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Harmonics Mitigation of a Microgrid System using Modified SRF-UPQC Method

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Abstract

Objectives: To describe the mitigation of power quality problem using modified Synchronous Reference Frame (SRF) Unified Power Quality Conditioner (UPQC) method. To design a Micro grid system using solar PV/wind/energy storage system like battery and power quality analysis i.e. reduction of harmonics and compensation of reactive power flow of the Microgrid system without using phased locked loop (PLL) circuit. **Methods/Statistical Analysis:** In the proposed system solar PV/Wind/ Battery system are combined to form a Microgrid using MATLAB Simulink environment and the power quality problem is solve by using modified Synchronous Reference Frame (SRF) Unified Power Quality Conditioner (UPQC) method. In order to identify a suitable controller for better compensation of UPQC, modified SRF method is used. This method mainly focuses on regulation on DC link voltage and unit vector generation. PLL circuit is required in case of conventional SRF method for vector orientation but in the proposed method vector orientation is obtain without using PLL. **Findings:** The drawback of PLL is eliminated by using modified SRF method and the result shown in First Fourier Transform (FFT) analysis that modified SRF method has a better performance than normal SRF method considering both harmonic elimination and reactive power compensation. The performance of the system is verified under both the condition i.e. microgrid with UPQC and without UPQC. The proposed controller compensates harmonics from 16.29% to 3.33% and maintains the DC link voltage constant. **Application/Improvements:** The issues in the power distribution system are voltage sag, swell, harmonics in both current and voltage waveform. In order to achieve a pure sinusoidal waveform with proper magnitude and phase is a great concern and UPQC is a device which can mitigate all PQ related problem in Microgrid system. This proposed work mainly used in power distribution system based on Microgrid.

Keywords: Harmonics, Microgrid, Modified Synchronous Reference Frame (SRF) Method, Unified Power Quality Conditioner (UPQC)

1. Introduction

The microgrid is nothing but the combination of number of micro energy sources, battery system with different electronics converters are connected to utility grid[1]. In a grid connected microgrid system the Power Quality(PQ) problem is mainly divided into two categories that PQ problem in utility side and PQ problem in customer side. Voltage sag & swell, voltage interruption & flickering are mainly related to utility side and harmonics distortion, reactive power demand and lagging power factor are mainly related to customer PQ problem[2-3]. Unified Power Quality Conditioner (UPQC) is a device which normally connected in between source and load to mitigate the PQ problems related to utility and Microgrid[4].To maintain the power quality problem power electronics switches with advance controller mechanism are used[5-7]. Unified power quality conditioner modeling has been described[8]. Perturb and Observes (P&O) maximum power point tracking method has been developed by[9]. Analysis of two models of UPQC for enhancement power quality has been explained by[10]. Different controller used in shunt active filter explained in[11]. Different controller used in series active filter explained in[12]. The voltage sag elimination by

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using dynamic voltage restorer has been developed by[13]. The harmonics and reactive power compensation using shunt active filter by Matlab simulation and experimental design have presented by[14].

2. Proposed System

Here the general diagram for Microgrid system with UPQC was shown in Figure 1. The diagram shows the combination of solar Photo Voltaic (PV) / wind energy and battery system. A boost converter is use to convert the DC voltage to required DC voltage as by the DC bus. A power converter is required to converter DC bus to AC bus voltage. The UPQC is connected at the PCC point i.e in between grid and load.

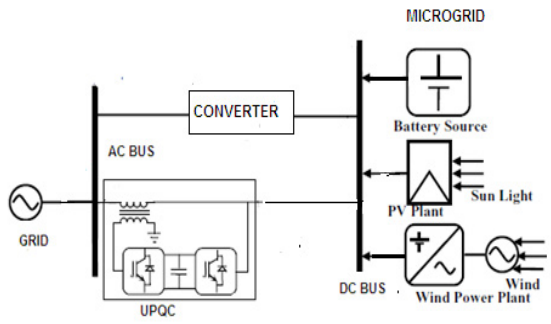


Figure 1. Block Diagram of Proposed System.

3. Control Strategies of the UPQC System

The operational block diagram for UPQC is shown in Figure 2. In order to generate the reference voltage and current of UPQC many control strategies are available. D-q theory with hysteresis current control mode is suitable for parallel mode operation of UPQC system and d-q theory with PWM voltage control mode is suitable for interruption mode operation. The hysteresis control method is simple to implement and it has enhanced system stability, increased reliability and mitigates power quality problems.

UPQC consists of two main controllers as follows:

- Series APF
- Shunt APF

3.1 Series Active Filter

Figure 3 shows the block diagram of series active filter where the series active filter is connected at Point of Common Coupling (PCC) which compensates the sag, swell and voltage harmonics occurs in the source voltage.

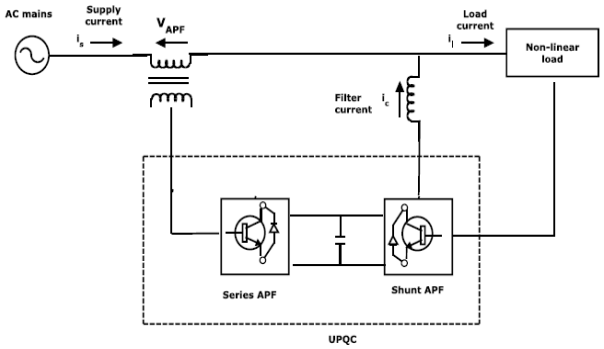


Figure 2. UPQC Block Diagram.

