CHAPTER 3
CONSTANT FREQUENCY UNIFIED POWER QUALITY CONDITIONER

Frequency Regulator + Unified Power Quality Conditioner = Constant Frequency Power Quality Conditioner (Basic Model of UPLM)

3.1 INTRODUCTION

A unified power quality conditioner is an advanced concept in the area of power quality control. The basic working principle of a unified power quality conditioner is based on series active filter converters and parallel active filter power converters that share a common DC link [98]. A unified power quality conditioner is used to compensate the voltage sag, voltage swell [99] and current harmonics [100]. It is also used to compensate an impact on the reactive power [101] through a series voltage source inverter and a shunt voltage source inverter mentioned in the previous chapter. In order to avoid the switching oscillation passive filters are placed at the output of each inverter.

Fig. 3.1: Basic Configuration of Unified Power Quality Conditioner

The controller of the UPQC provides the compensated voltage through the UPQC series inverter and condition the current through the shunt inverter by instantaneous sampling of the source voltage and load current. Fig 3.1 shows the structure of a unified power quality conditioner. The reference current is compared with the shunt inverter output current \(I_{a}, I_{b}, I_{c}\) and both of them are fed to a hysteresis type PWM
current controller.

The UPQC has some major drawbacks. The UPQC cannot regulate the supply frequency variations. As the supply frequency changes, the UPQC cannot regulate the supply frequency as it has no device to regulate the supply frequency. The supply frequency regulation is the most important power quality issue in MicroGrid systems. Frequency regulation is achieved by frequency regulator. The different types of frequency regulators have been discussed in the subsequent sections.

3.2 TYPES OF FREQUENCY REGULATORS

3.2.1 Overview of PWM based Frequency Converters with DC Link

A two-level voltage source inverter (VSI) whose DC link is supplied by a three-phase diode bridge, as shown in Fig. 3.2 where the inverted bridge consists of Insulated Gate Bipolar Transistors (IGBT). This VSC based converter can act as a frequency regulator. This type of frequency converter is called a two-level voltage source converter (VSC) [102].

![Two-level voltage source converter (VSC).](image)

The drawback of a two-level voltage source converter (VSC) is that the supply side (a, b and c) currents are highly distorted, containing high amounts of low-order harmonics [103]. Through the impedance of the mains, the low-order current harmonics may distort the voltage of the Point Of Common Coupling (PCC), which may further interfere with the other electrical systems in the network.

A conventional solution for the problem caused by the VSC diode bridges advocates the use a similar IGBT bridge as a supply bridge too, i.e. a back-to-back voltage source converter (BBVSC) which was introduced in the late 1970s [104]. A PWM BBVSC produces sinusoidal supply current waveforms.
It is a boost-type converter, i.e. its DC link side voltage has to be higher than the peak value of the supply line-to-line voltage. The BBVSC contains a DC link capacitor, which separates the supply- and load-side bridges, enabling the possibility of controlling both separately.

Thus, the BBVSC can control the DC link voltage, compensate the reactive power in the supply and supply the load, all at the same time. The drawback is that the DC link capacitor of the VSCs and the BBVSCs is a bulky component with a limited lifetime. In the BBVSCs supply filter inductors are also required which can be considered a severe problem because the inductors are bulkier and heavier than the DC link capacitor in low and medium power converters.

A substitute for the voltage source converters is the PWM current source converter (CSC), shown in Fig 3.4 [105]. According to [106] the concept of a CSC was first suggested in the 1980s. The CSC produces sinusoidal supply current waveforms like the BBVSC and can also compensate the reactive power supply. Instead of a DC link capacitor, the CSC contains a DC link inductor which is generally bulkier and heavier than the link capacitor in voltage source converters.

The supply filter of the CSC consists of capacitors and inductors. The supply filter’s capacitors provide a path for the supply current for high frequency AC components. Thus, the inductance value and the physical size of the supply filter inductors of the CSC can be smaller than those of the BBVSC filter inductors which have to filter high frequency components alone. The capacitance value and physical size of the CSC AC capacitors are also small compared to the DC link capacitor of the BBVSC.
In addition, the CSC usually requires series connected diodes with every IGBT. This increases the semiconductor on-state loss and the complexity of the main circuit. Loss and additional components increase the price of the system. The Reverse Blocking IGBT (RBIGBT) makes serial diodes unnecessary [107], but the RBIGBT is still quite a new device so its development is still not complete and its availability is limited too [108]. A conventional mitigation strategy for common-mode voltages is to increase the number of voltage levels [109]. However, the drawback of this CSC is that the control system is more complex.

3.2.2 Direct Frequency Converter (Cyclo converter)

The PWM frequency converters contain either DC link capacitors or inductors. The drawback of both the capacitors and inductors is physically large and heavy in most cases. In addition, electrolytic capacitors are subject to ageing and cannot be used in all applications. The passive components also cause power loss. Thus, direct frequency converters converting AC power to AC power directly without DC link passive components. According to [110] the idea of direct frequency conversion was originally presented in the 1920s and even applied in the 1930s. The first semiconductor-based direct frequency converters were developed in the 1960s after the invention of the thyristor. A main circuit of a phase-controlled thyristor-based three-to-three phase cycloconverters is given in Fig 3.5.

The circuit presented is a six-pulse cycloconverter, which assumes isolated loads so that a supply transformer is not necessary. For simplicity, the cycloconverter in Fig 3.4 does not include circulating current reactors which are sometimes used to enhance load power quality with discontinuous load current [111]. Although reactors and supply transformers are sometimes avoided, they are necessary in many cases to make the cycloconverter’s system possible in practice. For example, the
supply transformer is not avoided with non-isolated load because in this case all the supplies of all three bridges are required to be isolated from each other.

Fig 3.5: Cycloconverter

In addition, the six-pulse three-to-three phase cycloconverters require 36 thyristors and a twelve-pulse version requires 72 thyristors. The drawback of the cycloconverter is that the load voltage and input current waveforms are heavily distorted and the fundamental power factor of the input is quite poor irrespective of the fundamental power factor of the load [112]. In practice, its load frequency is also usually limited to half of the supply frequency because normal loads cannot tolerate the voltage distortion produced with higher input-to-output frequency ratios [113].

