[1] K. Swarna Latha

[2]Dr. P. Mallikarjuna Sharma

[3]Prof. M. Manjula

Power Quality Enhancements with MC-UPQC Optimized with Hybrid Algorithm in IEEE33 and IEEE57 Bus System

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Abstract: - The implementation of MC-UPQC optimized with a hybrid algorithm in IEEE33 and IEEE57 bus systems has demonstrated significant improvements in power quality. This approach effectively mitigates issues such as voltage sags, swells, and harmonic distortions. Optimizing power quality in the IEEE 33 and IEEE 57 bus systems can lead to improved reliability and efficiency of the distributed system. By using nature-inspired hybrid algorithms, the accuracy of power quality optimization can be significantly enhanced, resulting in reduced power losses, minimized voltage fluctuations, and enhanced overall system performance.To decrease the installation cost for optimizing the power quality MC-UPQC proposed with better optimal technique. Cuckoo search algorithm taken as base concept of optimization to overcome the compensation time in selected two bus systems the algorithm hybridized with AI based random forest algorithm and named it as Multi agent Random Cuckoo forest search algorithm which given compensation time less than 0.3 seconds.

Keywords: Power quality, MC-UPQC, IEEE 33, IEEE-57, Hybrid algorithms, THD

1. Introduction:

PQ issues are gaining attention and have become a big problem for users of energy [1]. The distribution system is facing increasing issues in terms of voltage sag/swell and harmonics production. These challenges are a result of the growing use of nonlinear loads, such as modern power electronics and computer-controlled equipment [2]. These issues can potentially damage delicate equipment and cause costly losses for electrical networks [3]. Poor power quality causes electrical equipment to malfunction and causes loads to behave abnormally. Harmonic current and more reactive power demand are caused by several electronic devices, which generate unbalanced loads and fluctuating voltages [4]. These problems can be solved in part via LC passive filters. However, this filter type is unable to address the issue of unpredictable fluctuations in the load voltage and source current waveforms. To ensure conformance with power quality regulations, various forms of active power filters (APFs) are now widely utilized [5]. The UPQC system, designed by Fujita and Akagi in 1998, to improve PQ at both the source and load ends [6]. Since then, a large number of researchers have worked on this device. These researches are separated into four major groups according to the physical composition of the UPQC, techniques utilized to compensate for sag/swell in the source voltage, different UPQC control systems, and various algorithms for determining the best location of the UPQC.

2. Related Works:

In 2020, Gaddala & Raju [7] have proposed a “new power quality improvement model” by placing the UPQC optimally in the power system. The optimal placement was accomplished with Genetically Modified DA algorithm, which was a conceptual blending of both the DA and GA. the optimal location was identified on the basis of certain objectives like “UPQC cost, power losses, and Voltage stability Index”. They have tested the proposed model on “IEEE 69, and IEEE 33 test bus systems” to shows the efficiency of the proposed work. In 2017, Gupta & Kumar [8] have presented an efficient model for optimum location identification of D-STATCOM and UPQC in the “radial distribution system”. The optimal location was found using the PLI method and the bus with highest PLI was said to be the most favorable bus. They have tested the proposed model on “IEEE 33-bus and 69-bus radial distribution systems “. The “IEEE 33 and IEEE 69 benchmark test

[1] Research Scholar, EE Department, University College of Engineering, Osmania University, Hyderabad

swarna.kandukuri2007@gmail.com

[2]Professor, EE Department, Vasavi College of Engineering, Hyderabad

pmsarma2010@gmail.com

[3]Professor, EE Department, University College of Engineering, Osmania University, Hyderabad

majulagooga@gmail.com

bus systems" were utilized for testing the proposed work. In 2017, Lakshmi and Ganguly [9] have developed a new planning model based on PSO for incorporating the UPQC-O into the power system for enhancing the PQ and losses. The reactive power compensation as provided by the shunt inverter after the elimination of the harmonics generated by the load. The objective behind the current research work was the minimization of the "energy loss under the voltage, thermal overloading, and the desirable PQ constraints". Sharma and Kumar [10] have proposed a new methodology for PQ improvement by means of compensating the reactive power during the placement of UPQC. This optimal placement was based on the development of the new sensitivity index. The results from the proposed model had exhibited its superiority in terms of power quality.

2.1 Research gap and Objective of the work

In the distribution systems, the DFACTS are utilized and the prominent devices among DFACTS are the UPQC, DSTATCOM and Dynamic Voltage Restorer. Among all these the UPQC is the most preferred DFACTS device, as it is good in solving the current-related problems and voltage mitigation in distribution systems. Cost of installation of these different system have to check for economical viability. Placing DG attached to MC-UPQC with Multi agent Random cuckoo forest search Algorithm (MARCFSA) at the located bus and compensating the sag & swell in IEEE 33 & 57 bus system for power quality enhancement.

2.2 Significance

The novelty of placing Distributed Generation (DG) attached to a Multi-Converter Unified Power Quality Conditioner (MC-UPQC) with the Multi-agent Random Cuckoo Forest Search Algorithm (MARCFSA) lies in its enhanced optimization capabilities. This approach significantly improves the stability and efficiency of the power quality management system. This innovative approach optimizes energy distribution and minimizes disturbances more effectively than traditional methods.

3. Problem formulation and Objective function

The optimal power flow problem solution aims to optimize a selected objective function via optimal adjustment of the power system control variables, while at the same time satisfying various equality and inequality constraints. Generally, the OPF problem can be mathematically written as follows:

$$\text{Min } J(x,u) \quad (1)$$

Subject to

$$g(x,u)=0$$
$$h(x,u)\le 0 \quad (2)$$

where J is objective function to be minimized, g is the equality constraints represent typical load flow equations, h is the inequality constraints represent the system operating constraints, x is the vector of dependent variables or state vector consisting of: (1) Active power of generators at slack bus PG1. (2) Load bus voltage VL. (3) Generator reactive power output QG. (4) Transmission line loading (line flow) Sl.

