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Application of Whale Optimization Algorithm Based FOPI Controllers UPQC to Mitigate Harmonics and Voltage Instability in Modern Distribution Power Grids

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Abstract

This paper embarks on a journey into the realm of power value development in solar-wind hybrid power systems through simulation-based investigations. By seamlessly integrating the capabilities of STATCOM and UPQC into the hybrid system, this research aims to mitigate power quality topics stemming from voltage fluctuations, harmonics, and reactive power imbalances. Through meticulous analysis and simulation, the effectiveness of these devices in enhancing the overall system performance will be rigorously examined. As we delve into the details of this simulation study, we will travel the intricate interplay between renewable energy sources, cutting-edge power electronics, and control algorithms. The ultimate goal is to pave the way for a future where solar-wind hybrid power systems can seamlessly deliver reliable, high-quality electricity while minimizing their environmental footprint. Join us as we embark on this exploration at the nexus of renewable energy and advanced power electronics, working towards a cleaner and more sustainable energy landscape for generations to come.

1. Introduction

These days, there are numerous challenges with regard to power quality in low voltage networks due to the high penetration of distributed generation resources and the rise in non-linear and unbalanced loads, which account for a significant portion of the total load of a small-scale system. This calls for in-depth research in this area. Due to the two constraints that centralized production systems face—the depletion of fossil fuels and the requirement to minimize pollution—the significance of distributed generation resources has grown as a result of the integration of renewable energy systems with grids. Microgrids have been given considerable consideration as a means of maximizing the utilization of scattered generation resources. Microgrids are local networks comprising energy storage devices, dispersed generation sources, and loads that can function in both grid-connected and island modes. Controlling power fluctuations, voltage, power distribution, and preserving power quality in both grid-connected and island modes are the key issues microgrids face [1].

2. UPQC CONFIGURATION

The primary components of UPQC are as follows: Shunt inverter: An inverter coupled to a shunt voltage source functions as a shunt inverter. It helps to cancel out current distortions by compensating for the load's harmonic current. Not only does it help maintain a constant DC link capacitor voltage, but it also contributes to increasing system power factor. Additionally, it helps with load reactive current correction. Typically, the shunt inverter output current is controlled using a hysteresis band controller. The reference current can be adjusted to follow the output current and remain inside the designated hysteresis band by modifying the semiconductor switches. Inverter in series: It is a voltage-source inverter, or VSI, that is coupled in series to provide voltage. Through the use of a series transformer, it is connected in series with the line. It aids in eliminating distortions caused by voltage. By removing load voltage imbalances and terminal voltage flickers, it aids in maintaining a sinusoidal load voltage. The series inverter is controlled using PWM techniques. The most common method of pulse width modulation is the hysteresis band technique. There are numerous benefits to use this PWM method. It offers a quicker and more accurate response time, is simple to set up, and functions well even if one is ignorant of the system's specifications.

DC link capacitor: It is utilized for shunt VSIs and back-to-back series connections. In order for both series and shunt inverters to operate correctly, a constant voltage is created across the capacitor. Proper regulation of the voltage produced by this capacitor can eliminate the need for any external DC source, such as batteries, and serve as a source for both active and reactive power.

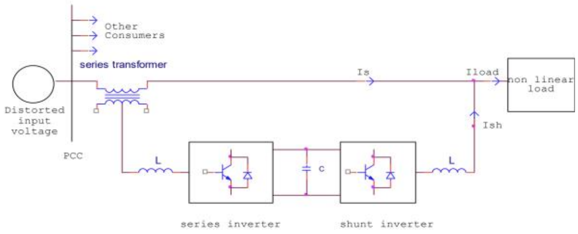

Figure 3 Basic block figure of UPQC

Shunt coupling inductor: It facilitates the shunt inverter's interface with the network. The primary advantage of this is that it eliminates the ripples that are created in the current, smoothing out its wave pattern. LC filter: It is located next to the UPQC's series inerter output. It helps to attenuate high-frequency voltage components of the series inverter's output voltage by functioning as a low-pass filter (LPF).

Series transformer: The series inverter produces a voltage to maintain the load voltage at a specific necessary value in a sinusoidal fashion. This voltage is injected through the series transformer with the assistance of a series inverter. To keep the current flowing through the series inverter at a low level, a specific turn-ratio must be maintained.

