

Power Quality Conditioning of PV-Wind Microgrid to Provide Harmonic Reactive Power Compensation using Series APF

M. T. L. Gayatri and Alivelu M. Parimi

Department of Electrical Engineering, BITS Pilani-Hyderabad Campus, BITS Pilani Hyderabad Campus, Secunderabad - 500078, Telangana, India; gayathri2682@yahoo.co.in, alivelu@hyderabad.bits-pilani.ac.in

Abstract

Objectives: In this analysis, PV-Wind Microgrid with real time environmental conditions is compensated for harmonics and reactive power. **Methods/Analysis:** Microgrids suffer from many power quality problems which require harmonic and reactive power compensation being connected with different sources and loads. In this regard, initially a microgrid has been developed using the data from the weather monitoring system in BITS Pilani, Hyderabad Campus. Later compensation requirement has been identified and Series APF with its unique control is applied to provide power quality enhancement. **Findings:** The microgrid suitable for all practical conditions is developed to give an equivalent output of conventional 3 phase distribution system and the variations in the power flows causing power quality issues are observed when connected to dynamically varying reactive loads. By using Series APF in microgrid, these issues like voltage swells and sags are mitigated and thus the reactive power compensation is provided. The % THD of voltage harmonics in the microgrid is effectively improved using the novel control technique that has been implemented. **Novelty/Improvement:** Power quality improvement in microgrids using active power filter topology specifically in islanded mode, Identity Vector Template Generation Approach specifically towards harmonic compensation.

Keywords: Distributed Generation, Harmonic Compensation, Microgrid, Reactive Power Compensation, Series APF

1. Introduction

Distributed generation based microgrid (MG) is a tiny power system designed for a low voltage distribution system. The power generation is mainly based on renewable energy resources. The two operating modes of the MG are grid connected (connected to the conventional grid thereby allowing power exchange) and individual/islanded mode. The major elements of MG have distributed generation units like PV and wind generators, storage devices, different loads, controllers with power electronic converters etc. The interconnection of the MG to the conventional grid is normally achieved using power converters which create a plethora of power quality problems such as consumption of VAR, introducing current and voltage harmonics etc. The presence of these issues in voltage deteriorates the performance of the power distribution systems despite offering vast benefits

like optimal operation and flexible control¹. Load reactive power, impulse transients, interruptions, sag and swell in voltage altogether constitute various power quality problems. These problems are to be mitigated by providing harmonic, reactive power compensation and thus load balancing². Otherwise, they cause disturbance to other consumers and interference in nearby communication networks. Usage of capacitor banks, application of TSC and TCR devices from classical technology mitigates some of these problems. Conventional passive LC filters can be used to mitigate harmonics and reduce the number of capacitor banks and improves power factor. However, the main drawbacks like bulkiness, resonance, and fixation in the compensation further lead to the development of active power conditioning/filtering technology. Power conditioning with the help of active power filters (APFs) can easily handle the major power quality issues. Recent advancements suggest the approach of the APF devices

* Author for correspondence

towards the power quality enhancement especially in distribution systems with unbalanced loads. The power management analysis of PV based microgrid in both grid connected and islanded mode is discussed in³ for various power quality issues and different loading conditions. The application of DVR for mitigation of voltage sag/swell and other power quality problems is discussed in⁴ for the wind generating islanded system in which PV generator is acting as the DC source for the inverter. Multi-level inverter topology based APF for the mitigation of harmonics is presented in⁵. Reactive power compensation to achieve power factor improvement and good voltage regulation in PV based renewable energy system is presented in⁶. The control theory in this case is based on the implementation of SRF theory. With this motivation, an MG constituted with different renewable sources is modelled and simulated with different power quality problems. In the existing literature, the application of APF in MG is not properly presented. In this regard, the Series APF is further incorporated into MG to provide compensation. The following sections describe the modelling of MG, Series APF with its unique control, incorporation of Series APF into MG followed by the results concluding with the effective performance of the device in mitigating the major power quality issues.