Hence, x can be expressed as:

$$x^T = [P_{G1}, V_{L1} \cdots V_{LNL}, Q_{G1} \cdots Q_{GNG}, S_{l1} \cdots S_{lnl}] \quad (3)$$

where NT and NC are the number of the regulating transformer and VAR compensators, respectively.

Equality Constraints: These constraints are specific load flow equations which can be described as follows:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} V_j [G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)] = 0 \quad (4)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} V_j [G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j)] = 0 \quad (5)$$

where, i=1,…, NB, NB is the number of buses; PG is the active power generated, QG is the reactive power generated, PD is the load active power, QD is the load reactive power, Gij and Bij respectively indicate the real part and imaginary part of the ij-th element of the node admittance matrix.

Inequality constraints: These constraints reflect the system operating limits as follows: 1. Generator constraints: generator voltages, real power outputs, and reactive power outputs are restricted by their lower and upper limits as follows:

$$V_{Gi}^{\min} \leq V_{Gi} \leq V_{Gi}^{\max},\ i=1,\ldots,NG \quad (6)$$
$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max},\ i=1,\ldots,NG \quad (7)$$
$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max},\ i=1,\ldots,NG \quad (8)$$

2. The transformer constraints: transformer tap settings are bounded as follows:

$$T_i^{\min} \leq T_i \leq T_i^{\max},\ i=1,\ldots,NT \quad (9)$$

3. Security constraints: these include the constraints of voltages at load busses and transmission line loading as follows:

$$V_{Li}^{\min} \leq V_{Li} \leq V_{Li}^{\max},\ i=1,\ldots,NL \quad (10)$$
$$S_{li} \leq S_{li}^{\max},\ i=1,\ldots,nl \quad (11)$$

The major objective behind this research work is to enhance the power quality by means of placing the UPQC in an appropriate position. The objective function is shown in Eq.12

$$OB = \min\left(UPQC_{cost} + VSI + Loss\right) \quad (12)$$

The VSI formula is shown in Eq. (13), in which min Vol , max Vol and b Vol are the minimum bus voltage, maximal bus voltage and the voltage of the th b bus respectively. The VSI is fixed within the range 0.9 to 1.1

$$VSI = \begin{cases} 1 & \text{if } Vol^{\min} \leq Vol^{b} \leq Vol^{\max} \\ \exp\left(\mu \left|1 - Vol^{b}\right|\right) & \text{otherwise} \end{cases} \quad (13)$$

In addition, the mathematical formula for loss is expressed in Eq. (14).

$$Loss = \sum_{k=1}^{N_L} Loss_k = \sum_{k=1}^{N_L} O_k \left\{V_i^2 + V_j^2 - 2V_iV_j\cos\left(\delta_i - \delta_j\right)\right\} \quad (14)$$

Equality Constraints: The active line power is represented in terms of “voltage magnitude of the bus”, while the reactive line power is described in terms of phase angle of bus. In the “distribution system”, the “active power balance” is expressed as

$$Pactive_{H_i} - Pactive_{E_i} - \sum_{k=1}^{N_L} o_{ik} \begin{Bmatrix} Vol_i^2 + Vol_j^2 - \\ -2Vol_iVol_j\cos\left(\delta_i - \delta_j\right) \end{Bmatrix} = 0 \quad (15)$$

In addition, the reactive power balance is mathematically defined as per Eq. (15). Here, Hi Qreact is the injected reactive power at th i bus and Ei Qreact is the reactive power demand. In addition, oik and pik are the conductance and susceptance between th i and th j bus, respectively. The magnitude of the voltage at the th i and th j bus is denoted as Voli and Volj , respectively.

$$Qreact_{H_i} - Qreact_{E_i} - \sum_{k=1}^{N_L} p_{ik} \begin{Bmatrix} Vol_i^2 + Vol_j^2 - \\ -2Vol_iVol_j\sin\left(\delta_i - \delta_j\right) \end{Bmatrix} = 0 \quad (16)$$

Minimization of power losses

$$\min f_1 = \sum_{i}^{N_{br}} R_i \frac{P_i^2 + Q_i^2}{V_i^2} \qquad (17)$$

where Nbr is the total number of branches, Ri is the branch resistance i, Vi is the voltage at sending end node of i^{th} branch, and Pi and Qi are the active and reactive power at the sending end node of i^{th} branch.

In this paper, a new configuration of a UPQC called the multiconverter unified power-quality conditioner (MC-UPQC) is presented. The system is extended by adding a series-VSC in an adjacent feeder. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected.

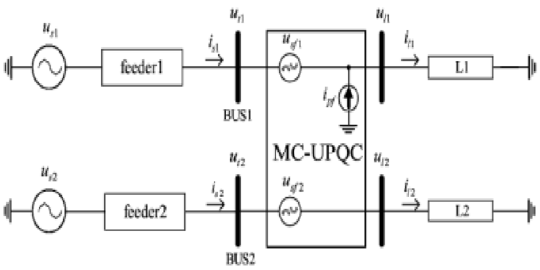

Figure:1 Schematic diagram for MC-UPQC

The proposed control mechanism allowed the UPQC-MC to inject energy into the distribution system while minimizing the losses caused by switching of the inverters. Moreover, a modified phase-freezing algorithm was introduced in order to measure the phase of the grid voltage during a voltage sag which is useful when generating reference voltage and current values and the proposed UPQC shown in the figure2.

