Mitigation of Power Quality Issues using PV- UPQC and MTG - UPQC in a Distribution system

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Abstract: Maintaining power quality at the distribution end is a serious concern that the power system faces today. The usage of power conditioning devices like UPQC mitigates the power quality problems to certain extent. Nowadays the distributed generation sources like photo voltaic cells and micro turbine generation are integrated in the existing distribution system to improve power quality and reliability. This paper proposes the installation of Photo Voltaic cell - Unified Power Quality Conditioner and Micro Turbine Generator - Unified Power Quality Conditioner in a distribution system to solve the power quality problems. Also this paper compares the effective usage of PV- UPQC and MTG – UPQC in the distribution system to mitigate the power quality issues. Due to the installation of PV-UPQC or MTG-UPQC the total harmonic distortion in the source current is reduced and the problem of voltage sag is avoided. MTG-UPQC installed in the distribution system performs better in the mitigation of power quality issues than PV-UPQC. The results are validated using MATLAB/Simulink.

Keywords: Microturbine Generation (MTG), Photo Voltaic (PV), Voltage Sag, Total Harmonic Distortion (THD)

1. INTRODUCTION

Normally, in three phase power systems, all the three phase voltages are displaced by 120º each resulting in sinusoidal and equal magnitude voltages in each phase. But at the point of utilization, these voltages become unbalanced and suffer from various power quality problems such as fundamental frequency deviation, fundamental phase angle deviation and unequal levels of harmonic distortion between the phases. This is due to the nature of unpredictable loads and deployment of Adjustable Speed Drives (ASD) at customer premises as Energy saving measure [1,2]. Now-a-days due to the usage of inverters in residential households the problem of power quality at the customer end is alarming. In many applications, at the customer end, power electronic converters serves as the interface for many electronic loads. Most of these power electronic converters consist of a diode rectifier, a dc link capacitor and a PWM inverter which draws non sinusoidal currents. Hence the problem of harmonic distortion arises [3-5]. In the proposed paper the need to balance the voltage at the customer premises is discussed. The voltage balance problem becomes difficult due to the large usage of single phase non linear switch mode power supply based loads such as computers. Moreover the increase of lighting loads in a particular phase also imposes serious voltage unbalance problems [6]. Many measures are being taken to correct the voltage unbalance in the distribution system and are discussed in literature. The addition of passive filters reduces the voltage unbalance by adding reactive elements parallel to the load. Also the introduction of thyristor controlled shunt compensators in the distribution system reduces the voltage unbalance. But the disadvantage of this system is the introduction of harmonics due to the power electronic components [7].

The installation of custom power devices is a solution for Voltage Unbalance problem. UPQC is used in this paper to mitigate the voltage sag and swell. It consists of both series and shunt converter and by controlling the magnitude of series injected voltage and phase angle, voltage profile is improved in the distribution system [8].

The integration of distributed generation in the distribution system is increasing day by day. The distributed generation includes the penetration of photo voltaic cells, Micro turbine generation, wind, fuel cell and other sources. The penetration of these sources in the distribution network reduces pollution, increases reliability, effective load management and reduces losses [9].

In recent times the installation of single phase grid connected roof top photo voltaic cells in residential homes imposes serious voltage unbalance problems [10]. The penetration of photo voltaic cell, its rating and its location in the distribution system is unpredictable and so a sensitivity analysis needs to be carried out to study the effect of voltage unbalance. From VU sensitivity analysis it is found that the VU problem is more pronounced at the feeder end [11]. The performance of single and multiple PV arrays connected with UPQC for Voltage Unbalance problem is analyzed [12]. Single phase energy storage systems added to the PV-UPQC distribution system further improves the voltage profile of the system [13].

The MTG system generates power from 25 kW to 500 kW. This type of generation is operated as standalone systems or interconnected with utility applications. The main applications of this type of generation are base load power and peak shaving [14]. The load following performance of MTGs in grid connected and islanded modes are analyzed. The grid tied MTG suffers from voltage instability and synchronization problems. But the performance of MTG for microgrid networks is acceptable [15]. Even in grid tied MTGs the problem of VU is improved using UPQC and by varying the output of MTG. The dynamic behavior of PMSG coupled MTG is analyzed and it is found suitable for micro grid distribution system [16].

The organization of the proposed paper is as follows: Section 1 describes the need for installing power quality devices at the distribution side. Section 2 outlines the role of the proposed system in mitigating power quality issues in the distribution system. Section 3 describes the PV-UPQC compensated distribution system and the role of UPQC and PV in improving the voltage sag and reducing the Total Harmonic Distortion of the source current and voltage. Section 4 discusses about the results obtained through PV-UPQC system. Section 5 details the role of MTG-UPQC in mitigating power quality issues like voltage unbalances and reduction of Total Harmonic Distortion of the source current and voltage. Section 6 discusses about the results obtained through MTG-UPQC system. Section 7 discusses about the results of the proposed system and compares the performance of PV-UPQC and MTG-UPQC systems in mitigating the power quality problems.

