MICROGRID VOLTAGE AND CURRENT HARMONICS COMPENSATION USING COORDINATED CONTROL OF DUAL-INTERFACING-CONVERTERS

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Abstract: The main aim of this paper presents function of compensation of micro grid voltage and current harmonics by employing coordinated control of dual interfacing converters. The developing installation of distributed generation (DG) units in low voltage distribution systems has popularized the concept of nonlinear load harmonic current compensation using multi-functional DG interfacing converters. A new simultaneous supply voltage and grid current harmonic compensation strategy is proposed using coordinated control of two shunt interfacing converters. By using this proposed controller in distribution systems, there will be sudden increase or decreases in the load similar to nonlinear load. The load draws non-sinusoidal currents from the AC mains and these causes the load harmonics, reactive power, and excessive neutral currents that pollute power systems. Most of the power quality issues are created by nonlinear characteristics and fast switching of power electronic devices. A single distribution generation interfacing converters are generally used for harmonic compensation in DG but this may cause amplification of supply voltage harmonics when the system is connected to a sensitive load. In this paper we proposed a compensation strategy in which to shunt interfacing converters are used, first one for voltage harmonic suppression and the second one for current harmonic suppression that resulted due to the interaction between the first interfacing converter and the local nonlinear load. To realize a simple control of parallel converters, microgrid voltage and current harmonics compensation using coordinated control of dual-interfacing-converters is assessed using MATLAB/SIMULINK (MLS) with the Sim Power System block set and the results of simulations are presented to evaluate the behaviour and feasibility of the proposed topology. Simulated and experimental outcomes are captured to validate the performance of the proposed topology and the control strategy.

Index Terms—Parallel Converters; Active Power Filter; Dynamic Voltage Restorer; LCL filter; Resonance; Power Quality; Harmonic Detection; Phase-Locked Loop.

I.INTRODUCTION

The usage of renewable energy resources has popularized due to the increased advantages. The advantages of renewable energy include the low or nil cost of fuel, pollution free, improved efficiency. The great potential of such resources for green energy production has led the technological society to the implementation of a new type of distribution system, the microgrid. there is one major challenge in implementation of distributed generation. For the interfacing of Renewable Energy Resources (RES) to the distributed system requires power electronics devices. Therefore, power electronics devices play a vital role in the integration of the Renewable Energy system to the Distributed System which has the advantages of fast voltage and frequency regulation. The major disadvantage of using power electronics devices is that the switching operation of the semiconductors employed in the inverters causes voltage and current harmonic distortion to the grid. This distortion is increased by the nonlinear loads such as transformers, computers, saturated coils and switching operation of the power electronic devices. It is necessary to overcome these issues such as low power efficiency and low power factor. The commonly used harmonic compensation technique includes the passive filters and active power conditioning equipment. The shunt passive filters consist of tuned LC filters and high passive filters are used to suppress the harmonics. It has the disadvantages such as the possibility of resonance, and requirement of tuning, and it can compensate only particular order harmonics for which it is tuned. In order to overcome this, Active power filters are generally used to compensate harmonics. There are various topologies of active power filters has been developed. The active power conditioning equipment such as Active Power Filter, Unified Power Quality Conditioner, Dynamic Voltage Regulators are generally used. When a single DG shunt interfacing converter is used for the harmonic compensation there is possibility of amplification of supply voltage harmonics.

Previous research mainly focused on the control of a single DG shunt interfacing converter as an APF, as their power electronics circuits have similar topology. To realize an enhanced active filtering objective, the conventional current control methods for grid tied DG interfacing converter shall be modified.

In recent literature, the hybrid voltage and current control is also developed to realize a fundamental voltage control for DG power regulation and a harmonic current control for local load harmonic compensation. Nevertheless, it is important to emphasise that even when the local load harmonic current is properly compensated using various controller's high quality supply voltage to local load cannot be guaranteed at the same time. This problem is particularly serious when the DG interfacing converter is interconnected to a weak micro grid with nontrivial upstream grid voltage distortions. To overcome this limitation, the Dynamics Voltage restorer (DVR) with series harmonic voltage compensation capability can be installed in the power distribution system. Unfortunately, the functionality of a DVR can hardly be implemented in a shunt DG interfacing converter. Using an additional series power conditioning equipment to ensure very low steady-state harmonic supply voltage to local loads is definitely feasible. However, it is associated with more expenses which might not be accepted for cost-effective power distribution systems .

