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MGWO-PI controller for enhanced power flow compensation using unified power quality conditioner in wind turbine squirrel cage induction generator

S. Lakshmi Kanthan Bharathi [a,*], S. Selvaperumal [b]

[a] Assistant Professor, Department of Electrical & Electronics Engineering, Mohamed Sathak Engineering College, Kilakarai, Tamilnadu, India
[b] Professor, Department of Electrical & Electronics Engineering, Syed Ammal Engineering College, Ramanathapuram, Tamilnadu, India

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A B S T R A C T

Power quality is considered to be the major challenging one in the realization of the smart grid. So as to compensate for the issues occurring in power quality, active power filter (APFs) is mainly chosen as they are capable of filtering fast and has some active compensation. Also, load current related power quality constraint can be solved, such as unbalanced power, huge (Total harmonic distortion) THD level, and reduced power factor. For correcting the inappropriate supply of voltage and load current, the unified power quality conditioner (UPQC) and an effective integration of wind turbine are employed. A UPQC is a group of both shunt and series APF in a continuous manner having a conventional DC link capacitor. The voltage control of the DC link capacitor is significant in attaining a preferred performance on UPQC. In this paper, the UPQC with a Modified Grey Wolf Optimization (MGWO) based PI controller integrated with renewable energy like Wind turbine squirrel cage induction generator (SCIG) was implemented for the elimination of voltage and current harmonics imperfection precisely. Likewise, the Modified Grey Wolf Optimization (MGWO) was also exploited in UPQC. The performance analysis was made with UPQC, without UPQC, and with MGWO & UPQC and the simulation, outcomes are estimated and compared for the parameters THD values, load voltage and current. Also, the performance analysis was implemented in hardware prototype set-up and the results attained are depicted.

1. Introduction

At present, power quality (PQ) is regarded as the indispensable conditions of several power delivery systems. Reduced quality of power has an adverse effect on power consumers in several manners. The reduced quality of power also leads to the production loss, appliance or equipment damage, communication lines interference, enhanced loss of power and so on. Hence, it is essential to maintain a typical quality of power.

A small enhancement in the usual power quality affects the performance and duration of utility equipment considerably [1]. Nearly all delivery centers have recognized centers of quality control to offer flexible, intelligent, and reliable power supply to consumers, still in irregular conditions. The incorporation of renewable energy source at the customer end in the type of Distributed generation units has deteriorated the power quality problem [2]. The offered equipment of power quality enhancement is not dependable to deal with several issues. That's why it is indispensable to widen strategy that is cap[able to handling various power quality constraints [3]. The distribution systems power quality has enhanced on account of the power electronic devices introduction, termed custom power devices, like dynamic voltage restorers (DVRs), distribution static compensators (DSTATCOMs), and unified power quality conditioners (UPQC). UPQC unite the DVR and DSTATCOM functions [4,5], and in turn eradicates the voltage sag, load balancing, and harmonics. On comparing, the permanent-magnet synchronous and the double-fed wind power generation systems, the SCIG scheme is capable of offering benefits like technical maturity, small size, low cost, easy for maintenance, and stable performance [6]. Thus in the future, the system SCIG with a DC/AC power inverter and an AC/DC power converter will be the best combination in terms of performance and cost.

To compensate for the issues related to power quality, active power filters (APFs) is chosen over passive filters owing to their dynamic and fast compensation. Series APF mainly compensates supply voltage-related power quality issues like voltage sag, harmonics, and swell as shunt APF mostly compensate power quality issues related to load current like unbalance, harmonics, and re-

* Corresponding author.
E-mail address: lkbharathi.tum@gmail.com (S. Lakshmi Kanthan Bharathi).

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duced power factor. UPQC, a series and shunt APFs combination which in turn shares a general DC link, incorporates advantages of both series and shunt APF.

The remaining portion of this paper is schematized as follows: section II gives the detailed narration of various existing techniques employed so far. Section III is the depiction of proposed mechanism. Section IV provides the performance analysis of proposed scheme. Finally, the conclusion of entire workflow is concluded in section V.

2. Related works

This section provides the detailed depiction of various existing techniques.

The author in this work [7]. projected a new topological pattern for a unified power quality conditioner (UPQC). Usually, UPQC three-phase-three-wire power structure comprises two six switch inverters that were connected in a back-to-back form. For this design, six series inverter switches out of twelve switches were not used so much at most times. To enhance the utilization of semiconductor and thus to decrease the count of the total switch, this work presented a unique topology of the reduced switch for UPQC. The projected topology was revealed with the utilization of ten switches and in turn, gains entire performance metrics of the twelve-switch UPQC on minimizing the underutilization without increasing VA rating switch.

In the paper [8]. the author introduced a UPQC fed through solar energy that will provide dynamic power flow to the grid. The photovoltaic system is employed by conditioner, and their topology was created by hybrid APF (Active power filter) combination. This arrangement was based on similar APF that divides a frequent DC voltage guaranteed through the PV system by a serial APF. Concerning the estimation, proposed UPQC, in turn, eradicates the distortion of supply current due to non-linear load and the distortion of load voltage caused by the addition of seventh and fifth harmonics to the AC voltage.

This paper [9]. examines the control and operation of three-leg single-phase UPQC (TL-UPQC), at which a novel space vector modulation technique was presented for resolving the problem of coupling obviously provided by the frequent switching leg. The method of modulation is related to the modulation of identified space vector extensively utilized using 3-phase voltage source converters that attains additional TL-UPQC system flexibility. Two modulation modes that were optimized by both harmonic distortion and condensed switching loss are evaluated, discussed, and derived, to reveal the flexibility attained by the TL-UPQC space vector modulated.