1.2. Proposed System

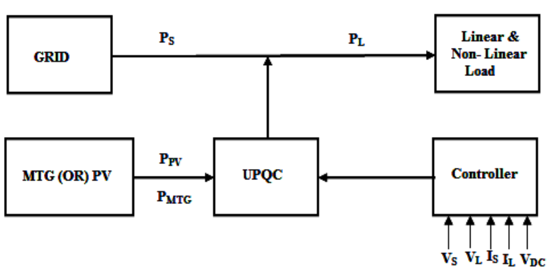

Fig. 1 Block Diagram of the Proposed System

P_s - Power from grid
P_L - Power to load
P_{MTG} - Power from micro turbine
P_{PV} - Power from PV

Figure 1 shows the block diagram of the proposed system. UPQC is placed between the Grid and the Load. UPQC along with MTG or PV is inserted into the system during heavy load conditions. When the non linear loading is high in the proposed system the source current and the load current suffers from harmonics and the problem of voltage sag also arises. The insertion of PV-UPQC or MTG-UPQC in the proposed system restores the voltage and reduces the Total Harmonic Distortion of source current and load current. The controller compares the actual voltage with the reference voltage and an error signal is produced. The series and the shunt converter of UPQC inject voltage and current in proportional to the error signal to mitigate the power quality issues.

1.3. PV-UPQC Compensated Distributed System

The block diagram of Distribution system compensated by PV-UPQC is shown in Figure 2. This system has a load connected to the feeder. The feeder is powered by a source. UPQC is placed between source and the load. At the point of common coupling the source voltage V_s would be equal to Thevenin's voltage V_{th} and the feeder impedance is assumed to be Thevenin's impedance. To match the load voltage with the source voltage the series converter of UPQC inserts a voltage so that the load voltage is balanced with respect to source voltage. The shunt converter of UPQC injects a current of proper magnitude to obtain a nearly sinusoidal source current.

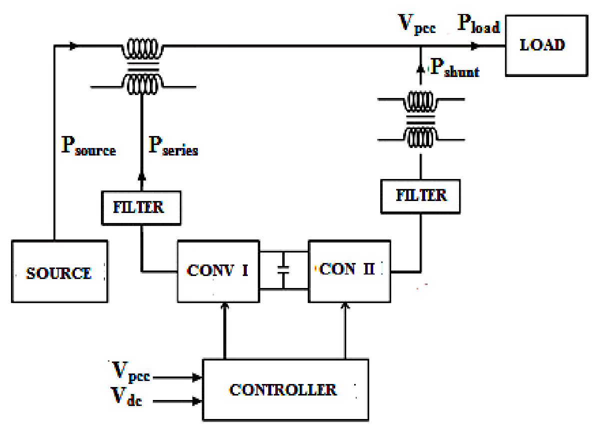

Fig. 2 Block Diagram of UPQC compensated Distribution system

Consider the equivalent circuit of the PV-UPQC compensated distribution system as shown in Figure 3.

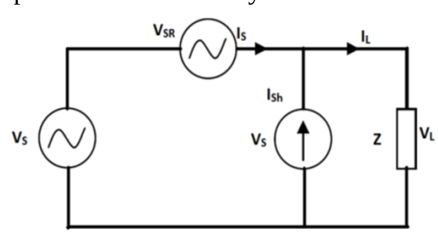

Fig. 3 Equivalent circuit of PV-UPQC compensated Distribution system

V_S - Voltage at power supply

V_{SR}- Series-Active Power Filter for voltage compensation

V_L - Load voltage and

I_{Sh} - Shunt-Active Power Filter for current and V_{SR} compensation

In general, the source voltage is expressed as

$$V_S + V_{SR} = V_L \quad (1)$$

Balanced sinusoidal load voltage with fixed amplitude V is obtained from the given expression [16]

$$V_{SR} = (V - V_{1P})\sin(\omega t + \theta_{1P}) - V_{Ln} - \sum_{k=2}^{\infty} V_k(t) \quad (2)$$

where

V_{1P} - positive sequence voltage amplitude of fundamental frequency

Θ_{1P} - initial phase of voltage for positive sequence

V_{Ln} - negative sequence component

The load current is given by the expression [16]

$$I_L = I_{1p}\cos(\omega t + \theta_{1P})\sin\varphi + I_{Ln} + \sum_{k=2}^{\infty} I_{Lk} \quad (3)$$

$$\phi_{1P} = \varphi_{1P} - \theta_{1P} \quad (4)$$

where

φ_{1P} - initial phase of current for positive sequence

The terminal source current is harmonic free sinusoid and has the same phase angle as the phase voltage at the load terminal and is expressed as [16]

$$I_S = I_L - I_{sh} \quad (5)$$

$$= I_{1p}\sin(\omega t - \theta_{1p})\cos\varphi_{1p} \quad (6)$$

The block diagram of the PV-UPQC system is shown in Figure 4. The PV is connected to the dc link of the UPQC. The load is fed by PV and utility grid. The nature of load is non linear and the shunt and series filter provides compensation for the load. The Simulink diagram of MPPT controlled PV-UPQC is shown in Figure 5. The simulink diagram of MPPT controlled PV system is shown in Figure 6.