3. Examined STATCOM System Modeling and Control Structure

In order to improve voltage quality and lessen other PQ interruptions in the EPS, STATCOM units can provide Q to the EPS with a very quick response. The efficiency and general stability of the electrical grid can also be enhanced by these technologies. It's a shunt reactive compensator that can cause Q in the EPS to be generated or absorbed [34]. An equivalent circuit using the suggested control approach is shown in Figure 4. It sends P and Q to the EPS, and the firing angle (α) and modulation index (m) of the voltage source converter's PWM control the transmitted power (VSC).

The following formulas can be used to determine VSC and STATCOM in the three-phase structure:

$$L\frac{dia}{dt} = -RI_a + (V_a - V_{a1})$$

$$L\frac{dib}{dt} = -RI_b + (V_b - V_{b1})$$

$$L\frac{dic}{dt} = -RI_c + (V_c - V_{c1})$$

where Ia, Ib, and Ic are the system currents. The output voltages of the inverter are Va1, Vb1, and

Vc1, while the PCC voltages are Va, Vb, and Vc. Furthermore, the power transformer's equivalent resistance and inductance are represented by R and L, respectively.

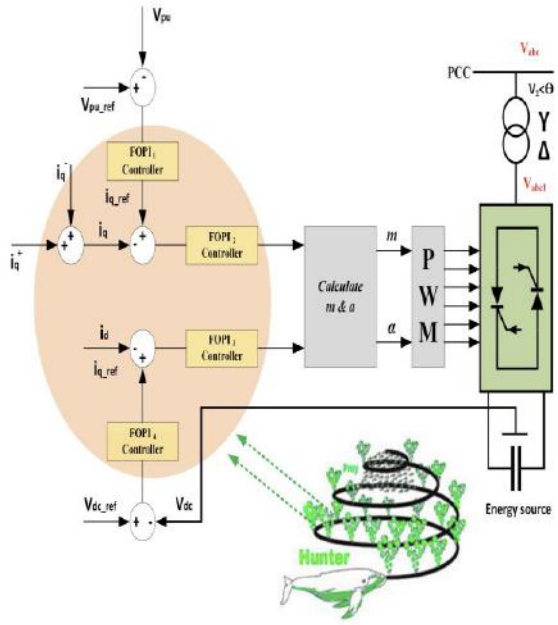

Figure 4 shows how the grid-connected STATCOM's WOA-based FOPI is configured.

A d-q frame representation of the three-phase parameters looks like this:

$$L\frac{did}{dt} = -RI_d + \omega LI_d(V_d - V_{d1})$$

$$L\frac{did}{dt} = -RI_q + \omega LI_d(V_q - V_{q1})$$

The d- and q-axis powers of the grid and the STATCOM are signified by the symbols Vd, Vd1, Vq, and Vq1, and ! is the synchronous bony speed of the important grid voltage.

The inverter's DC link voltage can be strongminded as shown below:

$$V_{d1} = KmV_{dc}\sin(^{\delta})$$

$$V_{q1} = KmV_{dc}\cos(^{\delta})$$

where m is the PWM modulation index, Vdc is the DC-link voltage of the STATCOM, d is the firing angle, and K is the inverter steady-state constant associated with the inverter architecture. Below are the PWM control parameters (m and d):

$$M = \sqrt{\frac{V_{d1}^2 + V_{q1}^2}{km}}$$

$$^{\delta} = \tan -1 = \frac{V_{q1}}{V_{d1}}$$

The conveyed Pac and Qac to the net are given below:

$$P_{ac} = 1.5(V_d I_d + V_q I_q) = 0$$

$$Q_{ac} = (1.5(V_d I_d + V_q I_q)$$

Pac is taken to be zero for the STATCOM does not allocation any P to the grid and instead controls the PCC point voltage by gripping or liberating the Q. To prevent P from being swapped with the power grid, d in this method must be attuned to a value equal to the PCCV phase angle. The PCC's modest internal losses must also be reduced for the PCCV to be somewhat in the lag phase with respect to d. This is made feasible by the closed-loop control mechanism shown in Figure 4. In the event that internal losses exist, this will lower the DC link voltage level, avoiding the input signals into the WOA-based FOPIC. This will eliminate the capacitor voltage's steady-state error and modify d such that the grid encloses its internal losses.

