Performance and Analysis of Power Quality Improvement in TransmissionSystem using Optimal Unified Power Flow Controller

[1]Rajesh Reddy Duvvuru, Research Scholar, EEE Department, Dr. A. P. J. Abdul Kalam University, Indore

[2]Dr. Vikas Kumar Aharwal, Assistant professor, EEE Department, Dr. A. P. J. Abdul Kalam University, Indore

Abstract:

Voltage Source Converters (VSC) are used by the OUPFC, a FACTS controller, to account for shunt and series losses in multiline transmission networks. The OUPFC has improved system efficiency and offers the same control capabilities as comparable devices at a lower cost. This OUPFC device is installed in the gearbox line to reduce the various power quality issues in the gearbox system, such as voltage sag, current swell, and total harmonic distortion.Low frequency power oscillations are a major issue that reduces the effectiveness of the power system. To get over these restrictions, OUPFC with POD controller is utilised to eliminate low frequency power fluctuations in the gearbox system. This study employs PID and POD controllers to monitor the efficacy of the results. The recommended findings are validated and their efficacy is evaluated using MATLAB/SIMULINK software.

I. Introduction

Series shunt and combination controllers are two examples of FACTS devices that have their own control capabilities [1]. When compared to other devices, the Optimal Unified Power Flow Controller (OUPFC), one of the FACTS controllers, offers better control capabilities. The need for electricity has been growing quickly over time, necessitating the installation of several power plants to supply the demand. This causes a number of serious issues, including low-frequency power oscillations and power quality issues. These oscillations will be between 0.2 and 3 HZ, and in order to counteract the effect of loss-of-synchronism, their size will continue to increase [2].The system will experience significant oscillations when a set of generators in one area travels together and is connected to another group in a different location. Power System Stabilisers (PSSs) were used in earlier studies to eliminate all of these hazardous oscillations. This work provides a Power Oscillation Damping (POD) controller to demonstrate how these kinds of oscillations can be suppressed [3-4].

The Gate Turn Off (GTO) thyristor, which is the most powerful switching device available, is frequently employed in gearbox system active and reactive power regulation. OUPFC is regarded as a three converter controller since it has two series and one shunt converters. Both converters are connected by a common DC link, and real and reactive power are transferred between them via this link. The OUPFC is one of the FACTS devices that monitors five power system parameters, including real and reactive powers, bus voltages at both ends, and reactive power compensation.A 48-pulse GTO based VSC full model is utilized in an OUPFC together with four 12-pulse converters to create a single 48-pulse converter [5]. In comparison to other converters, the 48-pulse VSC minimizes the issues with power quality and produces less harmonic distortion as the pulse number increases. Without altering the order of bridges, a converter's THD in output voltage can be reduced. The overall cost of these converters can be minimized by lowering the number of transformers in them [6].

II. OUPFC Structure

The OUPFC is a Voltage Source Converter (VSC) based FACTS controller [7]. The operation of two series converters is similar to SSSC which is used for injecting the voltages into the line and also minimizes the transmission losses in power system as shown in figure .1.

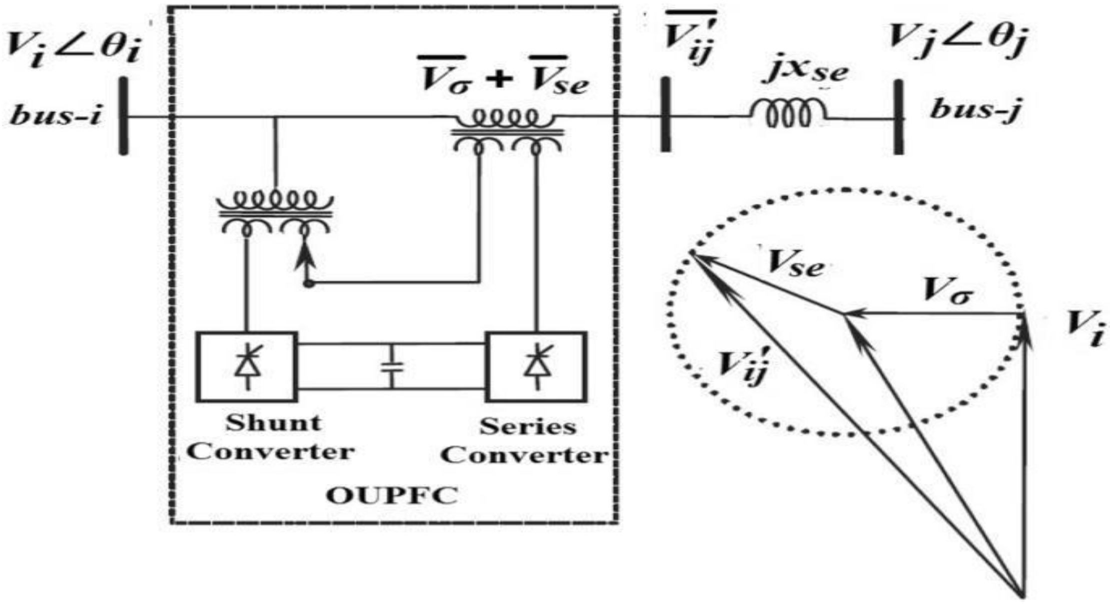


Figure.1. Schematic diagram of OUPFC

The equivalent shunt circuit diagram comprises a 3-phase GTO thyristor, step down transformer provided with single leakage reactance and a capacitor which placed at DC side as shown in figure .2. The primary objective of shunt converter is to control the magnitude of bus voltages by producing the reactive power through the transformer leakage reactance, the reactive power can be transmitted by keeping the secondary voltage in phase with the primary voltage of the transformer.

The corresponding OUPFC is represented in figure.2, which is implemented in making changes in IPFC and UPFC circuit diagram [8]. Where V_p be the output voltage of the transformer L_p, L_c be the leakage inductances and R_p, R_c be the resistances related to particular transformers. The shunt converter acts as an inductor, when the voltage across the secondary side is less than system voltage, similarly shunt converter acts as a capacitor when the secondary side is more than system voltage. When the converter acts as an inductor the converter absorbs the reactive power and the converter generates the reactive power when it acts as a capacitor. Due to losses occurred in the inverter, the voltage across every bus leads the voltage across the inverter with a minute angle during the stable region. The main objective of voltage source converter is to generate a pure sinusoidal waveform with least waveform distortions [9].

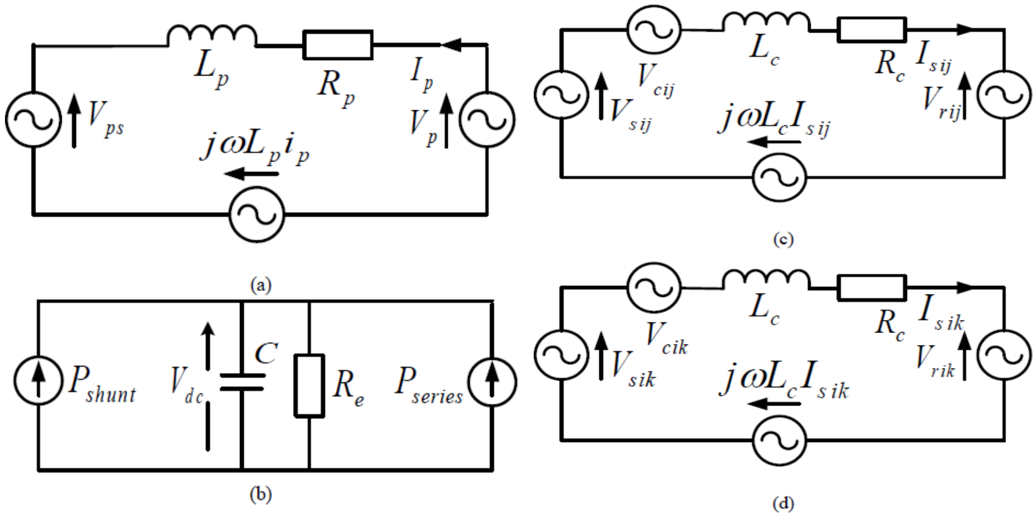


Figure .2. Corresponding circuit of OUPFC (a) shunt element of synchronous d-q frame (b)AC/DC active power flow (c) & (d) series element in the synchronous d-q frame

In general, three techniques are utilised to remove harmonics from the system that are brought on by switching processes. By employing magnetic coupling, pulse width modulation switching, and multilayer converter topologies that use four 12-pulse converters instead of a single 48-pulse converter, harmonics can be eliminated. Lower order harmonics may simply be cancelled out by increasing the number of pulses since the third harmonic is the most hazardous harmonic of all. When compared to other converters like the (6,12,24, and 36) pulse voltage source converter, the 48-pulse voltage source converter produces less harmonic distortion because harmonics become less prominent as the pulse number increases.