The author in this work [10]. presented a placement of UPQC problem in the radial distribution systems. The UPQC placement intention was to decrease the losses of real power and enhance the voltage contour. The problem was expressed as a non-linear single objective problem. The injection made the compensation of voltage of active and reactive power through UPQC series compensator. The shunt compensator is responsible for offering reactive load power with series compensator. The placement of optimal UPQC has been resolved with the use of recent optimization technique termed as Ant Lion Optimization (ALO) technique. The projected method is verified using standard distribution systems.

In this work [11]. the author stated an approach of UPQC, which functions as the bidirectional connection once the DG system was located among grid, generic load or ac microgrid. In the mode of grid-connected, the DG scheme, in turn, performs active power-line conditioning at the energy injection created by PV array in the grid. In the islanded process, the structure will be operated as an ac grid that has been formed through a corresponding inverter if there was an energy storage system presence. A complete review which involves power flow over the PV-UPQC was a mandatory one for attaining entire system knowledge, the operation of the system and the design of power converter in a proper way.

The study and implementation of active power quality conditioners (PQCs) were described in the paper [12], which was applied for the improvement of power quality in the system 3-phase four-wire (3P4W). Using the strategy of similar control, the structure employed for the implementation of PQCs will be operated as unified PQC (UPQC) or over the modifications of some circuit as an uninterruptible power supply (UPS) scheme. Because of systems 3P4W, the dual compensation strategy use in PQCs consists of two converters with four-leg (4-Leg), which was the significant contribution of this work.

A technique of UPQC-1Ph-to-3Ph was projected in [13]. which was capable of draining a sinusoidal current, single-phase electrical grid and voltage in the phase that in turn results in high power factor. Besides, the structure was capable of suppressing harmonics in the grid voltage, and also for compensating other disturbances like voltage sag. Therefore, a 3P4W system with balanced, sinusoidal and regulated voltages using low harmonic ingredients had been offered for the single and three-phase load. The power flow analysis over the parallel and series converters was carried out to assist the power converter design.

In this work, [14]. the author analyzed the feasibility of capacity improvement and functional feasibility of UPQC over corresponding existing resources control. This UPQC comprises of multiple shunt APF (APFsh) units and single unit series active power filters (APFse) in a parallel (distributed) form. These units will be connected with separate or conventional dc capacitors that were lined. The capacity enhancement constraint evolves through the increased harmonic load demand flexibility at low voltage (LV) distribution system. This could be attained with the coordinated control in which multiple units APFsh were operated through the utilization of APFse capacity as it is in low/idle mode.

The author in the paper [15]. stated a strategy of compensation depending on the simultaneous injection of reactive power for UPQC had been presented for addressing the voltage sag issue. The projected UPQC-SRI recognizes the insertion perspective of voltage compensation by considering optimal UPQC current-carrying design. Furthermore, the current-carrying UPQC limit was found by the compensation approach, and then the UPQC-SRI zero active power injection region was attained. At the condition which exceeds UPQC-SRI region, the shunt current's limit value will be identified with the use of the presented approach.

The design of hybrid fuzzy back-propagation control scheme was stated in [16]. to enhance the power quality of UPQC. The UPQC's gating pulses were produced with the use of hybrid fuzzy-back propagation controllers. The controller's reference currents were projected using algorithm back-propagation by load currents and source currents as parameters of input control. For the controllers, the reference voltages were evaluated with a terminal voltage for the dc voltage regulator with the use of fuzzy logic controllers, and a dc voltage on behalf of input control parameters.

A converter-dependent multilevel Unified Power Quality Conditioner (UPQC) was considered in [17]. for solving power quality problem. The proposed UPQC impact on the parameters power quality was described in IEEE 14-bus system. To verify the outcome, software PSCAD/EMTDC was employed for the simulation of the system.

The author in the paper [18]. introduced a novel approach of multi-converter-based unified power quality conditioner (MCB-UPQC). In this, three optimization techniques were presented depending on the traditional UPQC. A controller multi-proportional resonant (PR) was implemented in the regulation of voltage and compensation of reactive power control processes.

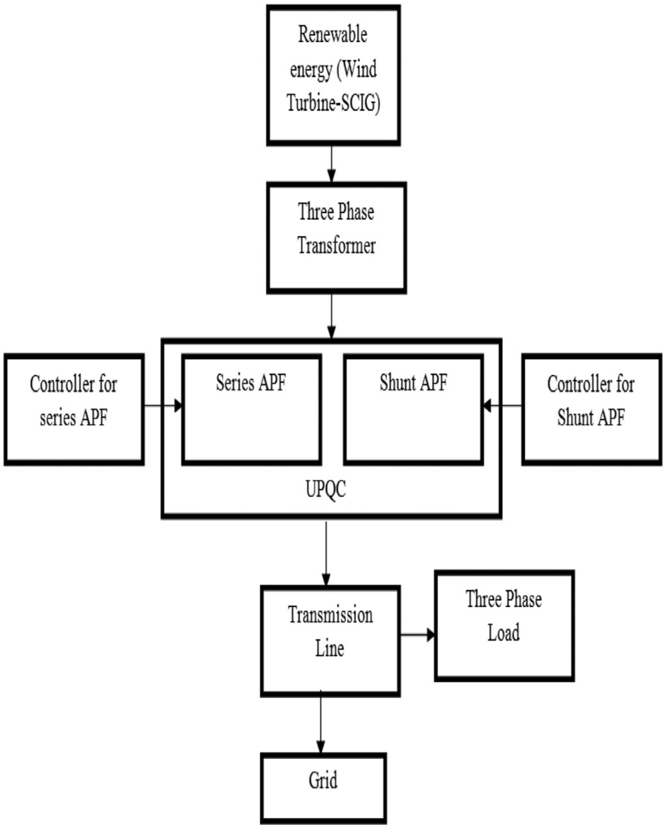

Fig. 1. Overall workflow of the proposed scheme.