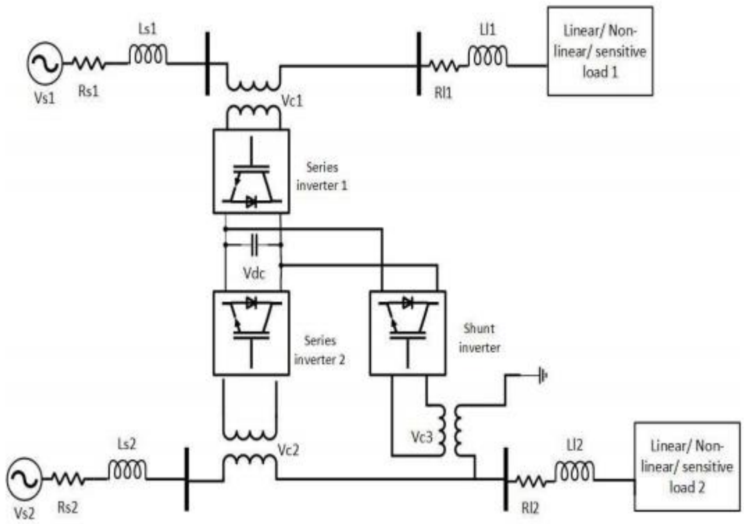

Figure : 2 Multilevel-converter-based UPQC

3.1 Multi agent Random Cuckoo forest search algorithm for MCUPQC

An integrated cuckoo random forest search algorithm implemented for optimizing the power quality in selected bus systems.

3.1.1 Cuckoo random searching system

Computational steps for Random cuckoo seearch can be summarized as the pseudo-code shown bellows:

Step 1: Initialize the population of cuckoo with eggs.

Step 2: Calculate the fitness of function Fi= f (xi), i=1, 2, ..., n, for each generation until the number of objective evaluation is less than the maximum number of evaluation.

Step 3: Arrange all the fitness function values in the order of their fitness.

Step 4: After the evaluation, calculate the number of nests to be abandoned.

Step 5: Calculate the Lévy flight step size by using α = A/√G. Generate a new egg by performing the Lévy flight from a randomly selected position of an egg. If the generated new egg is better than the other randomly selected egg than this egg is moved to new position.

Step 6: The random search of Lévy flight is controlled by multiplying it with α and now α = A/G2 is to explore the abandoned nests.

Step 7: The new generated egg is randomly chosen. The egg having the best fitness are grouped in one and from these a second egg is randomly taken and a new egg is generated along the distance which is calculated using,

$$dx = \left|x_i - x_j\right| / \varphi$$

The distance is such calculated that the nest is moved towards the worst to the best position of an egg.

Step 8: The best nest is being selected as the best objective value so far.

UPQC working control is as follows

Step1: As before discussed the cuckoos search very randomly the bus power in and out.

Step 2: Optimal finding and communicate the UPQC system to compensate.

Step3: Checking the fitness of each bus very randomly once compensation done.

Step 4: Continuous checking of harmonics.

Step5: Feed back mechanism once the issue solved.

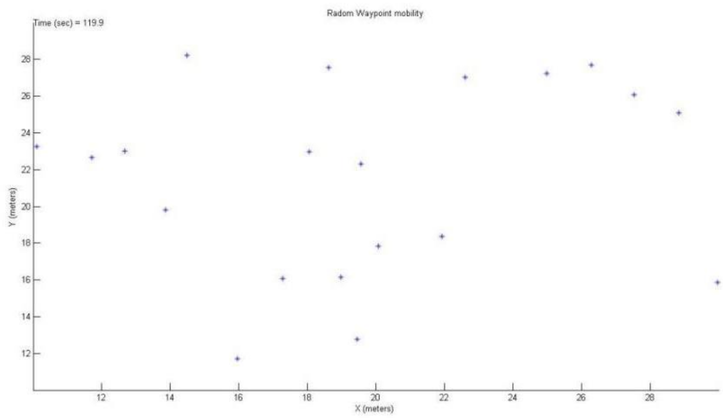

Figure 3: Multi agent Random cuckoo forest search for optimal power and voltage in bus system

Table: 1 Power flow optimization

steps	steps
1	Generate Initial propulsion of Host nests
2	Run power flow Evaluate OF and Call it OF (i)
3	Put Min (fitness) in best Solution
4	**i=i+1**
5	Run power flow Evaluate OF and Call it OF (i+1)
6	Put Min (fitness) in best Solution from equation 17
7	$i=i_{Ut}$

8	Confirm low time compensation
9	Update best

Table: 2 Algorithm for bus searching in selected bus system

	Algorithm for UPQC Compensation for voltage and current in bus
	Begin
	% Initialization
1	Generate randomly population of host nests Xi with i- 1,2 ,……………N
2	Find the fitness function of population Fi
3	While (current iteration < $iteration_{max}$) or (Stop criterion)
4	% generation new solutions by Levy flights
5	From the current population (Called k) Generate randomly a new population (Called I)by Levy flights and evaluate their fitness
6	Update the current population by comparing the fitness of each solution in to population:(F_{li} is better than the F_{kj}) Replace $nest_{ki}$:**end if**
7	% generation new solutions Random Walk
8	From the current population (Called k) Generate a new population (Called I) by Random Walk
9	K-rand(N,D)>Pa
10	For i=1:N
11	$X_i^{new}\ Xbest_i + rand\ \times (i,:) \otimes (Xbest_j - Xbest_k)$
12	**End for i**
13	Update the current population by comparing the fitness of each solution in two population: **If**(F_{li} is better than the $F_{k,i}$) replace nestk,I by nestI,I; **end if**
14	Find the best solution by ranking the current population
15	% update the best solution by local search
16	Calculate RI based on the best fitness in two iterations by (17)
17	If RI<toll
18	K=eye(D,D);
19	**For** j=1:D
20	$X_{1new,j}$= $k_{(j,i)} \times d_{max}$×rand+ $Xbes\ (i)$
21	$X_{2new,j}$= $k_{(j,i)} \times d_{min}$×rand+ $Xbes\ (i)$
22	End for j
23	If D> Pr,Kr = rand (D,D)>0.8
24	For j=1:D
25	$X_{3new,j}$= $kr_{(j,i)} \times d_{max}$×rand× $Xbes\ (i)$
26	$X_{4new,j}$= $kr_{(j,i)} \times d_{min}$×rand× $Xbes\ (i)$
27	**End for j**
28	**End if**
29	Update the current best solution by comparing the fitness of each solution with the new solutions Check steps in table 1.
30	**End if RI**
31	**% Stop criterion**
32	**Update RI by Eq (9)**
33	**If** RI < toll, toll **= toll +1; else** tall =0; **End if**
34	**If tall>tall $_{max}$, break while; End if**
35	**End While**