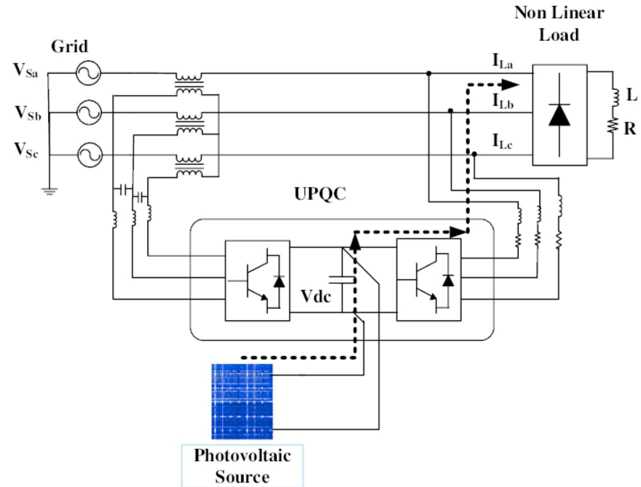

Fig. 4 Circuit Diagram of PV-UPQC compensated Distribution system

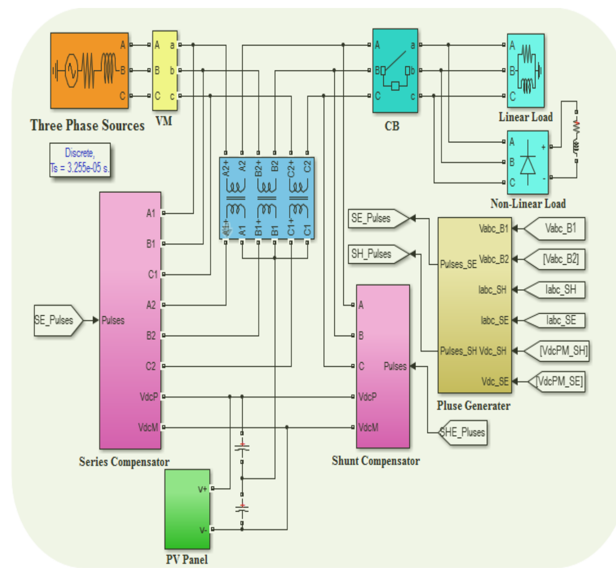

Fig. 5 SIMULINK diagram of PV-UPQC compensated Distribution system

The proposed system configuration of UPQC consists of a 600V, 60 Hz generation system, feeding two transmission lines through a 3- winding transformer connected in Δ /Δ/Δ, 115/25/25 kV. To verify the working of UPQC for voltage compensation, both linear and nonlinear loads are connected at the distribution end. The UPQC is simulated to be in operation only for the heavy load condition. Thus, UPQC will be inserted in series with the load to help improving the supply voltage before it is being fed to the load. The system parameters of UPQC are given in the Table 1.

Table 1

Parameters of UPQC

Sl. No.	Parameters	Values
1	Source Voltage	600V
2	No. of bridge arms	3
3	Transition time	0.1 to 0.2 sec
4	Snubber resistance	0.1 mΩ
5	Breaker resistance	0.0001Ω
6	Line frequency	50 Hz
7	Generator Voltage	126 V

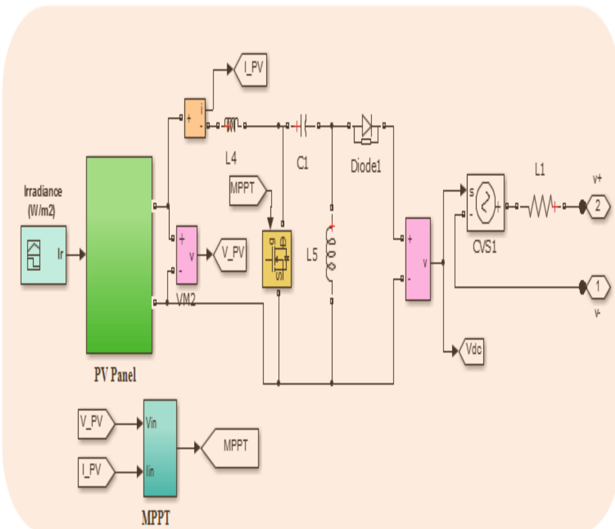

Fig. 6 SIMULINK diagram of PV Panel with MPPT

Maximum Power Point Tracking (MPPT) algorithm is used to improve the performance of the solar panel. This algorithm tracks the point of maximum power. There are many types of MPPT algorithm in which Perturb and Observe type algorithm is implemented in the proposed system. The implementation of maximum power point tracking is shown in Figure 7.