3.3. MATRIX CONVERTER IS AN EFFICIENT FREQUENCY REGULATOR

Over the decades, the Matrix Converter (MC) has established its name in the field of direct frequency converters [114]. The basic principle of a three-to-three phase MC is presented in the previous chapter where each ideal switch describes a bidirectional switch which can conduct current and block voltage in both directions depending only on the control signal of the switch. The matrix converter can work as an efficient frequency regulator When a proper control system is used in the matrix converter it can control the load frequency at a constant level. Frequency regulation is very important. Because in a MicroGrid both the voltage and frequency are not stable. In the detailed diagram of a matrix converter and load shown in Fig 3.6, \( L_o \) and \( R_o \) are the load inductor and resistor respectively.
Fig 3.6: Circuit diagram of a matrix converter acting as a frequency regulator

The supply is an ideal voltage source having 440 V line-to-line voltage and 60 Hz frequency. The supply impedance ($Z_{\text{sup}}$) between the voltage source and the PCC was neglected. The supply impedance is modeled by a series-connected resistance and inductance having values of 0.03 Ω and 0.1 mH respectively.

In Fig 3.7 the block diagram of a matrix converter acting as a frequency regulator can be seen. Initially the supply frequency is calculated by a phase locked loop (PLL) and it is compared with the reference value $f_{\text{ref}}$. For accuracy the load side frequency is also calculated by the PLL and compared with the reference value. When the error frequency is added to the input frequency the required frequency $f^{*}_{\text{ref}}$ is found. This is fed to the PLL the corresponding $\theta$ can be found which will determine the output frequency of the matrix converter. In the MicroGrid the frequency may fall or rise due to the power production and load variation. Consider a frequency rising condition, assume that the frequency $f_{\text{in}}$ is 57 Hz. The reference frequency which is 60 Hz which is compared with the input frequency by a comparator and the error signal +3 is produced. The error signal is again compared with an adder and the required signal of $f_{\text{ref}}$ is obtained. This is fed to the PLL and a corresponding $\theta$ will be produced.

If the supply frequency is greater than the required frequency (e.g. 64 Hz), the comparator compares the two signals and negative error signal is produced. That value is fed to the adder and it produces the ref signal. Here the output frequency is also compared with the reference value for more accuracy.
Fig 3.7: Block diagram of a frequency regulator using a matrix converter

Fig 3.8 shows the matrix converter based frequency regulation. Fig 3.8a shows that the supply frequency varies from above power quality limit i.e. 60 Hz to 63Hz. But the matrix converter based frequency regulator effectively regulates the frequency and maintains the same constant as shown in Fig 3.8b.

Fig 3.8: Matrix converter based frequency regulation at high frequency. (a) supply frequency, (b) load frequency.
Fig 3.9: Matrix converter based frequency regulation at low frequency (a) supply frequency, (b) load frequency.

Fig 3.9 shows that the Matrix Converter regulates the supply frequency when the supply frequency falls below the power quality limit. Fig 3.9a shows the supply frequency varies from 60 Hz to 56 Hz from 0-1.8 Sec. But matrix converter based frequency regulator regulate the supply frequency at a constant level(60Hz) as shown in fig3.9(b).

### 3.4 CONSTANT FREQUENCY - UNIFIED POWER QUALITY CONDITIONER (CF-UPQC)

(Unified Power Quality Conditioner with Frequency Regulator)

Fig3.10: Block diagram of a CF-UPQC

A unified power quality conditioner can solve almost all power quality issues.
Its main drawback is that it cannot control the frequency variations. The matrix converter is an efficient frequency regulator. So, adding the frequency regulator in series with the UPQC achieves the desired frequency regulation. Fig 3.10 shows the proposed improved configuration of a unified power quality conditioner called CF-UPQC. It consists of a combination of a UPQC and a matrix converter based frequency regulator for simultaneous compensation of voltage current power quality problem and regulates the supply frequency in a MicroGrid connected utility. It is also applicable to power distribution systems being connected close to harmonic and frequency sensitive load. The harmonic producing load may affect other harmonic sensitive load connected at the same AC bus terminal. The CF-UPQC consists one of the most flexible devices for harmonic compensation in the concept of custom power. The CF-UPQC not only compensates the harmonic current, imbalance of non-linear load, supply frequency variations, harmonic voltage and imbalance of power supply. It also compensates the input current harmonics and output voltage harmonics. Thus, the CF-UPQC joins all the principles of a shunt current compensator and a series voltage compensator and a supply frequency regulator into a single device as illustrated in Fig 3.10. An advantage of this integrated approach is that it produces a compact compensator with improved overall performance since it is possible to coordinate the functionalities. CF-UPQC must be connected as close as possible to the nonlinear and frequency sensitive load.

### 3.4.1 General Description of CF-UPQC

The Constant Frequency- Unified Power Quality Conditioner has three distinct parts:

1) Unified Power Quality Conditioner
2) Matrix converter based frequency regulator
3) Control system

Fig 3.11 shows the detailed basic configuration of a constant frequency unified power quality conditioner. It is a combination of a unified power quality conditioner and a matrix converter based frequency regulator. The series PWM converter of the CF-UPQC behaves as a controlled voltage source i.e. also it behaves as a series active filter. Whereas the shunt PWM converter behaves as a controlled current source i.e. it behaves as a shunt active filter and the matrix converter acts as a frequency regulator.

The integrated controller of the CF-UPQC realize a synchronous reference
frame control theory to provide the compensating voltage reference \( (V_\text{c}^*) \) as well as the compensating current reference \( (i_\text{c}^*) \) to be synchronized by the PWM converters. The CF-UPQC is very useful in MicroGrids for power quality conditioning. The CF-UPQC is similar to the UPQC except that it has a frequency changing section. The effective frequency conversion is achieved by the matrix converter.

The main advantage of a matrix converter based frequency converter is that it can increase or decrease the frequency. It also does not have a DC link storage element, so losses and harmonics are minimized. The CF-UPQC’s matrix converter regulates the frequency of the supply voltage.

The CF-UPQC’s series active filter is used for compensating the voltage harmonics and voltage imbalance. The CF-UPQC consists of a parallel active filter (PAF) that eliminates load harmonics and compensates the load reactive power. In addition the parallel active filter converter supplies the AC to DC power and is fed to the common DC link. The control equation is

\[
I_{pf} = G.I_L \rightarrow \left| G(j\omega) \right|_{I_0,\omega=\omega_1} \{0,\omega=\omega_1 \}
\]

Where \( G \) is the control function, \( \omega \) is the fundamental frequency, \( I_L \) is the load current and \( I_{pf} \) is the parallel filter input current.