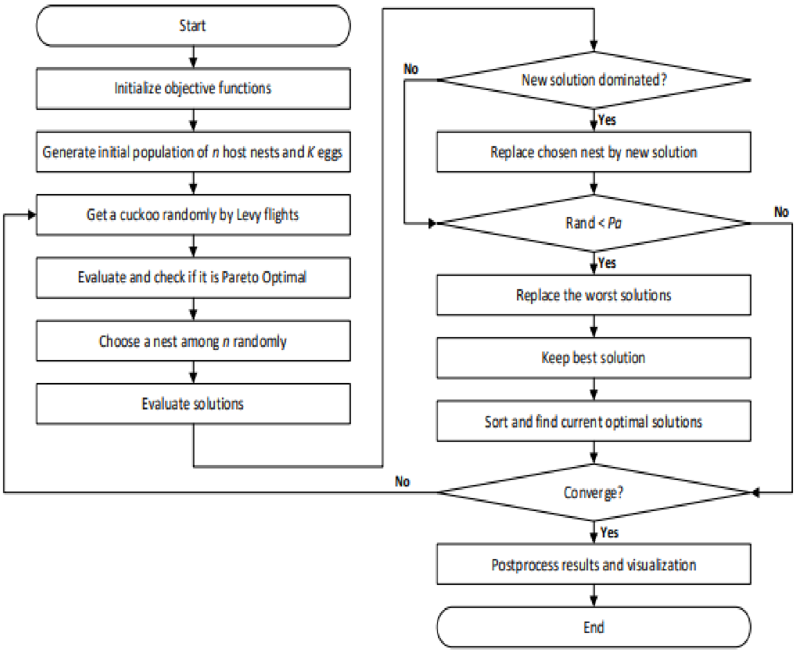

Figure 4: Flow chart for MACRFS algorithm

3.1 Modelling in Mat-Lab simulation

The model was validated through extensive simulations on IEEE bus systems using MATLAB. These simulations demonstrated the model's effectiveness in enhancing power quality and stability in various network configurations. Two models has been designed one for 33 and another for 57 bus systems for Mat-lab/Simulink simulations for optimal tracking and compensation.

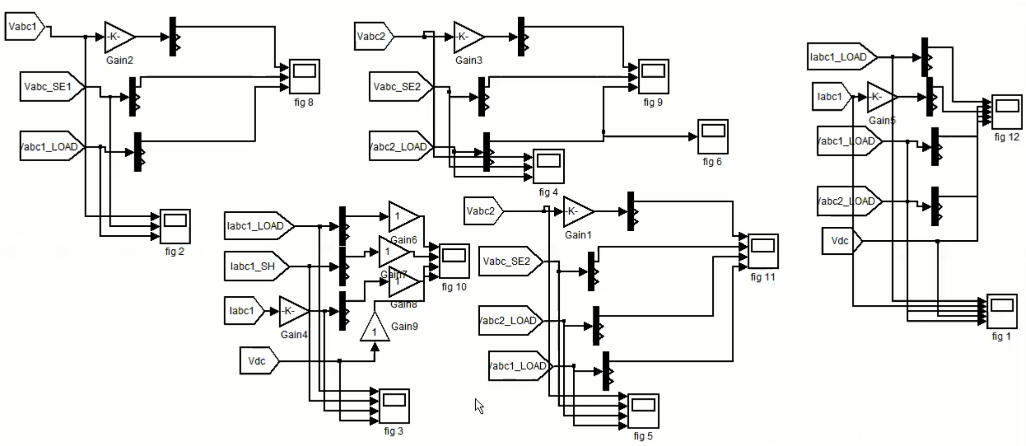

Figure:5 voltage and Loads in buss system

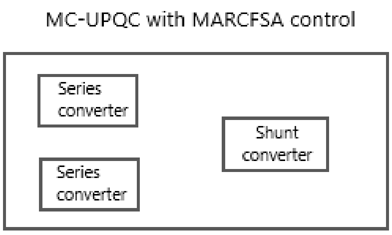

Figure:6 Control system strategy

In present two bus system the MC- UPQC control by MARCFSA injected for compensation at 18th bus for IEEE-33 bus system and at 30th bus for 57 bus system two check the voltage swell, sag and harmonic distortions in the present simulation. The mat lab models for both the systems shown in the figures 7 and 8.

