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Unified Power Flow Controller Application for Power Quality Improvement in Power System Network

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Abstract—**For maintaining the stability of electric power system it is necessary to keep voltage profile within the limits. Due to faults, fluctuations of load (voltage sags and voltage swells) are produced, so it is very difficult to maintain the voltage in all buses. Sustain better economy and useful operations of end user equipment require continuous and superior quality of power. In order to keep the power system stable and provide power with good quality there is need of advance techniques to eliminate issues of Power Quality (PQ) such as voltage swells and sags and make power system more reliable. The perception of Flexible alternating current transmission systems (FACTS) devices is relying on power electronic controllers, these devices are very useful to enhance the performance of transmission system by maximize the utilization of their ability. FACTS devices make the ac transmission network flexible by adapting the altering stipulation caused by contingencies and load variation. In this research paper, unified power flow controller (UPFC), one of the significant associate of FACTS Technology is used to make power system further consistent. Simulation without and with UPFC is done in MATLAB/Simulink software to see the effectiveness of UPFC for resolving power quality issues. Close loop simulation is completed with the help of proportional integral derivative (PID) controller. A comparison has been made between open loop and close loop. To authenticate the performance of UPFC the outcomes of simulation are given.**

***Index Terms*— voltage sags, voltage swells, UPFC, PID controller, power quality**

I. INTRODUCTION

Designing of electrical equipment which utilizes electrical power is done on the basis of their rated voltages. When voltage sags and swells are produced the applied voltage may not match to the rated voltage values of the equipment [1].

Voltage issues (sag and swell) can cause failure of equipment, as well as tripping of breakers and blowing of fuses due to the creation of large unbalance current. These power quality issues badly affect all type of electrical consumers. Voltage sag is defined as "the decreasing of rms value of voltage starting from 0.1 pu to 0.9 pu for the time period range in between 1/2 cycle to one minute. Voltage swell may be defined as "the increment of rms value of voltage from 1.1 pu to 1.8 pu for the period range in between 0.5 cycle of wave to one minute. FACTS devices give high-speed control of power (real and reactive) through transmission lines (T/Ls). To retain applied voltage in limits FACTS play huge responsibility [2].

II. UNIFIED POWER FLOW CONTROLLER

UPFC is one of the very important part of FACTS devices. UPFC merge the characteristics of static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC). The abilities of UPFC to transfer the flow of real power bi-directionally and sustain operating conditions are the reasons of its wide spread use in power system. UPFC involves double voltage source converters shunt and series. These converters unite with each other by a common dc link. Shunt and series transformers are used to connect (shunt and series) converters with the feeder [3, 4].

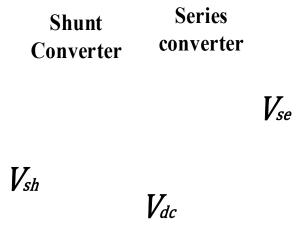


Fig. 1. Basic representation of UPFC

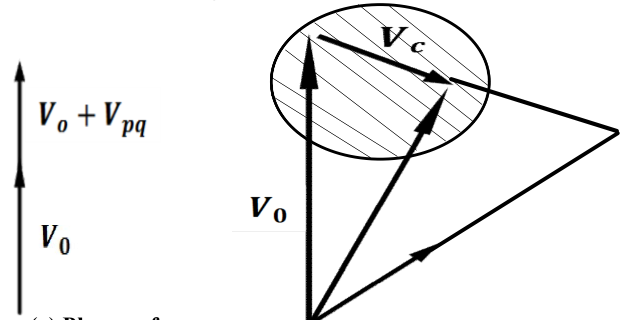
Fig. 1 shows the basic structure of UPFC, the Shunt connected converter provides the task of managing the flow of reactive power, also gives dc power essential for both controllers, whereas series converter accomplishes the functions of phase angle compensation, regulation of voltage. To achieve these functions, UPFC injecting the voltage through series transformer (T/F) to the line. Changes in phase angle of this injected voltage V_{pq} can be made in between 0 to 2π and magnitude of injected voltage changes in between ($0 \leq V_{pq} \leq V_{pqmax}$) [5] [6]. The equations which describes the control of power by UPFC are given below

$$P = \frac{V_1 V_2}{X} Sin\,(\delta - \beta) \tag{1}$$

$$Q = \frac{V_2}{X}(V_1 - V_2) \tag{2}$$

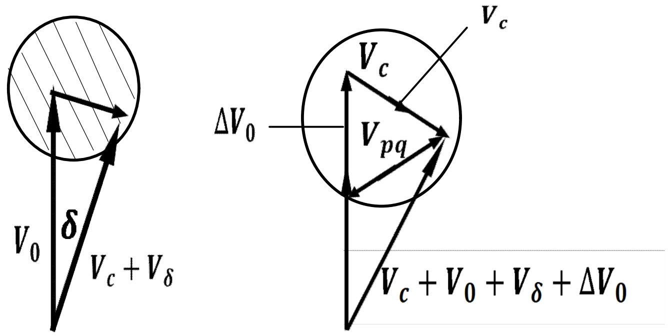
III. BASIC CONTROL OF UPFC FUNCTIONS

The unified power flow controller can accomplish the functions of phase shifting, reactive shunt compensation and series compensation by injecting voltage V_{pq} with the terminal voltage V_0. Phasor representation of the various functions of the UPFC shown in Fig. 2.