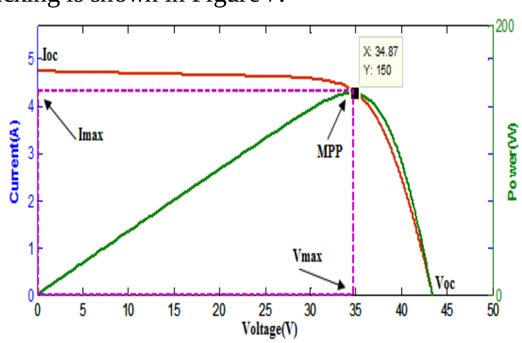

Fig. 7 Maximum Power Point Tracking in PV

1.4. Results and Discussion for PV-UPQC

The simulation was done initially without connecting the PV-UPQC in the three phase grid line. The voltage at the grid side contains sag, swell and unbalanced current due to non-linear loads. The voltage sag is created for a period of 500 to 1000 seconds. The grid voltage without PV-UPQC compensated distribution system is shown in Figure 8. Figure 9 shows the grid current obtained without PV-UPQC compensated distribution system for non linear loads. The THD of grid voltage without PV-UPQC compensated distribution system is 13.96% as shown in Figure 10. The THD of source current for non-linear load without PV-UPQC compensated distribution system is 16.04% as shown in Figure 11.

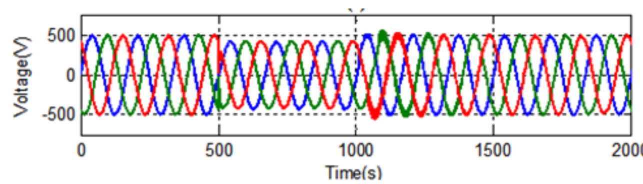

Fig. 8 Grid voltage obtained without PV-UPQC

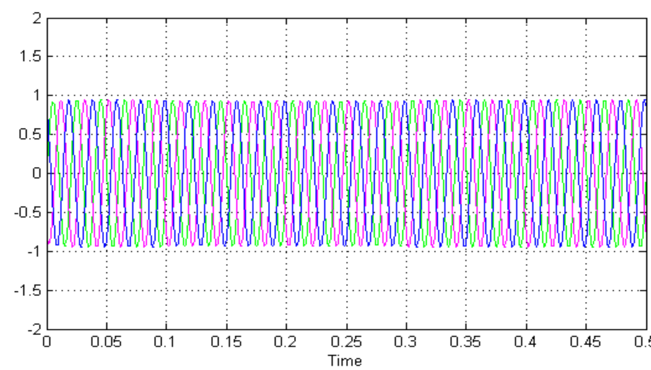

Fig. 9 Grid Current obtained without PV-UPQC

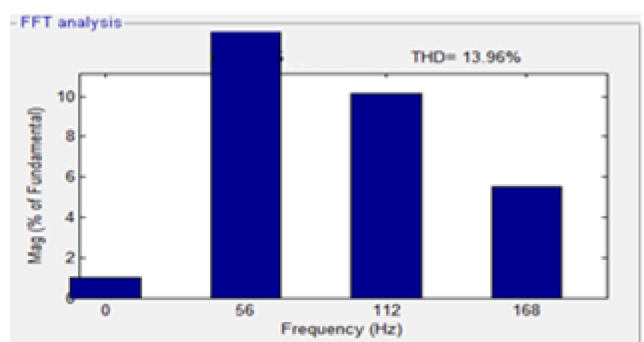

Fig. 10 THD of Grid voltage without PV-UPQC

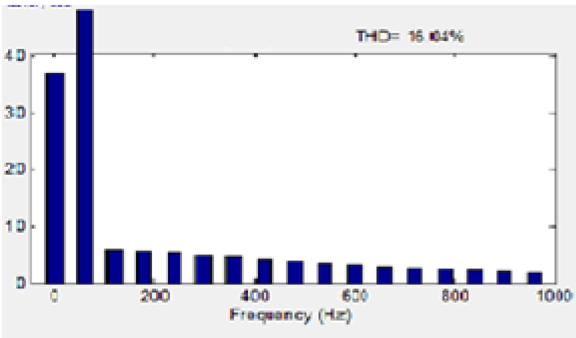

Fig. 11 THD of source current without PV-UPQC

By connecting the PV-UPQC in the three phases of the grid line, the grid current gets balanced also voltage sag and swell gets reduced. The grid voltage with PV-UPQC is shown in Figure 12. Figure 13 shows the grid current obtained with PV-UPQC for non linear loads. The THD of grid voltage with PV-UPQC is 0.15% as shown in Figure 14. The THD of source current for non-linear loads with PV-UPQC is 0.26% as shown in Figure 15.

