delta_{cR})] + V_k V_{vR}[G_{vR}\,cos(\theta_k - \delta_{vR}) + B_{vR}\,sin(\theta_k - \delta_{vR})] \qquad (7)$$
$$Q_k = -V_k^2 B_{kk} + V_k V_m [G_{km}\,sin(\theta_k - \theta_m) - B_{km}\,cos(\theta_k - \theta_m)] + V_k V_{cR}[G_{km}\,sin(\theta_k - \delta_{cR}) -$$
$$B_{km}\,cos(\theta_k - \delta_{cR})] + V_k V_{vR}[G_{vR}\,sin(\theta_k - \delta_{vR}) + B_{vR}\,cos(\theta_k - \delta_{vR})] \qquad (8)$$

At bus m:
$$P_m = V_m^2 G_{mm} + V_m V_k [G_{mk}\,cos(\theta_m - \theta_k) + B_{mk}\,sin(\theta_m - \theta_k)] + V_m V_{cR}[G_{mm}\,cos(\theta_m -$$
$$\delta_{cR}) + B_{mm}\,sin(\theta_m - \delta_{cR})] \qquad (9)$$
$$Q_k = -V_m^2 B_{mm} + V_m V_k [G_{mk}\,sin(\theta_m - \theta_k) - B_{mk}\,cos(\theta_m - \theta_k)] + V_m V_{cR}[G_{mm}\,sin(\theta_m -$$
$$\delta_{cR}) - B_{mm}\,cos(\theta_m - \delta_{cR})] \qquad (10)$$

3.2 Overloaded Line s
In order to minimize the power flow in over load line must be calculated the active and reactive power in each line: **(Salman, 2015)**

$$P_{Gi} - P_{Di} = V_i \sum_{k=1}^{N_B} V_j \left[G_K\,cos(\delta_i - \delta_j) + B_K\,sin(\delta_i - \delta_j) \right] \qquad (11)$$
$$Q_{Gi} - Q_{Di} = V_i \sum_{k=1}^{N_B} V_j \left[G_K\,sin(\delta_i - \delta_j) + B_K\,cos(\delta_i - \delta_j) \right] \qquad (12)$$

3. 3 Active and Reactive Power Losses:
By choosing the suitable variable from the UPFC device that will be injected in the network and can achieve the must goals that will reduce the active and reactive power losses of the transmission system, this value can have calculated by: **(Acha, 2004)**

$$P_L = \sum_{i=1}^{N_L} G_i \left[V_k^2 + V_m^2 - 2V_k V_m\,cos(\delta_k - \delta_m) \right] \qquad (13)$$
$$Q_L = \sum_{i=1}^{N_L} B_i \left[V_k^2 + V_m^2 - 2V_k V_m\,sin(\delta_k - \delta_m) \right] \qquad (14)$$

3.4 Voltage Deviation (VD)

In order to achieving a good voltage regulation to the load bus which the UPFC connected, the voltage deviation must be as small as possible and can be represent as follows: (Salman & et, 2018)

$$V_D = \sum_{i=1}^{nPQ}|V_i - 1|^2 \hspace{4cm} (15)$$

4. Treatment Procedure using UPFC:

In this paper adding UPFC to the network treated the must problems that are exposed the transmission system. this will be chive by choosing the optimal parameters of UPFC device which can be through it control of the power flow, reduce from overload line and make the voltage within the limit. **(Takkolu Kalyani and T. Ramesh Kumar, 2016)**

This work building according to several point:

a. Using **M-FILE** coding in **MATLAB** programs in order to define the transmission lines data, the number and types of buses, generation and load data of IEEE-30 buses also the UPFC parameter and solve the system in **Newton Raphson** method The algorithm for solving a power flow problem embedded with UPFC is represent as the flow chart shown in **Fig.12.** The power flow constraint of the UPFC is included in the Jacobin. The inclusion of these variables increases the dimension of the Jacobin. The power equations are mismatched until convergence is achieved. A scalar multiplier is used to control the updating of variables to ensure that they converge in an optimal way to the solution point

b. Implemented UPFC device in **PSS\E** programs and limited the overload line in all system

c. Suppose the system will be exposed to increase in load (MW) as a percentage (5%, 10%, 15%, 20%).

d. Choosing the suitable parameters and position of UPFC device which can be through it minimize the overload line and total active and reactive power losses of all system, control of active and reactive power flow, regulate the buses voltage, reactive power composition, and compare the result between two programs.

5. SIMULATION RESULTS:

The implementation of UPFC in IEEE 30 bus as a test system. The system consists of 6 generators, 30 buses, 21 loads and 41 lines **(Saadat, 1999)**. The configuration IEEE 30 buses electrical network represent in PSS\E programs as shown in **Fig.3.**

In this paper in order to study the effect of add UPFC to the network were taken normal case (actual active and reactive load power) as a first case. After that was increased the total active load power at (5%,10%,15%,20%) in MW with keep the total reactive power constant (126.2 Mvar) for all system.

In all these cases were calculated total active and reactive losses for system at with and without UPFC and find out how the addition of UPFC can maximize from the load ability and reduce from overload line and compare the result between MATLAB and PSS\E programs as shown in **Table.1** and **2.**

The suitable size, location and the number of UPFC(NUPFC) device as shown in **Table.2** are choosing based on maintain bus voltage with in limit as shown in **Fig.4** and **5,** reducing the power flow in overloaded lines and reduce total MW and Mvar losses.