A control algorithm was described in the paper [19]. depending on instantaneous symmetrical component theory (ISCT) for the switching of Series Active Power Filter (SEAPF). The injected series voltage using SEAPF controls the load end voltage efficiently not in favor of different voltage allied issues like swell, harmonics and sag. The Shunt Active Power Filter (SHAPF) is proscribed using power balance hypothesis for compensating the demand for reactive power, unbalanced loads, and harmonic current.

In this work [20]. the author presented a UPQC system which was regarded as a power conditioning device and was capable of compensating the entire types of power quality faults. This will be used as a filter for both voltage and current harmonics for compensating voltage sag. This, in turn, deals with a manner of improving performance of voltage compensation in the series APF.

An integration configuration of novel PV grid was suggested in [21]. which protects the unfavorable circumstances concerning voltage or current in a power system. The issues related to voltage were sustained by the UPQC series component and the problems related to current were handled using the UPQC shunt part. The PV-UPQC schemes diverse modes of operation were classified generally about the power flow direction. This PV-UPQC was having an advantage over traditional UPQC system since it was developed as the ability for compensating voltage interaction issue control algorithm.

3. Proposed work

This section offers the detailed description of the proposed mechanism.

Fig. 1 depicts the overall workflow of the proposed scheme.In this, the UPQC with a Modified Grey Wolf Optimization (MGWO) based PI controller integrated with renewable energy like Wind turbine (SCIG) was implemented for the elimination of voltage and current harmonics fault correctly. The primary intention of this work is to compensate or enhance the power quality factor and to eradicate the errors occurred during the transmission of power. To compensate the power quality UPQC device is used in which the total harmonic distortions are eliminated, and it mainly depends on shunt and series active power filter controller (APFs). For this, Modified Grey wolf optimization-based PI controller is utilized. The PI controller is tuned, and the modified grey wolf optimization technique provides the best and optimized values. Thus, from a renewable source of transmission, power is compensated by eradicating faults and enhanced power are then stored in the grid.

The main simulation diagram is shown below in Figs. 2–4

3.1. Renewable energy source (wind turbine-SCIG)

In recent years, the considerable quantity of power fed by wind farmhouse has impacted the power system previously, from a technical as well as in the regulatory point. Huge wind plants cover a remarkable impact on the operation of the power system as they are correlated with the primary source's irregularity. Accordingly, wind turbines should enhance their eminence production for ensuring the reliability and stability of a power system like usual power plants. The wind energy is not stable and since the output of wind turbines is comparative/proportional to the wind speed cube. This, in turn, leads to the power output of the Squirrel Cage Induction Generator Wind Turbine (SCIG WT) to oscillate, which in turn leads to power fluctuation or decrease in quality of power in the transmission line. Therefore, it is essential to compensate for the loss. For this purpose, a new strategy is designed by implementing the UPQC device along with MGWO based PI controller. The primary function or operation of this proposed mechanism is described below.

3.2. Control mechanism

The overall UPQC function depends mostly on the shunt and series APF controller. A Modified Grey Wolf Optimization (MGWO) based PI controller is recommended for the power quality compensation. The Grey Wolf Optimization (GWO) algorithm modification is presented by the approach which sustains proper stability among exploitation and exploration phases of algorithm which in turn offers more significance to the fittest wolves for identifying the grey wolves' new position all through the iterations.

A series active filter offers high impedance for the current harmonics and obstruct its source to load headings and load to the source streaming, and delivers as a voltage supply in time. The eradication of the harmonic mechanism in the voltage supply is the foremost intention of series compensators.

Additionally, it is free and simple on behalf of computational difficulty. Furthermore, MGWO can be programmed and effortlessness to realize. Though the original GWO is understood and programming is easy however it has a drawback that it sacrifices its half portion of iteration for the exploration and the other partial one for exploitation, neglecting the exact contact stability between them to offer an accurate global optimum estimation. The incorporated MGWO method is projected to adjust the PI controllers parameters of doubly-fed induction generator dependent wind turbine wherever the transmission among exploitation and exploration is attained through two self-determining groups of grey wolves, at which the supportive hunt grouping employ four kinds of grey wolves intended for a deep utilization. In contrast, the indiscriminate explore grouping adopt several scouts for an extensive investigation. The algorithm for MGWO approach is shown below: (Algorithm 1).

Thus, the power compensation can be measured by injecting some fault in the transmission line. This is to check and examine the effectiveness of power stability in this proposed mechanism.