Therefore, we need simultaneous mitigation of the grid current and the supply voltage harmonics. So in this paper we proposed technique in which two shunt interfacing converters are used where the local nonlinear load is directly installed to the shunt filter capacitor of the first converter. The first converter is used for voltage harmonic mitigation. There arises current harmonic due to the interaction between the first interfacing converter and the local nonlinear load. The second converter is employed for the current harmonic compensation that resulted due to the interaction of first interfacing converter with the local nonlinear load. The current reference is to be generated for closed loop control. The hybrid voltage and current control is used to realize a fundamental voltage control for DG power regulation and a harmonic current control for local load harmonic compensation. Note that this paper focuses on the compensation of supply voltage and grid current harmonics. When there are significant disturbances in the main grids, such as sags/swells and interruptions, the shunt Converter is less effective to compensate these grid issues. The hybrid controller allows an interfacing converter to compensate harmonics in both grid-tied and islanding micro grids [6].

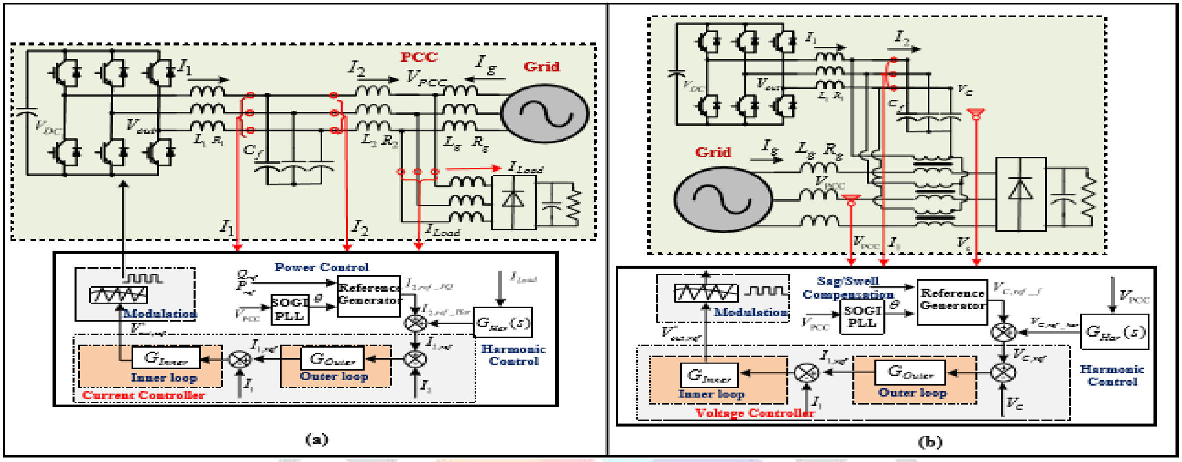

figure 1. microgrid voltage and current harmonics compensation using coordinated control of dual-interfacing-converters.

II. ANALYZATION OF DVR AND APF

This section briefly reviews the management of shunt APFs for network current harmonic mitigation and arrangement DVRs for provide voltage harmonic reduction. The distinction and also the introducing concurrent-converter is employed to adjusted hybrid current and voltage controller as appeared within the following section, the well understood double-loop current management and voltage management square measure connected to APFs and DVRs, individually.

A. Shunt Interfacing Converters for Grid Current Harmonic Mitigation

A shunt active power filter is a controlled current source which injects a compensating current depending upon the load current. The active power filters are used to filter out both higher and lower order harmonics in the power system. It injects the harmonic compensating current of same magnitude as the load current harmonics, but shifted in phase by 180° and thus compensates load current harmonics.

Fig.1(a) demonstrates the structure associated system of an interfacing convertor for compensating generation harmonic current from an area of local nonlinear load. To start out with, the local load is related to the output of the interfacing convertor, and afterwards, they are coupled to the main grid through the grid feeder.

The parameters of network feeder and interfacing converter LCL filter are recorded is

$z1(s) = sL1 + R1$, $z2(s) = sL2 + R2$, $z3(s) = 1/ (sc_f)$, and $zg(s) = sLg + Rg$,

where $L1$, $L2$ is the inductance and $R1$, $R2$ is the resistance of the filter arrangement chokes, Cf is that the capacitance of the parallel capacitor, and Lg is grid inductance and Rg is square measure grid resistance.