Adding UPFC to transmission line will reduce from line current and regulate the system voltage so this will reduce from line losses as shown in **Table.2,** at normal case the total losses are (17.5MW ,67.6 Mvar) without UPFC. By adding one UPFC the rating of the total losses reduces to (12.293MW,40.143Mvar). Can observe the rest of the cases as shown in the **Table.1** and **2.**

Fig.6 shows the loading of the lines before the addition of the UPFC device, by using contours in PSS\E programs observed that when take the five case as example (at 20% increase in load) the

four line are up to the maximum degrees of the overloading more than 100%. While **Fig.7** shows the loading of the same lines after the addition of UPFC device between bus (2) and (6).

As can see in **Table.1.** the line between bus (1-2) most exposed to overload state where it appears in five cases with increase in active and reactive power losses.

as shown in **Fig.8** and **9** decreases in active and reactive line losses when add one UPFC unit between bus (2-6) .in this position UPFC start to inject power to bus (2) to compensate for rate power demand in line between (1-2) buses and reduce from overload.

The addition of UPFC can also reduce from the rate of the total real power generation (Pg.) in MW and reactive power generation(Qg) in Mvar in all cases as shown in **Fig.10** and **11,** In addition to a decreasing the stress on the lines overloaded by the permissible limits.

5. CONCLUSION

This paper investigates one of the most promising FACTS devices, UPFC is used to achieve the fundamentals (voltage regulation, reactive power and power flow controller) to make the system more efficient and reliable.

Here, using randomly choosing to limiting the location and the size of UPFC taking into consideration the voltage limits and reduce overload lines under thermal limit (100%).

From the IEEE30 bus result can show the number of UPFC is increase with increase load at (15% and 20%) because one UPFC cannot reduce from overload in lines so by using tow unit of UPFC device in different position can improve maximum load ability and minimum line losses.

Also can show the using Newton Raphson technique based on MATLAB m-file, and take its result and applying this result in PSS\E programs that represent the practical part and to understand the UPFC working and knowledge Extent of their impact on the network.

6. REFERENCES

- Firas M. Tuaimah, Yasser N. Al-Aani, Hassan A. Abdulmajeed Salbi, 2015. Optimal Loation of Static Synchronous Compensator (STATCOM) for IEEE 5-Bus Standard System Using Genetic Algorithm, Journal of Engineering,7(21), PP72-84.

- Hanan Mikhael Habbi, Ahmed Alhamadan,2018. Power System Stabilizer PSS4B Model for Iraqi National Gridusing PSS/E Software. Journal of Engineering,5(24), PP29-45.

- Hassan A bdullah Kubba, Mounir Thamer Esmieel,2018. Flexible Genetic Algorithm Based Optimal Power Flow of Power Systems, Journal of Engineering, 3(24), PP 84-96.

- Afaneen A. Abood, Firas M. Tuaimah, Aseel H. Maktoof, 2012. Modeling of SVC Controller based on Adaptive PID Controller using Neural Networks, International Journal of Computer Applications.59(6), pp9-16.

- G. A. Salman, 2015. Implementation SVC and TCSC to Improvement the Efficacy of Diyala Electric Network (132 kV), *American Journal of Engineering Research (AJER)*, 4(5), pp. 163-170.

- Mohanad Azeez Joodi, Ibraheem Kasim Ibraheem, Firas Mohammed Tuaimah,2018. Power transmission system midpoint voltage fixation using SVC with genetic tuned simple PID controller, International Journal of Engineering & Technolog,7(4), pp. 5438-5443.

- H. A. Hassonny, K. Pfeiffer, Firas M. Tuaimah,2013, V/VAR Control for the Iraqi National SHV Grid by Optimum Placement of SVC using Genetic Algorithm, International Journal of Computer Applications,66(12), pp (27-32)

- F.M. Tuaimah, Y.N. Abd, A.A. Najim, 2011.Static VAR Compensator (SVC) Implementation On Super High Voltage Network,Mediterranean Journal Of Electrical Power Mangement And Distribution,1(1),pp27-33

- Sapna Khanchi1, Vijay Kumar Garg,2013. Unified Power Flow Controller (FACTS Device): A Review, Sapna Khanchi, Vijay Kumar Garg / International Journal of Engineering Research and Applications (IJERA),3(4), pp. pp.1430-1435

- E. Acha, *et al,* 2004. FACTS Modeling and Simulation in Power Networks, *John Wiley and Sons LTD, England*.

- N. G. Hingorani and L. Gyugyi, 2000. Understanding FACTS Concepts and Technology of Flexible AC   Transmission Systems, New York: IEEE Press.

- M. Sarkar, 2013. Load Flow Studies with UPFC Power Injection Model, Department of Electrical Engineering National Institute of Technology, Rourkela. pp 1-53.

- Takkolu Kalyani and T. Ramesh Kumar, G. Siva Prasad,2016. Power Flow Control and Voltage Profile Improvement Using Unified Power Flow Controller (UPFC) in a Grid Network, International Journal of Electronics and Electrical Engineering,4(6),pp 482-487

- B. H. Chang, J. B. Choo, S. J. Im, J. S. Yoon, S. Y. Kim, X. K. Xu and B. P. Lam.,2005, Study of Operational Strategies of UPFC in KEPCO Transmission System. IEEE/PES Transmission and Distribution, Conference & Exhibition: Asia and Pacific Dalian, China, pp. 1-6.