4. The Examined UPQC System's Control Structure and Modeling

As seen in Figure 5, the UPQC provides the advantages of both FACTS devices—DVR and STATCOM—at the same time [35]. However, the efficacy of PQ improvement is restricted by UPQC's methodology. In this work, current and voltage harmonics in an EPS are minimized by the application of a recently developed UPQC. The UPQC's mathematical model is expressed as follows. As can be observed in [36,37], the cited three-phase currents are estimates.

$$\begin{bmatrix} I_{sa} \\ I_{sb} \\ I_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \sqrt{\frac{3}{2}} \\ \frac{-1}{2} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{vmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{vmatrix} \begin{vmatrix} P \\ Q \end{vmatrix}$$

The gained prompt load power (P and Q) is used to calculate the prompt power angle (j), as shown below:

$$\varphi = Sin^{-1}\frac{Q\ handeled\ by\ the\ DVR}{P\ of\ load}$$

source powers (k), is signified by:

$$S_{UPQC}(\varphi,k) = S_{shunt}(\varphi,k) + S_{series}(\varphi,k)$$

The VA loading of the series and shunt can be determined by the following equations:

$$S_{series}(\varphi,k) = \sqrt{|P_{series}(\varphi,k)2| + |Q_{series}(\varphi,k)2|}$$

$$S_{shunt}(\varphi,k) = \sqrt{|P_{shunt}(\varphi,k)2| + |Q_{shunt}(\varphi,k)2|}$$

The Vdc greatness is;

$$V_{dc} = \frac{2\sqrt{2V11}}{\sqrt{3m}}$$

The condenser at the DC bus is:

$$C_{dc} = \frac{3kaV_{ph}1_{STATCOM}t}{0.5(V_{dc}^2 - V_{dc1}^2}$$

where t is the amount of time needed to reach the rated value following an abnormal circumstance and an is the overloading factor.

The interfacing inductance for STATCOM is:

$$L_{sh} = \frac{\sqrt{3mV_{dc}}}{12af_{sh}I_{cr,pp}}$$

The DVR interfacing inductance is:

$$L_r = \frac{\sqrt{3mV_{dc}K_{se}}}{12af_{se}I_r}$$

where fsh and fse are the STATCOM and DVR swapping incidences, correspondingly. The transformation ratio of the series transformer is represented by the symbol Kse. As seen in Figure 5, this study presents an improved FOPIC with WOA's assistance to improve the performance of UPQC control. A WOA-based FOPIC can be used to cancel the system detectors, which enhances the dynamic response. Through the examined control system, the supply current and load voltage are tracked and modified to match the references that match them in the d-q reference frame. The voltage references. are used to generate the signals for the two components using a sinusoidal PWM approach. Furthermore, because the recommended technique is integrated into the d-q reference frame, a PLL is used to determine the phase angle of the supply voltage in order to carry out coordinated transformations.