The current control scheme is shown in the lower part of Fig. 1(a). According to the traditional APF control theory, the local load current is measured and the harmonic components are detected as:

$I_{2ref-h} = H_{Har}(s). I\ Load$ (1)

Here $HHar$ (s) is transfer function of the harmonic component detector and $ILoad$ is the nearby local load current.

At the point when these two fundamental key and the harmonic components are resolved, the reference current is acquired as $I2ref= I2ref\_f + I2ref\_h$ and it is utilized as the contribution for a double-loop line current $I2$ control [27] as:

$I1, ref=H\ outer(S). (I2, ref-I2)$ (2)

$Vouter.^{*}\ ref= H\ 1inner(S).(I1,ref-I1)$ (3)

Where $HOuter$ (s) is the external controller loop and $HInner$ (s) is the internal control loop of controllers, respectively. The $I1$, ref is the reference and $I1$ is the instantaneous inverter output current, separately. $Vout$, ref *is the final voltage reference of the inverter.

B. **Series Interfacing Converters for Supply Voltage Harmonic Mitigation**

It is important to note that even when the harmonic current is compensated, there is supply voltage harmonics present in the system is not always purely sinusoidal. This also causes the steady-state harmonic distortions in the main grid voltage. Suppose the grid current Ig in fig. 1(a) is ripple-free, the harmonic voltage drops on the grid feeder Rg and Lg is zero. The harmonic voltage at PCC is same as the harmonics from the main grid in this case. A DVR is a series-connected solid-state device in fig. 1(b), that injects voltage into the system in order to regulate the load side voltage. It is in a distribution system between the supply and a critical load feeder at the point of common coupling (PCC). Its function is to rapidly boost up the load -side voltage in the event of voltage sag in order to avoid any power disruption to that load. Therefore, a series DVR can be connected in series to the power distribution network using a series-connected matching transformer. The secondary of the transformer is connected to a converter with output LC filter. The voltage at PCC is measured by the DVR controller and the harmonic PCC voltage components are separated from the fundamental component.

The Point of coupling voltage was calculated by Dynamic voltage regulator. The central and PCC voltage segments are isolated. At that time, the provision voltage harmonic components are repaid by fixing the harmonic voltage reference of the DVR as $Vref$_h =$VPCC$_h [35] and also the basic voltage reference $Vref\_f$ of the DVR is resolved by the sag and swell compensation necessity of the system [3].

At the purpose once the fundamental and harmonic half references square measure resolved, the DVR reference voltage is obtained as VC, ref= VC, ref_f + VC, ref_h. A short while later, a double-loop voltage management is connected to ensure a fast voltage following is

I1 , ref = H outer(S).(V c, ref - V c) (4)
V out., ref = H inner(S).(I1,ref - I1) (5)

where $HOuter(s)$ and $HInner(s)$ are the regulator of the outer and the inner control loops, respectively. VC, ref and VC are the reference and the instantaneous value of DVR voltage, respectively.

III.THE PROPOSED COORDINATED CONTROL METHOD

In the proposed, the supply voltage and the grid current harmonics are mitigated simultaneous by using the compensation methods. The compensation method using coordinate control of two parallel interfacing converters. The hardware and management outlines of the projected system area unit appeared in fig.2 and fig.3, accordingly. At the start a DG unit with two coincidental interface convertors having an identical DC rail is related to the PCC. Each interfacing convertor having an output LCL filter and also the local nonlinear load is place at the output electrical phenomenon filter of converter1. During present topology, the provision voltage to neighbourhood local load is upgraded to dominant within the harmonic a part of interfacing converter1.

A DG unit with two parallel interfacing converters sharing the same DC rail is connected to PCC. In this topology, the supply voltage to local nonlinear load is enhanced by controlling the harmonic component of interfacing converter1. Meanwhile, the grid current harmonic is mitigated via the power conditioning through interfacing converter2. The converters used here are two leg three phase converter. The capacitors used reduce the switching losses. The output of the converters will have filters. Ig represents the grid current at the Point of Common Coupling (PCC). The output current of the converter 1 and converter 2 is represented by I1,c1, I1, c2. The output current from the filter circuit is represented by I2, c1, I2, c2. The injected current by the converter is represented by Iinj. The harmonic component is compensated by the injected current. The amount of current that needed to be injected is computed by the control strategy. The gating circuit is controlled by the Pulse Width Modulation technique. The pulses are generated with the help of the PI controller. The PI controller generates gating signal such that the current injected is equal in magnitude to the harmonics present in the system but injected with phase opposition. Therefore, the injected voltage and current will cancel out the voltage and current harmonics. Thus reduces the current and voltage harmonics.