2. Structure of the Microgrid

A system containing a microgrid with two DG sources

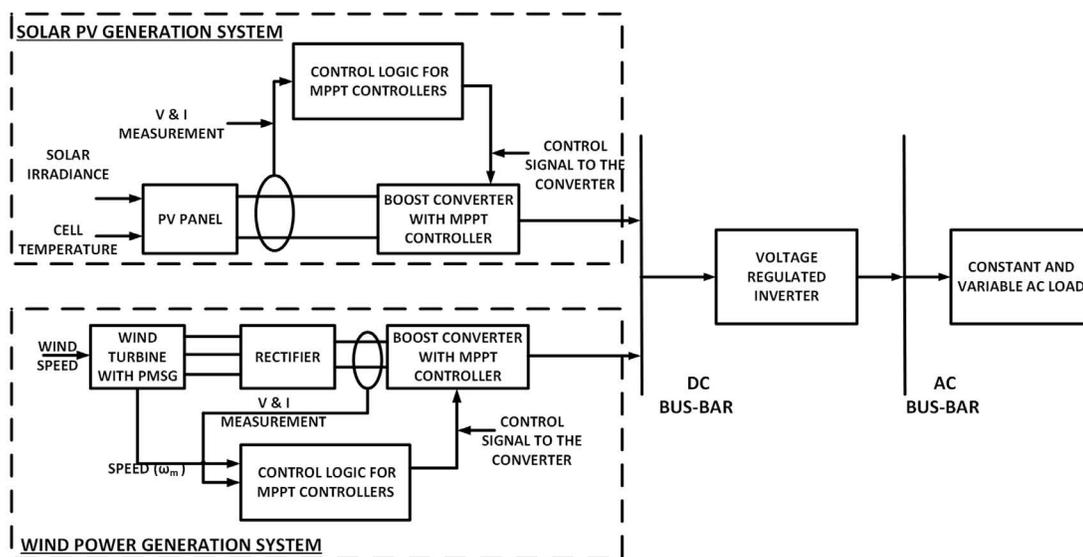


Figure 1. Structure of microgrid.

connected to a common AC bus is shown in the Figure 1. An inverter converts the DC from the combined WECS and solar PV system to AC of a fixed frequency & fixed voltage value. At the terminals of the inverter, a load system, a compensating device and a common AC interfacing system are connected. The parameters considered are same as in⁷.

2.1 Modeling of PV Modules in Microgrid

A PV cell based on the two-diode model is considered in the construction of MG. A mathematically modeled PV cell with a two-diode topology is observed with an improved performance when compared with the other various prototypes of PV cell which are based on single-diode model and also for lower illumination levels⁷. The PV cell with two diode equivalent model voltage and current relation is given in (1).

$$I = I_{ph} - I_{S1} \left[e^{\frac{V + R_s * I}{N_1 * V_t}} - 1 \right] - I_{S2} \left[e^{\frac{V + R_s * I}{N_2 * V_t}} - 1 \right] - \frac{V + R_s * I}{R_p} \quad (1)$$

The behavior of Current (I) - Voltage (V) and Power (P) - Voltage (V) of the two-diode model of PV cell when simulated in MATLAB, Simulink environment are shown in Figure 2. The electrical parameters obtained at standard test condition (STC) from simulation of the two diode model of PV panel are compared with the electrical parameters of the manufacturer datasheet⁷. The power

rating of modeled PV generator is 3 KW with 14 numbers of panels each has a power rating of 245W maximum. Perturb and Observe (P and O) algorithm is used to control the duty cycle of the boost converter.

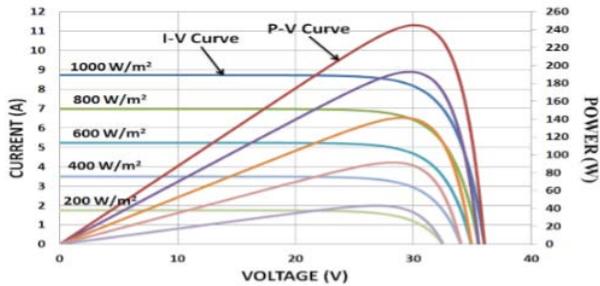


Figure 2. Structure of Microgrid.