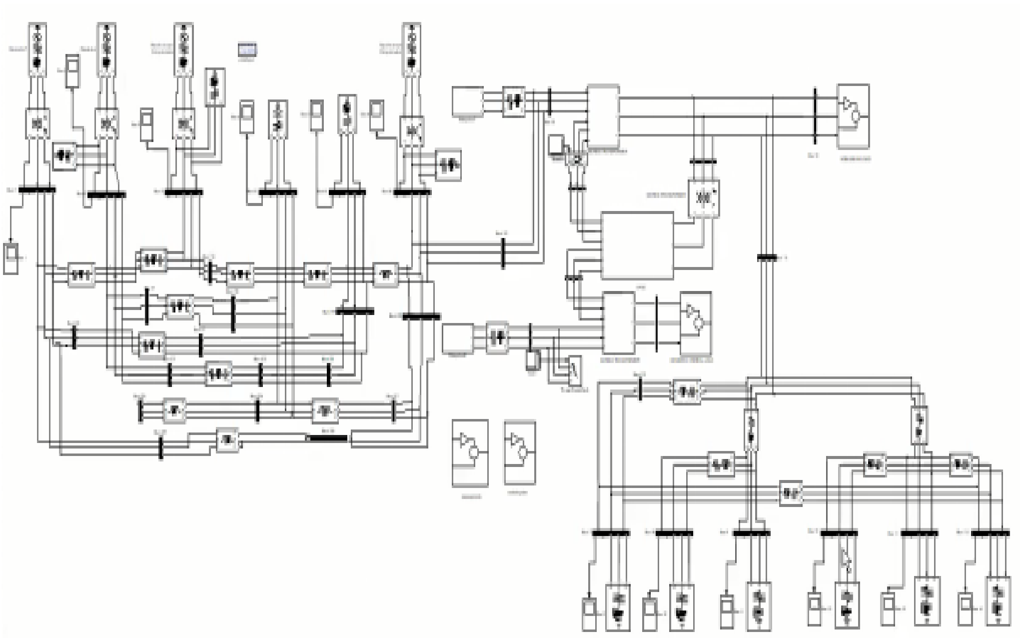

Figure:7 Design of 33 bus system

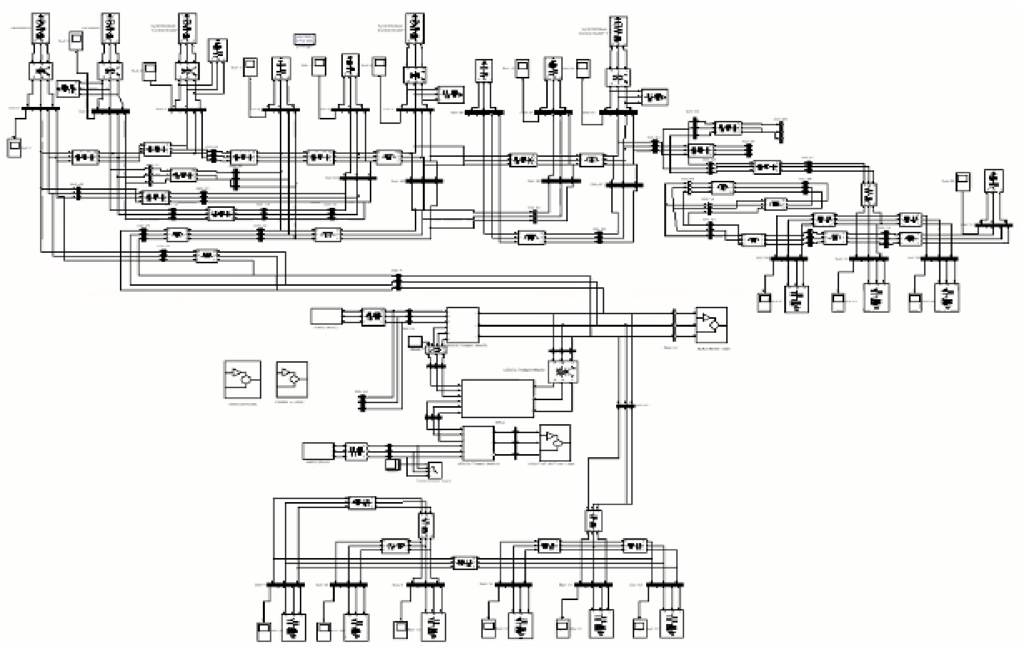

Figure:8 Design of 57 bus system

4. Results and Discussions

The proposed MC-UPQC and its control schemes have been tested through extensive case study simulations using MATLAB/SIMILINK In this section, simulation results are presented, and the performance of the proposed MC-UPQC system is shown.