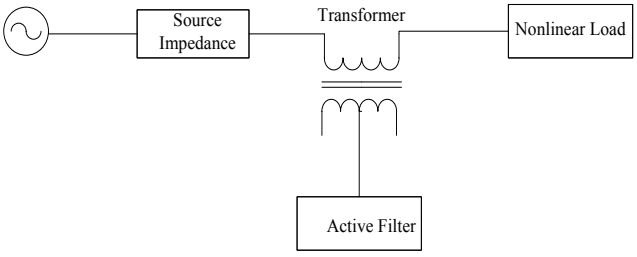


Figure 3. Series Active Filter Block Diagram.

3.2 Series active Filter Control Scheme

In order to design the control scheme for series APF abc to dq transformation method is used which is shown in Figure 4. The actual and reference voltage are converted to dq0 from abc coordinates and both are compared in dq0 reference frame. After the comparison both are again converted to abc reference frame. From Phased Locked Loop (PLL) θ can be generated which is required for Park's transformation and inverse Park's transformation. The switching pulses required for VSI conduction are generated from the comparison of selected output voltage (Vc*) with the sensed series APF output voltage (Vc) in a hysteresis voltage controller.

ABC to dq and dq to ABC transformation equation is given below.

$$\begin{bmatrix} v_q \\ v_d \\ v_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ \sin\theta & \sin(\theta-120) & \sin(\theta+120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120) & \sin(\theta-120) & 1 \\ \cos(\theta+120) & \sin(\theta+120) & 1 \end{bmatrix}\begin{bmatrix} v_q \\ v_d \\ v_0 \end{bmatrix}$$

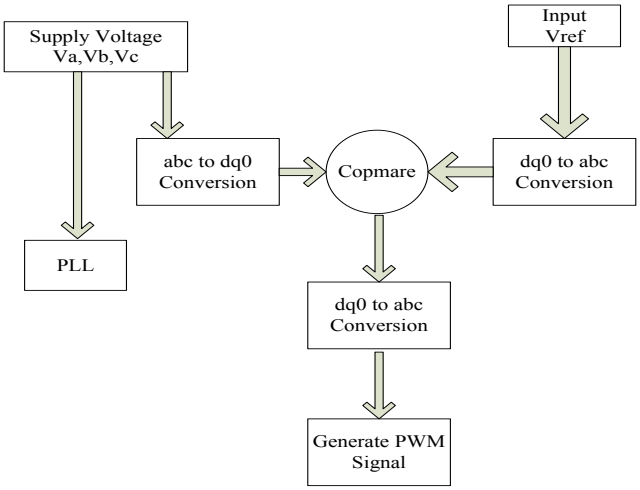


Figure 4. Control Scheme for Series APF.

3.3 Shunt Active Power Filter

Figure 5 shows the block diagram of shunt active filter where the shunt active filter is connected at Point of Common Coupling (PCC) which compensates current & voltage harmonics occurs due to the non-linear load.

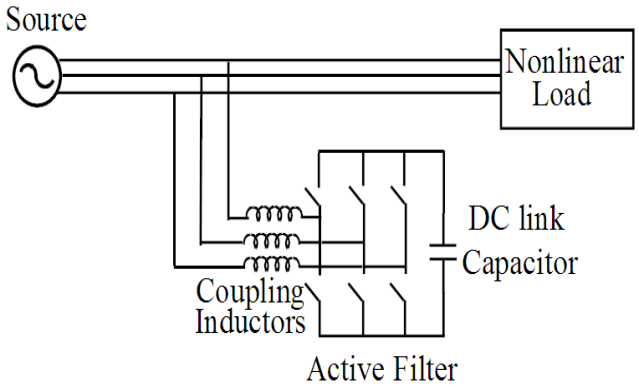


Figure 5. Block Diagram Shunt APF.

3.4 Shunt Active Power Filter Control Scheme

3.4.1 Conventional-SRF

Figure 6 shows control scheme block diagram of conventional SRF method. The control scheme includes the transfer of source current from a-b-c to d-q frame and to eliminate the harmonics, an equal amount of harmonic compensating current is injected in opposite phase w.r.t the harmonic current. The shunt active filter also compensates the reactive power flow by injecting or absorbing reactive power from the PCC.

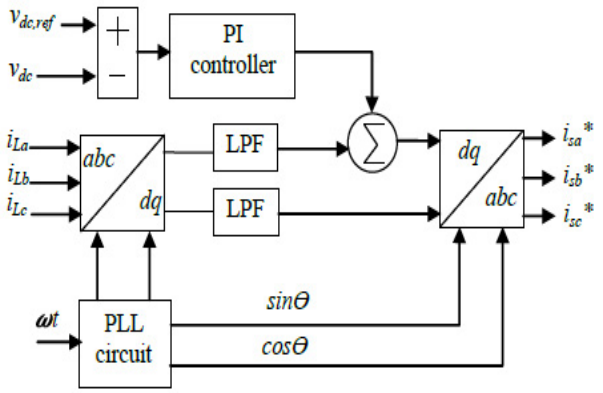


Figure 6. Shunt Active Filter Control Scheme.