- Hadi-Saadat,1999. Power System Analysis.Milwaukee School of Engineering.

- Vikash Anand, Dr. M. M. Chaudhary,2014. UPFC in order to Enhance the Power System Reliability, International OPEN Journal of Modern Engineering Research (IJMER),4(8). pp 68-75

- Nitin Pawar, C. Veeresh,2015. Role of UPFC in Power Flow Control of Distribution Line, International Journal of Science and Research (IJSR) ISSN (Online),4(12). pp. 613-615.

- S. T. Jaya Christa, and P. Venkatesh,2006. Optimal Placement of Unified Power Flow Controllers: An Approach to Maximize the Loadability of Transmission Lines, J. Electrical Systems,2(2), pp.82-94

- Gaurav Singh Yadav, Amit Agrawal, Dr. Dharmendra Kumar Singh,2015. Power Flow Problem Reduced Using Unified Power Flow Controller, International Journal of Science and Research (IJSR),6(4), pp.2871-2874.

- Pengcheng Song, Zheng Xu, Huanfeng Dong,2017. UPFC-based line overload control for power system security enhancement, IET Generation, Transmission & Distribution.11(13), pp. (1-8).

- Ghassan Abdullah Salman, Mohammed Hasan Ali, Ali Najim Abdullah,2018. Implementation Optimal Location and Sizing of UPFC on Iraqi Power System Grid (132 kV) Using Genetic Algorithm, International Journal of Power Electronics and Drive System (IJPEDS),9(4), PP. 1607-1615.

NOMENCLATURE:

P =Active power, MW.

Q=Reactive power, Mvar.

V_S= Supply voltage, Volt.

V_{vR}= the shunt source voltage magnitude p.u.

V_{cR}= the series source voltage magnitude p.u.

$\delta vR=$ the shunt source voltage angle rad.
δcR= the series source voltage angle rad.
$X_l=$ Inductive reactance of transmission line, p.u.
$Evr=$ The UPFC shunt voltage sources
$Ecr=$ The UPFC series voltage sources
$I_k=$ the current for bus k, Amp.
$I_m=$ the current for bus m, Amp.
$V_m=$ the voltage for bus m, volt.
$V_k=$ the voltage for bus k, volt.
$Y_{cR}=$ the series admittance, pu.
$Y_{vR}=$ the shunt admittance, pu.
$B_{km}=$ the sustenance for line between bus(k) and (m)
$G_{km}=$ the conductance for line between bus(k) and (m)
$P_{Gi}=$ the real power generation for (i=30) buses, MW.
$P_{Di}=$ the real power demand at bus i buses, MW.
$Q_{Gi}=$ the reactive power generation at bus i buses, Mvar.
$Q_{Di}=$ the reactive power demand at bus i buses, Mvar.
$P_L=$ the total active power losses, MW.
$Q_L=$ the total reactive power losses, Mvar.

Table. 1 MATLAB and PSS\E result without UPFC.

NO.OF CASES	LOADING IN (MW)	MATLAB result		PSS\E result		OVERLOAD LINE
		TOTAL LINE LOSSES		TOTAL LINE LOSSES		
		MW	Mvar	MW	Mvar	
Normal case	283.4	17.5	67.6	17.5	67.6	(1-2)
Increase (5%)	297.6	19	77	19	75	(1-2), (6-8)
Increase (10%)	311.74	21.855	85.978	21.8	83.9	(1-2), (6-8)
Increase (15%)	325.91	24.1	94.6	24.2	92.9	(1-2), (6-8)(2-6)
Increase (20%)	340	26.86	105.6	26.7	102	(1-2), (2-6) (4-6), (6-8)

Table. 2 MATLAB and PSS\E result with UPFC.

NO. OF CASES	NUPFC\ LOCATI ON	UPFC SIZE	MATLAB result		PSS\E result		OVER LOAD LINE
			TOTAL LINE LOSSES		TOTAL LINE LOSSES		
			MW	Mvar	MW	Mvar	

Normal Case	NUPFC=1 (2-6)	**Vcr** =0.995, **δcr** =-0.0349, **Vvr** =0.0266, **δvr** =0.0129 **X**= 0.005	12.293	40.134	11.1	40.9	**NONE**
Increase (5%)	NUPFC=1 (2-6)	**Vcr** =0.289, **δcr** =-0.0183 **Vvr** =0.0, **δvr** =0.0, **X**=0.005	9.47	31.675	9.1	33.7	**NONE**
Increase (10%)	NUPFC=1 (2-6)	**Vcr**=0.356, **δcr**=-0.0559 **Vvr**=0.06, **δvr**=-0.0129 **X**=0.005	13.934	45.052	13.0	45.4	**NONE**
Increase (15%)	NUPFC=2 (6-7) (4-3)	**Vcr1**=0.6, **δcr1**=-0.0116 **Vvr1**=0.0, **δvr1**=0.0 **Vcr2**=0.07, **δcr2**=-0.022 **Vvr2**=0.07, **δvr2**=0.04 **X**=0.005	12.84	40.198	11.5	40.1	**NONE**
Increase (20%)	NUPFC=2 (6-7) (4-3)	**Vcr1**=0.0117, **δcr1**=-0.0015 **Vvr1**=0.077, **δvr1**=0.0046 **Vcr2**=0.1345, **δcr2**=-0.0664 **Vvr2**=0.0799, **δvr2**=0.006	13.01	41.2	12.1	41.1	**NONE**

Table. 3 IEEE-30 Bus Test System (Base MVA=100, Accuracy=0.001, matrix=100).