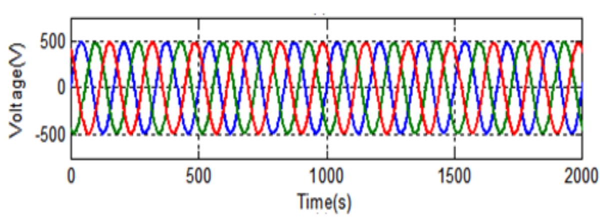

Fig. 12 Grid voltage obtained with PV-UPQC

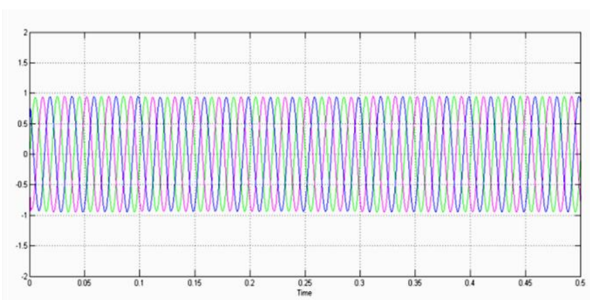

Fig. 13 Grid Current obtained with PV-UPQC

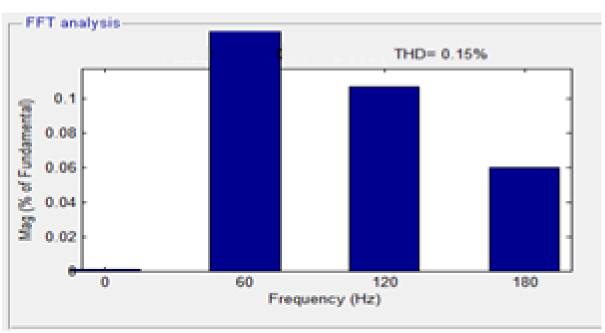

Fig. 14 THD of Grid voltage with PV-UPQC

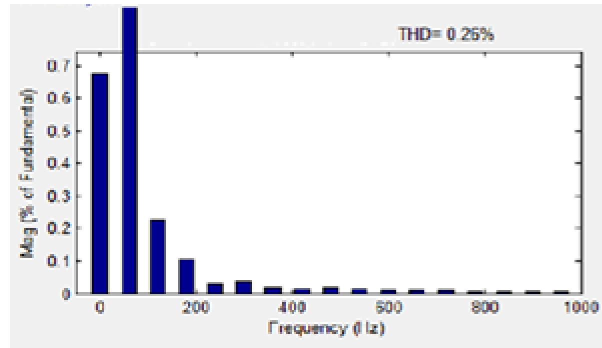

Fig. 15 THD of source current with PV-UPQC

1.5. MTG-UPQC Compensated Distribution System

The block diagram of the proposed MTG-UPQC is shown in Fig.16. Depending on the physical arrangement of Micro turbines they are classified as Single shaft or two shaft, simple cycle, or recuperated, inter-cooled and reheat. The rpm of MTG is generally 40,000. The MTG employed in our proposed system is of a single shaft type [17,18]. The rpm of MTG in the proposed system ranges from 90,000 – 1,20,000.

The modeling of a MTG system consists of three parts; the micro turbine, permanent magnet synchronous machine (PMSM) and rectifier circuit. There are two types of micro turbine designs available based on position of compressor turbine and generator [19, 20]. The generator generates the power at very high frequency ranging from 1500 to 4000 Hz. The high frequency voltage is first rectified and then inverted to a normal AC power at 50 or 60 Hz. The micro turbines are much smaller in physical dimension than a conventional gas turbine [21, 22].

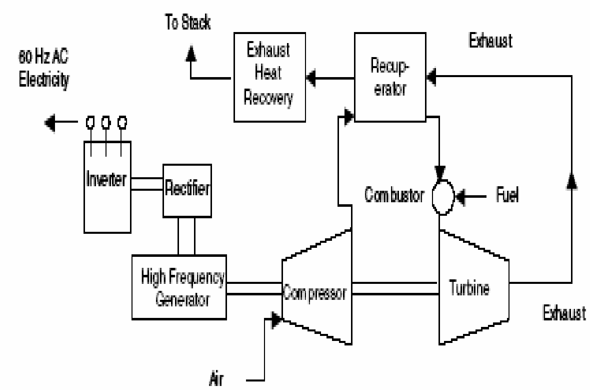

Fig. 16 Block Diagram of Micro Turbine Generator system

Here Permanent Magnet Synchronous Generator (PMSG) is used for energy conversion because it has the advantage of super high speed operation with small unit size of the machine which is directly proportional to the increase in speed [23, 24]. The Simulink diagram of micro turbine generator system is shown in Figure 17. Figure 18 shows the Simulink diagram of MTG with Permanent Magnet Synchronous Generator system. Figure 19 shows the Simulink diagram of MTG-UPQC compensated distribution system.