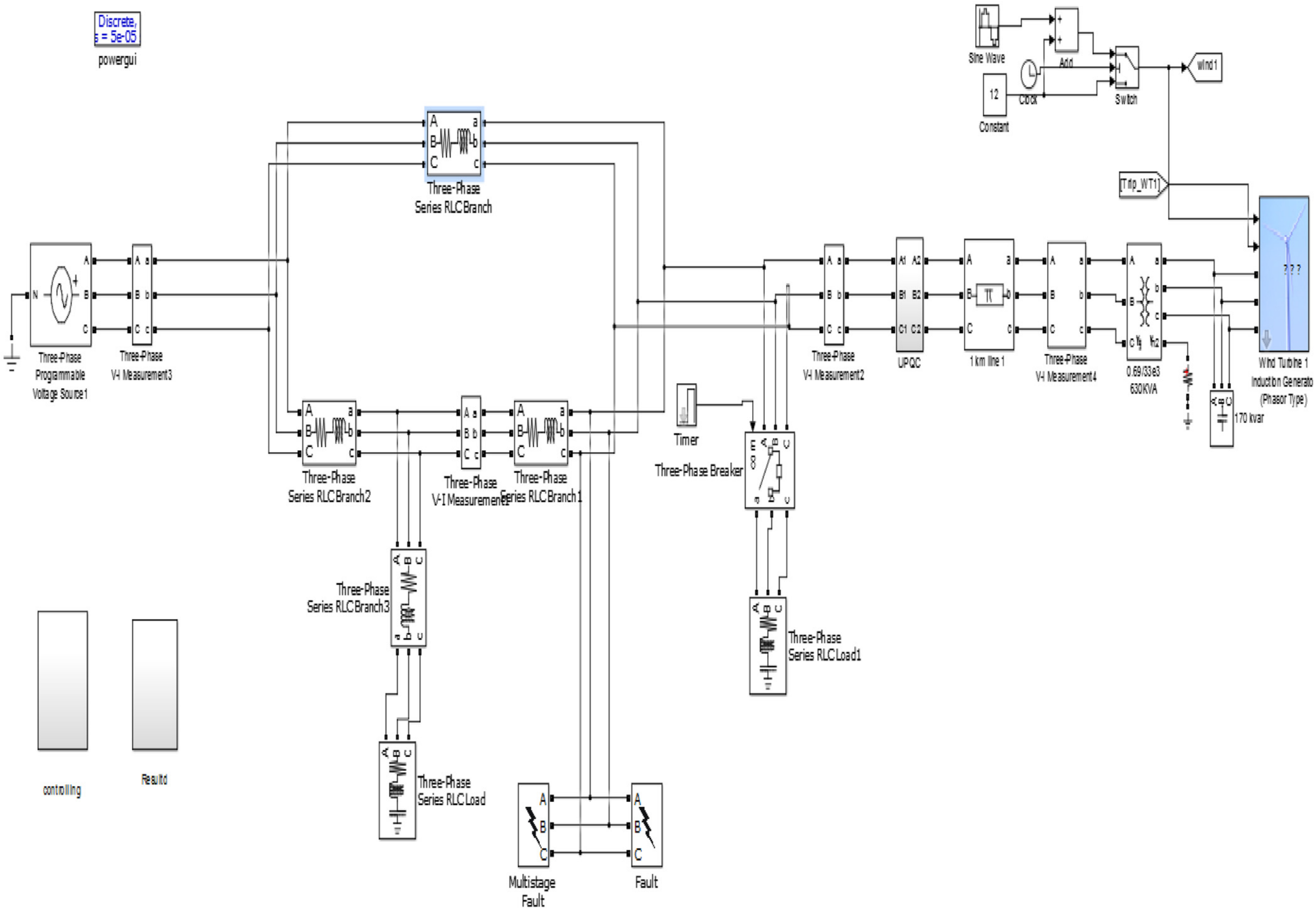

Fig. 2. Simulation diagram of the proposed mechanism.

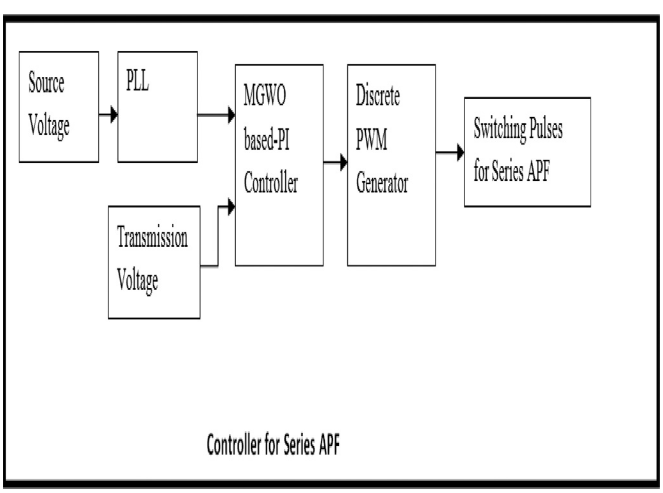

Fig. 3. Controllers for Shunt APF.

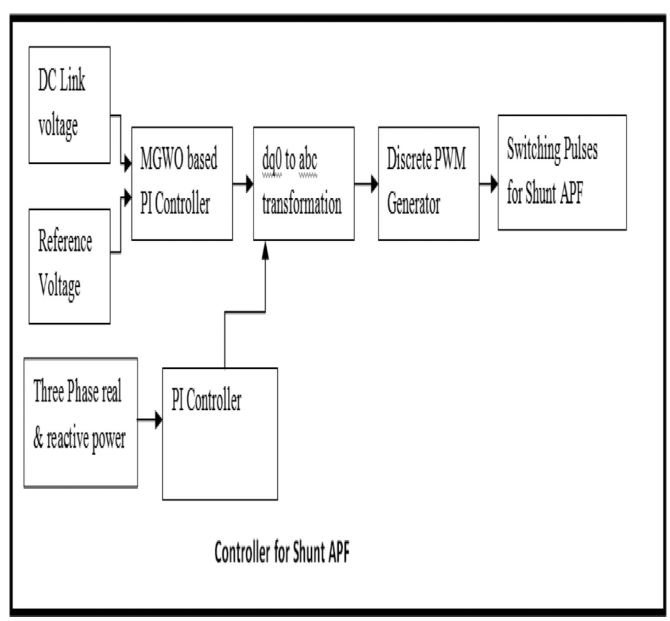

Fig. 4. Controllers for Series APF.