Bus No.	Bus Code	Voltage Mag.	Angle Degree	Load		Generation				Inject Mvar
				MW	**Mvar**	**MW**	**Mvar**	**Qmin**	**Qmax**	
1	1	1.06	0	0.0	0.0	0.0	0.0	0	0	0
2	2	1.043	0	21.7	12.7	40.0	0.0	-40	50	0
3	0	1.0	0	2.4	1.2	0.0	0.0	0	0	0
4	0	1.06	0	7.6	1.6	0.0	0.0	0	0	0
5	2	1.01	0	94.2	19.0	0.0	0.0	-40	40	0
6	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
7	0	1.0	0	22.8	10.9	0.0	0.0	0	0	0
8	2	1.01	0	30.0	30.0	0.0	0.0	-10	40	0
9	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
10	0	1.0	0	5.8	2.0	0.0	0.0	0	0	19
11	2	1.082	0	0.0	0.0	0.0	0.0	-6	24	0
12	0	1.0	0	11.2	7.5	0.0	0.0	0	0	0
13	2	1.071	0	0.0	0.0	0.0	0.0	-6	24	0
14	0	1.0	0	6.2	1.6	0.0	0.0	0	0	0
15	0	1.0	0	8.2	2.5	0.0	0.0	0	0	0
16	0	1.0	0	3.5	1.8	0.0	0.0	0	0	0
17	0	1.0	0	9.0	5.8	0.0	0.0	0	0	0
18	0	1.0	0	3.2	0.9	0.0	0.0	0	0	0
19	0	1.0	0	9.5	3.4	0.0	0.0	0	0	0
20	0	1.0	0	2.2	0.7	0.0	0.0	0	0	0
21	0	1.0	0	17.5	11.2	0.0	0.0	0	0	0

22	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
23	0	1.0	0	3.2	1.6	0.0	0.0	0	0	0
24	0	1.0	0	8.7	6.7	0.0	0.0	0	0	4.3
25	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
26	0	1.0	0	3.5	2.3	0.0	0.0	0	0	0
27	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
28	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
29	0	1.0	0	2.4	0.9	0.0	0.0	0	0	0
30	0	1.0	0	10.6	1.9	0.0	0.0	0	0	0

Table. 4 IEEE-30 Bus Line Data.

From Bus	To Bus	R p.u	X p.u	½ B p.u	Tap setting value
1	2	0.0192	0.0575	0.02640	1
1	3	0.0452	0.1852	0.02040	1
2	4	0.0570	0.1737	0.01840	1
3	4	0.0132	0.0379	0.00420	1
2	5	0.0472	0.1983	0.02090	1
2	6	0.0581	0.1763	0.01870	1
4	6	0.0119	0.0414	0.00450	1
5	7	0.0460	0.01160	0.01020	1
6	7	0.0120	0.0820	0.0085	1
6	8	0.0	0.0420	0.0045	1
6	9	0.0	0.2080	0.0	0.978
6	10	0.0	0.5560	0.0	0.969
9	11	0.0	0.2080	0.0	1
9	10	0.0	0.1100	0.0	1
4	12	0.0	0.2560	0.0	0.932
12	13	0.0	0.1400	0.0	1
12	14	0.1231	0.2559	0.0	1
12	15	0.0662	0.1304	0.0	1
12	16	0.0945	0.1987	0.0	1
14	15	0.2210	0.1997	0.0	1
16	17	0.0824	0.1923	0.0	1
15	18	0.1073	0.2185	0.0	1
18	19	0.0639	0.1292	0.0	1
19	20	0.0340	0.068	0.0	1
10	20	0.0936	0.2090	0.0	1
10	17	0.0324	0.0845	0.0	1
10	21	0.0348	0.0749	0.0	1
10	22	0.0727	0.1499	0.0	1
21	22	0.0116	0.0236	0.0	1