(a) Phasor of Voltage regulation

(b) Phasor of series compensation



(c) Phasor of phase angle regulation

(d) Phasor of Mulifunctional power flow control

Fig. 2. Basic Control Functions of Unified power flow controller : (a) phasor of Voltage regulation (b) phasor of series Compensation, (c) Phasor of phase angle regulation (d) phasor of Multifunctional power flow control.

A. Regulation of voltage: Phasor (a) of Fig. 2 shows voltage regulation where V_{pq} is injected out or in phase with the terminal voltage.

B. Series capacitor compensation: Phasor (b) of Fig. 2 shows series compensation here $V_{pq} = V_c$ is added in quadrature with the current (I) of the line

C. Regulation of phase angle: This function of UPFC is shown in phasor (c) of Fig. 2, where $V_{pq} = V_0$ is added with an angle (δ) with respect to V_0 to obtain phase shift without any alternation in magnitude.

D. Multifunctional Control of power flow: Phasor (d) of Fig. 2 shows combined functions (phase shifting, regulation of terminal voltage and Series capacitor compensation) simultaneously where $V_{pq} = \Delta V + V_c + V_0$ [7].

IV. POWER FLOW STUDIES BASED UPFC INJECTED MODEL

This section describes the influence of UPFC in steady state of the power system. Since series converter or compensator does the essential function of the UPFC, so modeling of this converter is obtained.

A. Modeling of series converter

Assume a voltage source of series connected is situated between 'i' and 'j' nodes of an electrical network system. Source voltage connected in series can be designed by adding reactance $X_{series}$and a series voltage V_{series} consider as ideal voltage as illustrated in Fg. 3.

Here $V_i' = V_{series} + V_i$ (3)

Where

V_i' = voltage (fictitious)

V_{series} = Voltage source connected in series

V_i= i node voltage

Controlling the voltage (V_{series}) is described in eq.4.

$V_{series} = rV_i e^{j\beta}$ (4)

where r = co-efficient of V_{series} ($0 < r < r_{max}$) and β is angle of V_{series} ($0 < \beta < 2\pi$)

The injected model is achieved by substituting the equivalent circuit (ckt) of V_{series} as Norton's equivalent circuit as illustrated in figure 4,

Where I_{series} (source current) $=-1 b_{series} V_{series}$ and $b_{series} = \frac{1}{X_{series}}$

The power inserted into the i^{th} bus is

$S_{iseries} = V_i I_{series}$ (5)

$S_{iseries} = V_i\ [j b_{series} V_i\ r e^{1\beta}]$

$S_{iseries} = -b_{series} V_i^2 \sin\beta - b_{series} V_i^2 \cos\beta$ (6)

Similarly the power inserted into the j^{th} is given by

$S_{jseries} = V_j\ (I_{series})$ (7)

$$S_{jseries} = V_j \left[-jb_{series} V_i e^{j\beta} \right]^*$$

$$S_{jseries} = b_{series} r V_i V_j \, sin(\alpha_{ij} + \gamma) \; rViVj \, cos(\alpha_{ij} + \gamma) \quad (8)$$

$$\alpha_{ij} = \alpha_i - \alpha_j$$

injected representation of VSC connected in series is shown in Fig. 5.

B. Modeling of VSC (shunt connected)

Basically shunt connected converter is inserted into the system for supplying the real power. Suppose power system is free from losses then

$$P_{shunt} = P_{series}$$

The real power delivered by the series connected VSC is

$$S_{series} = V_{series} I_{ij}^* = re^{j\beta} V_i (V_i - \frac{V_{series}}{jX_{series}}) \quad (9)$$

After solving above equation, power delivered by converter 2 is

$$P_{series} = rb_{series} V_i V_j \, sin(\alpha_i - \alpha_j + \beta) - rb_{series} V_i^2 \, sin\,\beta \quad (10)$$

$$Q_{series} = rb_{series} V_i V_j \cos(\alpha_i - \alpha_j + \beta) \, rb_{series} V_i^2 \cos\beta + r^2 \, b_{series} V_i^2 \quad (11)$$

UPFC independently controls the reactive power either supplied or consumed. Shunt controller perform this function, it is therefore designed as an independent shunt reactive controllable source. Suppose $Q_{shunt} = 0$ (In above the probability to control Q_{shunt} is examined). Hence, injected model of unified power flow controller construed from the model of V_{series} shown in (Fig. 5) with the joining of a power equivalent to $P_{shunt} = 0$ at i node. Therefore model illustrated in figure 6 clears that in a lossless UPFC, there is no real power exchange between UPFC and power system.