At last, the faults are eradicated with this proposed mechanism as discussed above with the use of UPQC controller which incorporates MGWO based PI controller. The distortion and errors are rectified, and the stabilized power is then stored in a three-phase grid.

3.3. Three-phase grid

Three-phase electric power is regarded as the standard technique of alternating current (ac) generation of electrical power, distribution, and transmission. It is a kind of polyphase system and is the, for the most part, it is the widespread technique employed globally by the electrical grids for transferring power. This can also be used for powering huge motors and the other heavy

Algorithm 1 Modified grey wolf optimization approach.

Input: dc voltage U_{DC}
Output: Optimized valued δ_p and δ_i (gain of Kp and Ki)
Step1: initialize the parameters,
u_{dc}=[Upper Limit lower limit]
Search agents_num τ_{san}=30;
Max_iteration max_{iter}=100;
Lower band l_b=min(u_{dc});
Upper band u_b=max(u_{dc})
Dimensions d_b=size(u_b, 2)
Step 2: initialize the alpha, beta and delta positions
Alpha_pos α_p=zeros(1, d_b)
beta_pos β_p=zeros(1, d_b)
delta_pos δ_p=zeros(1, d_b)
position pos_{data}=rand(τ_{san},1)*($u_b - l_b$)+ l_b
step 3: calculate objective function,
while 1< max_{iter}
for i=1:size(pos_{data}, 1)
flag4ub=pos_{data}(I,:)> u_b
flag4lb=pos_{data}(I,:)< l_b
pos_{data}(I,:)= $pos_{data}(i,:)$*(flag4ub+ flag4lb)+ u_b* flag4ub+l_b* flag4lb
d_b=size(PI,2)
Kp=PI(d_b, pos_{data})
Ki=size(PI,2)
obj_{fn}=-20*exp(-2*$\sqrt{\sum PI^2}$)/2-exp(Σcos($2\pi * PI$)/d_b)+20exp(1)
Step 4: Update the alpha, beta and delta positions,
If $obj_{fn} < \alpha_p$
$\alpha_p = obj_{fn}$
α_p=pos_{data}(I,:)
End
If $obj_{fn} < \alpha_p$ && $obj_{fn} < \beta_p$
β_p=obj_{fn}
End
If $obj_{fn} < \alpha_p$ && $obj_{fn} > \beta_p$ && $obj_{fn} < \gamma_p$
γ_p=obj_{fn}
End
end
end

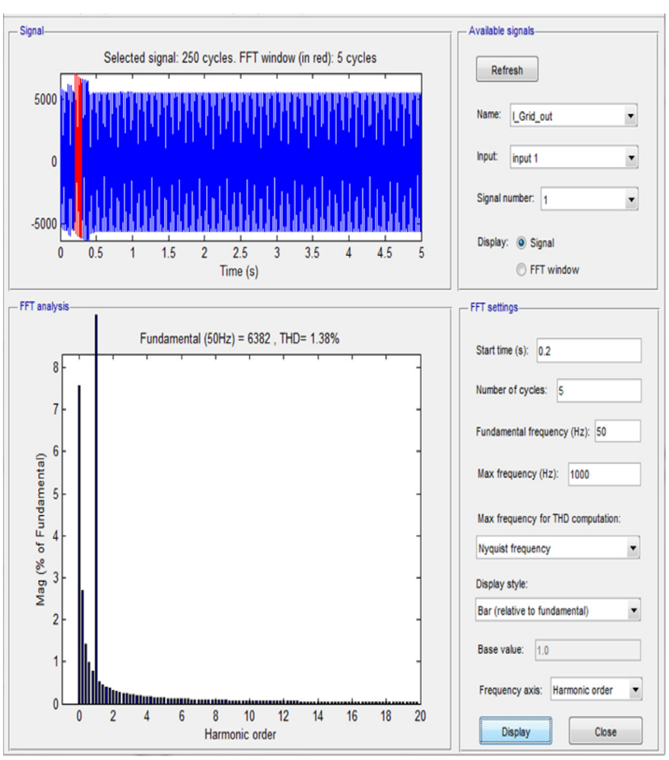

Fig 5. Performance analysis of grid current THD (before UPQC activation).

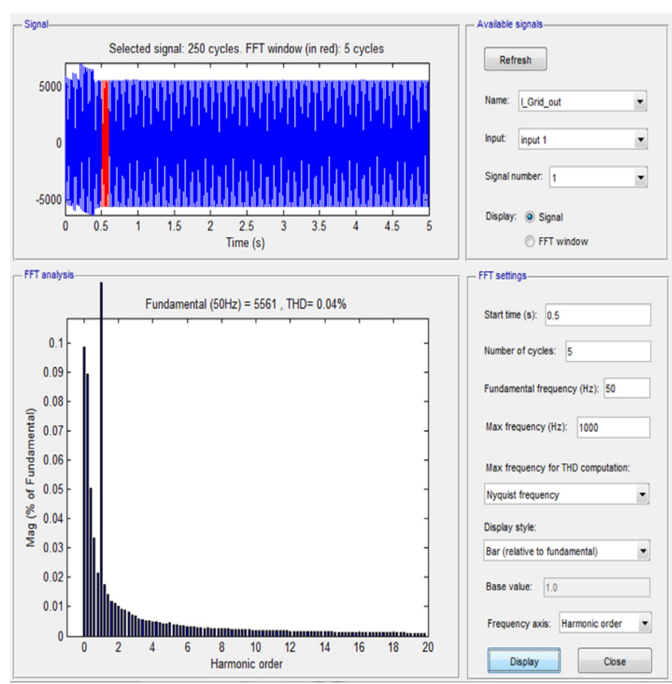

Fig. 6. Performance analysis of grid current THD (after UPQC activation).