15	23	0.1000	0.2020	0.0	1
22	24	0.115	0.1790	0.0	1
23	24	0.132	0.2700	0.0	1
24	25	0.1885	0.3292	0.0	1
25	26	0.2544	0.3800	0.0	1
25	27	0.1098	0.2087	0.0	1
28	27	0.0	0.3960	0.0	0.968
27	29	0.2198	0.4153	0.0	1
27	30	0.3202	0.6027	0.0	1
29	30	0.2399	0.4533	0.0	1
8	28	0.0636	0.2000	0.0214	1
6	28	0.0169	0.0599	0.65	1
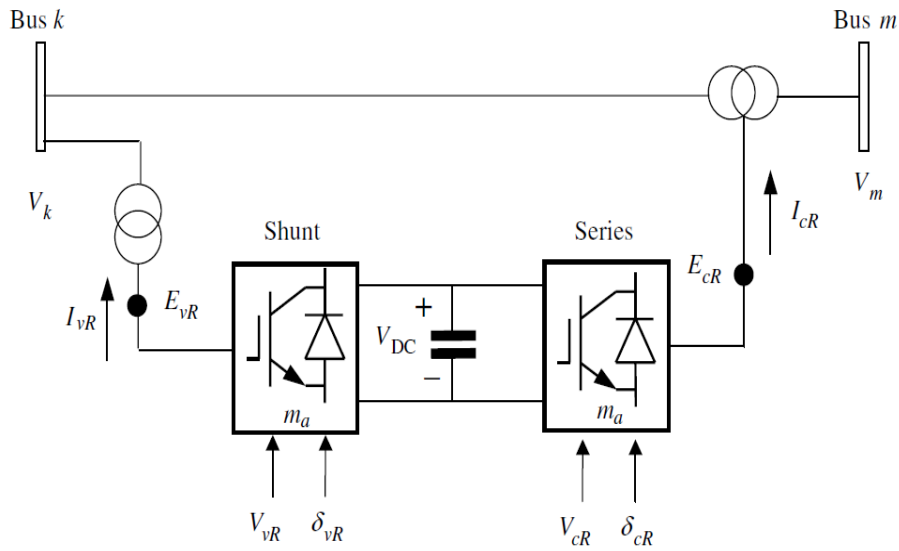
Figure 1. The Schematic diagram of UPFC
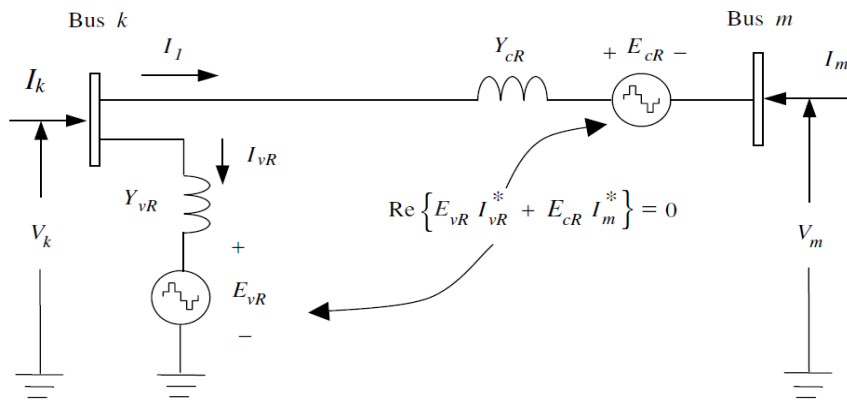
Figure. 2 equivalent circuit of UPFC model.
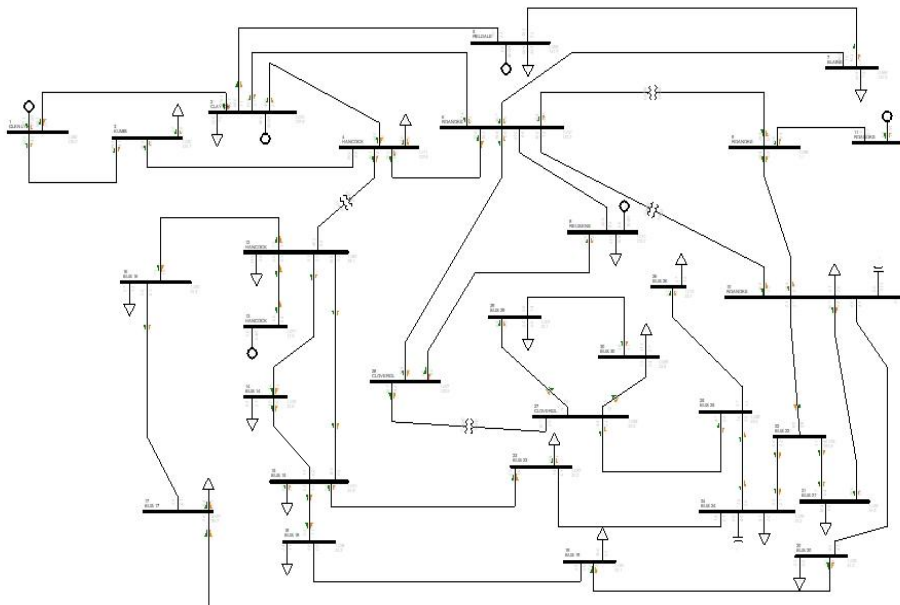