2.2 Modeling of Wind Generator in Microgrid

A wind generator with Permanent Magnet Synchronous Generator (PMSG) is considered as the second DER in the construction of MG. The wind turbine output power⁸ is given by (2).

$$P_0 = \frac{1}{2} \rho A V_{wind}^3 C_p(\lambda, \theta) \tag{2}$$

The duty cycle of the boost converter is controlled by an MPPT algorithm for the WECS namely Hill Climb Search (HCS). An MG containing PV-wind MG generating system is implemented in simulink/MATLAB environment by appropriately modeling the DG sources, MPPT controllers, Boost converters and the DC bus.

The developed system along with its controllers has been investigated for the real-time data measured at Birla Institute of Technology and Science, Hyderabad campus. The real-time data of wind speed and solar insolation levels at this location are analyzed. The variations in the output voltage and active and reactive power flows in each DG with the continuous varying behaviour of these parameters is considered. The output voltage and P responses in case of PV generating system due to the variation in solar irradiation within a range of 600-1000W/m² for a duration of 1 sec is analyzed. Similarly, the output voltage and P, Q responses in case of WECS due to the change in wind speed within a range of 8-12 m/s for a duration of 1 sec is considered. The variety in the nature of loads connected and their frequent variations

i.e, harmonic and reactive, compensation requirement in MG is identified and necessitates a compensating device as shown in Figure 1. Hence a compensating device, series APF is modeled and implemented to provide power quality enhancement in MG.

3. Series Active Power Filter in MG

The power quality disturbances especially voltage related issues in MG are mitigated by the series APF which can also be called as series custom power device⁹. The controller for the series APF initially computes the difference between the desired voltage profile and the actual voltage; from this, it deduces the actual voltage to be injected by the series APF. The gate pulses for the VSI functioning as series APF are generated by one of the PWM techniques. The voltage thus generated by the series APF is added to the source voltage by the transformer windings which are connected in series with the source. A novel control methodology for series APF is proposed and designated as Identity Vector Template Generation (IVTG) technique which is discussed with the help of Figure 3.

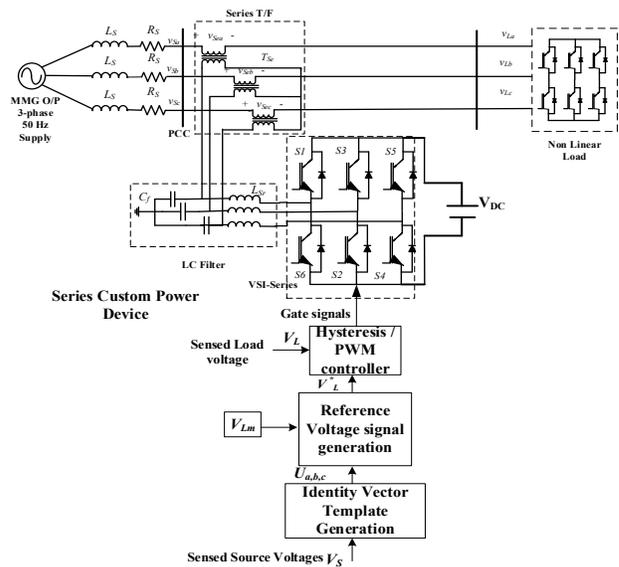


Figure 3. MG series APF schematic diagram.

The source voltage or MG reference voltage for phase ‘a’, V_s can be expressed as

$$V_{Sa}(\omega t) = V_{Sa,1} + V_{Sa,2} + V_{Sa,0} + V_{Sa,h} \tag{3}$$

where $V_{Sa,1}, V_{Sa,2}, V_{Sa,0}, V_{Sa,h}$ are fundamental positive, negative, zero sequence and harmonic components of phase 'a' voltage. The harmonic component of phase a can be expressed as

$$V_{Sa,h} = \sum_{n=2}^{\infty} V_{Sa,n} \sin(n\omega t + \theta_{na}) \tag{4}$$