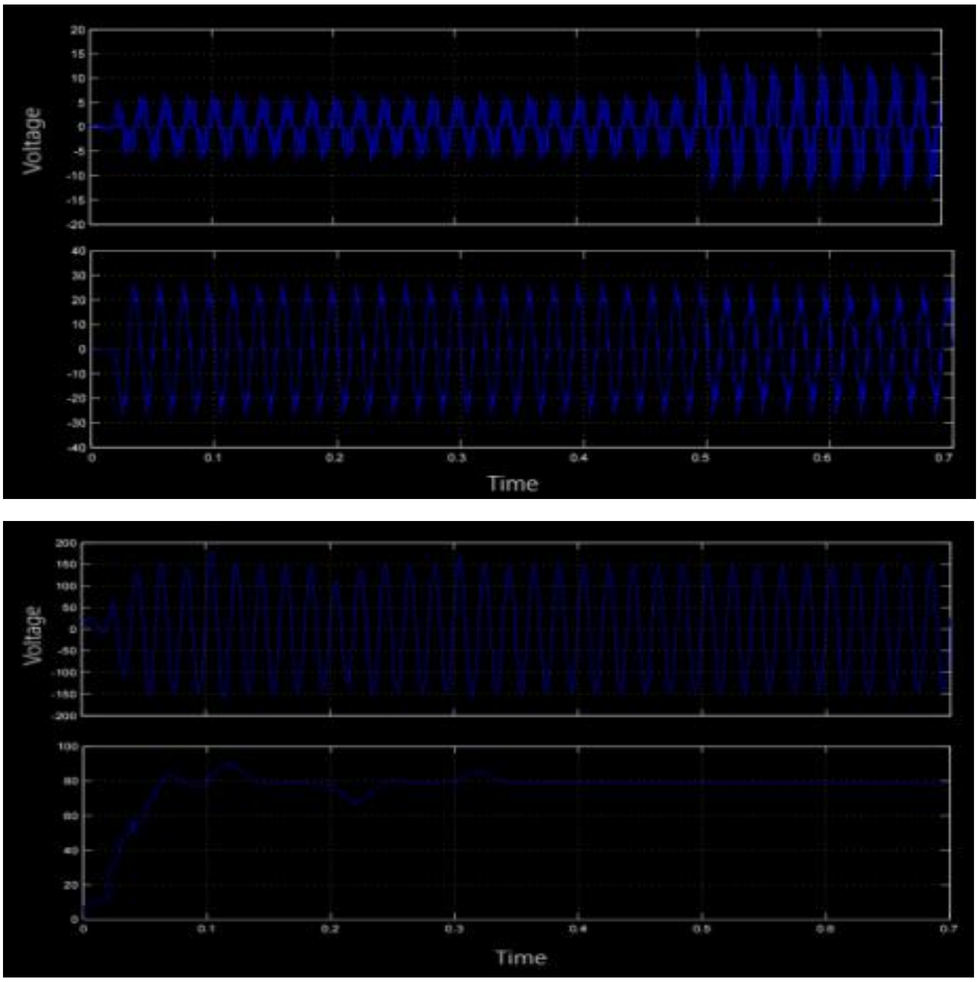

Figure:9 Sag compensation for voltage and current profiles For 33 bus system

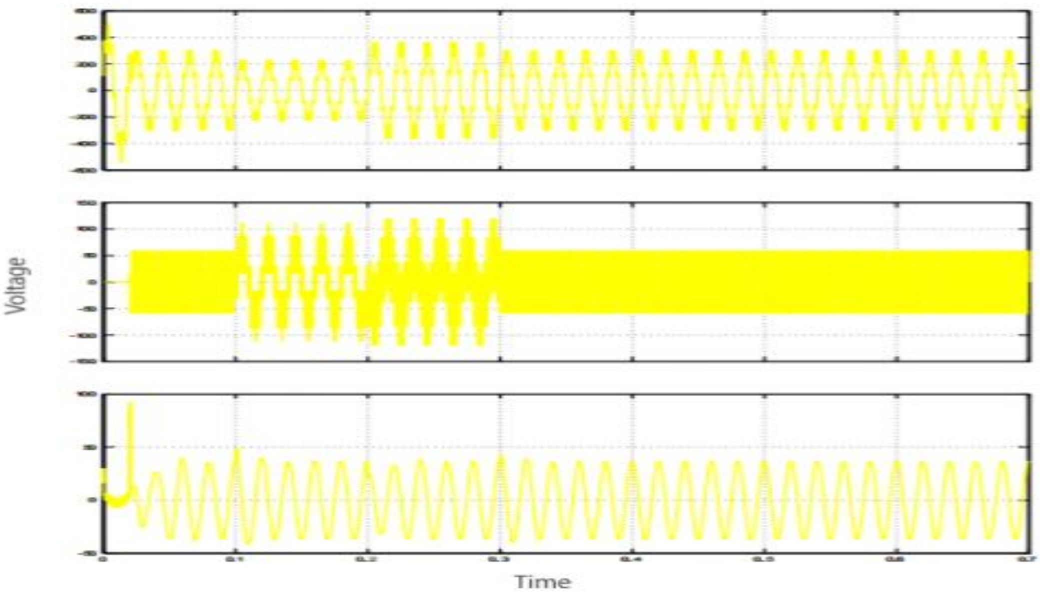

Figure:10 swell compensation for voltage and current profiles

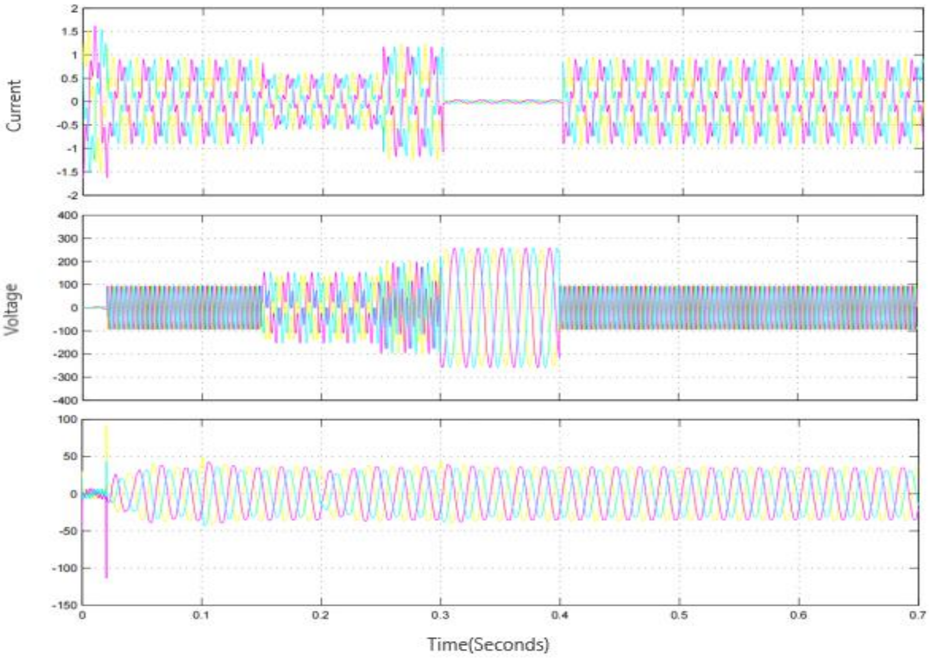

Figure:11 Unique compensation for voltage profiles in MC-UPQC 33 bus

The unique compensation time for 33 bus system is 0.25 seconds as shown in the figures 9,10and 11. The proposed model for optimal placement of UPQC is implemented in MATLAB. In this research work, the proposed model is implemented in "IEEE 57 bus system and IEEE 33 bus system".