III. Design of OUPFC with Power Oscillation Damping Controller

Power system connections might result in poor power quality issues including overloading of motors, short circuits between lines, gearbox line problems, etc. These issues can be resolved by the OUPFC, a novel power flow control device employed in this work [10].Low-frequency power oscillations that result from the interconnection power system are one of the biggest issues with power quality. Figure.3 depicts the development of an OUPFC-POD controller, which is subtly connected to the PSS controller. The POD controller has to be connected to the OUPFC controller in order to dampen these oscillations. Lead-lag blocks are employed in a method that provides phase-shifting features to get rid of the changes between the oscillation input signal and the OUPFC output variable. The lead-lag block time constants (Tlead, Tlag) and amplification gain (K) are regarded as the POD controller's design parameters. Any oscillatory signal, such as line current, power flow, or bus voltages, may be used as the input signal to the POD controller.

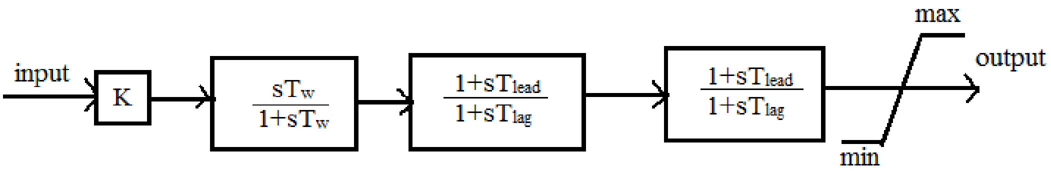


Figure.3. Block diagram of POD controller

IV. Simulation Results

The OUPFC is assessed using the three test cases. A three-phase fault is injected into the transmission line of the proposed system [11]. To reduce power quality concerns and low-frequency power oscillations in transmission networks, OUPFC with conventional controllers might be offered.

Case 1: Single machine connected to infinite bus system (SMIB)

Figure.4 shows the OUPFC device's transmission line connection from the Simulink schematic for SMIB with PID controller. It is recommended that a three phase fault be induced into the transmission line of the proposed system in order to evaluate the voltage sag, current swell, and THD values both with and without an OUPFC-PID controller.

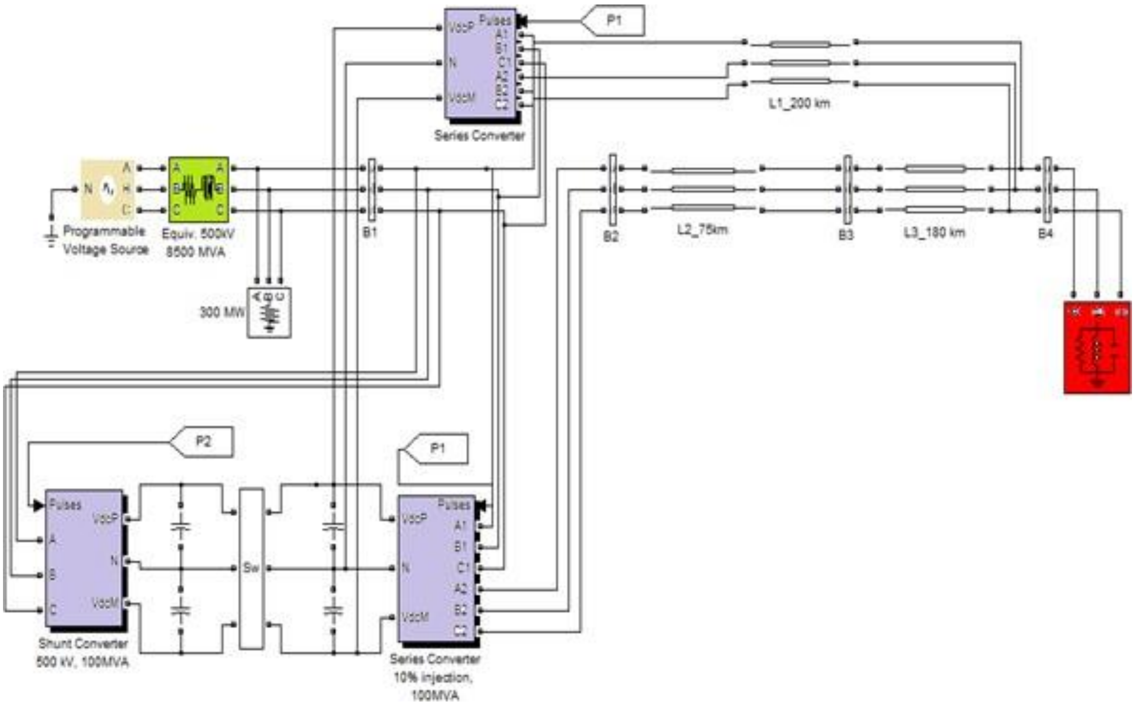


Figure.4 Simulink model of SMIB for OUPFC with PID controller

The OUPFC is placed between the bus1 and infinite bus as shown in figure.5. In this case voltage sag, current swell and total harmonic distortion are analyzed.

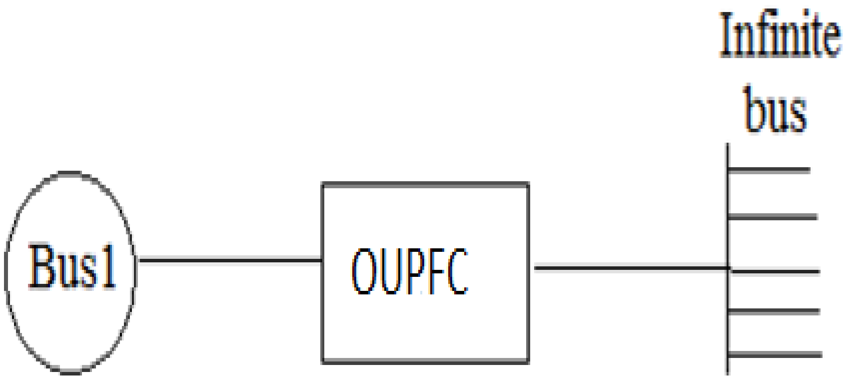
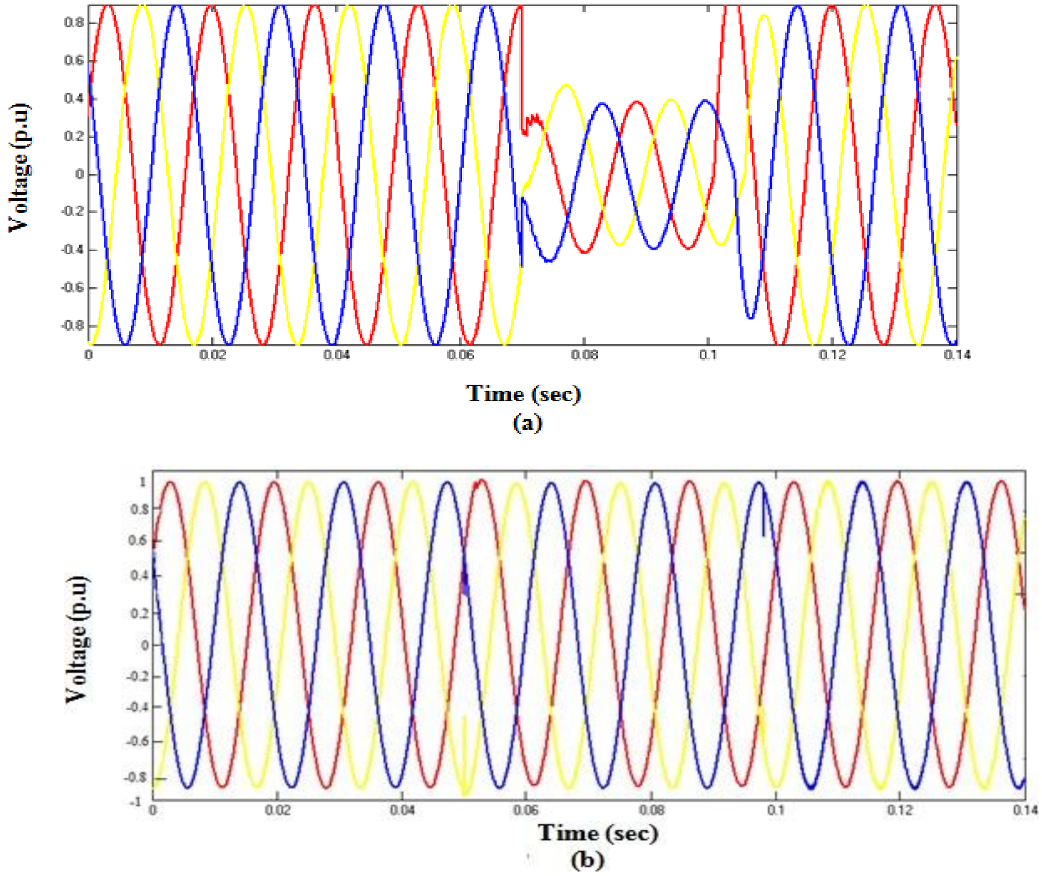