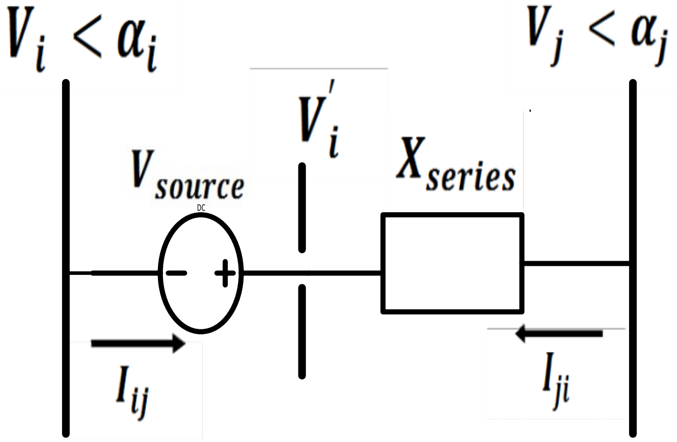


Fig. 3 Representation of series connected voltage source

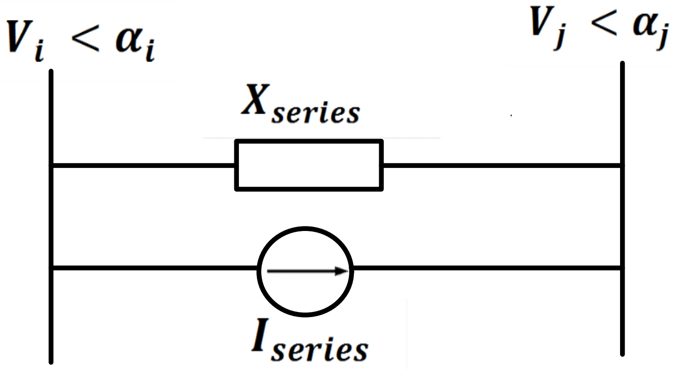


Fig. 4. Replacement of a series voltage source by a current source

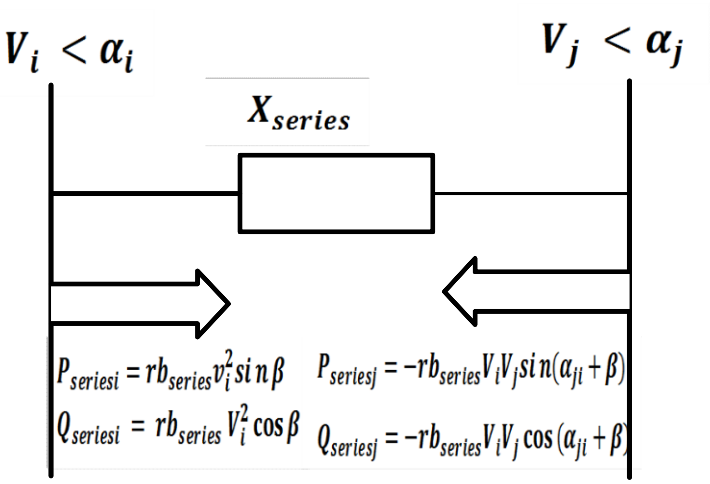


Fig. 5. Injection model for a series connected VSC

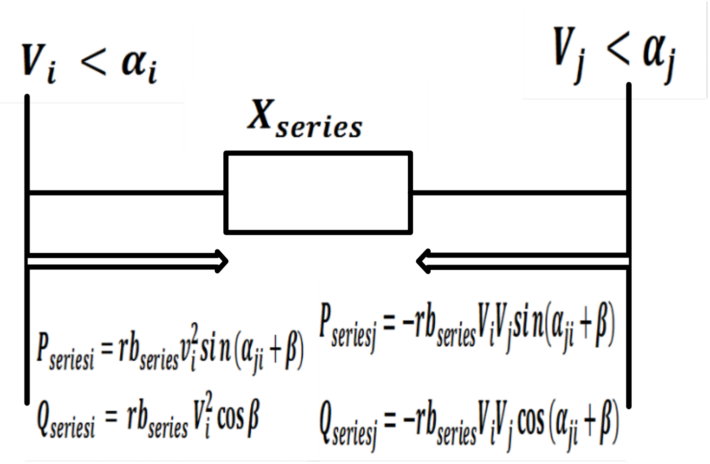


Fig. 6. Complete UPFC mode

V. LITERATURE REVIEW

A Matrix converter technique based UPFC permits direct conversion of AC/DC power & there is no need of any dc capacitor link, this decreases cost, volume and power losses in capacitor [8]. Due to high voltage & power abilities converters based on multi levels for UPFC are very effective. Neutral point clamp (three level) converter enhance the performance of UPFC by balancing dc capacitor voltage [9]. Unified power flow controller based on fuzzy logic controller increase the transfer of power flow and also reduces power losses and increases voltages [10]. A Cascade multilevel inverter (CMI) based UPFC which is transformer free technology has many advantages over conventional based UPFC. It is less weight, cheap, high reliable and quick response. It is very beneficial for those areas where fast power control is required [11]. A modulator multilevel converter for UPFC is very attractive under the situations of grid unbalance [12]. Restoration issues of electrical power system can be minimizing by using PI^2 controller with redox flow battery and unified power flow controller [13]. By placing UPFC at the optimal location the security of power system can be enhanced [14]. For the minimization of load buses voltage deviation and losses in T/Ls, dispatching of reactive power is necessary, a oppositional krill herd algorithm and installation of unified power