The series active filter (SAF) compensates the supply harmonics flicker, voltage sag, voltage swell and unbalanced load harmonics flow into the parallel filter. The control equation is

\[
U_{sf} = K.G.I_{sh} + U_{comp}
\]

Where \( K \) is the regulator gain, \( U_{sf} \) is the series filter voltage, \( I_{sh} \) is the harmonic supply current and \( U_{comp} \) is the compensation voltage needed to remove the supply voltage’s imperfection. \( I_{sh} \) is extracted by the \( dq \) theory.

The shunt active filter of CF-UPQC can compensate all undesirable current components including harmonics, imbalances due to negative and zero sequence components in the fundamental frequency and the load’s reactive power. The series active filter compensates the source voltage harmonics, blocks the harmonic current flowing to the source and improves the MicroGrid system stability. The matrix converter regulates the supply frequency to the load due to sudden load or fault in the
MicroGrid. Hence the simultaneous compensation performed by the CF-UPQC guarantees that the compensated voltage ($V_L$) and frequency ($V_f$) at the load terminal and remove the current harmonics and balance the load current. Therefore, they contain no unbalanced current from the negative and zero sequence components of the fundamental frequency. Moreover, they are sinusoidal and in phase, if the load’s reactive power is also compensated. Additionally the shunt active filter regulates the DC link voltage by absorbing or injecting energy from or into the power distribution system. The power circuit of the combined series, shunt and frequency regulator are presented in Fig 3.11. The series converter has a PWM voltage controller. The CF-UPQC generates an accurate compensating voltage through the PWM controller. This controller forces the converter to behave as a controlled voltage source. The series active filter compensates the supply voltage; hence the load voltage becomes balanced and free of harmonics.

![Detailed model of a CF-UPQC](image)

Fig 3.11: Detailed model of a CF-UPQC
The CF-UPQC’s control system realize almost synchronous reference control algorithms to provide the current reference $i_{ca}^*$, $i_{cb}^*$, and $i_{cc}^*$ to the shunt active filter, the voltage reference $v_{ca}^*$, $v_{cb}^*$, and $v_{cc}^*$ to the series active filter and $u_a$, $u_b$ to the frequency regulator. The high switching frequency of the PWM converter produce the currents $i_{fa}$, $i_{fb}$, and $i_{fc}$ and the voltage $v_{fa}$, $v_{fb}$, and $v_{fc}$ with some unwanted high order harmonics that can be easily filtered by using small passive filters represented by $c_p$, $r_p$, $c_s$ and $r_s$. This modified UPQC concept enables the PWM converter to perform active filtering and the matrix converter also performs the function of a frequency regulator.

The compensation principle of the CF-UPQC will be explained in the coming sections. The proposed CF-UPQC satisfies some important requirements. It maintains the reactive power at a minimum value. The load voltage is maintained by the CF-UPQC at the rated supply voltage. It not only maintains the input current with very low harmonic content but also assures that the supply frequency is permissible within the power quality limit.

3.4.2 CF-UPQC control system (Frequency Regulator System)

The control circuits of series active filter, shunt active filter and frequency regulator can be merged into an integrated controller for CF-UPQC by minimizing the computation time. The functional block diagram of the CF-UPQC controller is illustrated below in Fig 3.12.

The matrix converter consists of nine bi-directional switches arranged in three groups, each being associated with an output line. The arrangement of these bi-directional switches connects any of the input lines to any of the output lines. A matrix with elements $S_{ij}$, representing the state of each bi-directional switch ($on=1$, $off=0$), can be used to represent the matrix output voltages ($V_u$, $V_v$, $V_w$) as a function of inverters. At the same time, series active filter compensates the voltage problems. Fig 3.12 shows the control system of the frequency regulator. The matrix converter is controlled by space vector modulation. The reference voltage is used to control the regulation of the output voltage and its corresponding phase angle($\sin \theta$, $\cos \theta$) determine the output frequency.
The supply frequency $V_{f(abc)}$ is sensed by the frequency counter which is compared with the reference frequency $V_{f(ref)}$ and the error value is extracted. The compensated value is produced by the PI controller and compensated frequency is fed to the Phase Locked Loop (PLL). It produces the $\theta$ value that determines the output frequency of the matrix converter. When the supply frequency varies beyond the power quality limit, the frequency controlling system changes the required PLL frequency from the PI controller.

Fig. 3.12: Control System of the Frequency changer block (CF-UPQC)

The transformation of $dq$ to alpha beta is shown in equation 3.2.

$$
\begin{bmatrix}
V_d \\
V_q
\end{bmatrix} =
\begin{bmatrix}
\cos \omega t & -\sin \omega t \\
\sin \omega t & \cos \omega t
\end{bmatrix}
\begin{bmatrix}
V_a \\
V_b
\end{bmatrix}
$$

(3.2)

3.4.3 Control system of the CF-UPQC’s shunt Part

Harmonic control of the parallel converter in the CF-UPQC system is derived using the synchronous reference frame method. In the synchronous frame base method, the first three phase instantaneous load current $i_{La}$, $i_{Lb}$, $i_{Lc}$ and source voltage, $V_{La}$, $V_{Lb}$, $V_{Lc}$ are converted into $d-q$ domain. $d-q$ current and voltage are derived as follows:
\[
\begin{bmatrix}
v_a \\
v_b \\
v_c 
\end{bmatrix} = \sqrt{2/3} \begin{bmatrix}
1 & -1/2 & -1/2 \\
0 & \sqrt{3}/2 & \sqrt{3}/2 \\
1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2}
\end{bmatrix} \begin{bmatrix}
v_a \\
v_b \\
v_c 
\end{bmatrix}
\] (3.3)

\[
\begin{bmatrix}
i_a \\
i_b \\
i_c 
\end{bmatrix} = \sqrt{2/3} \begin{bmatrix}
1 & -1/2 & -1/2 \\
0 & \sqrt{3}/2 & \sqrt{3}/2 \\
1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2}
\end{bmatrix} \begin{bmatrix}
i_a \\
i_b \\
i_c 
\end{bmatrix}
\] (3.4)

\[
\begin{bmatrix}
v_d \\
v_q 
\end{bmatrix} = \begin{bmatrix}
\cos \theta & \sin \theta \\
-\sin \theta & \cos \theta
\end{bmatrix} \begin{bmatrix}
v_a \\
v_b 
\end{bmatrix}
\] (3.5)

\[
\begin{bmatrix}
i_d \\
i_q 
\end{bmatrix} = \begin{bmatrix}
\cos \theta & \sin \theta \\
-\sin \theta & \cos \theta
\end{bmatrix} \begin{bmatrix}
i_a \\
i_b 
\end{bmatrix}
\] (3.6)