Figure.5 Single line diagram of SMIB with OUPFC

In the simulation model up to time t = 0.07 sec the three phase source is supplying the power to the load, for time t = 0.07 sec the OUPFC is connected to the source.

1. Voltage Sag:



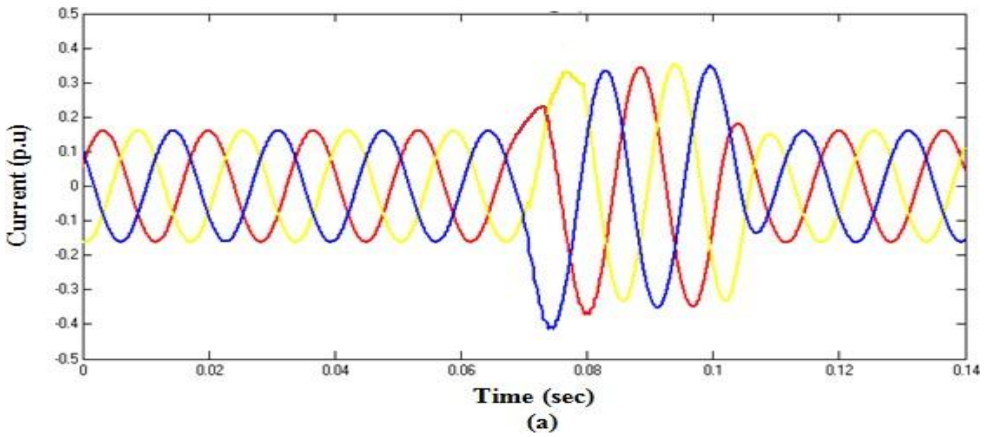
(a)

(b)

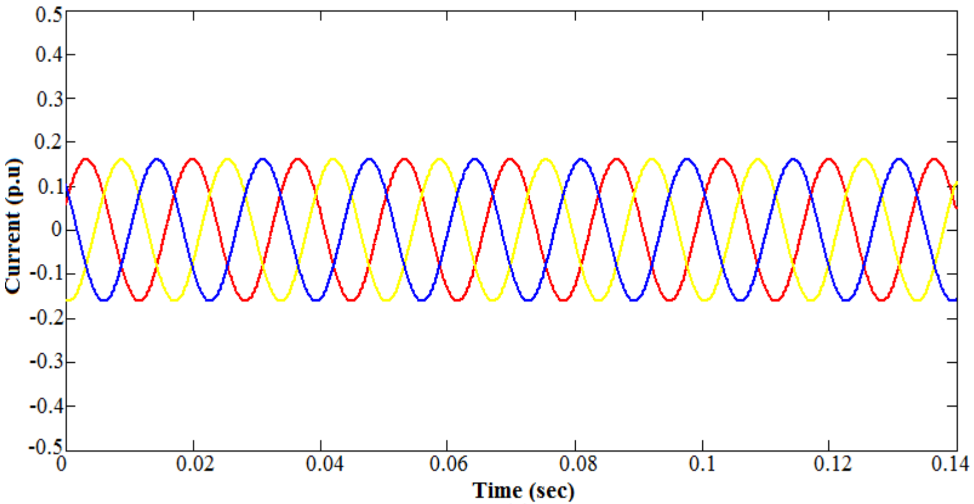
Figure.6 Three-phase voltage sags without and with OUPFC-PID

According to the aforementioned findings, the voltage sag value during the fault is approximately 0.41 p.u during the time period of 0.07 sec to 0.11 sec, as indicated in the aforementioned figure 6(a). The voltage sag can be efficiently reduced by installing an OUPFC, as seen in figure 6(b) above.

2. Current Swell:



(a)



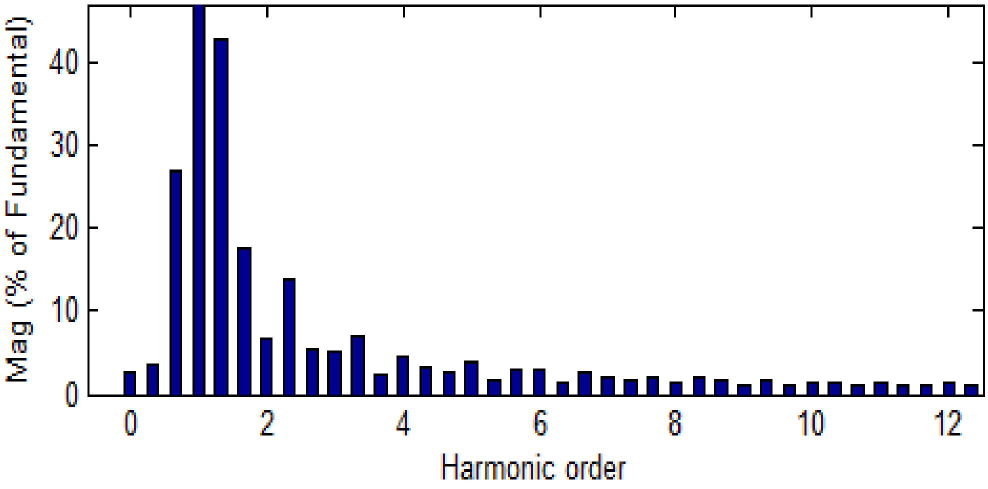
(b)

Figure.7 Three-phase current swells without and with OUPFC-PID

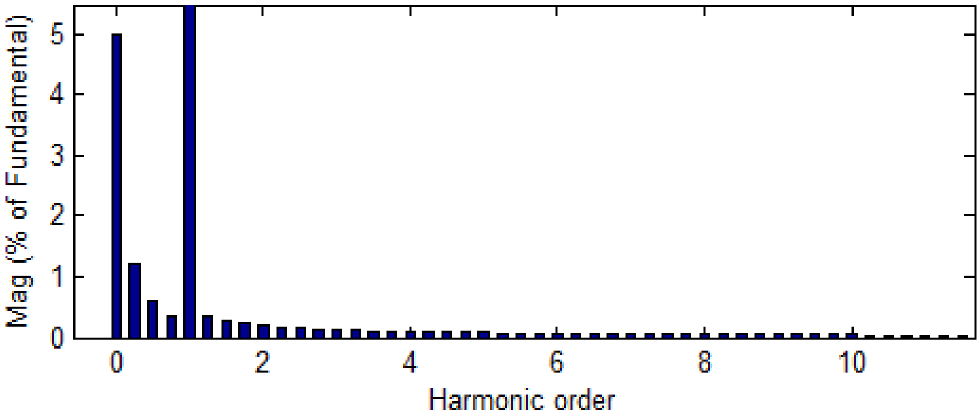
According to the aforementioned findings, the fault's current swell value is around 0.39 p.u between the time intervals of 0.07 and 0.11 seconds, as seen in the aforementioned figure.7(a). As seen in the above image, the current swell can be efficiently controlled by inserting an OUPFC.7(b).