Similarly, for other two phases

$$V_{Sb}(\omega t) = V_{Sb,1} + V_{Sb,2} + V_{Sb,0} + V_{Sb,h} \tag{5}$$

$$V_{Sc}(\omega t) = V_{Sc,1} + V_{Sc,2} + V_{Sc,0} + V_{Sc,h} \tag{6}$$

In the MG, if the load voltage is desired to be ideal with perfect balance condition and pure sinusoidal in nature (i.e. harmonic free), only the presence of fundamental positive sequence components is required and the other components should be avoided. To achieve this, initially, a phase locked loop (PLL) is used to give reference to fundamental components from the actual voltages i.e. the source/load (in terms of which the compensation is required) are sensed and divided by a constant equal to the supply/load voltage peak amplitude considered. Thus, identity templates for the considered voltages are generated. The generated signals are given to a PLL. The PLL produces the output as unit magnitude sine and cosine signals with a reference frequency i.e. 50 Hz. The sine signal represents the desired sinusoidal identity voltage signal of 'a' phase and the other two with +/- 120° phase delay. The identity vector templates for three-phase system are given by,

$$U_a = \sin(\omega t) \tag{7}$$

$$U_b = \sin(\omega t - 120^\circ) \tag{8}$$

$$U_c = \sin(\omega t + 120^\circ) \tag{9}$$

Let the load voltage magnitude, for a particular condition, is an identified and desired quantity. Let V_{LM} represents the maximum value of the load voltage. Now, the above set of equations are multiplied with the constant term V_{LM} with generated identity vector templates to

obtain the required load voltage, which is load bus anticipated voltage. These preferred load voltages can be represented as

$$V_{La}^*(\omega t) = V_{Lm} \cdot U_a = V_{Lm} \sin(\omega t) \tag{10}$$

$$V_{Lb}^*(\omega t) = V_{Lm} \cdot U_b = V_{Lm} \sin(\omega t - 120^\circ) \tag{11}$$

$$V_{Lc}^*(\omega t) = V_{Lm} \cdot U_c = V_{Lm} \sin(\omega t + 120^\circ) \tag{12}$$

The schematic diagram shown in Figure 4 represents the Series APF incorporating the above technique in MG to get the desired voltage profile. If the Series APF is effectively controlled to sustain the desired load voltages at the load terminal then the aforementioned power quality issues like voltage harmonics, voltage sag, and swells, voltage unbalances, etc., will get compensated easily.

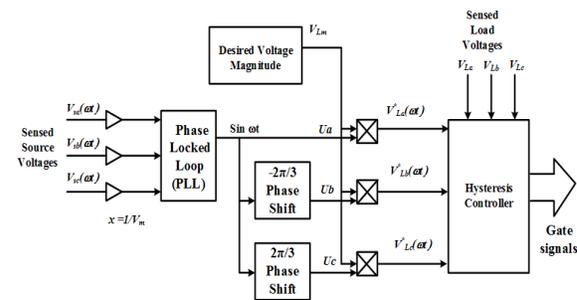


Figure 4. Series APF control.

In this situation, the comparison between actual load voltages and the anticipated load voltages using (10)-(12) to carry out the PWM operation is made and thus the corresponding gate signals are generated from the inverter that generates the required voltage to be injected.

4. Results and Discussion

A microgrid model shown in Figure 1 is developed initially with 2 DERS, a PV generator, and a wind generator. The MG is modeled and simulated based on equation-based modeling described in section 2 and delivers an output voltage of 415V RMS as shown in Figure 5(a), at common AC bus in MATLAB Simulink.