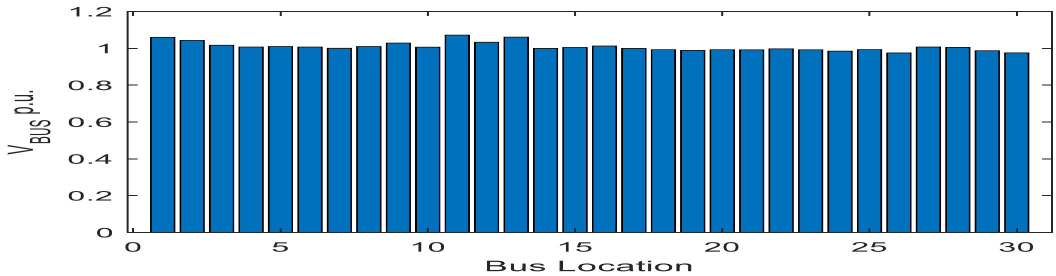

Figure 4 a: Bus Voltage for STATCOM 1=Bus 17, UPQC 1=Bus14

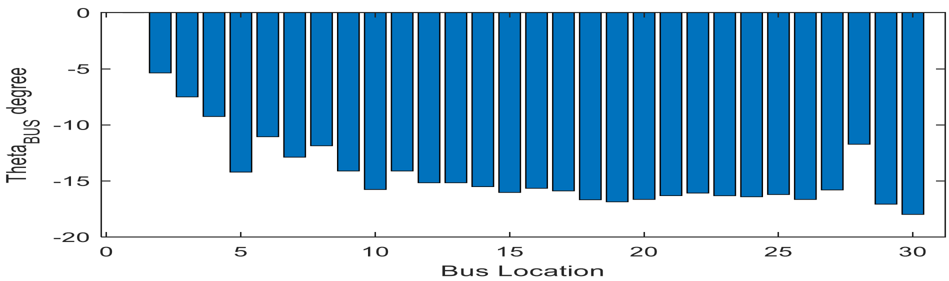

Figure 5 b: Bus Voltage angle (Theta) in degree STATCOM 1=Bus 17, UPQC 1=Bus14

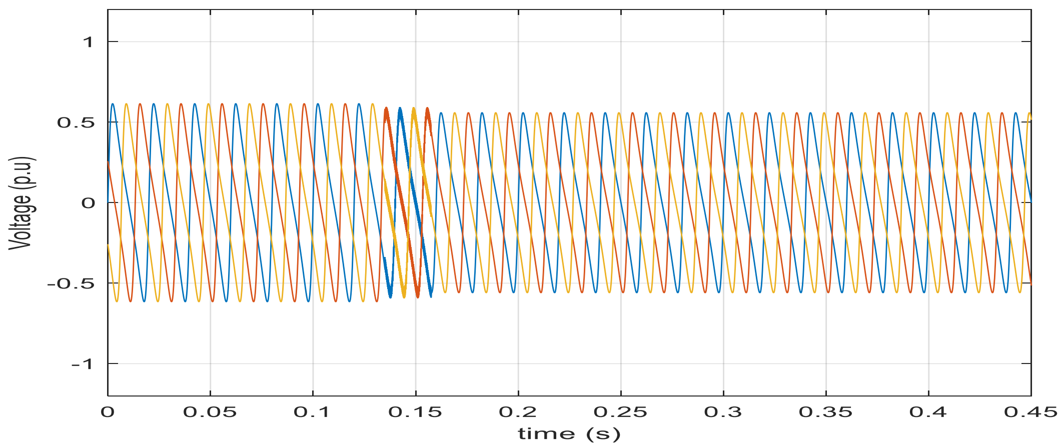

Figure 6 c: Fault Bus Voltage with respect to time for location STATCOM 1=Bus 17, UPQC 1=Bus

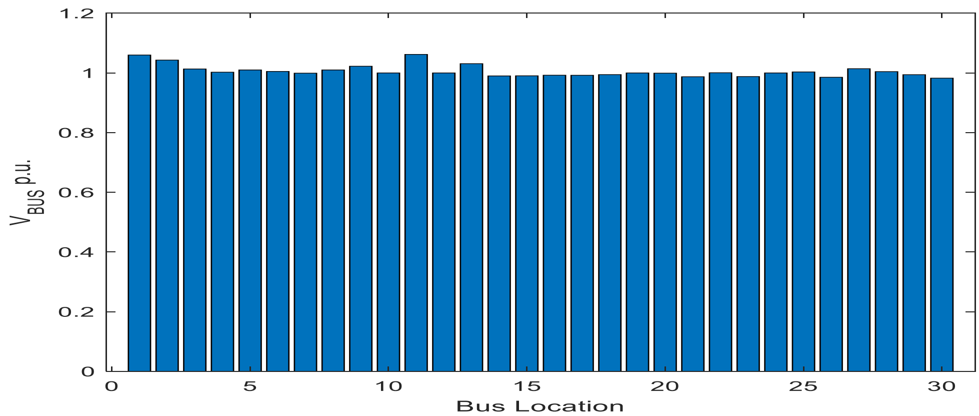

Figure 7 a: Bus Voltage in pu for location of STATCOM 1=Bus 10, STATCOM 2=Bus 12, UPQC 1=Bus 24, OPFC 2=Bus 19