3. Total Harmonic Distortion:

Load voltage harmonic analysis without and with OUPFC through FFT analysis is examined.



(a)



(b)

Figure.8 Total harmonic distortion of load voltage without and with OUPFC-PID

Figure.8 shows that the THD value of the load voltage is reduced from 11.83% to 0.30% after the OUPFC is installed, meaning that the standard THD is less than 5% in accordance with IEEE regulations.

Case 2: 30-bus system

Figures.9 shows the 30-bus system OUPFC device of simulink diagram with PID controller is connected in transmission line.

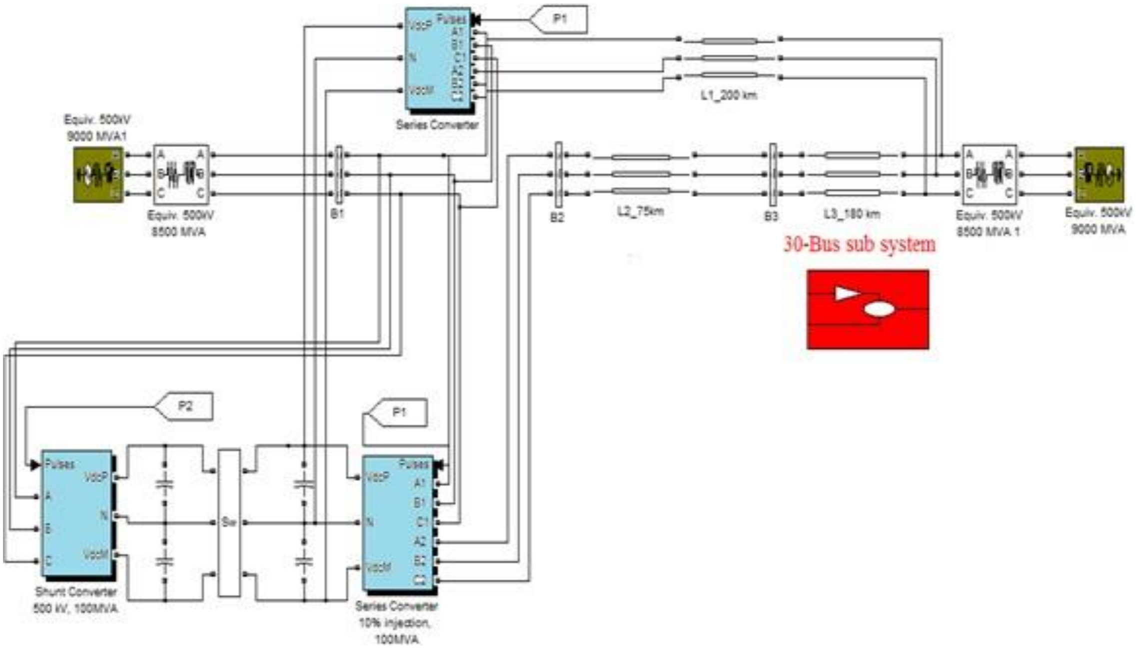


Figure.9 Simulink model of 30-bus system for OUPFC with PID controller

Using the Simulink model without the OUPFC, the power flow analysis, including active power and reactive power, may be determined. Between 8 and 28 bus systems, active power and reactive power may be raised by 1060 MW and -1024 MVAr, respectively.

Accordingly, the OUPFC is in the best location for this load condition between 8 and 28 buses based on variations in active and reactive powers. The OUPFC is currently placed at each site with the determined rating, and the system performance is assessed once more. The table below provides the outcomes using the OUPFC device at the specified table1. Analysis of the data reveals that when OUPFC places between 8 and 28 buses, losses are reduced and active and reactive power are balanced. Figures 10 and 11, respectively, depict the structure of the IEEE-30 bus without and with the OUPFC system. A comparison of the placement of 8 to 28 buses with and without OUPFC is made in terms of their active and reactive powers. The table below compares the performance of the system with and without OUPFC.2. This table shows that the active and reactive powers are 1060 MW and -1024 MVAr, respectively, in the absence of an OUPFC device. These valves are enlarged to 1567 MW and -1513 MVAr, respectively, after installing an OUPFC device.