3.5 Proposed Modified-SRF

The block diagram of modified SRF control scheme is shown in Figure 7 where the PLL circuit of conventional SRF method is replaced by unit vector generation. Figure 8 represents the unit vector generation method where the reference current is extracted by using dc-link capacitor voltage regulator and parks transformation technique.

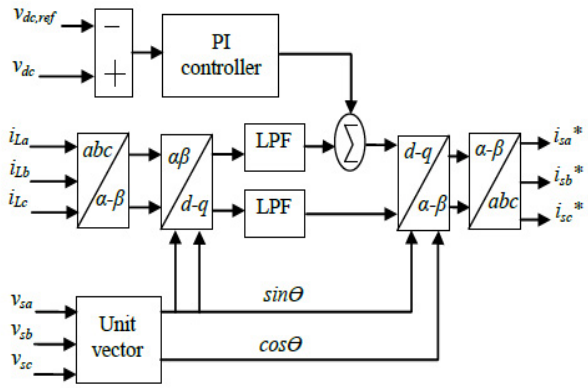


Figure 7. Modified SRF Method Block Diagram.

4. Design of Microgrid

4.1 Modeling of Solar PV

Solar photo-voltaic system works on the principle that when a light energy falls on solar cell it converts it to electrical energy. Figure 9 shows here is an equivalent model of solar PV system representing single diode model. It consist of a photo current I_{ph} which depends on temperature and irradiation, the series resistance represent the

internal resistance due to which current I flows and the shunt resistance describe the flow of I_{sh} which is a leakage current.

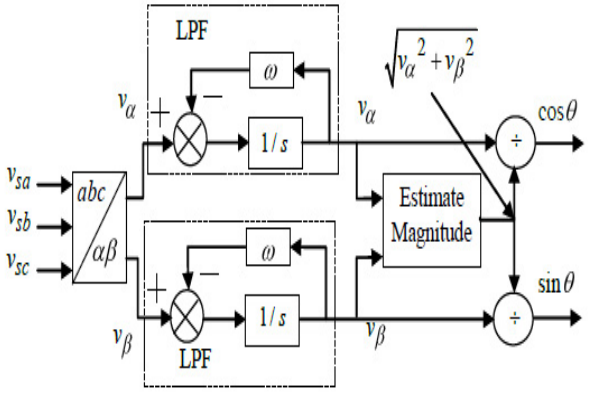


Figure 8. Unit Vector Generation Block Diagram.

The load current, photo current and other equation are given below

$$I = I_{ph} - I_0 - I_{sh} \quad (1)$$

$$I_{ph} = [I_{sc} + K_i(T_k - T)] \times \frac{G}{1000} \quad (2)$$

$$I_{RS} = \frac{I_{sc}}{[exp(q \times V_{oc}/N_s \times k \times A \times T) - 1]} \quad (3)$$

$$I_0 = I_{RS}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q \times E_{go}}{Ak}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] \quad (4)$$

$$I_{PV} = N_p \times I_{ph} - N_p \times I_0\left[\exp\left\{\frac{q \times V_{PV} + I_{PV} R_{se}}{N_s \times AkT}\right\} - 1\right] \quad (5)$$

Where

I_{PV}–Diode photo current

I_O–diode's Reverse saturation current

V_{pv}–Voltage across the diode

V_{oc} –Open circuit voltage

R_{se}–Resistance in series

R_{sh}–resistance in shunt

4.1.1 Simulation of Solar PV with MPPT and Boost Converter

The solar panel efficiency is increased by the use MPP technique. The MPPT is the application of maximum power transfer theorem which says that the load will receive maximum power when the source impedance is equal to load impedance. The MPPT is a device that extracts maximum power from the solar cell and changes the duty ratio of DC/DC boost converter in order to match the load impedance to the source. Figure 10 shows the simulation of solar PV with MPPT and boost converter. Figure 11 and 12 shows the (I-V) and (P-V) characteristics of PV module. The output voltage of boost converter is shown in Figure 13.

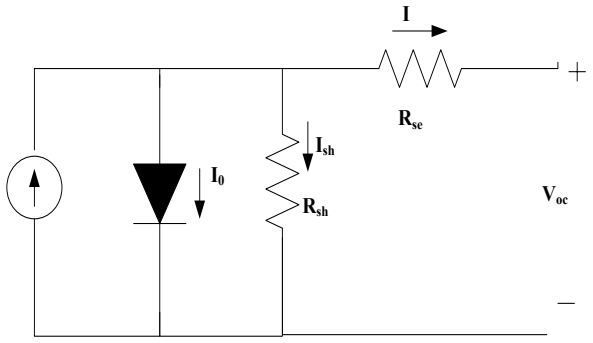


Figure 9. Solar Cell Single Diode Model.

4.2 Wind Energy System

The basic wind energy conversion system diagram is shown in Figure 14. The kinetic energy of the wind is converted to rotational motion and by the use of gear box it is matches the speed of turbine and generator. The function of generator is to convert turbine mechanical energy to electrical energy. This AC voltage is converting to DC by using rectifier and a battery is connected in bidirectional mode.