Figure. 3 The configuration IEEE 30 buses electrical network.
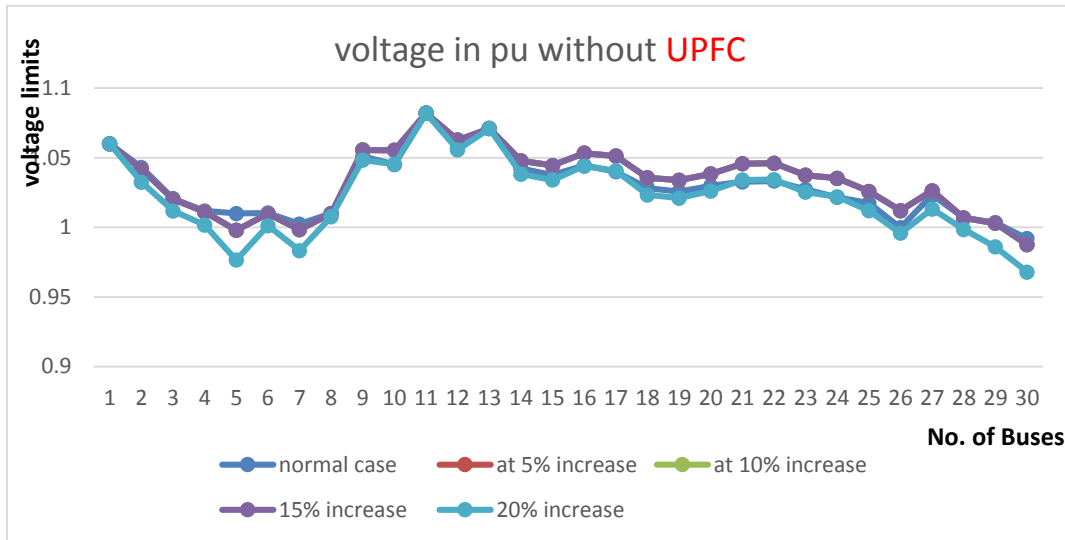
Figure. 4 rate of voltages at per unit (p.u) in five cases
Without UPFC.
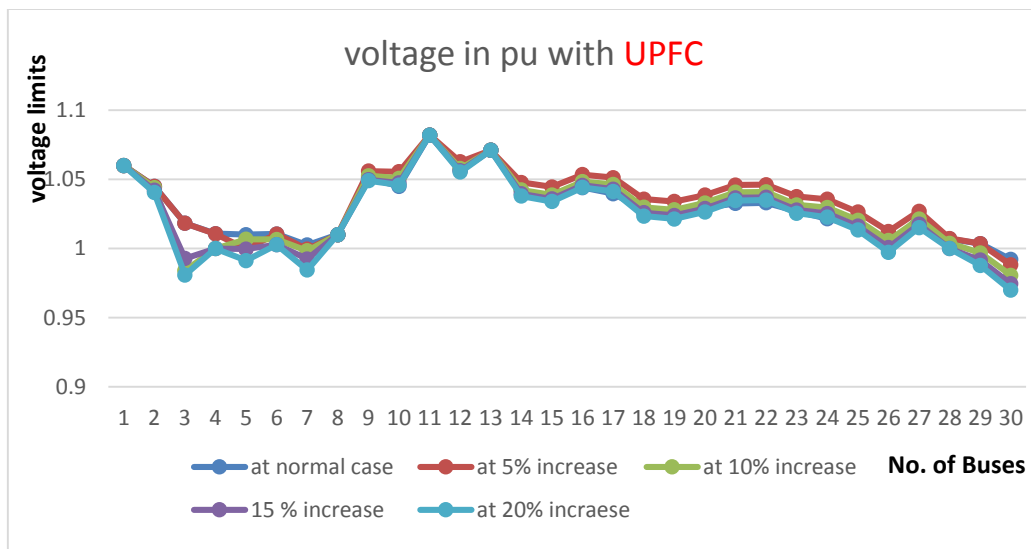
Figure. 5 rate of voltages at per unit (p.u) in five cases
With UPFC.
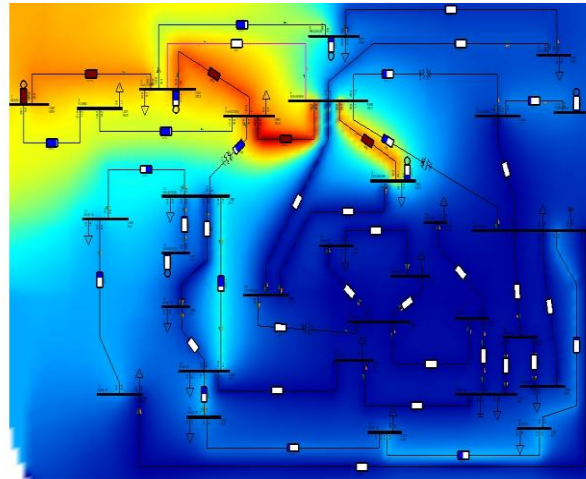
Figure. 6 the loading in IEEE 30bus transmission line without UPFC device.
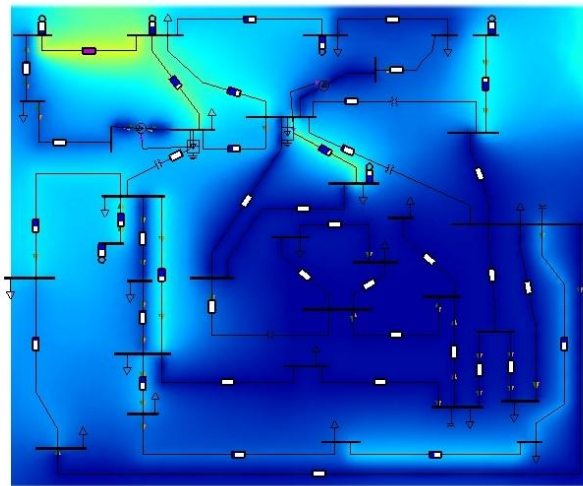
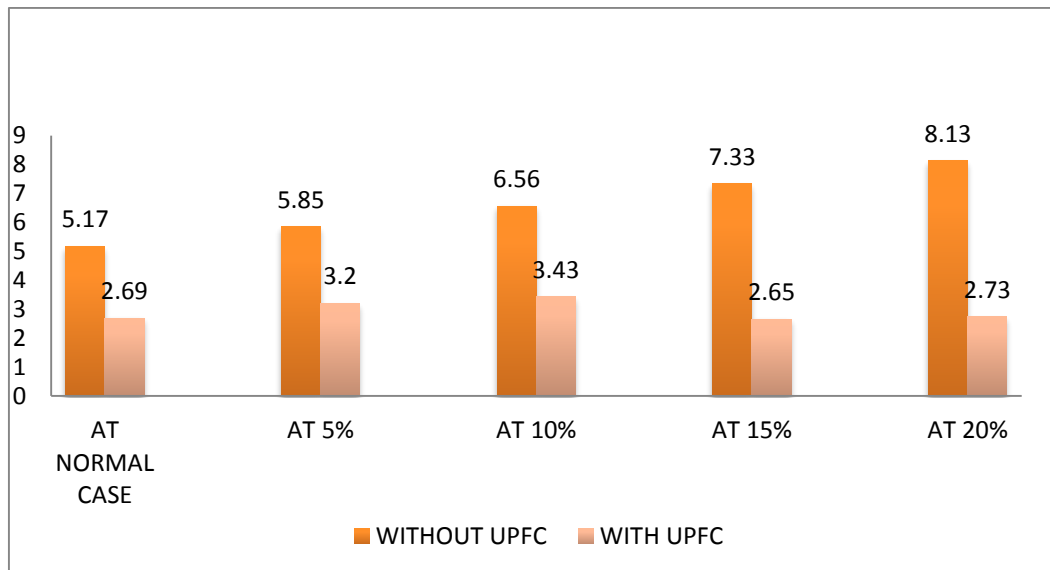**Figure. 7** the loading in IEEE 30bus transmission line with UPFC device.