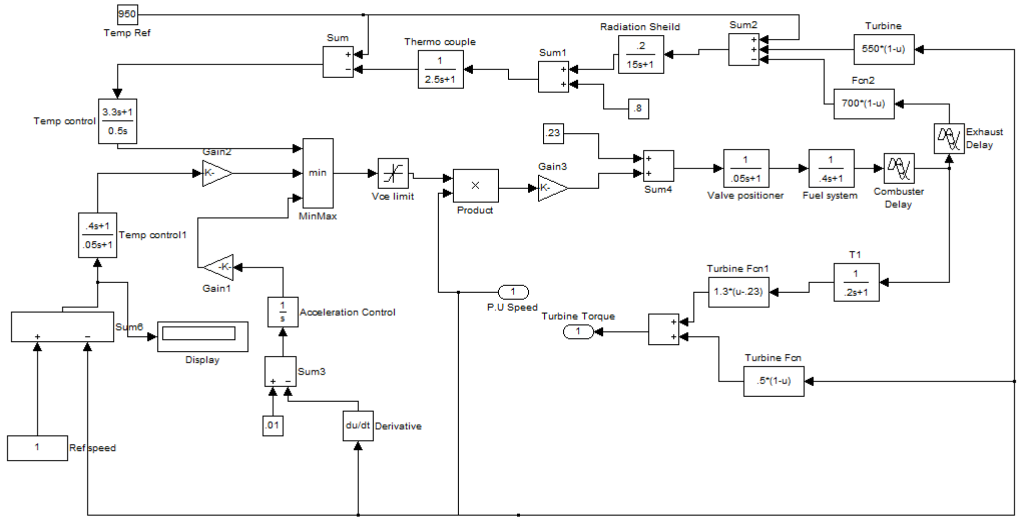

Fig. 17 Simulink Diagram of Micro Turbine system

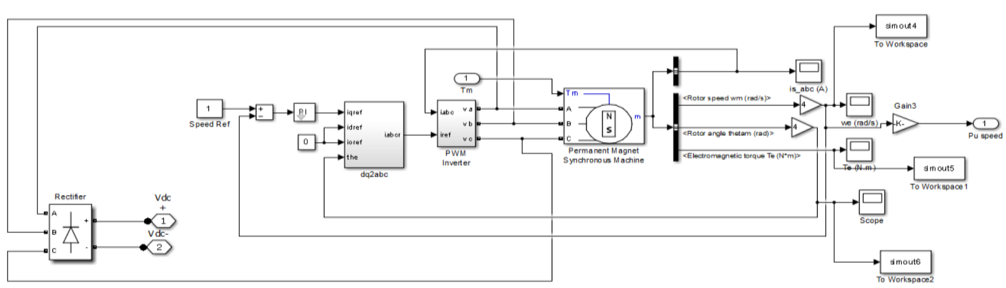

Fig. 18 Simulink Diagram of Micro Turbine Generator system employing Permanent Magnet Synchronous Generator

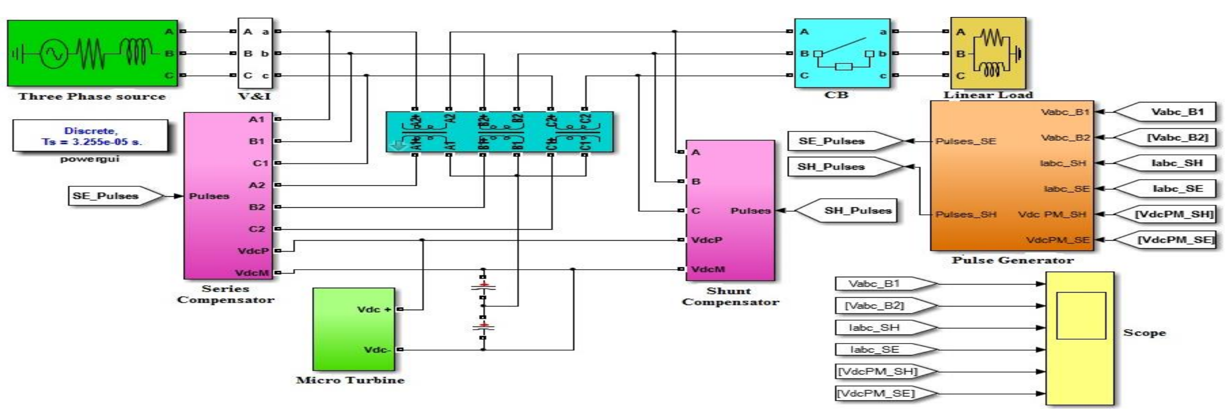

Fig. 19 Simulink Diagram of MTG-UPQC compensated Distribution system

1.6. Results and Discussion for MTG-UPQC

To demonstrate the effectiveness of the proposed system, UPQC is simulated using MATLAB/SIMULINK for the system disturbances. The results are shown for source voltage and load current. Two conditions are carried out in this system which is before and after connecting the MTG-UPQC in the feeder. The simulation was done initially without connecting the MTG-UPQC in the three phase grid line. The voltage at the grid side contains sag, swell and unbalanced current due to non-linear loads. The grid voltage without MTG-UPQC compensated distribution system is shown in Figure 20. Figure 21 shows the Load current obtained without MTG-UPQC compensated distribution system for non linear loads.