Where \( \theta \) is the angular frequency and \( V \) denotes the load current. \( i_{Ld} \) and \( i_{Lq} \) resulting from equation 3.6 include a DC and an AC part. The DC part of \( i_{Ld} \) corresponds to the active power in the load and the AC part of it corresponds to the current harmonics. The DC part of \( i_{Lq} \) produces reactive power and the AC part of it produces current harmonics.

When the harmonic compensation, reference current for the active filter in \( d \) and \( q \) axis are:

\[
i_{df}^* = -\tilde{i}_{Ld}
\] (3.7)

and

\[
i_{qf}^* = -\tilde{i}_{Lq} - \tilde{i}_{Lq}
\] (3.8)

Where \( \tilde{i}_{Lq} \) and \( \tilde{i}_{Ld} \) denote the AC value of \( i_{Ld} \). \( i_{Lq} \) and \( \tilde{i}_{Lq} \) is the DC value of \( i_{Lq} \) derived with a simple high pass filter. The DC part can be easily removed from \( i_{Ld} \) and the remaining can be transformed into its previous frequency.

Finally we get \( i_{Lq} \) and the oscillating part of \( i_{Ld} \) without any phase and magnitude error. Fig 3.13 shows the block diagram of the synchronous reference frame method for deriving reference currents for the shunt actiye filter converter. The

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three-phase output of this block diagram is used as a reference current for the shunt active filter converter.

Fig 3.13: Block diagram of the synchronous reference method for deriving current reference of the shunt part of CF-UPQC

Fig 3.14: Block diagram of the current harmonic controller for a phase of shunt active filter

Fig 3.14 shows the block diagram of the current harmonic controller for each phase. Considering $V_L$ as a disturbance, the transfer function of $i_{fa}/i_{fa}^*$ is

$$\frac{i_f}{i_f^*} = \frac{K_p s + K_i}{L_i s^2 + K_p s + K_i}$$

The bandwidth is mostly affected by $L_1$. The bandwidth increases when the inductance decreases. On the other hand when the inductance decreases current harmonics with switching frequency to appear in the line current. Therefore, an appropriate value must be chosen for this inductance. A PI controller is used to
control the voltage of the DC-link. Most importantly fundamental current is needed to recharge the capacitor.

![Block diagram of a DC bus charger](image)

**Fig 3.15: Block diagram of a DC bus charger**

The block diagram of the DC bus charger is shown in Fig 3.15. The low-pass filter cancels any spike or AC disturbance from the DC bus voltage. The time constant of this PI controller must be much larger than the time constant of the PI controller for the current. Multiplying the output of the controller by the DC sequence of $d-q$ component of the line voltage ensures that the fundamental component of the line current is used for charging the capacitor.

**Fig 3.16** shows the complete shunt active filter's block diagram of the CF-UPQC using synchronous reference frame theory where the loads current $I_a$, $I_b$, and $I_c$ are given. The measured load currents are transferred into $dq0$ frame using sinusoidal functions through $dq0$ synchronous reference frame conversion. The sinusoidal functions are obtained through the grid voltage using a phase locked loop (PLL). Here the current are divided into AC and DC components as follows:

$$I_{id} = \bar{I}_{id} + \tilde{I}_{id}$$  \hspace{1cm} (3.10)

$$I_{iq} = \bar{I}_{iq} + \tilde{I}_{iq}$$  \hspace{1cm} (3.11)

In the equation (3.10) and (3.11), $I_d$ and $I_q$ are the d-axis and quadrature components. AC components and DC elements can be derived by low pass filter. $\bar{I}_{iq}$, $\bar{I}_{id}$ are the DC components and $\tilde{I}_{iq}$, $\tilde{I}_{id}$ are the AC components of $I_{iq}$, $I_{id}$. The
control algorithm corrects the systems power factor and compensates all the current harmonic components by generating the reference currents.

![Complete block diagram of a shunt active filter of CF-UPQC](image)

The reference current is transferred into \((a-b-c)\) frame through reverse conversion of the synchronous reference frame as shown in equation (3.12) and (3.13). The resulting reference current \((I_{fa}^*, I_{fb}^*, I_{fc}^*)\) and the output currents of the shunt inverter \((I_{fa}, I_{fb}, I_{fc})\) are fed to the hysteresis band controller. Now the required controlling pulses are generated and the required compensation current is generated by the inverter by applying these signals to the shunt inverter’s power switch gates.

### 3.4.4 Hysteresis Current Controller

In a typical hysteresis current controller, the reference signal is compared with the feedback signal. The signal and predetermined amplitude of the error determine the output of the modulator, which has two possible level of \(V_{out}\). The duration between the two successive levels of \(V_{out}\) are determined by the slope of the reference signal. The output voltage tracks the reference signal within the upper and lower boundary level. In order to keep the switching frequency constant, the
hysteresis band varies with a function of \( \cos(\theta) \). Hysteresis current controllers have fast transient response, hence they are preferred for operations at high switching frequencies. The switching losses restrict their applications to lower power level.

### 3.4.5 CF-UPQC’s Series Inverter Control System

In CF-UPQC, the series converter regulates the line voltage. In the CF-UPQC system, two functions can be defined for this series converter. When the load is voltage sensitive, a series converter is used to regulate the line voltage to the load. It cancels outline voltage distortions such as voltage harmonics, sag, swell and voltage unbalance. It is capable of eliminating voltage harmonics. In this case, compensating voltage harmonics there is a need for active power. The shunt active filter produces the active power charges and supply it to the DC-link capacitor. This active power is supplied by the DC capacitor.