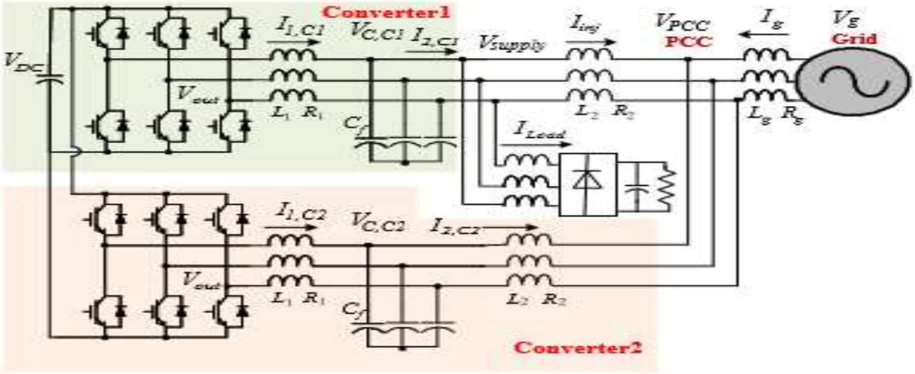

figure 2. diagram of the proposed topology

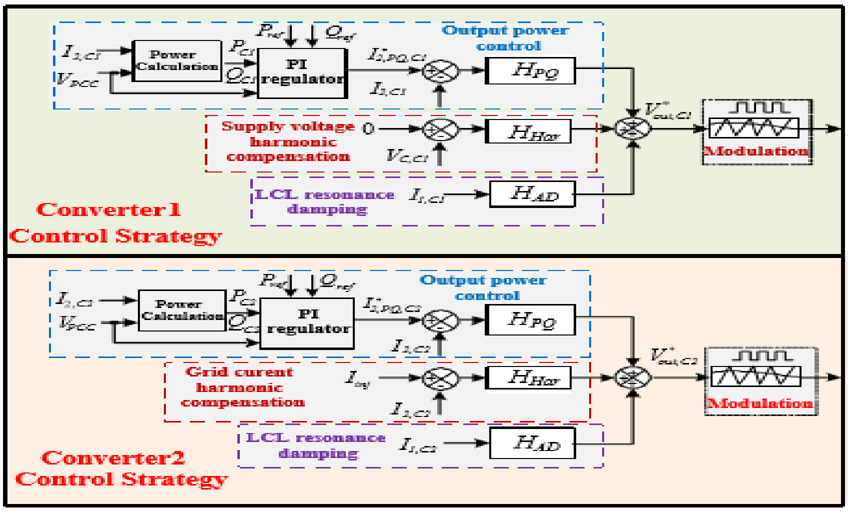

figure 3. diagram of the proposed interfacing converter control strategies.

a) Control Strategy for Converter1

To have simultaneous mitigation of the supply voltage and the grid current harmonics, a compensation method using coordinated control of two parallel interfacing converters is proposed in this section. The circuitry and control diagrams of the proposed system are shown in Fig.2 and Fig.3, respectively. First, a DG unit with two parallel interfacing converters sharing the same DC rail is connected to PCC. Each interfacing converter has an output LCL filter and the local nonlinear load is placed at the output filter capacitor of converter1. In this topology, the supply voltage to local nonlinear load is enhanced by controlling the harmonic component of interfacing converter1. Meanwhile, the grid current harmonic is mitigated via the power conditioning through interfacing converter2. Their detailed control strategies are discussed respectively, as shown below: To start with, the road current $I2$, c1 of convertor1 and $VPCC$ are appeared in fig.2 square measure calculate to the real and reactive output power of this converter.

$$\begin{cases} P_{C1} = \dfrac{3\tau}{2(s+\tau)}(V_{PCC,\alpha}\cdot I_{2\alpha,C1}+V_{PCC,\beta}\cdot I_{2\beta,C1}) \\ Q_{C1} = \dfrac{3\tau}{2(s+\tau)}(V_{PCC,\beta}\cdot I_{2\alpha,C1}-V_{PCC,\alpha}\cdot I_{2\beta,C1}) \end{cases} \qquad (6)$$