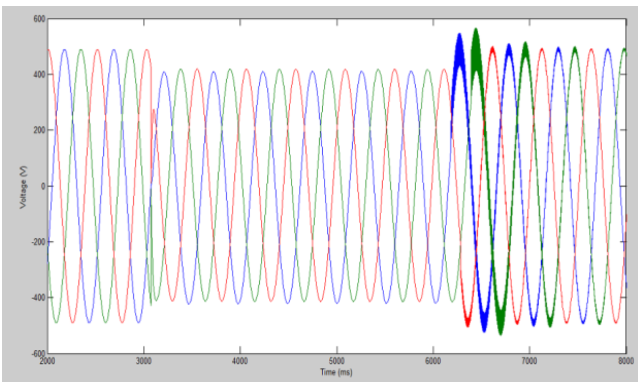

Fig. 20 Grid voltage obtained without MTG-UPQC

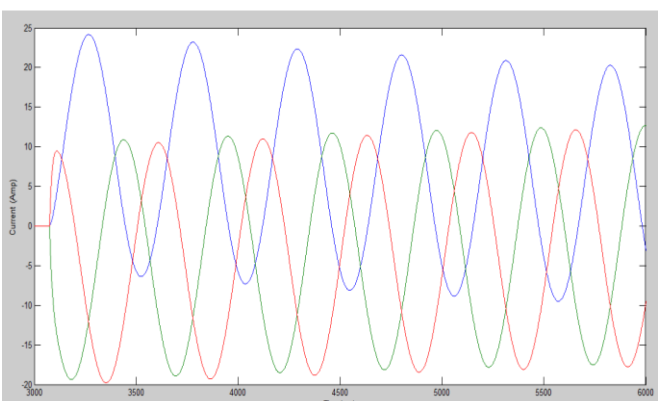

Fig. 21 Load current obtained without MTG-UPQC

By connecting the MTG-UPQC in the three phases of the grid line, the grid current gets balanced also voltage sag and swell gets reduced. The grid voltage with MTG-UPQC is shown in Figure 22. Figure 23 shows the load current obtained with MTG-UPQC for non linear loads. The THD of grid voltage with MTG-UPQC is 0.01% as shown in Figure 24. The THD of source current for non-linear loads with MTG-UPQC is 0.03% as shown in Figure 25.