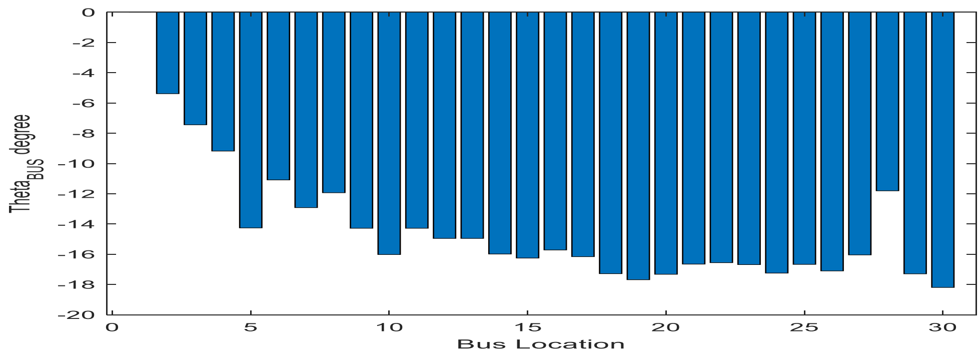

Figure 7 b :Bus Voltage angle (Theta)in degree for location of STATCOM 1=Bus 10, STATCOM 2=Bus 12, UPQC 1=Bus 24, OPFC 2=Bus 19

Table 2 a: Best bus Location for 2STATCOM and 2UPQC placement

Bus Location of STATCOM/UPQC				**Voltage Inserted by STATCOM/UPQC**				**Voltage Angle of STATCOM/UPQC**				**Power Inserted by STATCOM/UPQC**				
STAT	**STAT**	**UPQC**	**UPQC**	**STAT 1**	**STAT 2**	**UPQC 1**	**UPQC 2**	**STAT 1**	**STAT 2**	**UPQC 1**	**UPQC 2**	**STAT 1**	**STAT 2**	**UPQC 1**	**UPQC 2**	
Bus1	**Bus2**	**Bus3**	**Bus4**	**Vsh1 (p.u.)**	**Vsh2 (p.u.)**	**Vsh3 (p.u.)**	**Vsh4 (p.u.)**	**Theta1**	**Theta2**	**Theta3**	**Theta4**	**Psh (p.u.)**	**Psh (p.u.)**	**Psh (p.u.)**	**Psh (p.u.)**	**MSE**
10	12	24	19	0.985	0.958	1.015	1.014	-15.937	-14.714	-17.335	-17.766	0.145	0.419	-0.152	-0.137	0.020
10	12	18	24	0.988	0.957	1.013	1.015	-15.950	-14.710	-17.530	-17.333	0.120	0.433	-0.127	-0.150	0.021
10	12	20	24	0.985	0.959	1.012	1.015	-15.936	-14.718	-17.417	-17.334	0.146	0.406	-0.123	-0.153	0.021
10	12	24	15	0.989	0.949	1.014	1.021	-15.964	-14.677	-17.337	-16.679	0.111	0.512	-0.142	-0.205	0.021
10	15	24	12	0.989	1.021	1.014	0.949	-15.964	-16.679	-17.337	-14.677	0.111	-0.205	-0.142	0.512	0.021
10	12	26	18	0.997	0.958	1.004	1.013	-16.001	-14.714	-17.741	-17.532	0.029	0.423	-0.044	-0.131	0.021
10	12	19	26	0.995	0.959	1.014	1.004	-15.989	-14.718	-17.766	-17.743	0.053	0.408	-0.140	-0.044	0.021
10	12	26	19	0.995	0.959	1.004	1.014	-15.989	-14.718	-17.743	-17.766	0.053	0.408	-0.044	-0.140	0.021
10	12	23	19	0.977	0.955	1.026	1.013	-15.927	-14.716	-17.207	-17.791	0.227	0.452	-0.264	-0.127	0.021
10	12	19	23	0.977	0.955	1.013	1.026	-15.927	-14.716	-17.791	-17.207	0.227	0.452	-0.127	-0.264	0.021
10	12	23	18	0.980	0.954	1.026	1.011	-15.940	-14.713	-17.203	-17.550	0.198	0.462	-0.259	-0.113	0.021
10	12	18	23	0.980	0.954	1.011	1.026	-15.940	-14.713	-17.550	-17.203	0.198	0.462	-0.113	-0.259	0.021
10	15	12	26	0.997	1.022	0.949	1.004	-16.012	-16.688	-14.677	-17.736	0.029	-0.221	0.512	-0.042	0.021
10	12	26	15	0.997	0.949	1.004	1.022	-16.012	-14.677	-17.736	-16.688	0.029	0.512	-0.042	-0.221	0.021