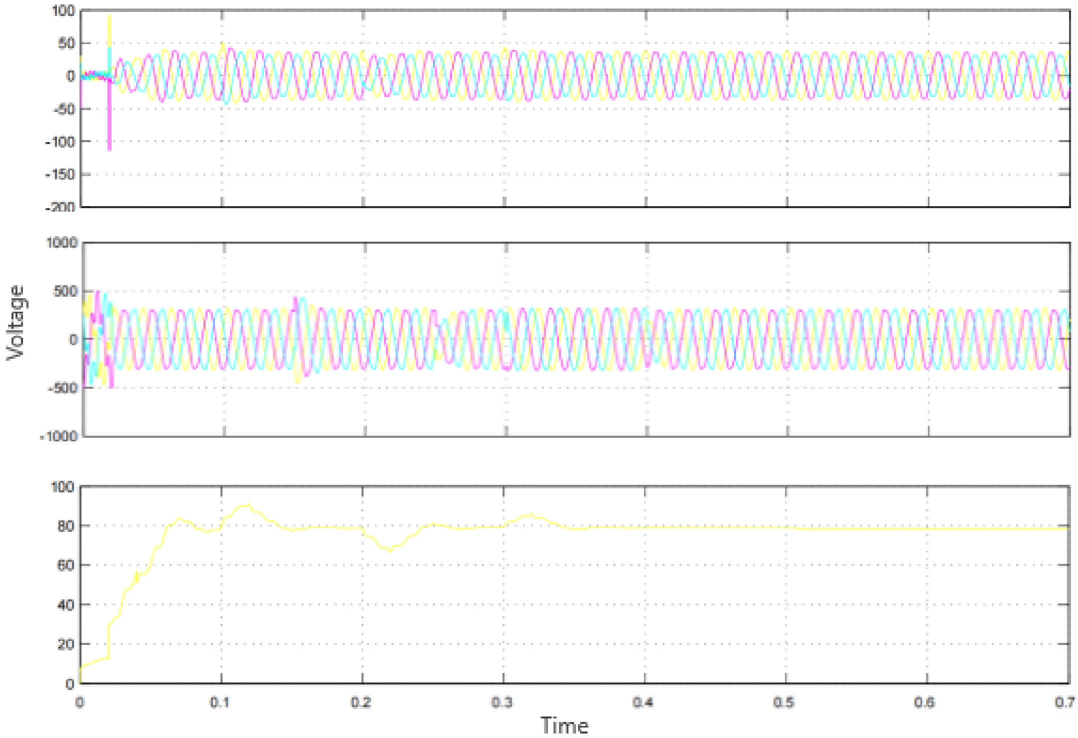

Figure:12 Swell and Sag compensation for voltage and current profiles 57 bus system

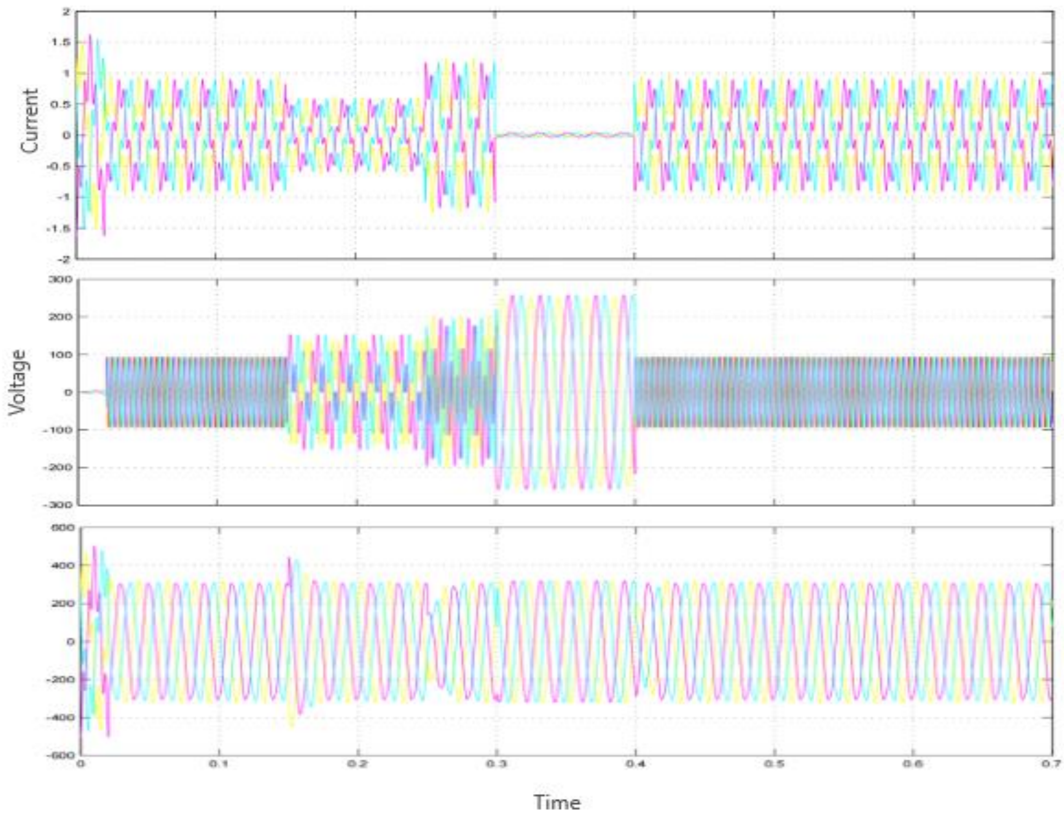

Figure:13 Unique compensation for profiles MC-UPQC for 57 bus system

The unique compensation time for 57 bus system is 0.28seconds as shown in the figures 12and 13. The power harmonics reduced to 0.63% THD and 0.56% THD for 33bus and 57 bus respectively as shown in the figures 14 and 15.