The function of the series converter of CF-UPQC, which is mostly considered in very high-power applications, to protect the power system against the voltage distortions originating from the load. Some nonlinear load which usually has a capacitor bank after a bridge rectifier appear to be voltage harmonic generators. The voltage harmonics at the point of common coupling (PCC) affect the other sensitive loads connected to this point. The series converter is for each phase capable of suppressing the voltage harmonics of the load. The voltage of each phase is controlled separately in the system. A three phase locked loop (PLL) produces the reference voltage for each phase. The inputs of the PLL are three-phase voltages and the outputs are three reference voltage for the controller. The block diagram of a

![Block diagram of the series voltage controller](image-url)
voltage controller for each phase with the first functionality of CF-UPQC is shown in Fig 3.17.

Considering $V_{sa}$ as a disturbance, the transfer function of the controller is achieved as

$$\frac{v_{fa}}{v_{fa}^*} = \frac{K_p s + K_i}{L_2 C_2 s^3 + (K_p + 1)s + K_i}$$

(3.14)

Fig.3.18: Control System of the Series part of CF-UPQC

Fig.3.18 shows the block diagram of the CF-UPQC’s series inverter controller using synchronous reference frame control theory. In this method the required value of the load phase voltages in d axis and q axis compare with the line/supply voltage and the result is considered as the reference signal. The supply voltage ($V_{abc}$) is detected and transformed into the synchronous $dq0$ reference frame using

$$V_{t_{dq0}} = T^{dq0}_{abc} V_{t_{abc}}$$

(3.15)

The compensating reference voltage in the synchronous $dq0$ reference frame is defined as

$$V_{s_{dq0}}^{ref} = V_{t_{dq0}} - V_{l_{dq0}}^{exp}$$

(3.16)
The compensating reference voltage in (3.16) is then transformed back into the (a-b-c) reference frame. The required controlling pulse is generated by the PWM and the required compensation voltage is generated by the series active filter.

### 3.5 SIMULATION RESULTS

The first model of a Universal Power Line Manager (Constant Frequency Unified Power Quality Conditioner) designed by Matlab/Simulink software and implemented in microgrid is shown in Fig 3.19. The simulated results are discussed below.

![Simulink mode of CF-UPQC](image)

Fig 3.19: Simulink mode of CF-UPQC

Fig 3.20 shows the speed of the induction motor when the micro grid supply voltage varies. When the voltage sag and swell occur the induction motor speed varies. Because the voltage sag and swell occur in the induction motor terminal, the resultant air gap flux will increase or decrease. So the induction motor speed will change. Fig 3.20 (a) shows the voltage sag occurred from 0.3 to 0.8(Sec). Fig 3.20 (b) shows that the induction motor speed oscillates from its rated speed of 1800 RPM to 1650 RPM. Here micro grid’s frequency is 60 Hz. At 0.8-1.2 Sec the
the voltage swell occurs, so the induction motor speed also increases from 1790 to 1795 RPM. All the simulations are done in Matlab/Simulink block.

Fig 3.20: Induction motor speed affected by sag and swell a) Supply voltage (b) Induction motor speed

Fig 3.21: Induction motor is connected with CF-UPQC . a) Supply voltage b) load voltage c) Induction motor speed

Fig 3.21 shows that after the connection of the CF-UPQC with the induction motor its speed does not vary. Fig 3.21 (a) shows the supply voltage in sag and swell condition. The voltage sag starts from 0.3 to 0.8 (Sec). The CF-UPQC regulates the load voltage as shown in Fig 3.21 (b), so the induction motor speed is maintained constant 1800 rpm. As shown in Fig 3.21 (c) voltage swell starts from 0.8 to 1.2 (sec). But CF-UPQC effectively regulates the voltage maintained constant. Hence the induction motor speed also maintains constant. The CF-UPQC effectively regulates the supply voltage variations. So the speed of the induction motor remains constant at 1800 RPM.
Fig 3.22: Micro grid voltage and induction motor speed at normal frequency (a) Supply voltage (b) Frequency (c) Induction motor speed

Fig 3.22 shows the speed of the induction motor at normal operating voltage of volt 440 and line frequency 60 Hz. Fig 3.22 (a) shows the supply voltage and (b) shows the supply frequency. Therefore, there is no speed variation in the MicroGrid’s utility side of the induction motor as shown in Fig 3.22 (c).

Fig 3.23: Induction motor speed affected by micro grid frequency (a) Supply voltage (b) Supply frequency (c) Speed of induction motor

Fig 3.23 (a) and (b) shows that the micro grid frequency varies above the power quality limit. Due to this the synchronous speed of the induction motor increases as shown in Fig 3.23 (c). Fig 3.23 (c) shows that at 0.4 Sec the supply frequency is 60 Hz.
Hz. So the induction motor speed is rated at 1800 RPM. After 0.5 Sec the supply frequency increases. So the induction motor speed also increases from 1800 RPM to 1850 RPM as shown in Fig 3.23 (c).

Fig 3.24: Microgrid supply frequency and the speed of the induction motor (a) Supply voltage (b) Supply frequency (c) Speed of induction motor

Fig 3.24 (a) and (b) shows that the micro grid frequency varies below the power quality limits. Due to this the synchronous speed of the induction motor decreases as shown in Fig 3.24 (c). Fig 3.24 (c) shows that at 0.4 sec the supply frequency is 60 Hz. So the induction motor speed is 1800 RPM. After 0.5 sec the frequency decreases from 1800 RPM to 1700 RPM as shown in Fig 3.24 (c).

Fig 3.25: Microgrid Frequency regulation with CF-UPQC compensation (at high frequency) (a) Supply frequency rises above the power quality limit (b) Output load frequency with proposed compensation (c) Induction motor speed
Fig. 3.25 (a) shows that the micro grid frequency increases above the power quality limits. It can be seen that as the frequency increases above power quality limits, the proposed system regulates the load frequency to a constant level. The frequency variations start from 0.1 sec to 2 sec linearly as shown in Fig. 3.25 (a). From Fig. 3.25 (b) it can be inferred that the microgrid frequency is almost constant even when the microgrid frequency varies. So the implementation of the CF-UPQC speed of the induction motor also is constant as shown in Fig. 3.25 (c).