Here $PC1$ and $QC1$ be the output real and reactive convertor1 power, $VPCC, \alpha$ and $VPCC, \beta$ area unit the PCC voltage in the two-axis stationary reference frame and $I2\alpha$, $C1$ and $I2\beta$, $C1$ be the converter1 line current, and the time τ constant of low pass filters. The time steady of the LPF is for the foremost half controlled by 2 elements. Here start with, the real and reactive power swells brought on by line current harmonics must be properly filtered out. Secondly, the rapid dynamic power control shall be maintained. It is important to note that the power reference is usually determined according to the available power from the back stage of the DG unit. When there is energy storage system in the DG unit, the power reference can also be determined by the energy management system of a DG unit or a microgrid. Therefore, for the sake of simplicity, the harmonic compensation service is usually activated when there is sufficient power rating in the interfacing converters [13 and 14].

Traditionally, the hybrid regulator in [27] controls the DG fundamental voltage for power control and the harmonic current for load harmonic current mitigation. As this converter is responsible for compensating harmonic components of the supply voltage, the regulators in the hybrid voltage and current controller is modified with harmonic supply voltage control and fundamental line current control.

At the same time, it can be seen that the output of the second Voltage Harmonic Mitigation term only has very low fundamental components, as only resonant controllers at the selected harmonicfrequencies are adopted in the control term. Thus, the Power Control term and Voltage Harmonic Mitigation term are very well decoupled. Accordingly, an interfacing converter can dispatch power to the grid and compensate supply voltage harmonics at the same time. In addition, unlike the conventional DVR with PCC harmonic voltage extractions, the Voltage Harmonic Mitigation term can realize active supply voltage harmonics compensation without any harmonic extractions. In addition, it can be seen that a closed-loop power control is realized without using phase-locked-loops. Finally, it is necessary to emphasise that comparing to the traditional hybrid controller [27] that uses the droop control to realize relatively slow power control dynamics, the fundamental current control could effectively improve the power control dynamic response.

b) Control Strategy for Converter2

The control strategy of converter2 is similar to that of converter1, as also demonstrated in Fig. 3. However, both the fundamental and the harmonic converter currents are controlled.

In summary, the proposed topology and the modified hybrid controller can realize an enhanced quality of supply voltage to the local load and the grid current to the main grid at the same time. Through the coordinated control of two parallel converters, the aforementioned power quality improvement objective is realized in a computationally effective manner, without involving any PLLs and harmonic voltage/current extractions in the entire process. In addition, when the fundamental current regulation in the Power Control term in (13) and (9) is replaced by the well understood droop control for fundamental voltage regulation [27], the proposed method can be used in an islanded microgrid in a similar manner.

IV. EVALUATION RESULTS

Simulated and experimental results are obtained to further verify the performance of the proposed controller for coordinated operation of parallel converters.

SIMULATION RESULTS

The proposed method is simulated using MATLAB/SIMULINK(R2014a) software. The Sim Power Systems package is used for the simulation of the converters incorporating the proposed control algorithms. The output voltage waveform before harmonic compensation and after harmonic compensation using dual interfacing converter is obtained.

The scheme of the block diagram describing the Microgrid voltage and current harmonic compensation using coordinated control of dual interfacing converters is shown in figure 4.