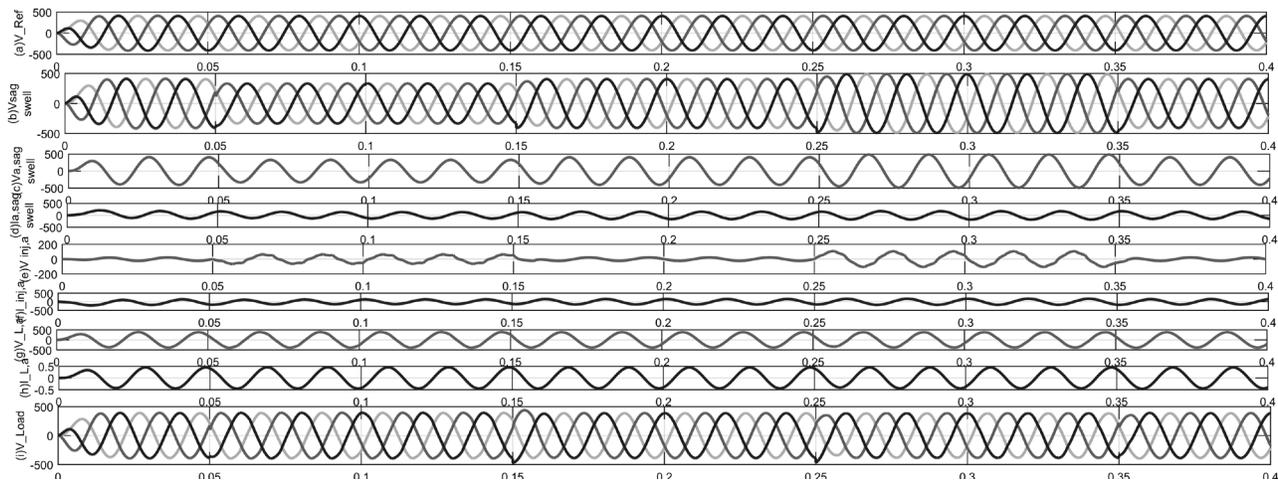


Figure 5. Mitigation of simultaneous sag/swell in supply voltage in MG.

The output voltage is the reference source voltage of the developed MG. From this reference, the distribution system is connected. To this modeled MG, reactive and harmonic loads are connected. The different operating conditions considered are sag, swell, simultaneous sag and swell in supply and load voltages, switching of loads creating voltage harmonics. The above-specified power quality problems are simulated and developed in the constructed MG. Later the modeled series APF with its control is incorporated. A supply disturbance to reduce and increase its peak value by 87.5V to create both sag and swell within short time is given and observed for the duration from 0.0 to 0.4 sec, (sag from 0.05 to 0.15 sec, swell from 0.25 to 0.35sec) that further disturbs the load voltage in the similar way, when there is no compensation provided into the system as shown in Figure 5(b). The reference voltage is indicated in Figure 5(a) for comparison. For clear analysis, only the phase ‘a’ components are considered. Figure 5(c),(d), represents sag voltage and currents in phase ‘a’, Figure 5(e),(f) represents injected voltage and current of phase ‘a’, Figure 5(g),(h) represents the mitigated load voltage and current for supply sag and swell. Figure 5(i) shows the recovered 3-phase output of MG load voltage using series APF against the supply sag and swell. It is found that the series APF is able to compensate for this abnormal condition very effectively without any reluctance. The active power and reactive power flows and power factor improvement by using series APF is shown in Figures 6, 7, 8 respectively.

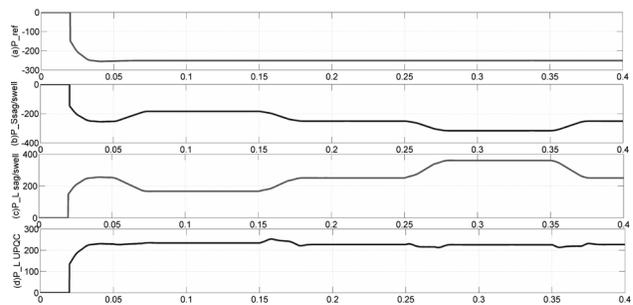


Figure 6. Active Power flow in MG.

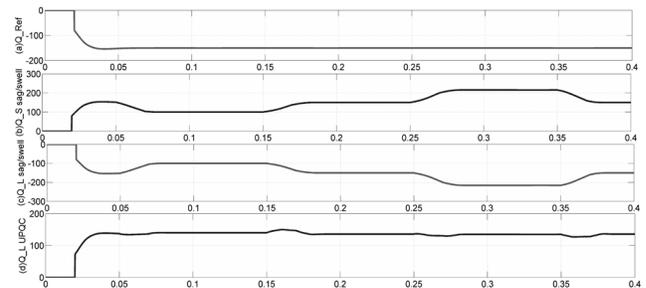


Figure 7. Reactive Power flow in MG.