Figure. 8 active power losses between bus (1-2) with jand without UPFC.

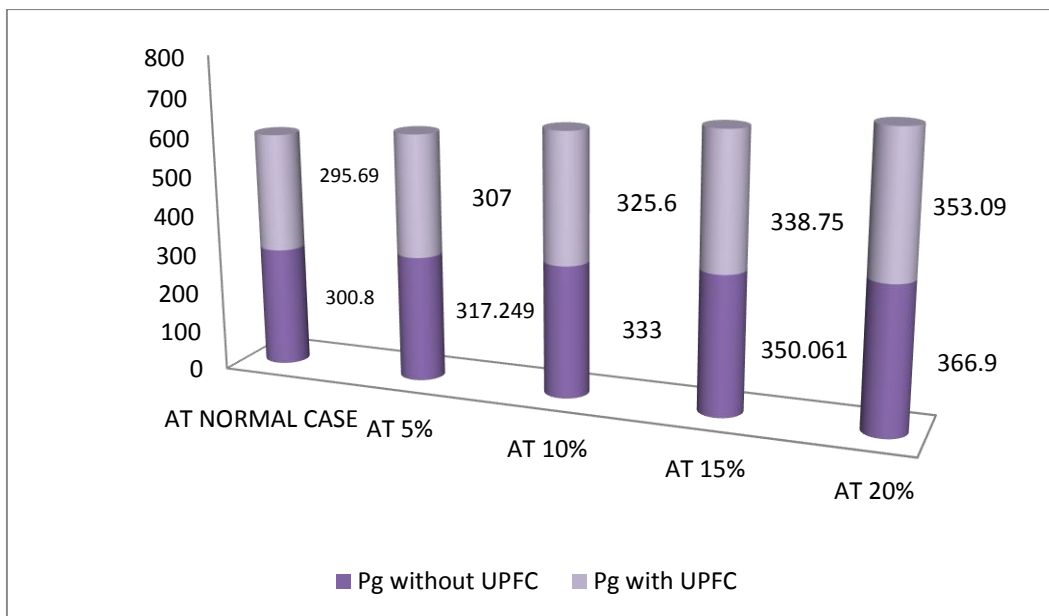**Figure. 9** reactive power losses between bus (1-2) with and without UPFC.

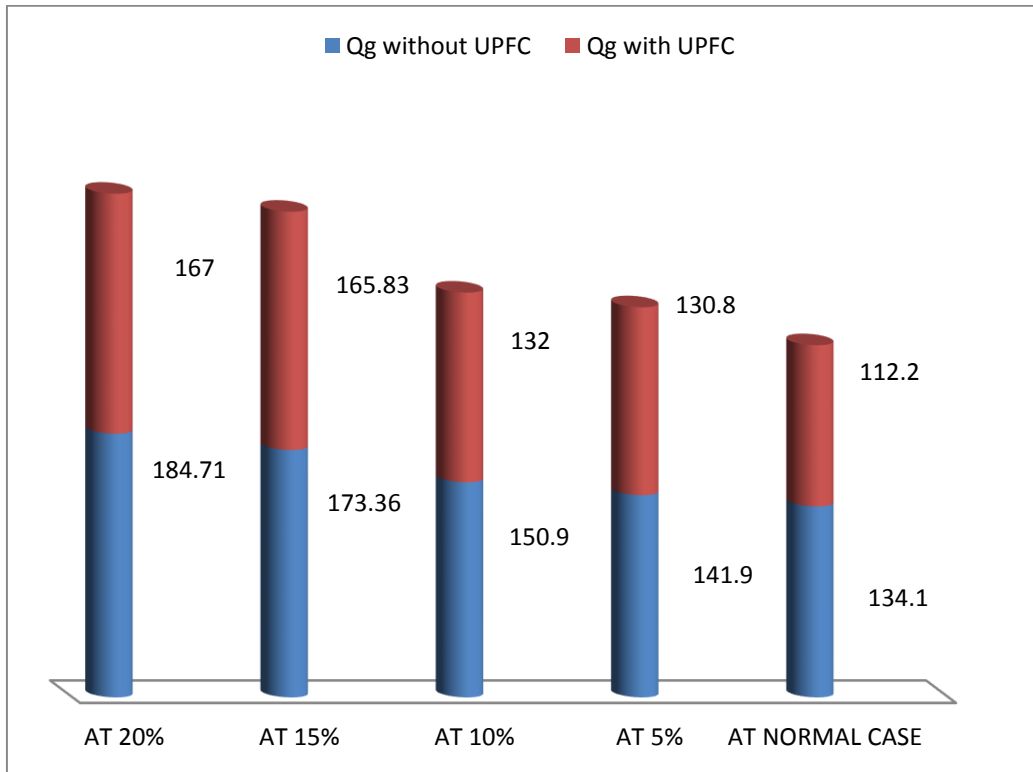**Figure. 10** Reduction in Pg. (MW) with and without UPFC.