flow controller in identical algorithm is very effective for reactive power dispatch [15]. UPFC with two individual neuro controllers one for shunt converter and other for series converter enhance large signal stability and controlling the flow power [16]. For the proper operation of electrical power system quality of power plays a major rule, UPFC is helpful to mitigates PQ issues like voltage sag, swell [17]. UPFC with z-source converter is identical for power control in large Transmission lines [18].

VI. METHODOLOGY

In order to describe the effect of UPFC for the mitigation of PQ issues, a feeder of Gulzar Colony Hyderabad is simulated by using MATLAB/SIMULINK software as described in Fig. 7. Rectifier and inverter circuit is described in Fig.8. Table I shows feeder's technical data used in simulation.

TABLE I
TECHNICAL DATA OF THE FEEDER

Single phase source	230 V,50 HZ
Feeder parameters	0.03 Ohm,1.067e-4 H
RL Load 1	3KW
RL Load 2	4KW
Dc capacitor link	330e-6
Inductance of filter	5.6e-3
Capacitance of filter	5e-3

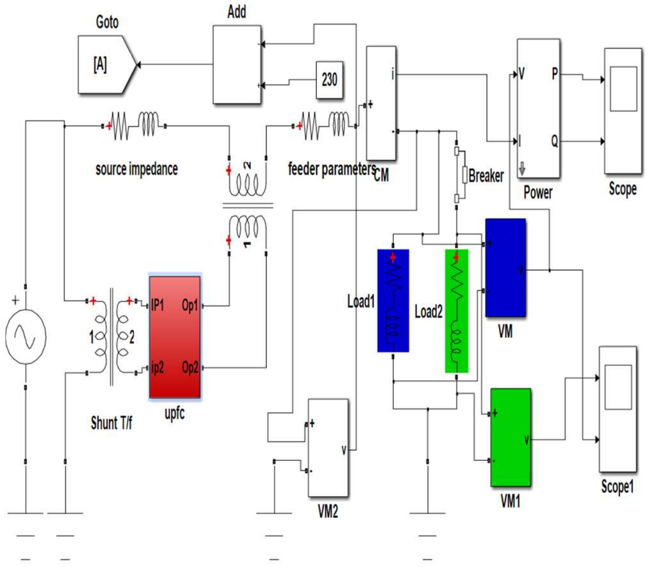


Fig. 7. UPFC with PID controller

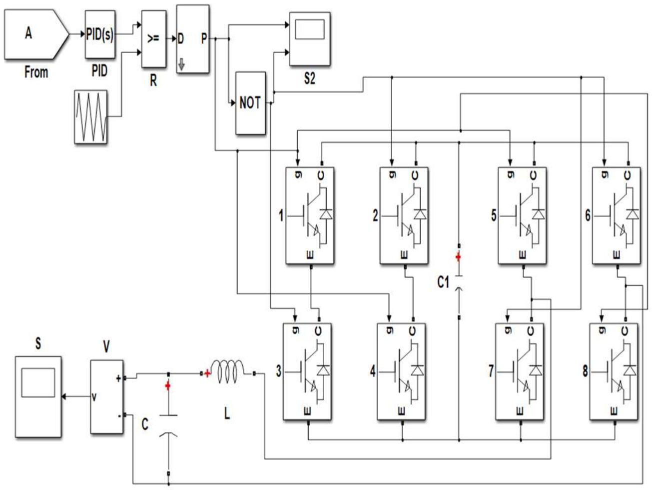


Fig. 8. Rectifier – inverter circuit

VII. RESULTS AND DISCUSSION

A. open loop simulation

This section is all about results obtained by performing simulations. Feeder has been investigated under the condition of adding heavy load in the system (voltage sag) condition and condition of removing heavy load (voltage swell) condition. Elimination of sags in open loop is pictured in Fig. 9. Sags are induced at 0.3 sec because of large load is introduced in the system. UPFC in connected in the system at 0.4 sec and sags are removed. Real and reactive power waveforms in sag elimination condition are shown in Fig. 10.