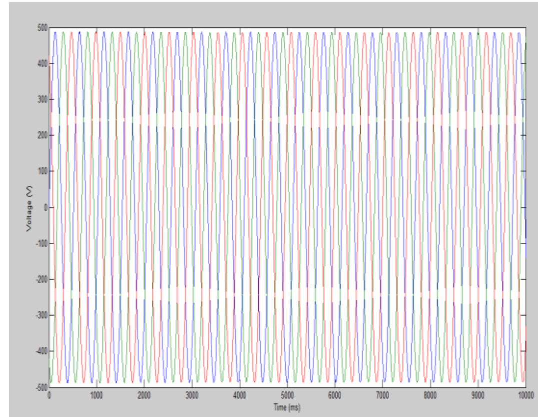

Fig. 22 Grid voltage with MTG-UPQC

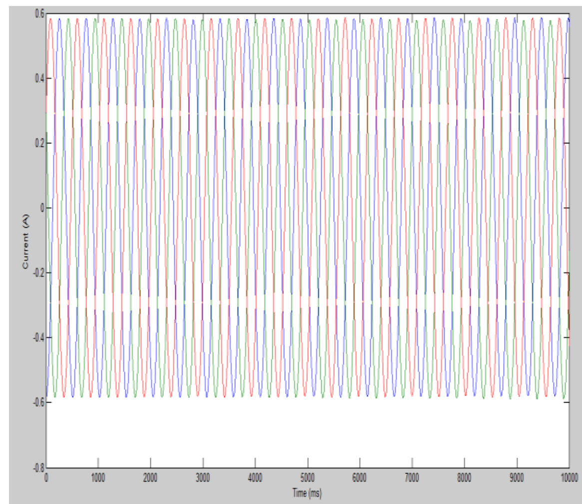

Fig. 23 Load current with MTG-UPQC

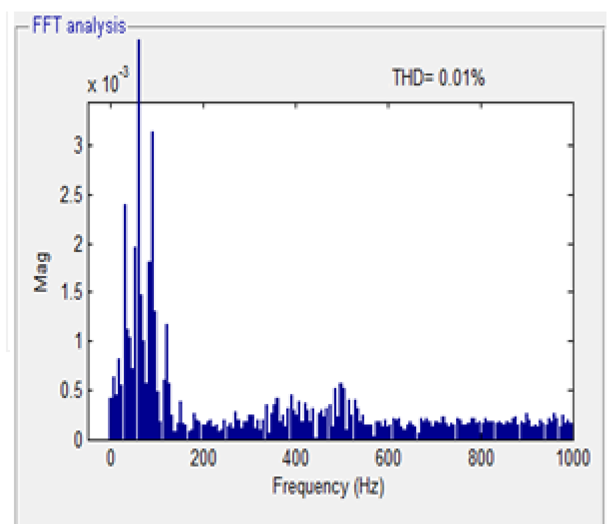

Fig. 24 THD of Grid voltage with MTG-UPQC

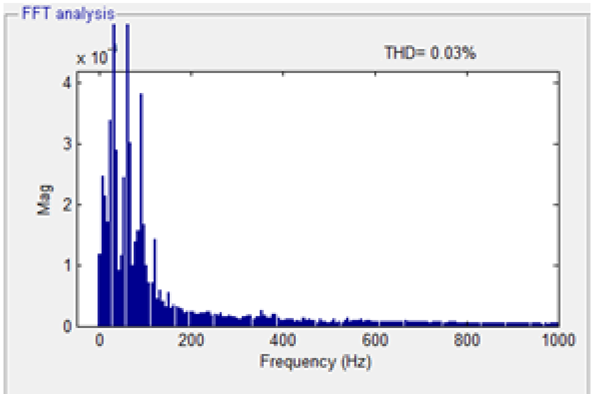

Fig. 25 THD of source current with MTG-UPQC

1.7. Results and Discussion

The performance comparison of the PV-UPQC compensated and MTG-UPQC compensated distributed system are shown in Table 2. The percentage THD for grid voltage and current is calculated with and without compensation and the results are compared. The percentage grid voltage THD for the uncompensated system is 13.96%. For PV-UPQC compensated distribution system the THD measured is 0.15% and for MTG-UPQC system it is found to be 0.01%. The percentage source current THD for the uncompensated system is 16.04%. For PV-UPQC compensated distribution system the THD measured is 0.26% and for MTG-UPQC system it is found to be 0.03%.

Table 2
Performance comparison of PV-UPQC and MTG-UPQC compensated Distribution System

Percentage THD	without PV-UPQC / without MTG-UPQC	with PV-UPQC	with MTG-UPQC
Percentage Grid Voltage THD	13.96	0.15	0.01
Percentage Source Current THD	16.04	0.26	0.03

The results show that MTG-UPQC compensated distribution system performs better than PV-UPQC compensated distribution system.

A photovoltaic panel is connected with UPQC in order to increase the voltage level of the three phase line. P & O method is proposed to improve the panel efficiency. The improvement of distorted current is reduced by connecting UPQC in the feeder. Also, sag, swell and distortion are also reduced in the distribution side. The PV-UPQC system provides a significant improvement in the unbalances and distortions due to linear and non-linear loads. The THD value gets reduced from 13.96% to 0.15% after connecting the PV-UPQC. Micro turbine Generator (MTG) System is also connected with UPQC in order to increase the voltage level of the three phase line. While connecting PV to UPQC, the % THD content in the source voltage and load current after compensation is 0.15% and 0.26%. While connecting Micro turbine to UPQC the % THD content in the source voltage and load current after compensation is reduced to 0.01% and 0.03%. Thus, the efficiency has been improved and % THD content has been reduced using this MTG-UPQC. The developed MTG-UPQC provides a significant improvement in the unbalances and distortions due to linear and non-linear loads.

The advantage of the proposed PV-UPQC is that it can be used to compensate for the long voltage interruption and it is suitable for active power supply. The advantage of the proposed MTG-UPQC is that in the case of reactive power compensation there is no need for a real power source at the DC link. The MTG is useful for this purpose. When the load is balanced and linear then the real power from the MTG can be injected into the line as a supplementary balanced three phase real power. In this way the MTG is useful.

1.8. Conclusion

The role of custom power device UPQC and the distributed generation sources such as Photo Voltaic cell and Micro Turbine Generator in mitigating the power quality issues like voltage unbalance, reduction of Total Harmonic Distortion and improvement of voltage sag has been discussed in this paper. The performance of the two systems is compared and it is found that MTG-UPQC system performs better than PV-UPQC system. PV is useful for real power compensation and MTG is for reactive power compensation. In future, the performance of a hybrid distributed generation system along with UPQC placed in a distribution system and their role in mitigating power quality issues can be studied.

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