![Graph showing microgrid frequency regulation with CF-UPQC compensation](image)

Fig. 3.26 : Microgrid frequency regulation with CF-UPQC compensation (at low frequency) (a) Supply frequency falls below the power quality limit (b) Output load frequency with CF-UPQC compensation (c) Induction motor speed

Fig. 3.26 shows the system response when the micro grid supply frequency decreases below the power quality limits. It is seen in fig. 3.26 (a) that as the frequency decreases from 60 Hz to 55 Hz the proposed system maintains the load frequency constant. The frequency variation starts from 0.2 sec to 2.5 sec linearly as shown in Fig. 3.26 (b). Fig 3.26 (c) shows the utility induction motor load. The Microgrid supply frequency variation is regulated by the CF-UPQC and the load frequency is maintained constant, so the speed deviation is not present.

Fig 3.27 shows the current harmonic mitigation function of the CF-UPQC (the first model of UPLM). Fig 3.27 (a) shows the supply current waveform, at 0-2 sec. Initially the load current is 2000 amps after that load is increased after 0.3 sec at 4000 amps. It clearly shows that the waveform is non sinusoidal and contains harmonics. The total harmonic distortion level is 45%. Fig 3.27 (b) shows that after the implementation of the CF-UPQC the current harmonics are mitigated efficiently.
Fig 3.27: Source current and its harmonics after implementation of the CF-UPQC (a) Load current (b) Source current (c) Source current harmonics (d) Load voltage and that the current waveform is sinusoidal. Fig 3.27 (c) shows that the total harmonic distortion level after implementation of the CF-UPQC decreases from 45 % to 4 %. The corresponding load voltage is shown in Fig. 3.27 (d).

3.6. CONSTANT FREQUENCY-UNIFIED POWER QUALITY CONDITIONER FOR WIND TURBINE GENERATOR.

A MicroGrid is a cluster of interconnected distributed generators, loads and storage units that co-operate with each other and can be treated as a grid. Typical MicroGrid sources include combustion engines, small wind turbines and photovoltaic systems [115]. Microgrids can operate in a grid-connected mode or in island mode. In the grid-connected mode, the MicroGrid either draws or supplies power to the main grid, depending on the power generation and load. Power quality problems and pre-set conditions will make the microgrid disconnect from the main grid and operate as a separate island. The main problem in a microgrid is the power quality issue when connected to heavy loads. If the load increases, the frequency and voltage will vary [116]. If the supply frequency and voltage varies beyond the power quality limits the utility equipment may not work properly. Micro grid connected generation units like wind turbine generators directly affect the power quality problems. Fixed Speed Induction Wind Turbine Generator (FSIWTG) is a part of
micro grid. It is directly affecting the power quality problems. In micro grid frequency is not stable for all conditions which is discussed in chapter 1.

Unified power quality conditioner can be applied in a power system for current harmonic compensation, voltage compensation and reactive power control. But the main drawback is that it cannot compensate frequency regulation. This drawback is overcome by introducing a Constant Frequency Unified Power Quality Conditioner (CF-UPQC). CF-UPQC is connected to fixed speed induction wind turbine generator, it isolates the harmonics, compensate the voltage sag/swell and regulate the frequency, so if micro grid frequency variation will not affect the performance of wind turbine generator.

3.6.1. Construction

Fig. 3.28 shows an arrangement of the constant frequency unified power quality conditioner for a windmill (FSIWTG). The constant frequency unified power quality conditioner can solve all power quality issues like voltage sag, voltage swell and also eliminate current harmonics and frequency regulation (by using the matrix converter). A matrix converter can convert the supply frequency in a wide range. It can also compensate the voltage sag and swell efficiently by adjusting the modulations. A matrix converter (MC), can control the phase angle between the voltage and current on the output side.

The basic components of the CF-UPQC is the voltage source inverter (VSI’s) sharing a common DC storage capacitor and a matrix converter connected to the power system through coupling transformers. One VSI is connected parallel to the transmission line via a shunt transformer, while the other one is connected in series through a series transformer. The series converter is connected in series with the supply through a transformer \((T_1, T_2, T_3)\) while the shunt converter is connected in parallel with the passive filters \((L_{P(1,2,3)}, R_{P(1,2,3)})\) and \((R_{P(1,2,3)}, C_{P(1,2,3)})\). The passive filters are used to minimize the switching oscillation in the converter’s output. Each converter and filter consists of three single phase voltage-source PWM inverters using power IGBTs.

The shunt converter compensates the reactive power, voltage stability and current harmonic rejection of the windmill. The series converter controls the voltage regulation and voltage harmonic rejection for fixed speed windmill. The matrix converter is used to regulate the supply frequency of the fixed speed induction wind turbine generator.
Fig 3.28: Constant Frequency Unified Power Quality Conditioner connected windmill

A detailed CF-UPQC construction scheme is shown in fig. 3.28. The main circuit of the Constant Frequency Unified Power Quality Conditioner consists of a matrix converter placed in-between the series converter and shunt converter arranged as per the circuit diagram. This type of arrangement is called a tandem based converter. This can avoid the limitations of a matrix converter. The matrix converter consists of a single-stage converter that has an array of $mn$ (3X3) bidirectional power switches. It consists of nine bidirectional switches arranged in three groups, each being associated with an output line. This bi-directional arrangement of switches connects $mn$ of the input lines to $mn$ of the output lines. Commonly, the matrix converter can change the input frequency to the output. The power rating of the matrix converter is 450 KVA, the input voltage of three phases is 440 V and the frequency of the output is regulated to 60 Hz.

The control system of constant frequency unified power quality conditioner is slightly modified for fixed speed induction wind turbine generator. The control system of CF-UPQC consists of three sections described bellow.
3.6.2 Frequency Regulating Control Block

The block diagram of the matrix converter based frequency regulated power supply for a MicroGrid connected fixed speed wind turbine generator is shown in Fig.3.29. Conventional space vector pulse width modulation is used to switch the matrix converter’s IGBTs. The control method of this frequency regulator is modified into the flux oriented vector control technique of AC induction motor drives. This control scheme is suitable to drive the induction generator based windmill. The speed control loop is omitted and the coordinate transformation angle $\theta$ is calculated with reference to the output frequency $f$ and the sampling time $t$.

The supply frequency $f_s$ is compared with the reference frequency $f_{s*}$. The frequency error signal $\Delta f_s$ is applied to a frequency regulator/controller. PI (proportional-integral) type controller generates the reference frequency $f_{ref}$. When $f_{ref}$ is added to $f_s$, the required supply frequency $f_{ref*}$ is obtained. This $f_{ref*}$ is fed to the PLL which produces the corresponding $\theta$($\sin \theta$, $\cos \theta$). The reference output voltage vector (represented by $U_{\alpha}$, $U_{\beta}$) is provided by the output current controller and the reference input current vector (represented by $I_{ref}$) is determined by the input voltages and the input displacement angle $\theta$ through the input power factor control.