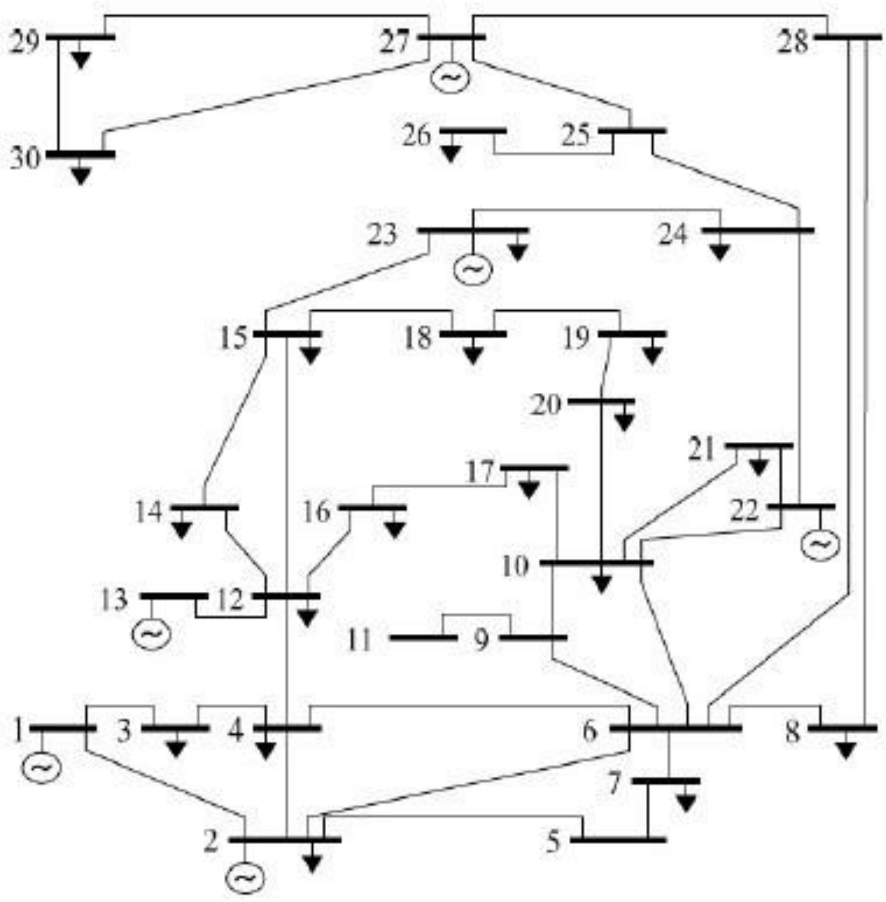


Figure.10 Standard 30-bus system

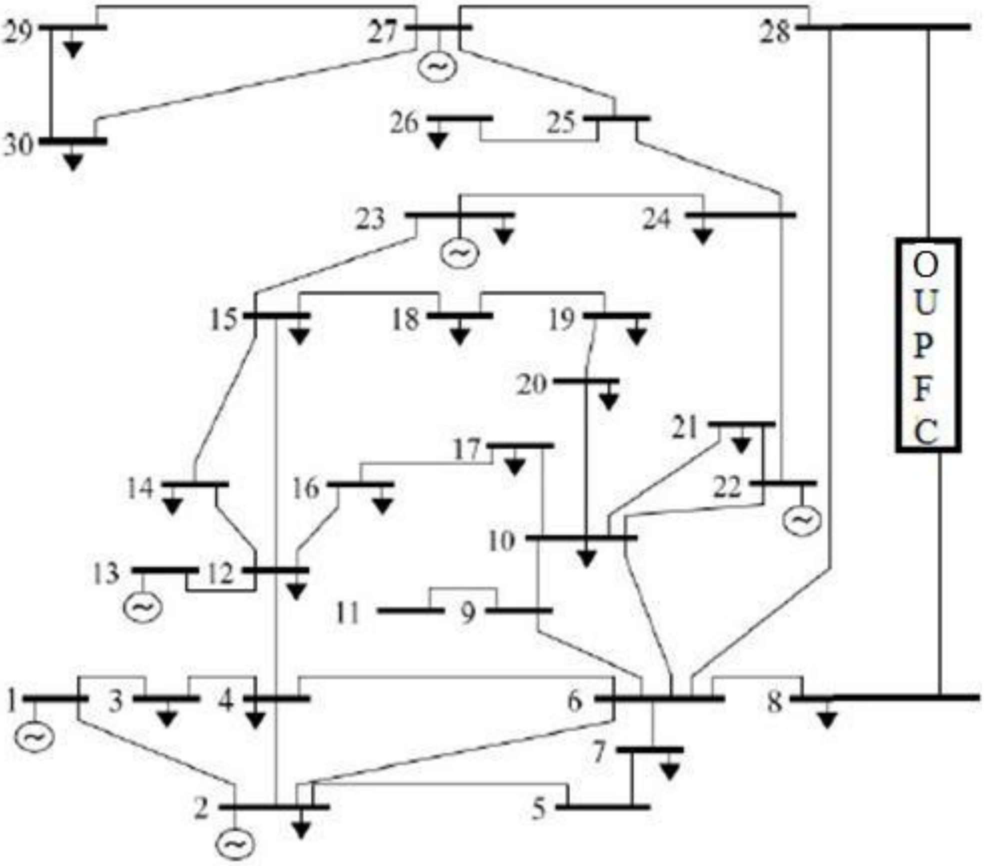
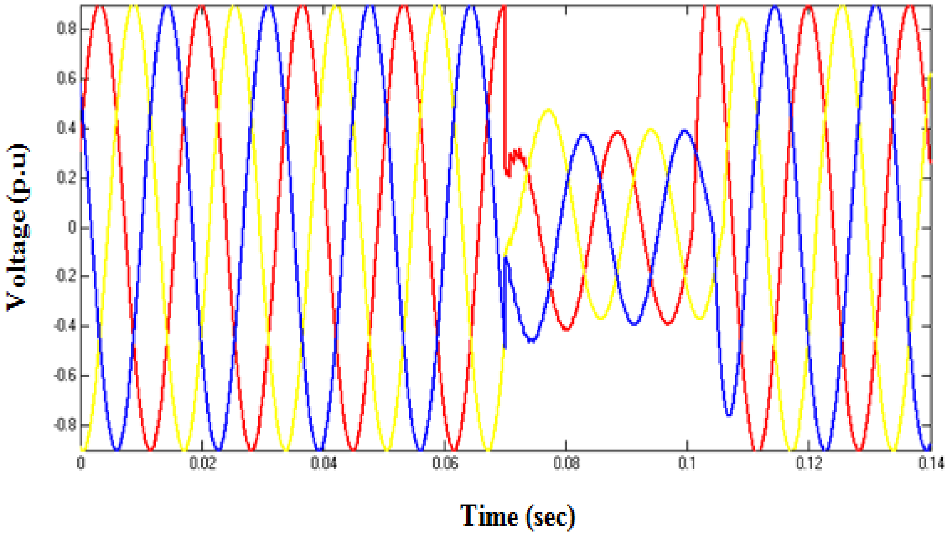


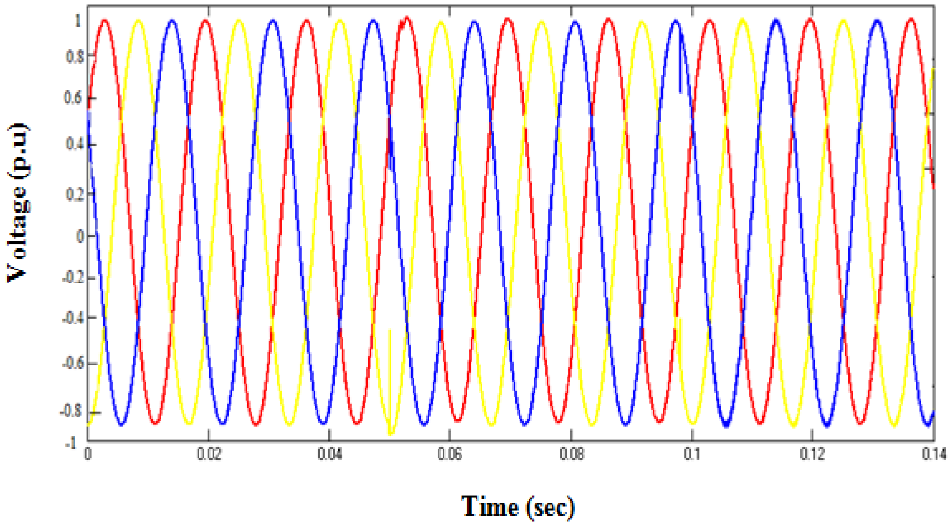
Figure .11 Standard 30-bus system with OUPFC

In the simulation model up to time t = 0.07 sec the three phase source is supplying the power to the load, for time t = 0.07 sec the OUPFC is connected to the source.

1. **Voltage Sag:**



(a)

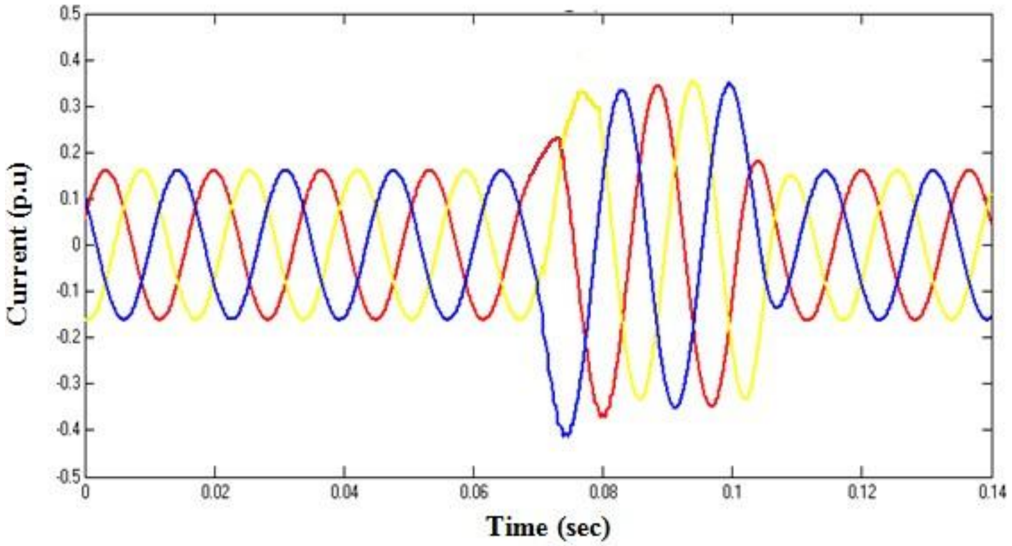


(b)