4.3 Modeling of Wind Turbines

Different equations are shown below for design of wind energy system.

$$Pm = \frac{1}{2}\pi\rho Cp(\lambda, \beta)R^2V^3 \quad (6)$$

Where

–Pitch angle

R–Blade radius

V–Wind Speed (in m/s)

– Air Density

R/ V

PM–Turbine Power

CP - Tip-speed ratio ( )

- Rotor speed (rad/sec)

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) exp^{\frac{-165}{\lambda_i}} \quad (7)$$

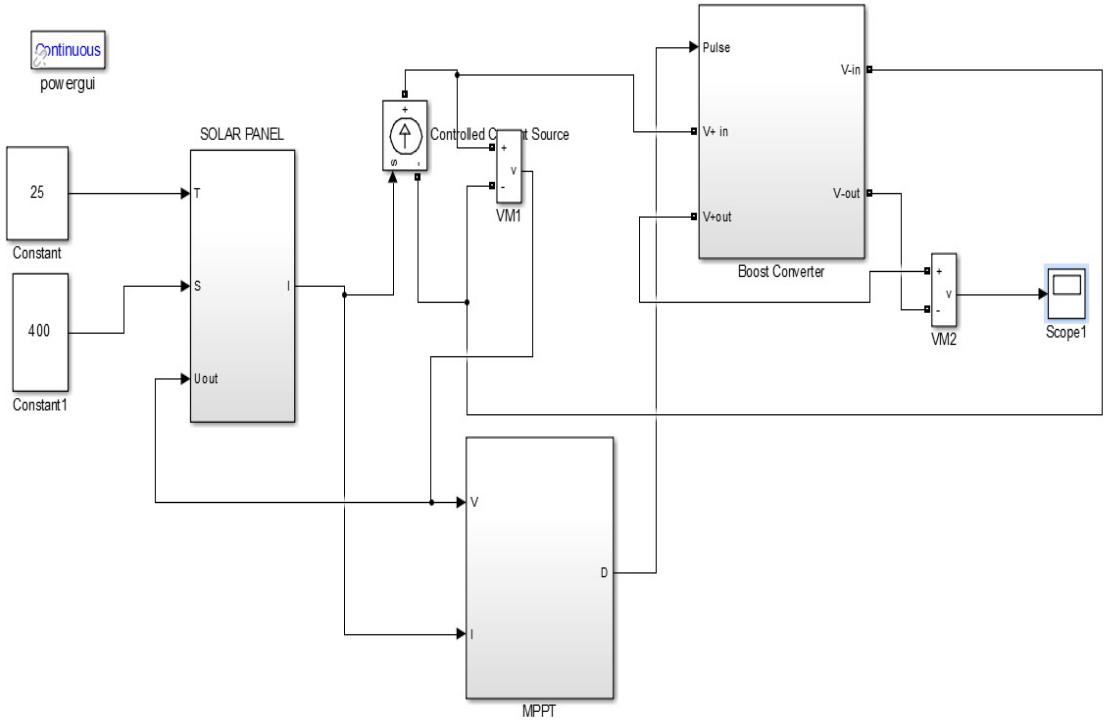


Figure 10. Simulation of Solar PV with MPPT and Boost Converter.

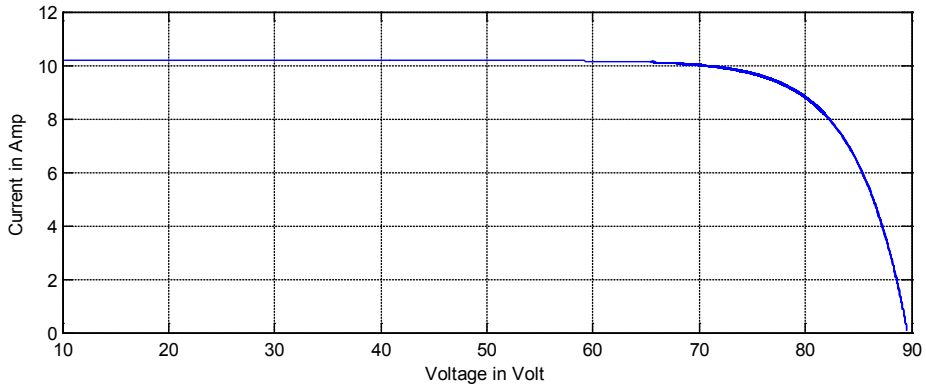


Figure 11. I-V Characteristics of PV Module.