Fig.3.29: Control system of the frequency regulator in CF-UPQC for windmill
The output currents have been transformed from \( i_{abc} \) into \( i_{\alpha\beta} \). Then it is converted to a \( d\-q \) reference frame (park transforms)

\[
\begin{bmatrix}
i_d \\ i_q
\end{bmatrix} = \begin{bmatrix}
\cos \theta & \sin \theta \\ -\sin \theta & \cos \theta
\end{bmatrix} \begin{bmatrix}
i_\alpha \\ i_\beta
\end{bmatrix}
\] (3.18)

The magnitude of output current can be controlled by setting the values of \( i_{d\text{ref}}, i_{q\text{ref}} \). When \( i_{d\text{ref}} \) and \( i_{q\text{ref}} \) is compared with the reference value, the corresponding voltage is generated. Again it is converted to Clark transformation.

When the above values are fed to the voltage controller, the phase voltage \( U_u, U_v \) and \( U_w \) will be obtained.

After the anti-transformation of the phase voltages \( (U_u, U_v \text{ and } U_w) \), the coordinate systems are obtained. Depending on the control signal, the space vector modulator produces the corresponding pulse width modulation (PWM) signal to the matrix converter.

### 3.6.3 Voltage sag/swell controller

The function of the series active filter is to compensate the voltage disturbance in the source side, which is due to the fault in the distribution line at the PCC. The series active filter control algorithm calculates the reference value to be injected by the series active filter transformers, comparing the positive-sequence component with the load’s sideline voltage. The series active filter’s reference voltage signal generation system is shown in Fig. 3.30. In equation (3.20), the supply voltage \( V_{\text{Sabc}} \) is transformed to \( dq\theta \) coordinates

\[
\begin{bmatrix}
V_{d} \\ V_{q}
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
1/2 & 1/2 & 1/2 \\ 3 \sin(\omega t) & 3 \sin(\omega t - 2\pi/3) & 3 \sin(\omega t + 2\pi/3) \\ 3 \cos(\omega t) & 3 \cos(\omega t - 2\pi/3) & 3 \cos(\omega t + 2\pi/3)
\end{bmatrix} \begin{bmatrix}
V_{sd} \\ V_{sq}
\end{bmatrix}
\] (3.20)

The voltage in \( d \) axis \( (v_{sd}) \) given in (3.21) consists of average and oscillating components of source voltage \( (\bar{v}_{sd} \text{ and } \tilde{v}_{sd}) \). The average voltage \( \bar{v}_{sd} \) is calculated by using a second order LPF (low pass filter).

\[
v_{sd} = \bar{v}_{sd} + \tilde{v}_{sd}
\] (3.21)
The load side reference voltages \( v_{Labc}^* \) are calculated as given in equation (3.22).

The switching signals are assessed by comparing the reference voltage \((v_{Labc}^*)\) and the load voltage \((V_{Labc})\) through a sinusoidal PWM controller.

\[
\begin{bmatrix}
V_{La}^* \\
V_{Lb}^* \\
V_{Lc}^*
\end{bmatrix}
= \frac{2}{3}
\begin{bmatrix}
\sin(\omega t) & \cos(\omega t) & 1 \\
\sin(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) & 1 \\
\sin(\omega t + \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) & 1
\end{bmatrix}
\begin{bmatrix}
\tau_{at} \\
0 \\
0
\end{bmatrix}
\]  

(3.22)

These three-phase load reference voltage are compared with the load line voltage. The errors are then processed by a sinusoidal PWM controller to generate the required switching signals for the series active filter’s IGBT switches.

**3.6.4 Current Harmonics Control block**

The shunt active filter described in this part is used to compensate the current harmonics and reactive power generated by the nonlinear loads. The block diagram of the shunt active filter’s reference current signal generation is shown in fig. 3.30. The instantaneous reactive power \((p-q)\) theory is used to control the shunt active filter in real time. In this theory the instantaneous three-phase current and voltage is transformed to \(\alpha\beta0\) as shown in equation 3.23

\[
\begin{bmatrix}
V_v \\
V_a \\
V_p
\end{bmatrix}
= \frac{2}{\sqrt{3}}
\begin{bmatrix}
\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
1 & -\frac{1}{2} & -\frac{1}{2} \\
0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}
\end{bmatrix}
\begin{bmatrix}
V_w \\
V_{wa} \\
V_{wb}
\end{bmatrix}
\]

(3.23)

The corresponding current coordinates as shown in equation (3.24)

\[
\begin{bmatrix}
i_v \\
i_a \\
i_p
\end{bmatrix}
= \frac{2}{\sqrt{3}}
\begin{bmatrix}
\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
1 & -\frac{1}{2} & -\frac{1}{2} \\
0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}
\end{bmatrix}
\begin{bmatrix}
i_w \\
i_{wa} \\
i_{wb}
\end{bmatrix}
\]

(3.24)

The source side instantaneous real and imaginary power components are calculated by using source current and phase-neutral voltage as given in (3.25). The instantaneous real and imaginary powers include both oscillating and average components.
Average components of $p$ and $q$ consist of positive sequence components ($\bar{p}$ and $\bar{q}$) of the source current. The oscillating components ($\tilde{p}$ and $\tilde{q}$) of $p$ and $q$ include harmonic and negative sequence components of source currents. In order to reduce neutral current, $p_0$ is calculated by using the average and oscillating components of the imaginary power and the oscillating components of the real power as given in equation (3.26). $i_{sa}^*, i_{sb}^*$ and $i_{s0}^*$ are the reference current of shunt active filter in $\alpha\beta0$ coordinates. These current are transformed to the three-phase system as shown in equation (3.27).
\[
\begin{bmatrix}
  p_0 \\
  p \\
  q
\end{bmatrix} = \sqrt{3}/2 \begin{bmatrix}
  v_0 & 0 & 0 \\
  0 & v_\alpha & v_\beta \\
  0 & -v_\beta & v_\alpha
\end{bmatrix} i_0
\]  