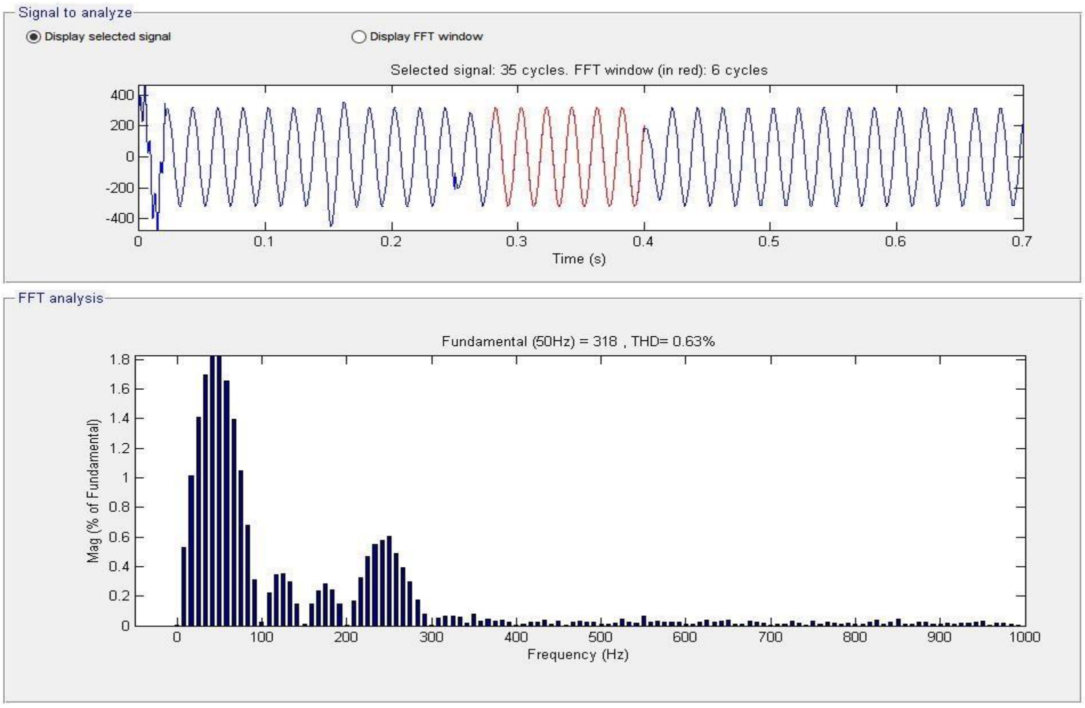

Figure:14 THD for 33 bus system with MC-UPQC

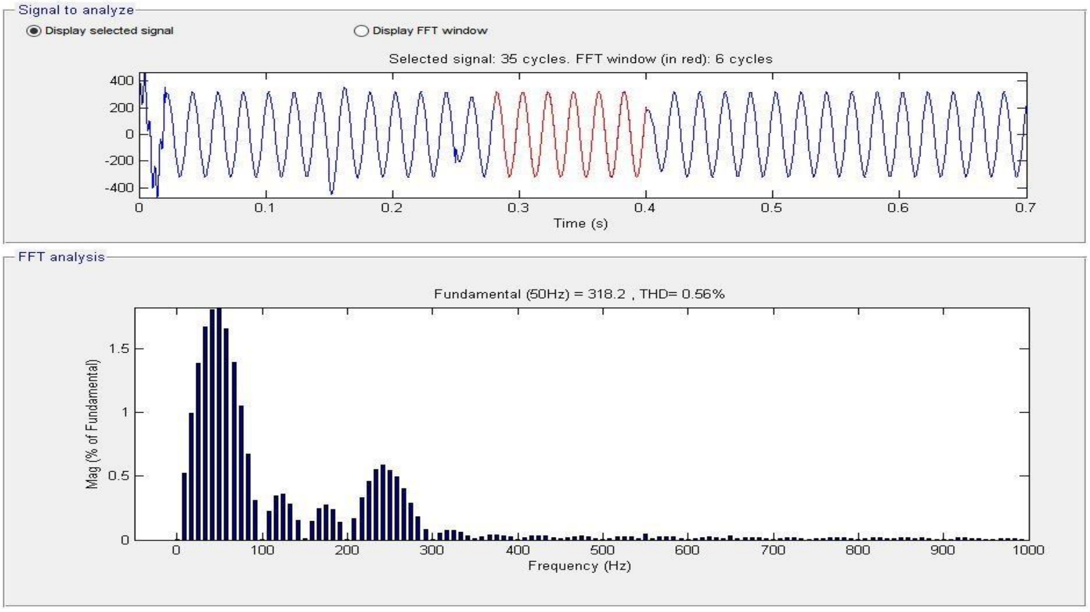

Figure:15 THD for 57 bus system with MC-UPQC

5.Conclusions

The Multi converter UPQC is a highly efficient device used to address PQ issues related to voltage and current. It effectively resolves problems such as voltage sags and swells, harmonics in voltage and current, voltage and current imbalances, flickers, and reactive power demand.MC- UPQC can be used in several power circuit configurations, each designed to address unique scenarios. In this work, various UPQC configurations are briefly discussed and the implementation done in MAT-LAB. Harmonics are greatly reduced with proposed algorithm. The compensation time also reduced to 0.25 to 0.28 seconds which is better than traditional approach.

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