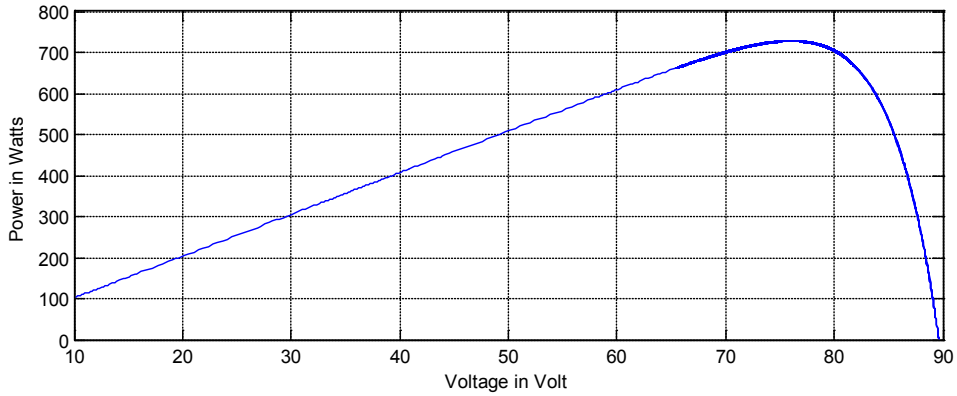


Figure 12. P-V Characteristics of PV Module.

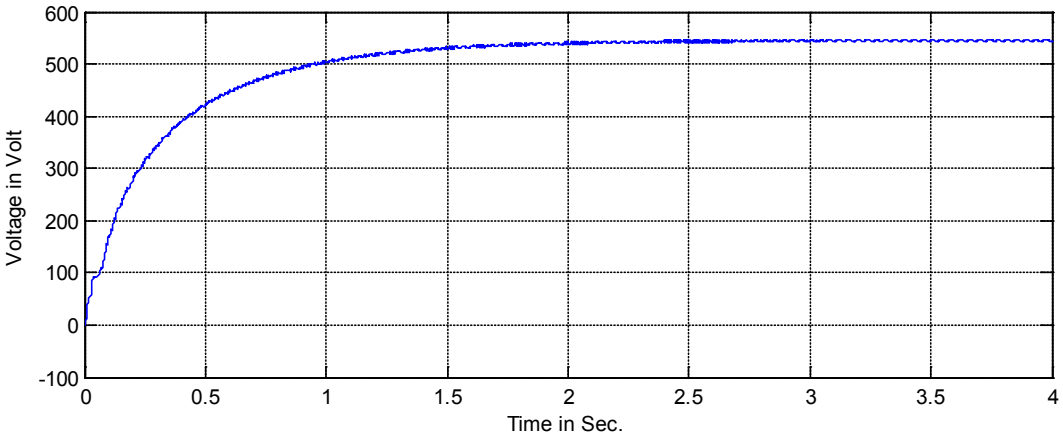


Figure 13. Output Voltage of Boost Converter.

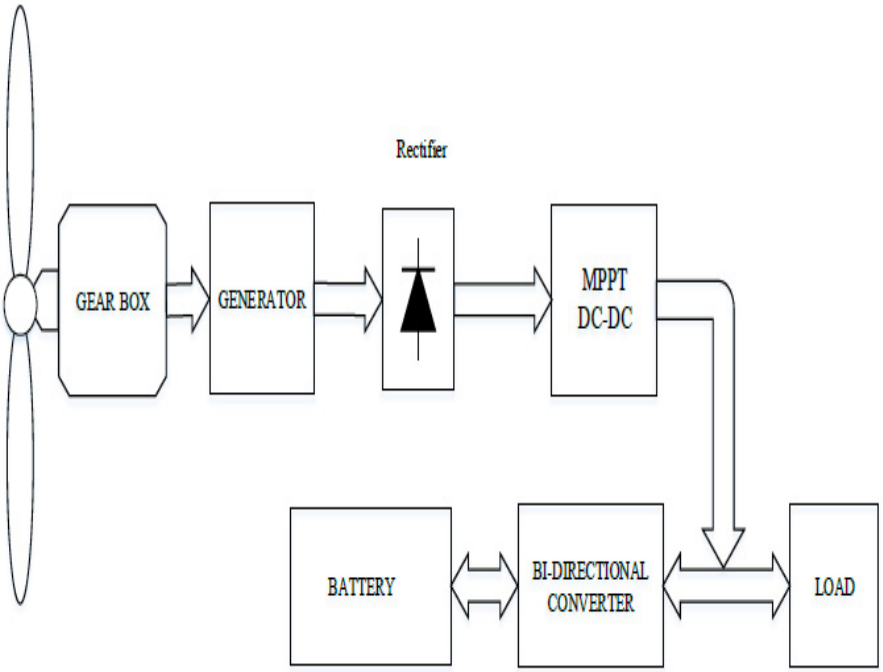


Figure 14. Block Diagram of Wind Energy System.

$$\lambda_1 = \left(\frac{1}{\frac{1}{\lambda + 0.089} - \frac{0.035}{\beta^3 + 1}} \right) \quad (8)$$

The e.m.f induced in a synchronous generator is given below.

$$E = 4.44 \emptyset_m t f \quad (9)$$

Where,

f frequency in Hz

Φm maximum flux in Wb

t number of turns.

The simulation of wind energy system with Permanent Magnet Synchronous Generator (PMSG) and rectifier is shown in Figure 15. The simulation of microgrid system with inverter and load is shown in Figure 16.