loads. A circuit of three-wire three-phase is more economical generally on comparing two-wire single-phase equivalent circuit in the same transmission line to ground voltage as it exploits less mate-

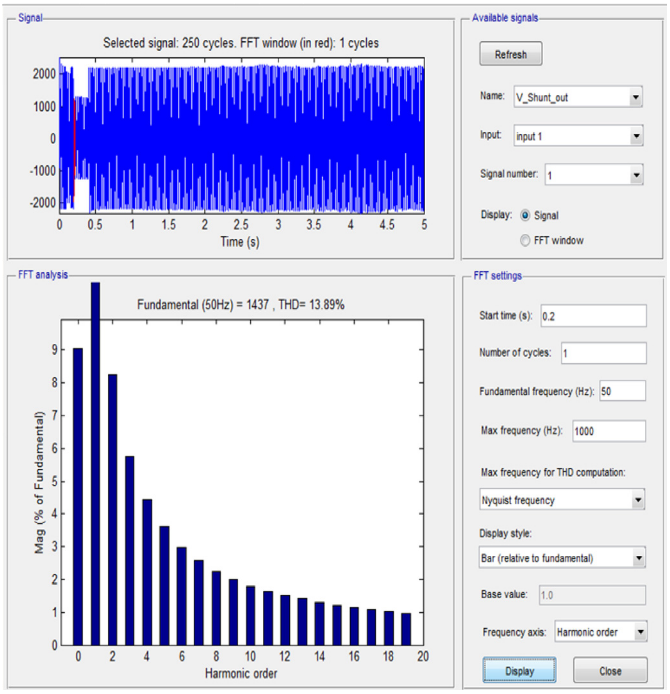

Fig. 7. Performance analysis of shunt voltage THD (before UPQC activation).

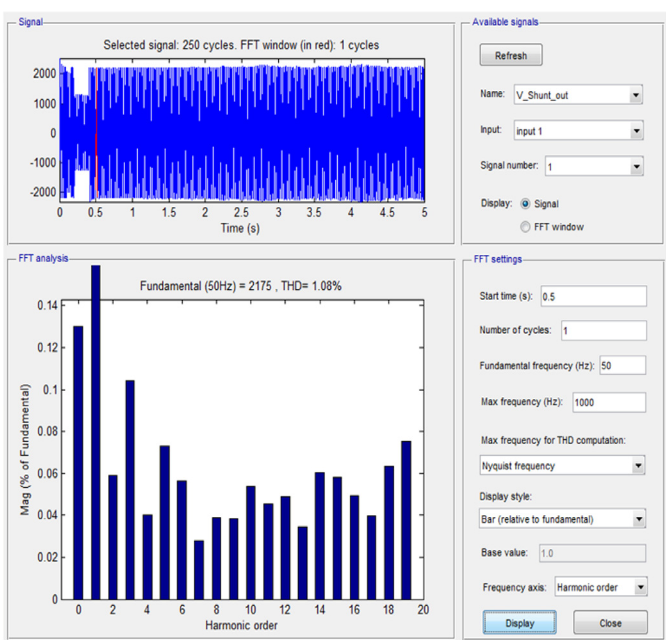

Fig. 8. Performance analysis of shunt voltage THD (after UPQC activation).

rial for the conductor to transfer a specified quantity of the electrical power.

Once the power quality is enhanced, and the loss is compensated then the power is stored in the grid for further usage. Through the transmission line, the power is transmitted to both three-phase load and grid. Thus, the effective power compensation was made by the use of this proposed methodology.

4. Performance analysis

This section offers the experimental analysis of the proposed mechanism.

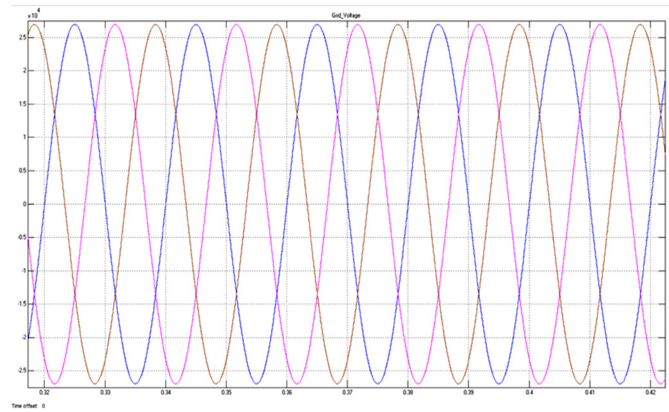

Fig. 9. performance analysis of Grid Voltage.