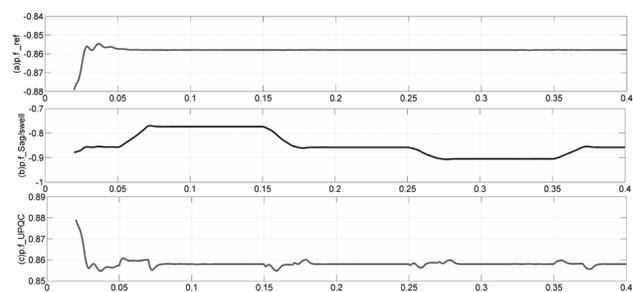


Figure 8. p.f variation in MG.

Similarly, A nonlinear load for voltage harmonic analysis is considered with 24.46 % THD and connected to MG on the distribution side. The control logic for improving THD is designed based on IVTG approach, modeled and developed in MATLAB/Simulink. However when series APF is connected, THD of load voltage is improved to 0.94 % as shown in Figure 9. Similarly, power quality enhancement and thus reactive power compensation with dynamically varying load is also presneted in Figure 10.

The simulation results prove that sag, swell in load voltage caused by reactive loads are compensated well with series APF as shown in Figure 10 and is able to maintain its load voltage near to reference voltage in MG.

5. Conclusions

Power distribution system is turning out to be very defenseless against various power quality issues as the microscale renewable energy penetration is

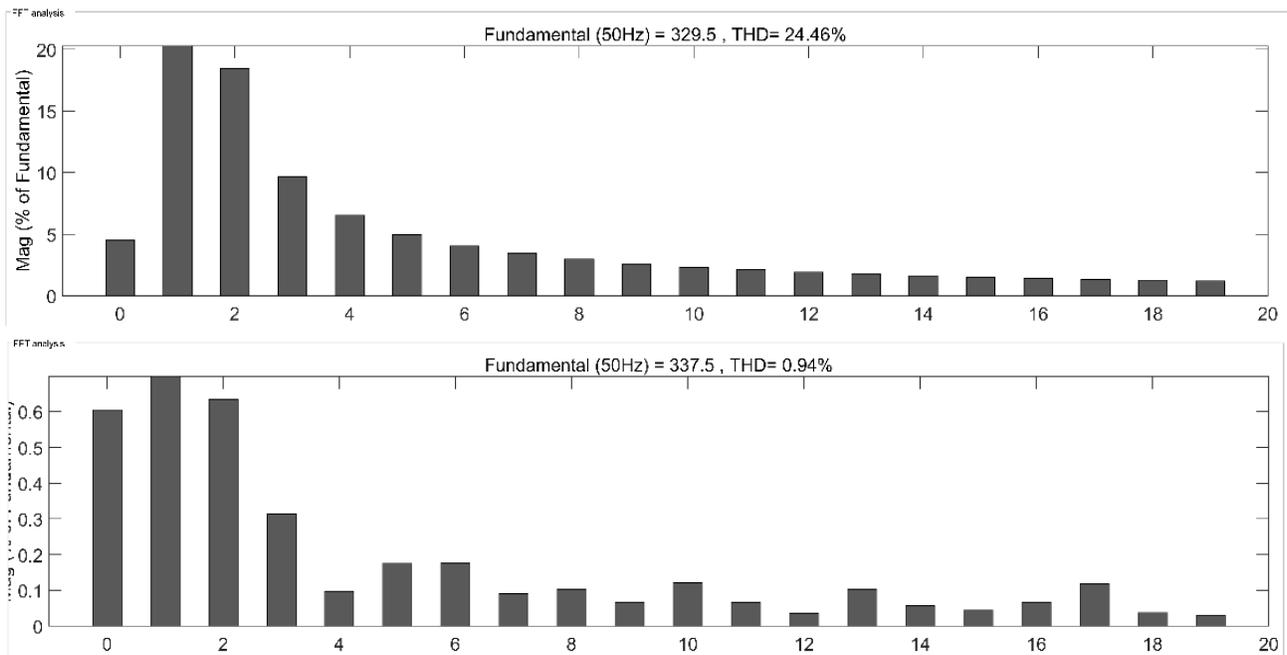


Figure 9. Load voltage with and without harmonic compensation.