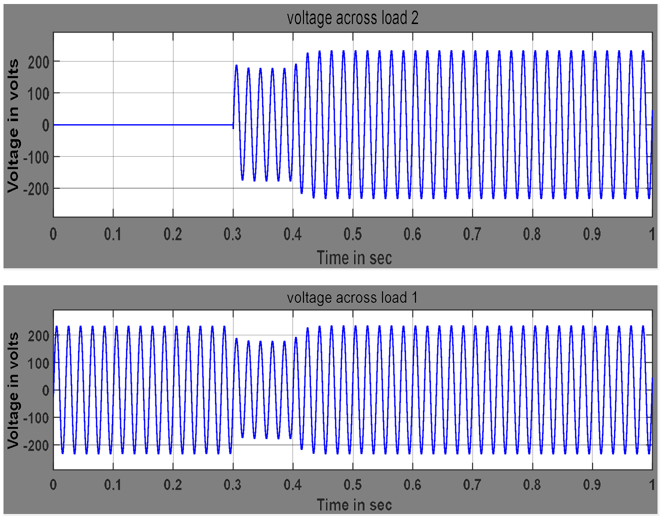


Fig. 9. Load voltage waveforms under mitigation of sag (open loop)

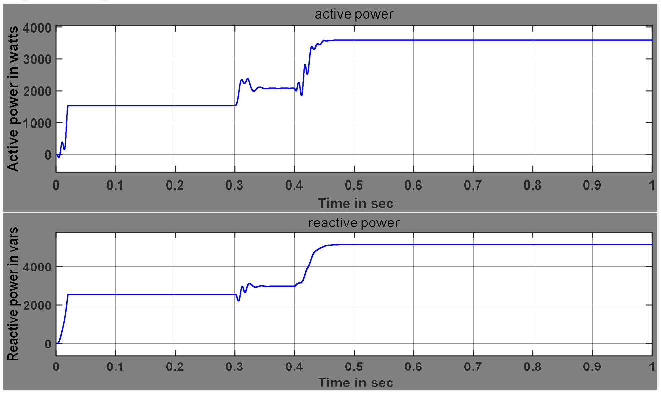


Fig. 10. real and reactive power waveforms under mitigation of sag (open loop)

The effect of UPFC for voltage swell compensation is illustrated in Fig. 11. Here in this case at 0.3 sec heavy load is suddenly disconnected from the network system as a result swells entered, UPFC eliminates these swells at 0.4 sec as shown in Fig.11. Power waveforms under swells mitigation situation are shown in Fig. 12.

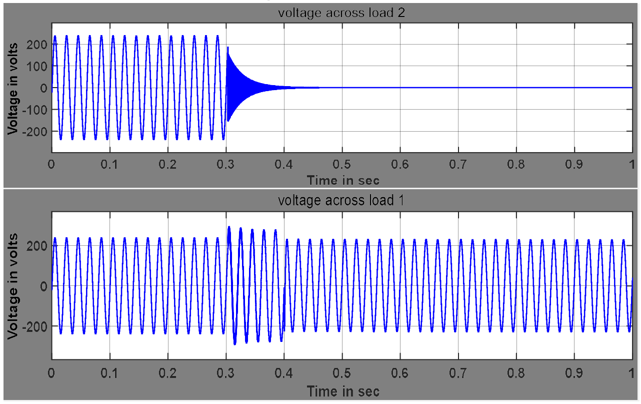


Fig. 11. Load voltage waveforms under mitigation of swell (open loop)

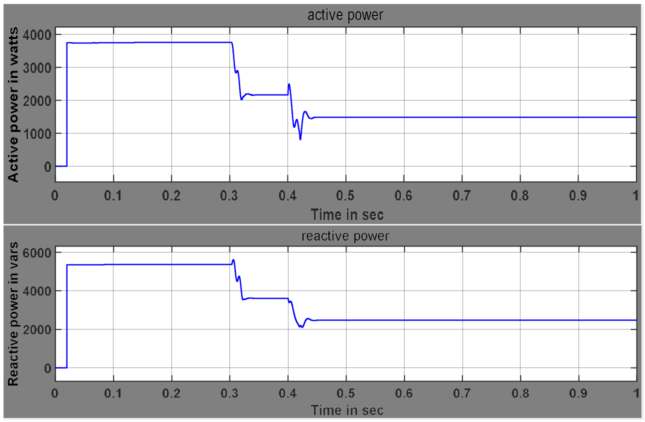


Fig. 12. Real and reactive power waveforms under mitigation of swell (open loop)

B. close loop simulation

In the close loop simulation as soon as sags are produced UPFC automatically comes into action and adding V_{series} to the line through series inverter to control the voltage dip. Fig. 13 shows load voltage waveforms and Fig.14 shows the waveform of power flow under sag compensation (close loop).