5. Matlab Simulation with Results

The block diagram of microgrid system with UPQC presented in Figure 1 is executed in Matlab/simulink. The microgrid without and with UPQC system is simulated in Figure 17. The result shown in Figure 18 (a) is the out-

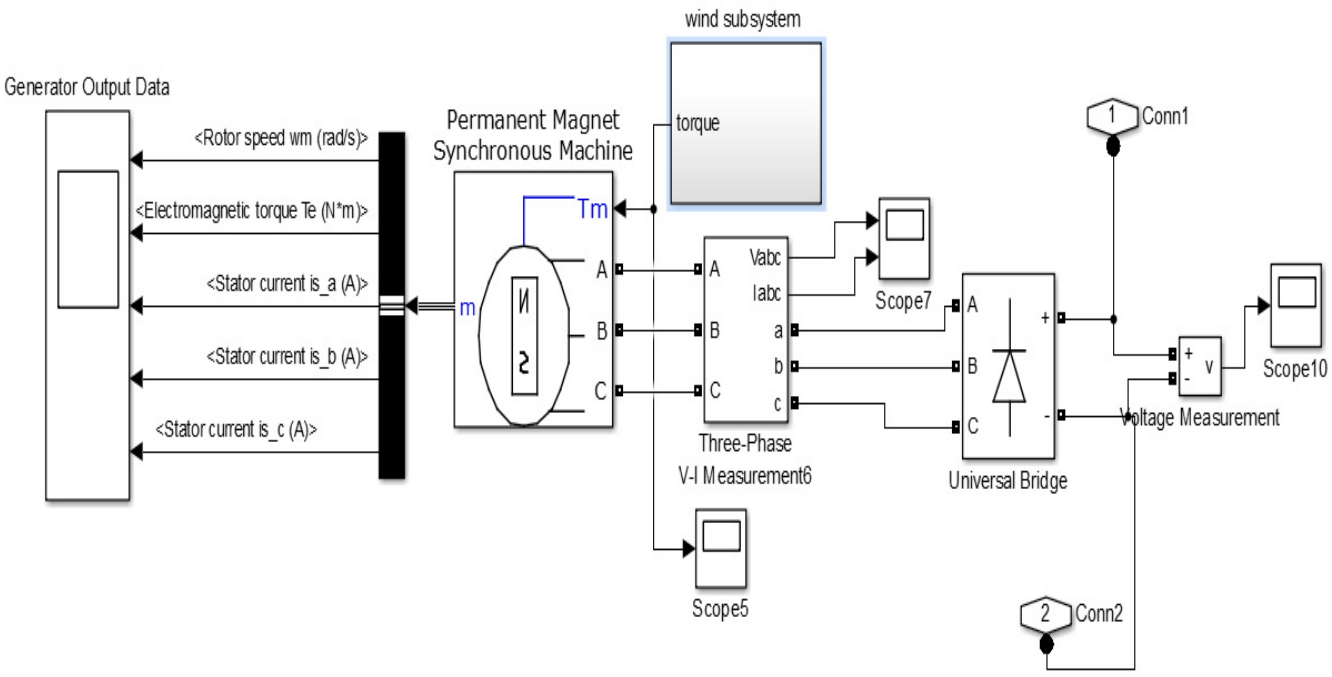


Figure 15. Wind System with PMSG and Rectifier.