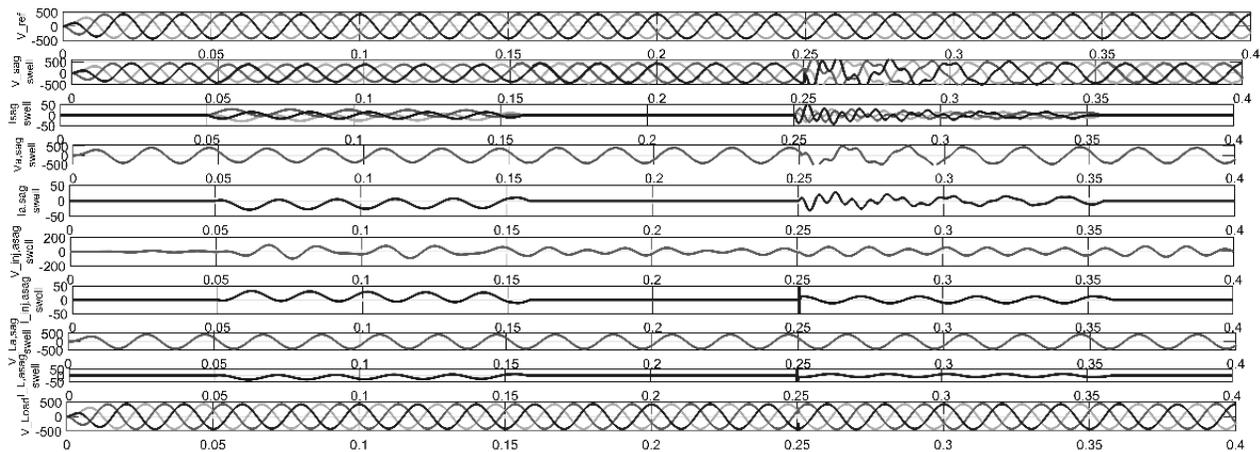


Figure 10. Load voltage compensation for reactive loads.

emerging vitally towards consumer end. However, this reconciliation of DERs in the power system is further forcing new difficulties like RPC to the industry. In this regard, harmonic and reactive compensation in MG for different power quality issues is studied and presented in this paper. Active power filters can easily mitigate these concerned issues. Initially, a microgrid has been modeled and developed consisting of PV and Wind generators. The series active power filter was designed with proper control and incorporated in MG and simulated. A controller using PI, PLL techniques that give a scaled error between MG reference and actual load voltages is applied for providing RPC using series APF in MG. In addition, a unique technique named IVTG approach has been applied to provide harmonic compensation in MG. The simulation shows that the Series APF effectively provides compensation thus the performance is satisfactory with quick response and excellent voltage regulation. The device is also able to compensate the harmonics and provides reactive power compensation with different load conditions effectively.

6. References

1. Hingorani NG. Introducing custom power. IEEE.1995; 32(6):41-8.
2. Hingorani NG. High power electronics and flexible AC transmission system. IEEE Power Engineering Review. 1988 July; 8(7):3-4.
3. Mythri Kodali, Manasa, Srikanth KS. Power management strategy for hybrid microgrid system under islanded condition using adaptive droop control. Indian Journal of Science and Technology. 2016 Jul.
4. Ravi, Mohanasundaram. Comparison of PV supported DVR and DSTATCOM with multiple feeders in stand alone WECS by mitigating power quality problems. Indian Journal of Science and Technology. 2015 Jul.
5. Madhu Ginga, Mittal Pardeep. Analytical review on MLI based active power filter to reduce harmonics for improvement in power quality. Indian Journal of Science and Technology. 2016 Aug.
6. Preethis Pauline Mary, Siva Chindambaranathan. Enhancement of active power filter operational performance using SRF theory for renewable source. Indian Journal of Science and Technology. 2015 Sep.
7. Pavan Kumar AV, Parimi AM and Uma Rao K. Performance analysis of a two-diode model of pv cell for pv based generation in matlab. ICACCCT, India. 2014; 68–72.
8. Kumar AVP, Parimi AM and Rao KU. Implementation of mppt control using fuzzy logic in solar-wind hybrid power system. SPICES, India. 2015; p. 1–5.
9. Gayatri MTL and Parimi AM. Mitigation of supply & load side disturbances in an AC microgrid using UPQC. ICPS, India. 2016; p. 1-6.