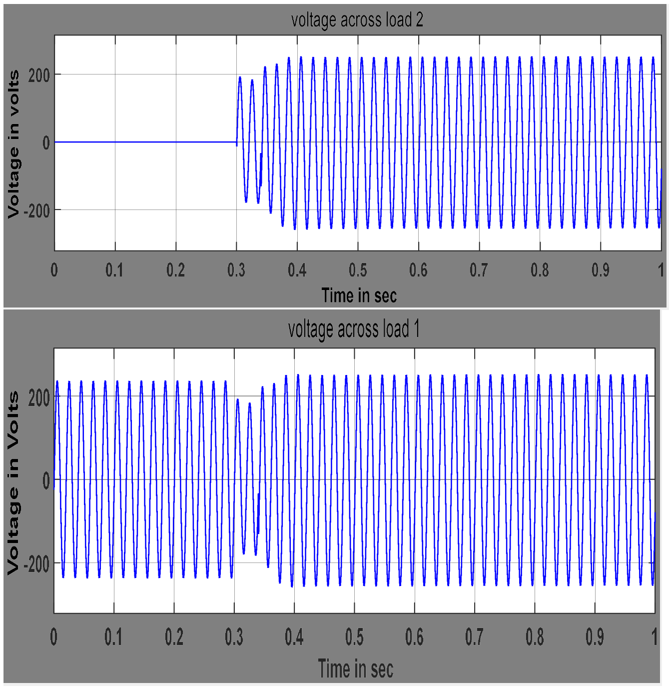


Fig. 13. Load voltage waveforms under mitigation of sag (close loop)

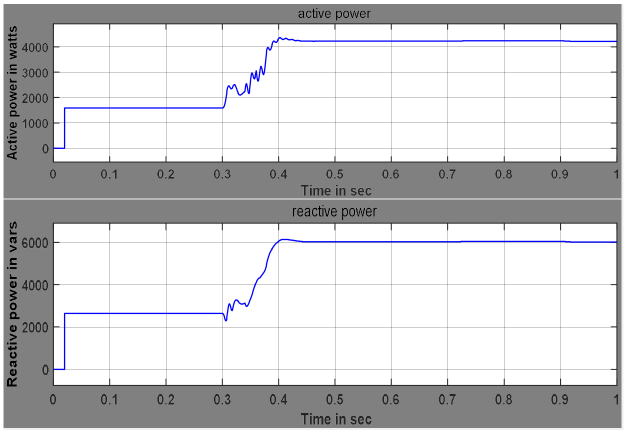


Figure 14. real and reactive power waveforms under mitigation of sag (close loop)

Similarly, the swells compensation in close loop by the usage of UPFC is described in Fig. 15 and Fig. 16 shows power flows (real and reactive) under voltage swell compensation

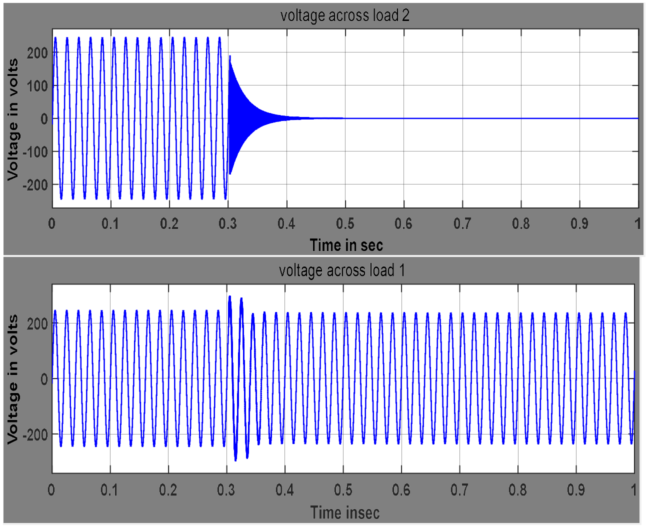


Fig. 15. Load voltage waveforms under mitigation of swell (close loop)

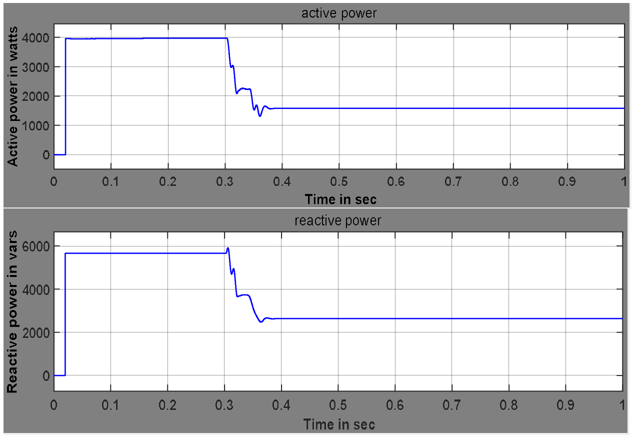


Fig. 16. real and reactive power waveforms under mitigation of swell (close loop)