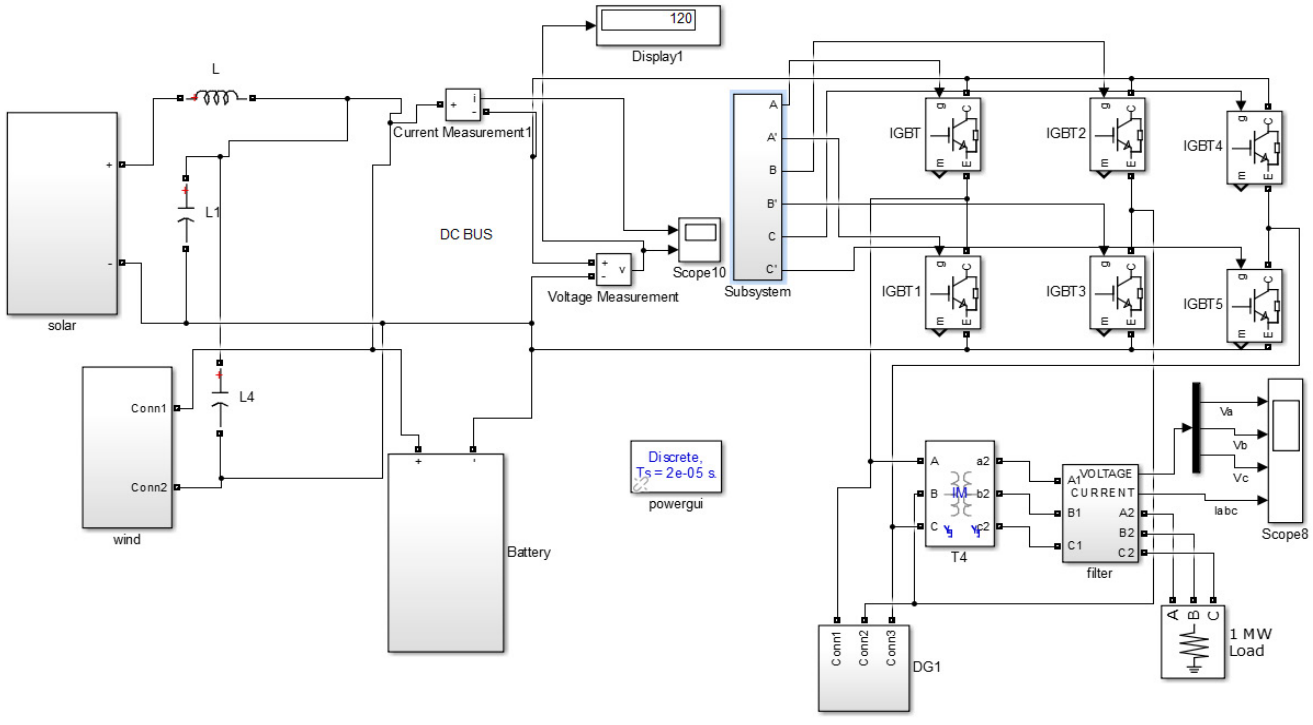


Figure 16. Microgrid System with Inverter and Load.

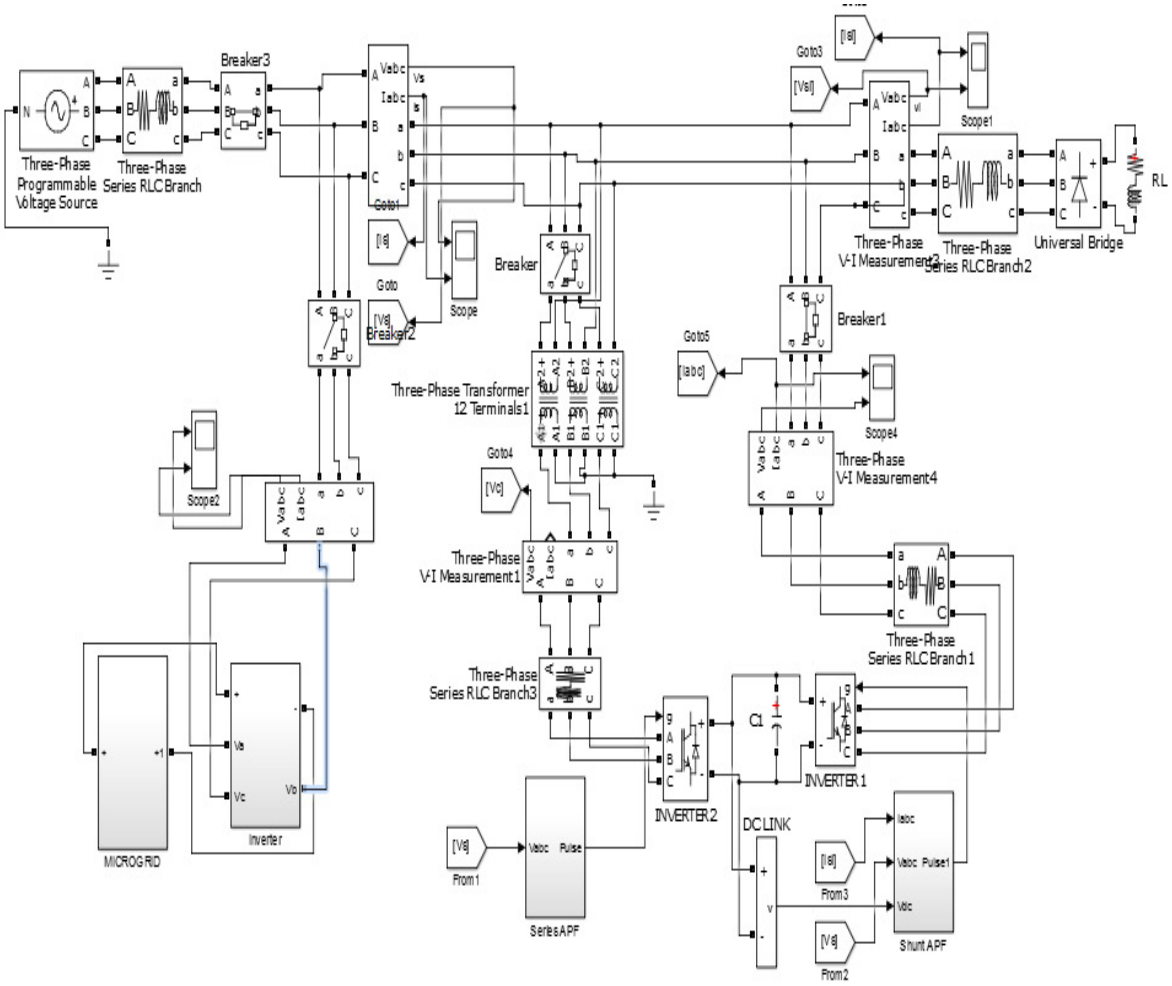


Figure 17. Simulink Model of UPQC with Microgrid.