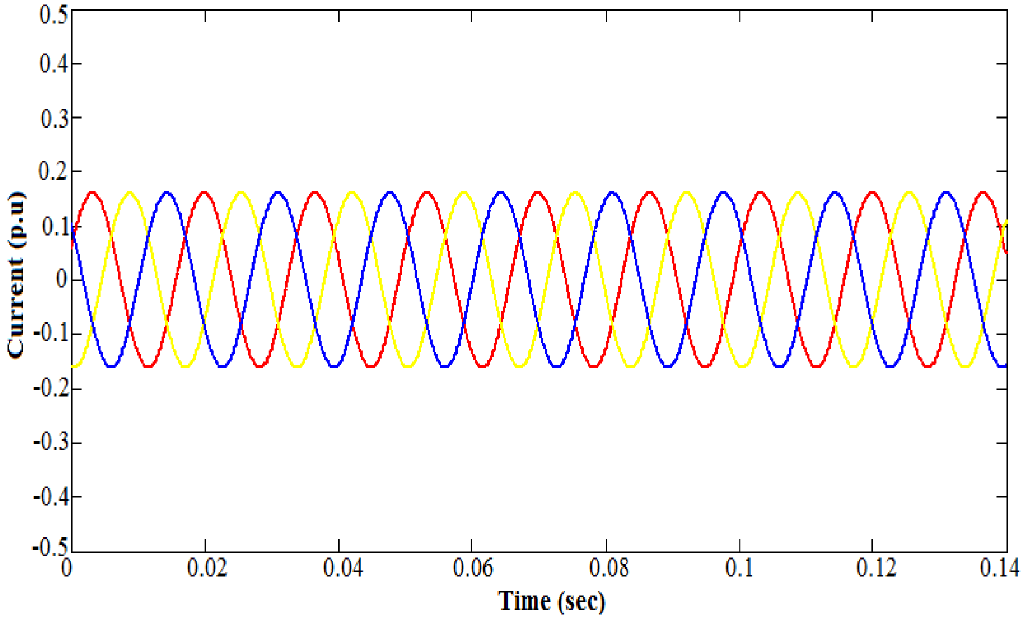
Figure.12 Three-phase voltage sags without and with OUPFC-PID

According to the aforementioned findings, the voltage sag value was around 0.42 p.u. during the fault, which lasted from 0.07 to 0.11 seconds, as indicated in the aforementioned figure.12(a). The voltage sag can be efficiently reduced by installing an OUPFC, as indicated in the above figure.12(b).

2. Current Swell:



(a)



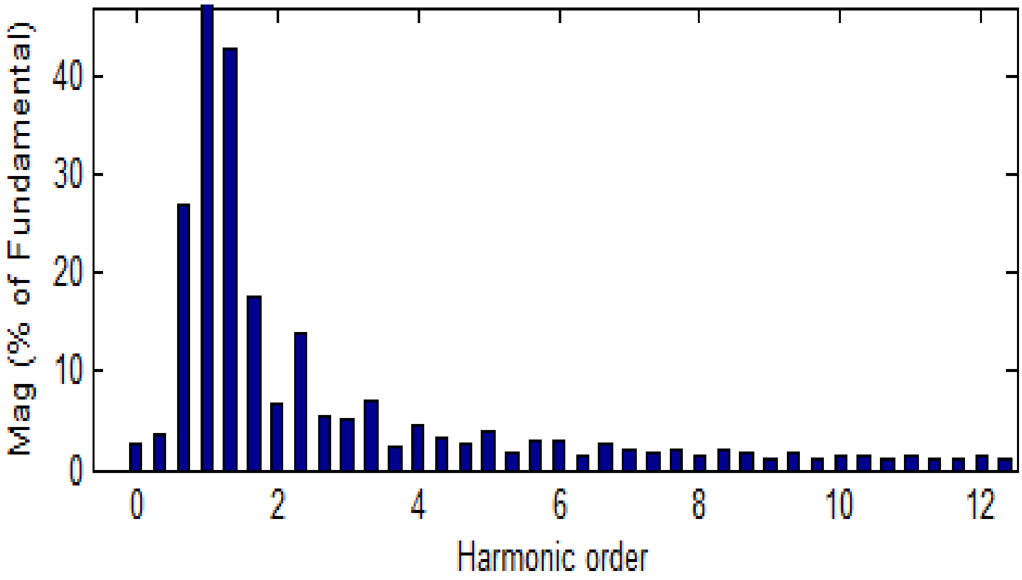
(b)

Figure.13 Three-Phase current swells without and with OUPFC-PID

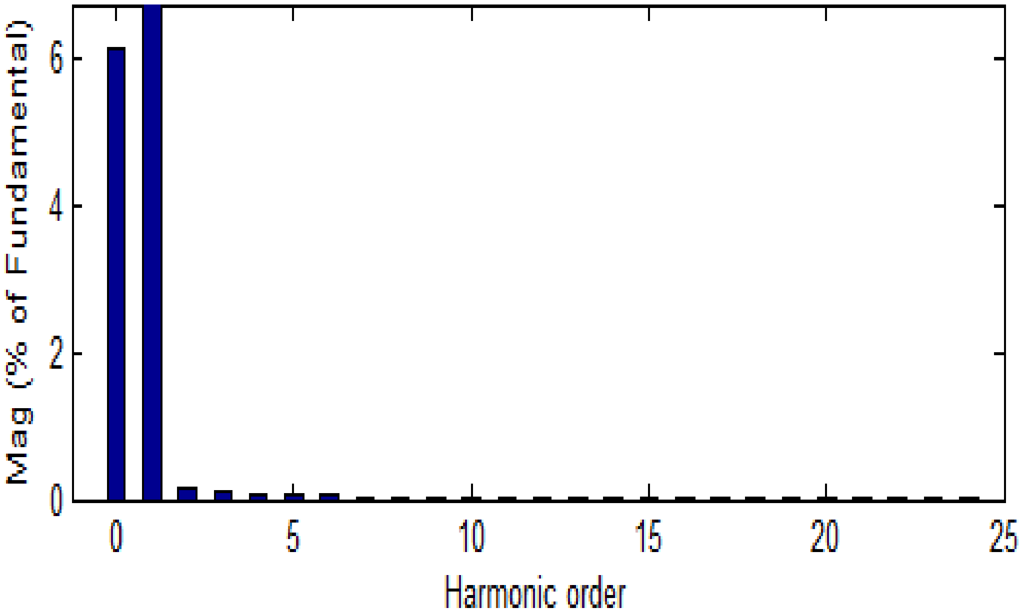
It is determined that, as shown in the above figure, the present swell value is around 0.38 p.u. during the fault and ranges from 0.07 to 0.11 seconds.13(a). As seen in the above image, the current swell can be efficiently controlled by inserting an OUPFC.13 (b).

3. Total Harmonic Distortion:

Load voltage harmonic analysis without and with OUPFC through Fast Fourier Transforms (FFT) analysis is examined.



(a)



(b)

Figure.14 Total harmonic distortion of load voltage without and with OUPFC-PID

From figure.14 it is noticed that after placing OUPFC the THD value of load voltage is reduced from 11.83% to 0.22 %, i.e., the standard THD is less than 5 % in IEEE standards.

Table.1: Power flow analysis for SMIB OUPFC with PID Controller

S. No	Bus from	Bus to	Power Flows without OUPFC(SMIB)		Power Flows with OUPFC (SMIB)	
			P (MW)	Q(MVAr)	P (MW)	Q (MVAr)
1	1	2	96	-120	132.0	-123.0

Table.2: Power flow analysis for 30-bus OUPFC with PID Controller

S. No	Bus from	Bus to	With out OUPFC		With OUPFC	
			Active power (P) (MW)	Reactive power (Q) (MVAr)	Active power (P) (MW)	Reactive power (Q) (MVAr)
1	1	2	9.70	-68.90	18.99	-116.7
2	1	3	0.00098	-0.000158	0.001983	-0.00098
3	2	4	9.70	-89.21	16.5	-160.5
4	3	4	9.70	-89.21	16.5	-160.5
5	4	6	9.70	-89.21	16.5	-160.5
6	5	7	1021	-969.20	1560	-1499
7	6	7	398	-1024	571	-1366

8	6	8	0.00089	-0.000102	0.002083	-0.000397
9	**8**	**28**	**1060**	**-1024**	**1567**	**-1513**