(3.25)

\[p_0 = v_0 * v_0 \text{ and } p = \bar{p} + \tilde{p}\]

(3.26)

\[
\begin{bmatrix}
  i_{s0}^* \\
  i_{sa}^* \\
  i_{sb}^* \\
\end{bmatrix} = \frac{1}{v_a^2 + v_\beta^2} \begin{bmatrix}
  v_\alpha & -v_\beta & v_\alpha \\
  -v_\beta & v_\alpha & v_\alpha
\end{bmatrix} \begin{bmatrix}
  \beta + p_0 + p_{lon} \\
  0
\end{bmatrix}
\]  

(3.27)

\[
\begin{bmatrix}
  i_\alpha \\
  i_\alpha \\
  i_\alpha
\end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix}
  \sqrt{2}/2 & 1 & 0 \\
  \sqrt{2}/2 & -1/2 & \sqrt{3}/2 \\
  \sqrt{2}/2 & -1/2 & -\sqrt{3}/2
\end{bmatrix} \begin{bmatrix}
  i_{s0}^* \\
  i_{sa}^* \\
  i_{sb}^*
\end{bmatrix}
\]  

(3.28)

Table 3.1: Functions of the constant frequency unified power quality conditioner

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compensate voltage harmonics</td>
</tr>
<tr>
<td>2</td>
<td>Compensate current harmonics</td>
</tr>
<tr>
<td>3</td>
<td>Regulate the supply frequency to the load</td>
</tr>
<tr>
<td>4</td>
<td>Regulate the terminal voltage of the power line</td>
</tr>
</tbody>
</table>

The reference current is calculated in order to compensate the neutral, harmonic and reactive current in the load. These reference source current signals are then compared with the three-phase source current and the errors are processed by a hysteresis band PWM controller to generate the required switching signals for the shunt active filter switches.

### 3.7 SIMULATION RESULTS

The model of a CF-UPQC connected with a MicroGrid connected FSIWTG designed by Matlab/Simulink software is shown in Fig 3.31. The simulated results are discussed below. To validate the effectiveness of the proposed system based FSIWTG, different cases have been examined for this study.
In the CF-UPQC connected wind mill topology, simulations is carried out using Matlab/ Simulink software for voltage sag, current harmonics and frequency regulation investigations. The results of each test are described below. All the simulations are simulated with the discrete sampling time of $T_s=3$ Sec.

A) Voltage sag

![Voltage sag diagram](image)

**Fig 3.32: Power production against voltage sag/swell condition**
In Fig. 3.32 the CF-UPQC compensates the voltage sags and swells effectively. When there voltage sags and swells directly affects the wind power production as shown in Fig 3.32. In the simulation result the voltage sag starts at 1.2 sec. at the same time the wind mill power production also oscillates. The red line indicates the RMS value of micro grid voltage.

![Figure 3.33: CF-UPQC based compensated power production at voltage sag/swell condition](image)

After implementing a CF-UPQC, the wind production is not affected by the voltage sags and swells as shown in Fig 3.33. At 1.2 sec voltage sag occurs but the CFUPQC connected wind mill not affected as shown in figure.

**B) Current harmonics**

The matrix converter draws non-sinusoidal current from the power supply as shown in Fig 3.34. From Fig 3.34 it is observed that the total current harmonic distortion level is 100%. Total harmonic distortion and current are plotted in a same graph shown in figure 3.34.

![Figure 3.34: Supply current before implementation of a CF-UPQC](image)
Fig 3.35: Supply current after implementation of a CF-UPQC in a FSIWTG

Fig 3.35 shows that after the implementation of a CF-UPQC, the input current is in sinusoidal waveform. It is clearly seen that the CF-UPQC effectively compensates the current harmonics. The simulation results show only the single phase of the supply voltage. In fig 3.35 the total current is 400A. The simulation is carried out for a period of 0.7 sec to 1.8 sec and current and its T.H.D plotted in the same graph as shown in Fig 3.35.

C) Power frequency variation control

Here the micro grid frequency is 60 Hz at normal conditions. The permissible limit of the supply frequency is 59.5 Hz to 60.5 Hz particularly for a FSIWTG. However, in a MicroGrid it will vary from 57 – 62 Hz. Due to this micro grid frequency, the windmill’s power production will be affected..

Fig 3.36: Supply frequency (Vs) power production
Fig 3.36 shows when the supply frequency increases rapidly, the generator’s power production rapidly decreases from 400 KW to 100 KW. The thick line shown the micro grid frequency and thin line shows the micro grid connected wind mill power production.

![Supply frequency (Vs) power production after implementation of a CF-UPQC in a FSIWTG](image)

After the implementation of the CF-UPQC the windmill terminal frequency of micro grid is 60 Hz constant when the input frequency fluctuates. So the power produced by a wind turbine generator is also constant as shown in Fig.3.37. Wind mill terminal frequency and its power production are plotted in a same graph.

### 3.8 SUMMARY

This chapter investigates the effects of voltage sag, voltage swell and supply frequency variations on a micro grid connected utility and micro grid fixed speed induction type wind turbine generator. In this chapter developed a model of custom power equipment, namely a Constant Frequency Unified Power Quality Conditioner (CF-UPQC). This model is the basic model of the Universal Power Line Manager. This chapter illustrates the operation and control of a CF-UPQC. This device is connected in between the micro grid and the utility. When an unbalanced and frequency sensitive load is supplied through the CF-UPQC, it will regulate the supply voltage, supply frequency and eliminate harmonics. The main aim of the CF-UPQC is to regulate the micro grid supply frequency, compensate the sag/swell voltages and mitigate the harmonics at the micro grid load terminal. The developed system can regulate the supply frequency efficiently using a matrix converter. The simulation result shows that the CF-UPQC system has the ability to mitigate the power quality issues. The CF-UPQC also works effectively in the FSIWTG.
connected with MicroGrid system. Simulation studies have been carried out in Matlab/Simulink software to examine the impacts on a FSIWTG in the steady-state, unbalanced and supply frequency fluctuation conditions. This power quality conditioner compensates the voltage sag, swell, supply frequency and mitigates the current harmonics. The simulation results show that the CF-UPQC behaves satisfactorily during steady state and transient periods.

Based on the simulation results the CF-UPQC not capable to control the power flow. In micro grid if power flow is not controlled/balanced the voltage and frequency variations occur. This may cause the instability of the micro grid power system.