A comparison between results (voltages and power flow) in graph representation is shown in below figures

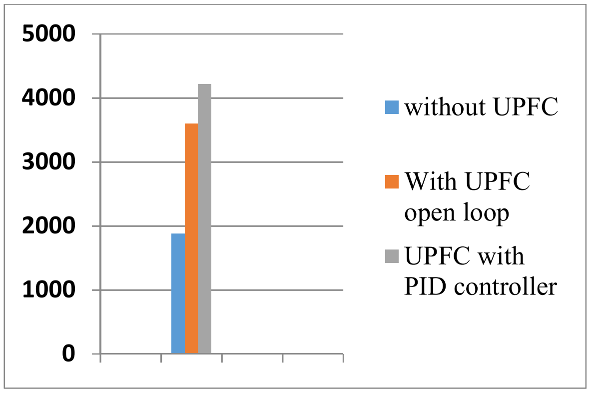


Fig. 17. comparison between real power flow

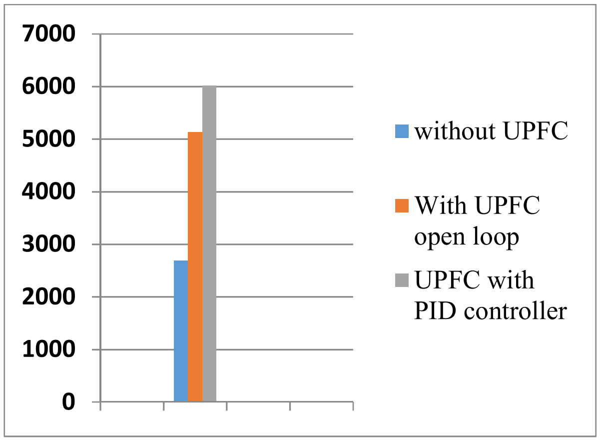


Fig. 18. comparison between reactive power flow

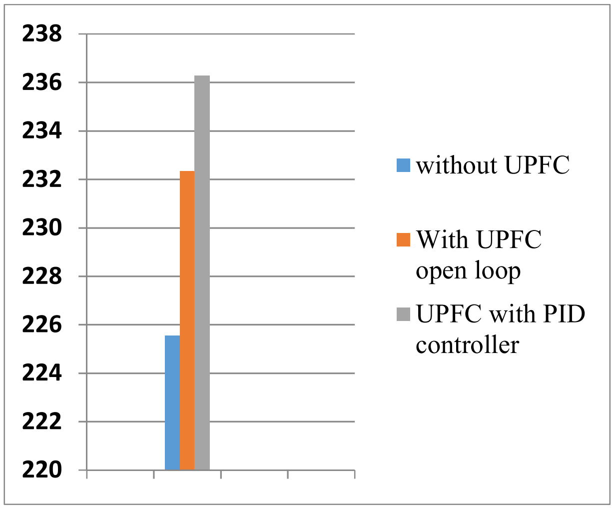


Fig. 19. comparison between load voltages

A comparison between results (voltages and power flow) in tabular form is shown in Table II.

.

TABLE II
COMPARISON BETWEEN RESULTS

S.NO	condition	Load voltages (V)	Real Power (W)	Reactive power (VAR)
01	Without UPFC	225.54	1878	2681
02	With UPFC (open loop)	232.33	3594	5129
t	With UPFC (close loop)	236.272	4211	6011

VIII. CONCLUSION

This paper presents UPFC based on a rectifier and inverter circuit to solve different PQ issues these are voltage sags and swells. MATLAB/simulink software is taken to simulate the test model to see the performance of UPFC for solving PQ issues. Results indicate that UPFC enhance power system's performance and maximizes the stability of the system and also improves quality of power. From the simulation outcomes, it is very much clear that the response of open loop is slower than close loop as for as time taken to reinstitute the normal voltage and the necessary amount of real and reactive powers for the prescribed load demand. With the use of UPFC power flows increases, real power is 1878 Watts when there is no UPFC installed in the system and maximizes to 3594 with UPFC, similarly there is a significant change in reactive power with the use of UPFC, without UPFC reactive power is 2681Vars and with UPFC it increases to 5129 Vars. Load voltages maximizes from 225.54 Volts to 232.33Votls. This paper uses PID controller in close loop superior outcomes can be achieved in Fuzzy controllers and adaptive Fuzzy controllers.

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REFRENCES

[1] M.R. Qader (2015), "Design and simulation of a different innovation controller-based UPFC (unified power flow controller) for the enhancement of power quality" pp.576-592 Elsevier science direct.