10	9	10	1.96	-35.2	3.71	-71.44
11	9	11	1.96	-35.2	3.71	-71.44
12	11	9	1.96	-35.2	3.71	-71.44
13	12	13	292.2	-201.3	399.7	-373.4
14	12	14	89.21	-289.34	139.2	-389
15	14	15	1.96	-45.7	3.71	-89.02
16	15	18	1.96	-45.7	3.71	-71.44
17	16	17	1.96	-45.7	3.71	-71.44
18	17	10	1.96	-45.7	3.71	-71.44
19	18	19	1.96	-45.7	3.71	-71.44
20	19	20	1.96	-45.7	3.71	-71.44
21	20	10	1.96	-45.7	3.71	-71.44
22	21	22	201.2	-201.3	399.7	-373.4
23	22	10	89.21	-289.34	139.2	-389
24	22	24	159.3	-520.7	310.4	-637.9
25	24	25	201.5	-863.6	397.8	-493.9
26	25	26	840.5	-920.3	1175	-1120
27	27	25	0.00104	-0.00024	0.001963	-0.000329
28	27	28	0.0040	-0.000254	0.00126	-0.00105
29	28	8	909.1	-1005	1210.8	-1206.66
30	29	30	0.00156	-0.00025	0.004052	-0.000859
31	30	27	0.00089	-0.00035	0.00198	-0.003297

Case 3: 2-Bus System

Figure.15 depicts the 2-bus system OUPFC device of simulink diagram with PID controller connected in transmission line.

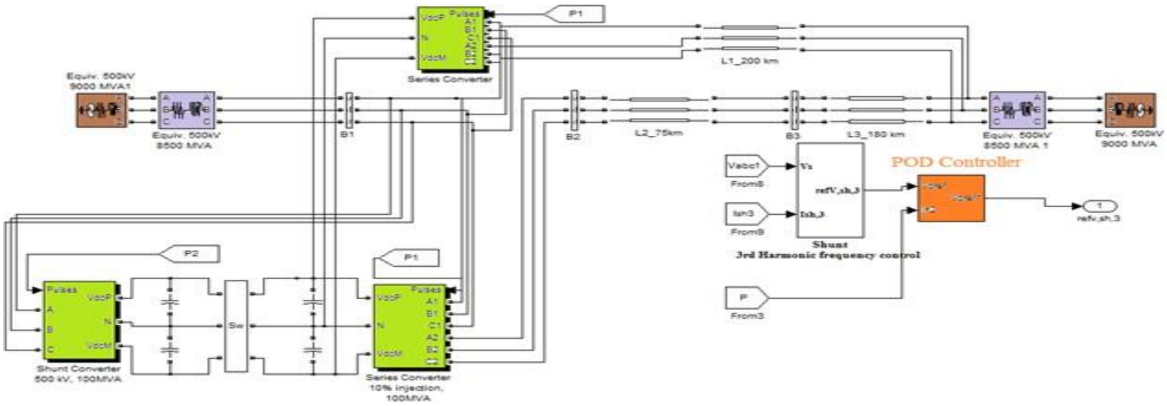


Figure.15 Simulink model of 2-bus system for OUPFC with POD controller

Two buses are used to analyse this case; two of them are regarded as generator buses. OUPFC is connected as depicted in the picture.16 between buses 1 and 2.

Figure.16 Single line diagram of two-bus system with OUPFC

It is recommended that a three phase fault be introduced into the transmission line of the proposed system in order to examine active power, reactive power oscillations, and bus voltages both with and without the OUPFC-POD controller. The three-phase source in the simulation model is feeding power to the load up until time t = 0.02 sec. The OUPFC is connected to the source at time t = 0.02 seconds.

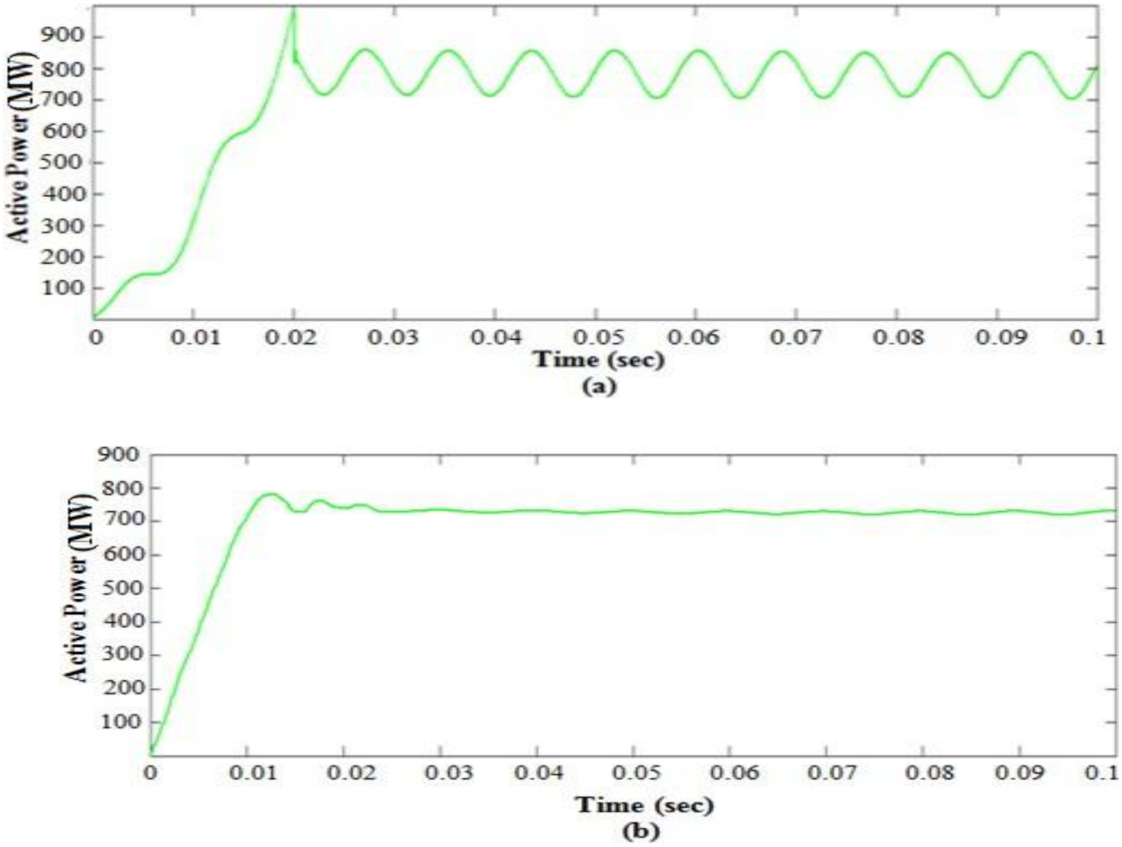


Figure.17 Active Powers without and with OUPFC-POD

According to the aforementioned findings, the active power oscillates more up until time t = 0.02 seconds into the fault, as illustrated in figure 17(a). As illustrated in figure.17(b), these oscillations are quickly decreased by adding an OUPFC.From time t=0.02 seconds on, these oscillations are stabilised.