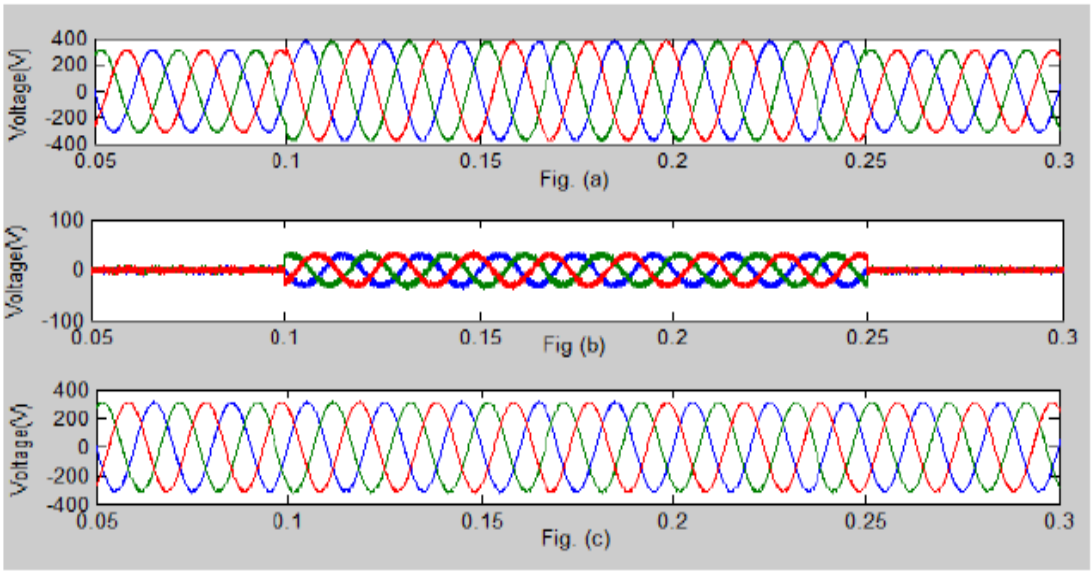


Figure 18. (a) Input Voltage (b) Injected Voltage (c) Load Voltage.

put voltage of microgrid system before compensation and in Figure 18 (c) is the output voltage of microgrid system after compensation where Figure 19 (b) shows the compensation voltage injected by the UPQC. The load voltage harmonics analysis is carried out by using FFT analyzer of both the system as shown in Figure 20.

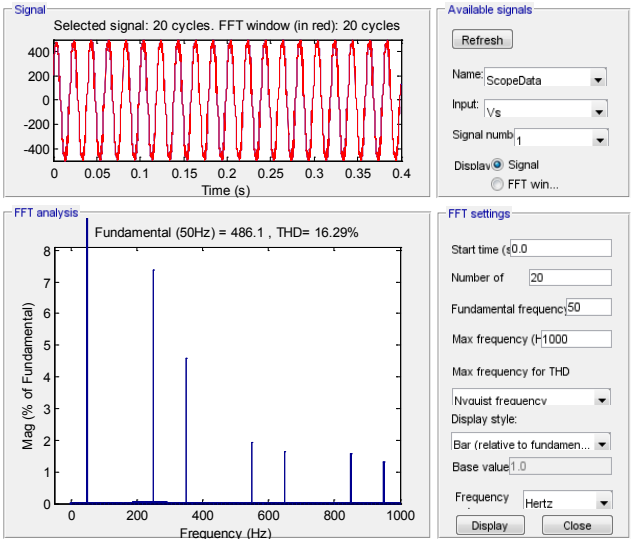


Figure 19. THD Analysis without UPQC

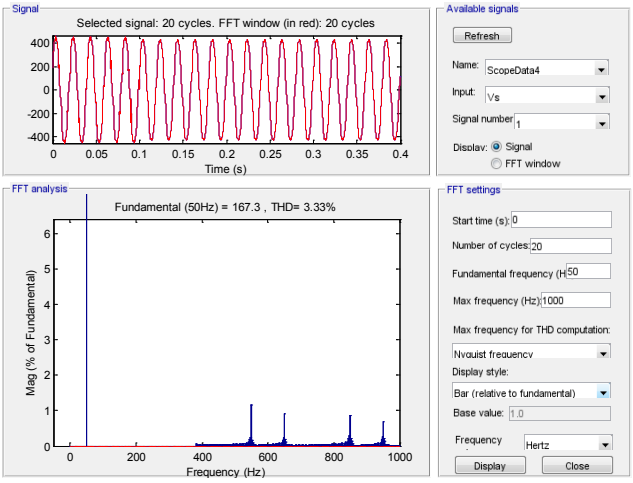


Figure 20. THD Analysis with UPQC.

5.1 Parameters Required for Design of PV System

Different Parameters	Ratings
Input Voltage	380 V at 50 Hz
Source Inductance	0.2 mH
Transformer turn ratio	1:2
Load Capacitance (C_{load})	1150 µF
load Inductance (L_{load})	2 mH
Resistance (R_{load})	5 ohm
DC link capacitor	1100 µF
filter inductor (L_r)	1.5 mH
filter capacitor (C_r)	20 µF

6. Conclusion

The modified *Synchronous Reference Frame* (SRF) method has an advantage that it does not required any Phased Locked Loop (PLL) circuit for vector orientation. The performance of modified synchronous reference method is improved without using PLL circuit and it maintains the voltage constant across the DC link. The simulation result shows voltage compensation both in source and load side. From the FFT analysis it is clear that microgrid without UPQC has harmonies of 16.29% and microgrid with UPQC it reduces to 3.33% as recommended in IEEE standard.

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