[2] S.Sumathi, Bansilal (2015),"Artificial Neural Network Application for Voltage Control and Power Flow control in Power Systems with UPFC" International Conference on Emerging Research in Electronics, Computer Science and Technology IEEE conference.pp.403-407.

[3] Jalal Khodaparast, Mojtaba Khederzadeh, Filipe Faria da Silva, Claus Leth Bak, "Power Swing Detection in UPFC-Compensated Line by Phase Angle of Current" IEEE JOURNAL ON EMERGING AND SELECTED TOPICS IN CIRCUITS AND SYSTEMS, VOL. 7, NO. 3, SEPTEMBER 2017.pp.459-468.

[4] Mahmoud A. Sayed, Takaharu Takeshita, "All Nodes Voltage Regulation and Line Loss Minimization in Loop Distribution Systems Using UPFC" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 6, JUNE 2011 pp.1694-1703.

[5] Mr.Narendra Neginhal, Mr. Girish Walke, "Application of UPFC for mitigating voltage and current related issues in Distribution System" International Conference on Energy Systems and Applications (ICESA 2015) IEEE International Conference, pp.669-674.

[6] Pengcheng Song, Zheng Xu, Chenxi Luo Hui Cai, and Zhenjian Xie," Voltage Sensitivity Analysis Based Bus Voltage Regulation in Transmission Systems with UPFC Series Converter" IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society. Pages: 483 – 488.

[7] H.Jmii, A.Meddeb, S.Chebbi, "Proper Placement of UPFC for the Improvement of Voltage Stability of IEEE-14 Bus System" Proceedings of 2016 4th International Conference on Control Engineering & Information Technology (CEIT-2016) Tunisia IEEE conference.pp.1-5

[8] J. Monteiro, J. Fernando Silva, S. F. Pinto and J. Palma, "Matrix Converter-Based Unified Power-Flow Controllers: Advanced Direct Power Control Method" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 26, NO. 1, JANUARY 2011 pp. 420-430.

[9] Natália M. R. Santos, J. Fernando Silva, Jan Verveckken, Vitor M. Fernão Pires and Rui Castro,"Enhancing the Ride-Through Capability of DC-Link Voltage in NPC MultilevelUnified Power-Flow Controllers" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 29, NO. 4, AUGUST 2014 pp. 1542-1550.

[10] Shameem Ahmad, Fadi M. Albatsh, Saad Mekhilef and Hazlie Mokhlis, "Fuzzy based controller for dynamic Unified Power Flow Controller to enhance power transfer capability"pp.652-665. Elsevier science direct.

[11] Fang Zheng Peng, Yang Liu, Shuitao Yang, Shao Zhang, and Ujjwal Karki, "Transformer-Less Unified Power-Flow Controller Using the Cascade Multilevel Inverter" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 31, NO. 8, AUGUST 2016 pp. 5461-5472.

[12] Quanrui Hao, Jiufang Man, Feng Gao and Minyuan Guan,"Voltage Limit Control of Modular Multilevel Converter Based Unified Power Flow ControllerUnder Unbalanced Grid Conditions" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 33, NO. 3, JUNE 2018 pp.1319-1327.

[13] R. Thirunavukarasu, I.A. Chidambaram, "PI2 controller based coordinated control with Redox Flow Battery and Unified Power Flow Controller for improved Restoration Indices in a deregulated power system" Ain Shams Engineering Journal (2016) 7, 1011–1027. Elsevier science direct.

[14] S. Ravindra, Chintalapudi V. Suresh, S. Sivanagaraju, V.C. Veera Reddy, " Power system security enhancement with unified power flow controller under multi-event contingency conditions" Ain Shams Engineering Journal (2017) 8, 9–28. Elsevier science direct.

[15] Susanta Dutta, Pranabesh Mukhopadhyaya, Provas Kumar Roy, Debashis Nandi, " Unified power flow controller based reactive power dispatch using oppositional krill herd algorithm" Electrical Power and Energy Systems 80 (2016) 10–25. Elsevier science direct.

[16] Ganesh K. Venayagamoorthy and Radha P. Kalyani, "Two Separate Continually Online-Trained Neurocontrollers for a Unified Power Flow Controller" IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 41, NO. 4, JULY/AUGUST 2005 pp.906-916.

[17] Abdul majeed khaskheli, Mukhtiar Ahmed Mahar, Abdul Sattar Larik and Shafquat Hussain Bhellar, " Power Quality Improvement in power system Network using Unified Power Flow Controller" 2018 5th International Multi-Topic ICT Conference (IMTIC). IEEE conference. DOI**:** 10.1109/IMTIC.2018.8467242.

[18] R. Thirumalaivasan, Yunjian Xu and M. Janaki, "Power Control With Z-Source Converter Based Unified Power Flow Controller" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 32, NO. 12, DECEMBER 2017 pp.9413-9423.