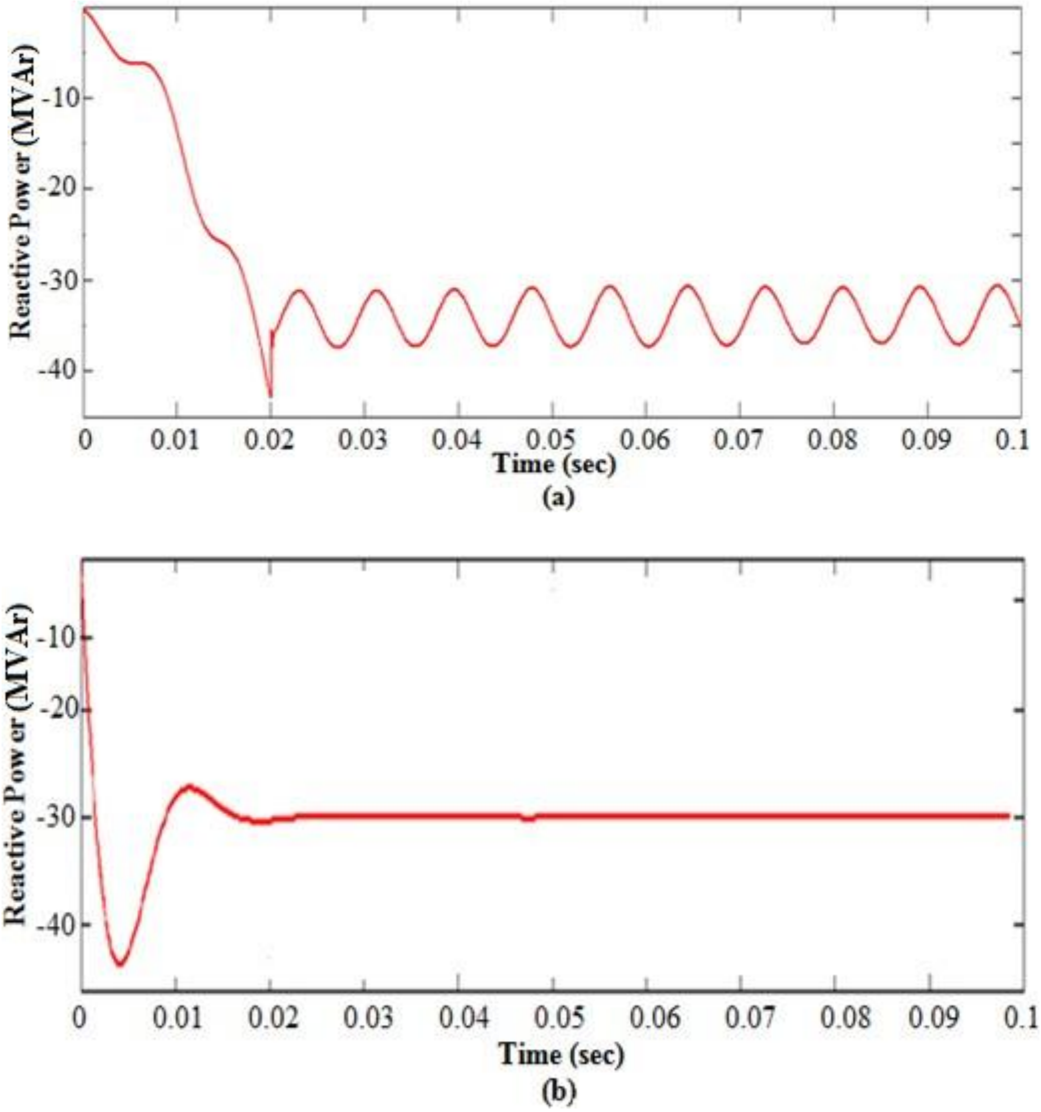


Figure.18 Reactive powers without and with OUPFC-POD

Reactive power oscillates more throughout the fault up to time t = 0.02 seconds, as illustrated in figure 18(a), as can be seen from the results above. As demonstrated in figure 18(b), these oscillations can be quickly minimised by installing an OUPFC-POD controller.From time t=0.02 seconds on, these oscillations are stabilised.

Conclusion

This work focuses mostly on improving the power quality in the power system; effective techniques are utilised to reduce voltage sag, current swell, and THD. In this instance, a three-phase fault is introduced into the transmission line in order to quantify the voltage sag, current swell, and THD. OUPFC with PID and without OUPFC are then placed in the transmission line, respectively. The outcomes shown that the voltage sag, current swell, and THD are decreased with the suggested PID controller. The PID based OUPFC controls power flow in the transmission line efficiently to enhance power quality. Power flow regulating devices are one of the ways to increase power quality. The table provides the outcomes of the suggested system.

Table.3: Summary of results for voltage sag, current swell and THD for OUPFC

Parameters	Without OUPFC	OUPFC with PID controller **(Proposed)**
Voltage sag	55%	9 %
Current swell	20 %	9 %
THD	11.83 %	0.20 %

It is suggested that a three-phase fault be introduced into the proposed system's transmission line in order to analyse oscillations in the active power and reactive power as well as bus voltages both with and without an OUPFC-POD controller. In order to offer a POD controller, the oscillations of both active and reactive power must be regulated. At the same time, low frequency and multiple frequency oscillations must be dampened. By combining OUPFC with POD controller, it can be shown that the oscillations of active and reactive power are significantly reduced, which enhances the performance of the gearbox system. The outcomes demonstrate that power oscillations will be successfully decreased and that voltage profiles are improved. The improvement of power quality in power system, a new controlling device is called OUPFC. Finally, by comparing HPFC and OUPFC, the OUPFC gives better performance compared to HPFC. The proposed system results are given in the table.4.

Table.4: Comparison summary of results for voltage sag, current swell and THD for HPFC and OUPFC

Parameters	Without OUPFC	HPFC with PID controller (SMIB)	OUPFC with PID controller (SMIB)
Voltage sag	55%	10%	9 %

Current swell	20 %	10%	9 %
THD	11.83 %	0.51 %	0.20 %

References:

1. C. Rehtanz and J. -J. Zhang, "New types of FACTS-devices for power system security and efficiency," 2007 IEEE Lausanne Power Tech, , pp. 293-29,Lausanne, Switzerland, 2007.
2. J. Chivite-Zabalza, M. A. Rodríguez Vidal, P. Izurza-Moreno, G. Calvo and D. Madariaga, "A Large Power, Low-Switching-Frequency Voltage Source Converter for FACTS Applications With Low Effects on the Transmission Line," in IEEE Transactions on Power Electronics, vol. 27, pp. 4868-4879, Dec. 2012.
3. S. Jiang, A. M. Gole, U. D. Annakkage and D. A. Jacobson, "Damping Performance Analysis of IPFC and UPFC Controllers Using Validated Small-Signal Models," in IEEE Transactions on Power Delivery, vol. 26, no. 1, pp. 446-454, Jan. 2011, doi: 10.1109/TPWRD.2010.2060371.
4. Rajendra K. Pandey and Deepak Kumar Gupta "Integrated Multi-stage LQR Power Oscillation Damping FACTS Controller "CSEE Journal Of Power And Energy Systems, Vol. 4, No. 1, March 2018.
5. Hnin Yu Lwin "Simulation of 3-Phase, 24 Pulse GTO Converter for Flow Control of Transmission System" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-3, Issue-5 , August 2019.
6. Arranz-Gimon, A.; Zorita-Lamadrid, A.; Morinigo-Sotelo, D.; Duque-Perez, O. A Review of Total Harmonic Distortion Factors for the Measurement of Harmonic and Interharmonic Pollution in Modern Power Systems. *Energies* 2021, *14*, 6467. https://doi.org/10.3390/en14206467.
7. A yiad, M.; Leite, H.; Martins, H. State Estimation for Hybrid VSC Based HVDC/AC Transmission Networks. *Energies* 2020, *13*, 4932. https://doi.org/10.3390/en13184932.
8. Lee, H.-J.; Lee, D.-S.; Yoon, Y.-D. Unified Power Flow Controller Based on Autotransformer Structure. *Electronics* 2019, *8*, 1542. https://doi.org/10.3390/electronics8121542
9. Yang, J.; Xu, Z.; Zhang, Z. Analysis of Unified Power Flow Controller Steady-State Power Flow Regulation Capability and Its Key Factors. *Energies* 2020, *13*, 4419. https://doi.org/10.3390/en13174419.
10. Solomon, E.; Khan, B.; Boulkaibet, I.; Neji, B.; Khezami, N.; Ali, A.; Mahela, O.P.; Pascual Barrera, A.E. Mitigating Low-Frequency Oscillations and Enhancing the Dynamic Stability of Power System Using Optimal Coordination of Power System Stabilizer and Unified Power Flow Controller. *Sustainability* 2023, *15*, 6980. https://doi.org/10.3390/su15086980.
11. M. E. Hussein, F. Rabea, S. Kamel and E. S. Oda, "Effective Modeling of OUPFC Into Newton-Raphson Power Flow Considering Multi-Control Modes and Operating Constraints," in IEEE Access, vol. 9, pp. 129394-129406, 2021.