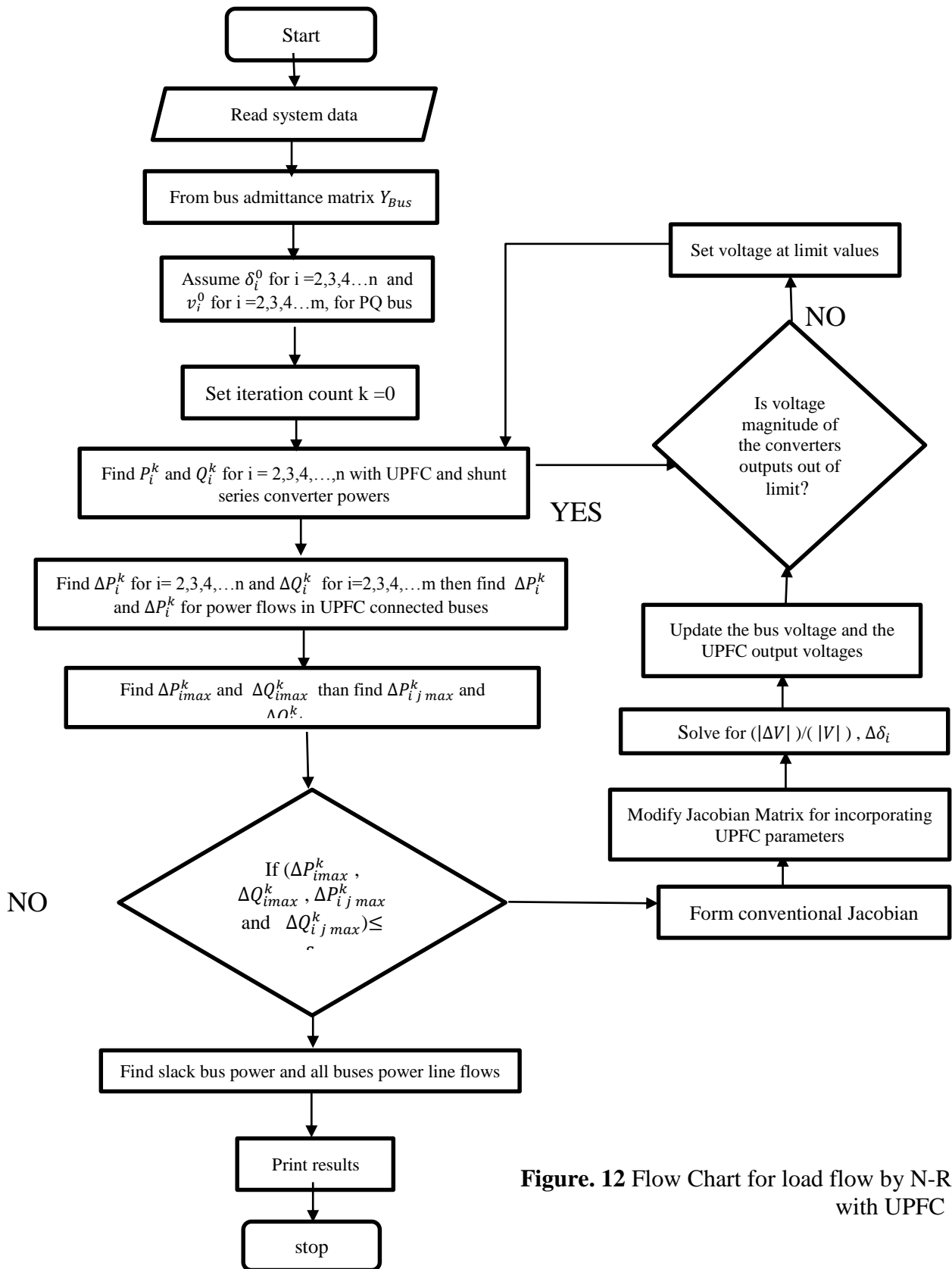**Figure. 11** Reduction in Qg. (Mvar) with and without UPFC.

Figure. 12 Flow Chart for load flow by N-R with UPFC