Table 4.2 b: Bus location STATCOM 1=Bus 10, STATCOM 2=Bus 12, UPQC 1=Bus 24, UPQC

BUS	V_{BUS}	$Theta_{BUS}$	BUS	V_{BUS}	$Theta_{BUS}$	BUS	V_{BUS}	$Theta_{BUS}$
1	1.06	0.00	11	1.06	-14.28	21	0.99	-16.65
2	1.04	-5.38	12	1.00	-14.95	22	1.00	-16.56
3	1.01	-7.44	13	1.03	-14.95	23	0.99	-16.69
4	1.00	-9.18	14	0.99	-15.99	24	1.00	-17.25
5	1.01	-14.26	15	0.99	-16.25	25	1.00	-16.67
6	1.00	-11.09	16	0.99	-15.72	26	0.99	-17.10
7	1.00	-12.92	17	0.99	-16.16	27	1.01	-16.04
8	1.01	-11.93	18	0.99	-17.29	28	1.00	-11.81
9	1.02	-14.28	19	1.00	-17.69	29	0.99	-17.30
10	1.00	-16.02	20	1.00	-17.33	30	0.98	-18.20

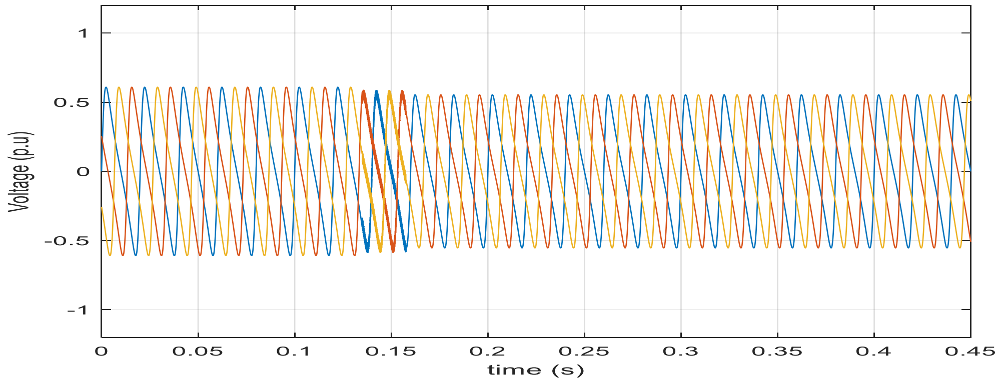

Figure 4.2 c: Fault Bus Voltage with respect to time for location of STATCOM 1=Bus 10, STATCOM 2=Bus 12, UPQC 1=Bus 24, OPFC 2=Bus 19

5. Conclusions and Future Scopes

Problems with EPQ are a growing concern for all usage levels, including utilities, commercial, and industrial. Short-lived occurrences like voltage dips, surges, or even transients lasting fewer than a few seconds are included in the power quality problems. PQ also includes power system harmonic and flicker problems, despite the fact that these problems typically occur at far longer intervals than sags and transients.

The two distinct types of power quality issues in microgrids have been the subject of this thesis work. First, there are issues with the voltage transmitted at the point of common connection, such as imbalance, fluctuations, outages, overvoltage, undervoltage, swell, and sag, as well as voltage harmonics. Second, issues with the current extracted from the network by nonlinear uninterruptible power supply processes, which can result in issues with power quality such as imbalanced currents, high reactive power, incorrect power factor, and harmonic currents, among other things. Therefore, it is suggested that various FACTS device types be used to solve power quality issues from both angles and attempt to guarantee that the voltage delivered to the load is standard regardless of network issues in order to improve the level of power quality in a network.

For the IEEE 30 bus system, the results are illustrated in terms of sag, swell, T.H.D., and short circuit current. The performance for 3STATCOM and 3QPFC are observed to be best\ in terms are all performance parameters. In future involvement of metaheuristic optimization approach may be used to set the rating of FACT devices and the number of FACTS device may further be revised for different combinations.

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