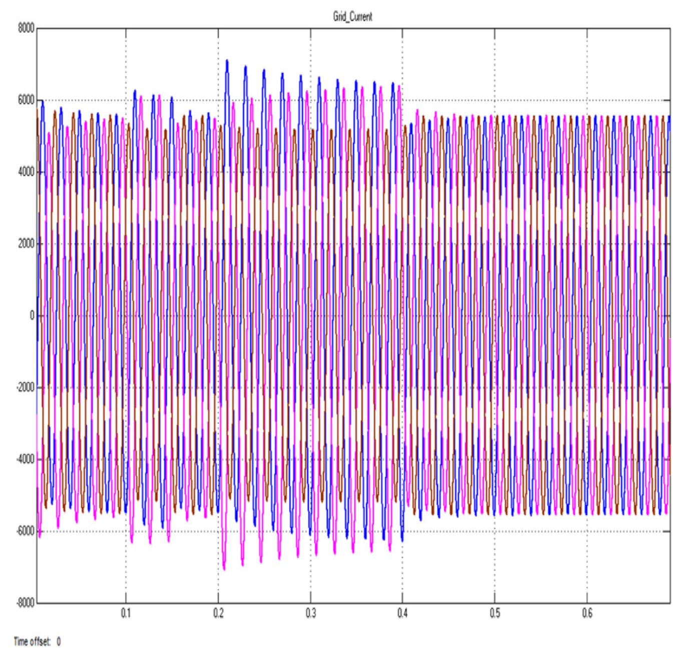

Fig. 10. performance analysis of Grid current.

4.1. Simulation analysis

The performance analysis of the proposed mechanism is simulated, and the results are represented in graphical form, as shown below:

Fig. 5 depicts the performance analysis of total harmonic distortion in grid current. In this, THD is 1.38% at initialization time 0.2. Thus, this is the outcome of grid current THD before the activation of UPQC.

Fig. 6 depicts the performance analysis of grid current THD after the activation of UPQC. Here, THD is about 0.04%

Fig. 7 is the representation of grid current THD before the activation of UPQC. In this, the THD value is 13.89%.

Fig. 8 is the analysis of THD grid current after the UPQC activation for the power flow compensation. Here, THD is 1.08%.

Table 1 depicts the comparative analysis of the total harmonic distortion of grid current and shunt voltage before and after UPQC activation. The analysis shows that the value of THD is lower in the activation of UPQC compared to the value get before the UPQC activation.

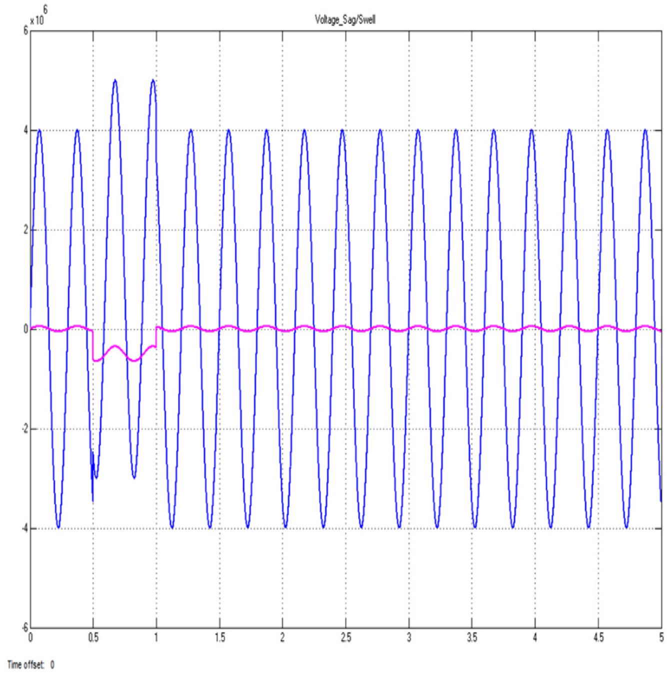

Fig. 11. performance analysis of Shunt Voltage: Sag/Swell.

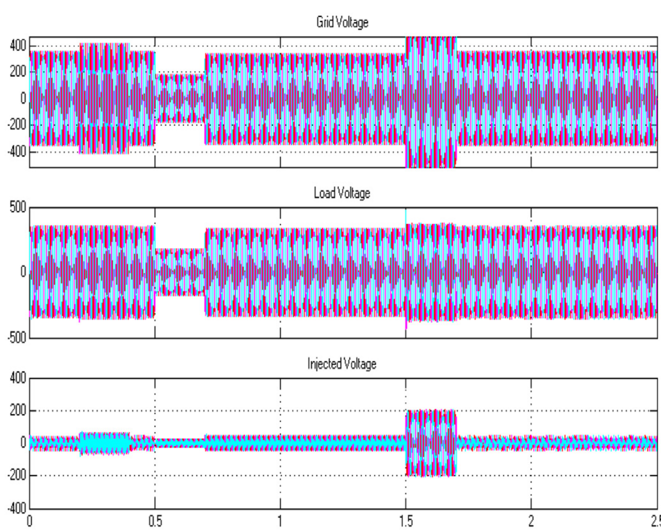

Fig. 12. Grid voltage and load voltage without UPQC.

Table 1
comparison of THD before and after UPQC activation.

Parameters	(Before UPQC activation)	(After UPQC activation)
Grid current THD	1.38%	0.04%
Shunt voltage THD	13.89%	1.08%

The performance analysis of grid voltage is depicted in the graphical form provided in Fig. 9. Here, the power fluctuation is eradicated, and the voltage power is maintained.

The performance analysis of the grid current is depicted in the graphical form provided in Fig. 10. This outcome shows the occurrence or presence of faults in the grid current.

Fig. 11 is the depiction of the performance analysis of shunt voltage: sag/swell. There is some fluctuation during transmission.

In Figs. 12 and 13, the grid voltage and load voltage without UPQC and after the compensation with UPQC is represented. The

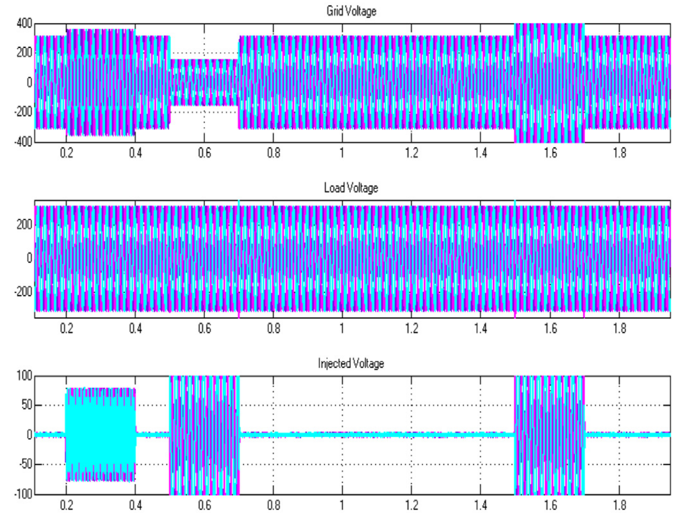

Fig. 13. Grid voltage and load voltage after compensation with UPQC.

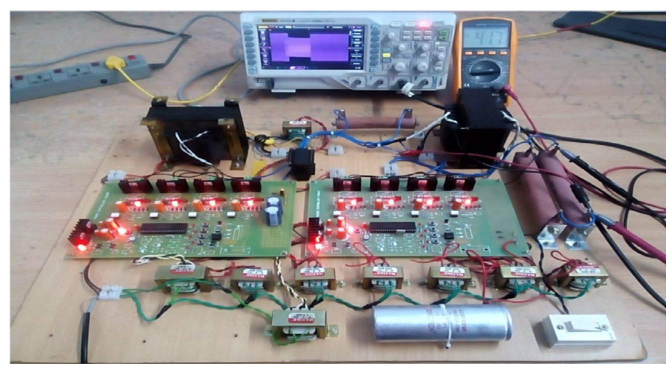

Fig. 14. Hardware prototype model.

Fig. 15. Hardware result in SAG creation and clearing with UPQC.

second waveform representation was also having Sag and swell arises in the first waveform itself, and this problem was overwhelmed by the use of UPQC. Therefore there is no Sag and swell. The third waveform representation depicts the injected voltage to the Grid.

Thus, these fault occurrences and fluctuations are being eradicated by the activation of UPQC.

4.2. Hardware prototype model implementation

The experimental analysis is also implemented in hardware, and the prototype set-up model is depicted. The implemented model is shown below with the attained outcome as in Fig. 14.

Fig. 15 depicts the hardware outcome in the creation and clearing of sag with UPQC. The attained output waveform is clearly shown in the figure provided above.

5. Conclusion

This proposed work intents at reducing the faults occurring at the time of power transmission, thereby compensating the quality of power supply to the three-phase grid. The UPQC with a Modified Grey Wolf Optimization (MGWO) based PI controller was implemented. This is incorporated with renewable energy like Wind turbine (SCIG) for the voltage and current harmonics fault elimination properly. The foremost objective of this work was to eradicate the faults occurred during the transmission of power and to enhance or compensate the power quality factor. For compensating the power quality, UPQC device was introduced, which eradicates THD, and it mostly depends on series and shunt APFs. Also, MGWO based PI controller was employed. The PI controller is tuned, which attains best and optimized values from MGWO technique. As a result, the renewable source of transmission the power is compensated by eradicating the faults and the enhanced power are then stored in the grid. On comparing DFIG, the application of SCIG results in lower cost and reduced rate of THD which is suitable for the real-time application.

6. Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Declaration of Competing Interests

This paper has not communicated anywhere till this moment, now only it is communicated to your esteemed journal for the publication with the knowledge of all co-authors.

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S. Lakshmi Kanthan Bharathi (1979) is presently PhD student in Department of Electrical Engineering at Anna University, Chennai, Tamilnadu, India. He received his B.E degree in Electrical and Electronics Engineering from Madurai Kamaraj University in 2002 and M.E degree in Power Systems Engineering from Anna University, Chennai in 2006. Since 2009 onwards , he is working as an Assistant Professor in Mohamed Sathak Engineering College, Kilakarai, Tamilnadu, India. His research interest are in the area of Power Systems, Wind Turbine, Multilevel Inverter and FACTS devices.

S. Selvaperumal was born in Virudhunagar, Tamilnadu, India, in 1977. He received the B.E. degree in electrical and electronics engineering and the M.E. degree in power electronics and drives both from Anna University, Chennai, Tamil Nadu, in 2005 and 2007, respectively and the Ph.D. degree in electrical and electronics engineering from Anna University, Chennai, Tamilnadu, in 2013.He is currently a Professor in the Department of Electrical & Electronics Engineering at Syed Ammal Engineering College, Ramanathapuram. He had published articles in reputed journals like IET and IEEE Transactions. He had published more than 40 journals all over the world. He acted as reviewer for more than 20 journals including IEEE & IET journals. He organized two international conferences and published 10 books. He acts as a recognized supervisor for Ph.D guidance in Anna University and guiding 12 Ph.D Scholars and produced 6 Ph.D scholar in the domain of Electrical Engineering. His areas of interest are Power Electronics, Embedded Systems and control system design.