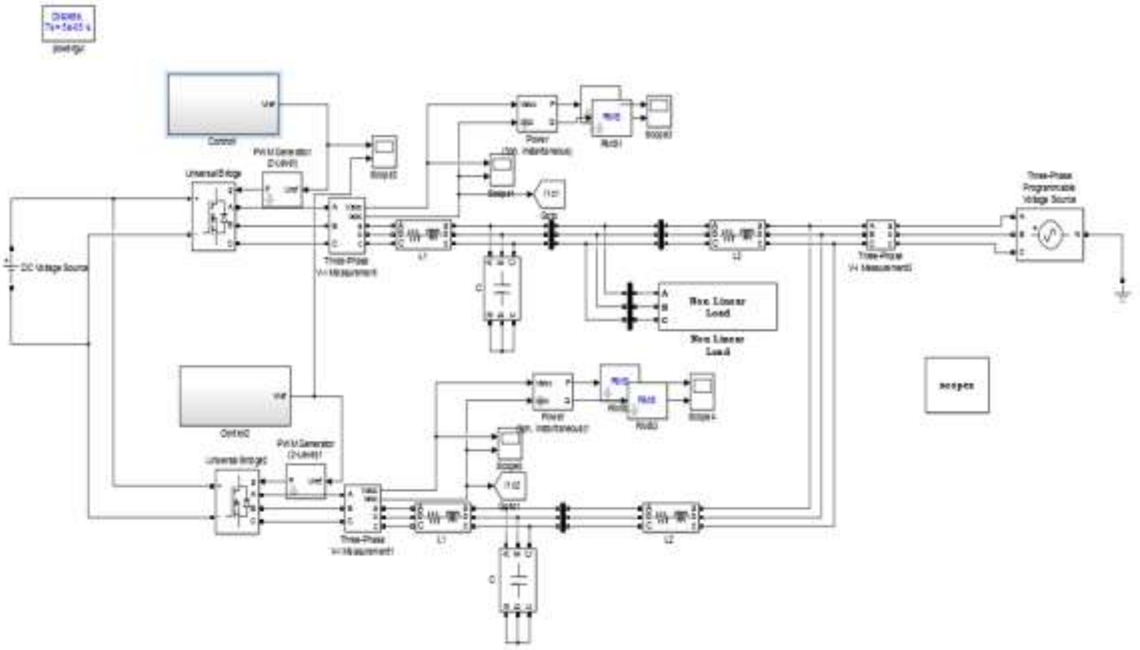

figure 4. matlab/simulink diagram of interfacing converter.

a. Harmonic Compensation Using PI Controller

The simultaneous supply voltage and grid current harmonics mitigation is tested by using a single DG unit with two parallel interfacing converters sharing the same DC rail. The circuitry and the control strategy of the system is the same as that in Fig. 2 and Fig. 3, in which the first converter is for supply harmonics voltage reduction and the second converter is employed for harmonic current compensation.

The performance of converter1 shown in fig 5 is applied to compensate the harmonics in the supply voltage, it can be seen that the voltage waveform in the top of the figure is almost ripple-free. However, the line current of this converter is shown below.

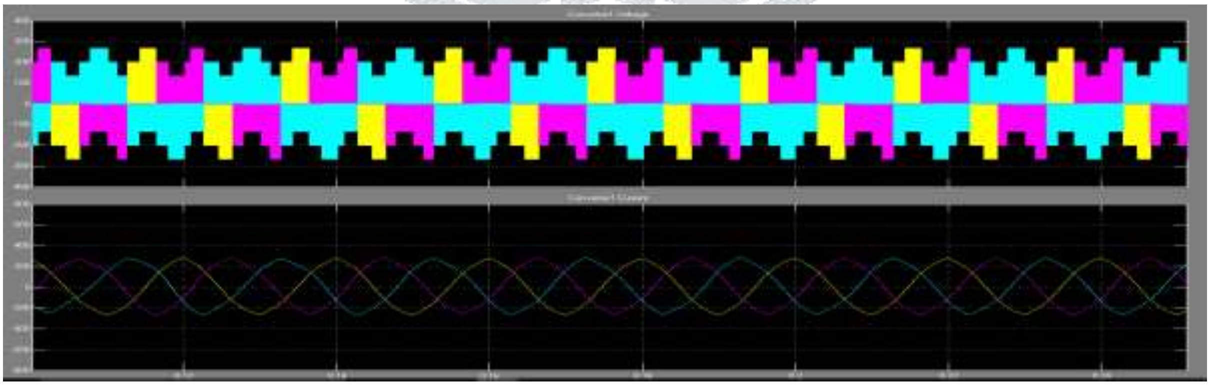

figure 5. simulation waveform for converter 1 with pi controller.

In addition, the performance of converter2 is shown in Fig.6. As the line current of converter1 produces a large amount of harmonic current, it must be properly compensated by converter2 by using the hybrid controller. The objective of this control strategy has been verified as the grid current is sinusoidal in the second channel of Fig.7. To have a clear understanding of the principle of the proposed controller for parallel converter coordinated control, the spectrum of grid current and supply voltage is shown in Fig.8. In this case, it can be noticed that both grid current and supply voltage quality are significantly improved.

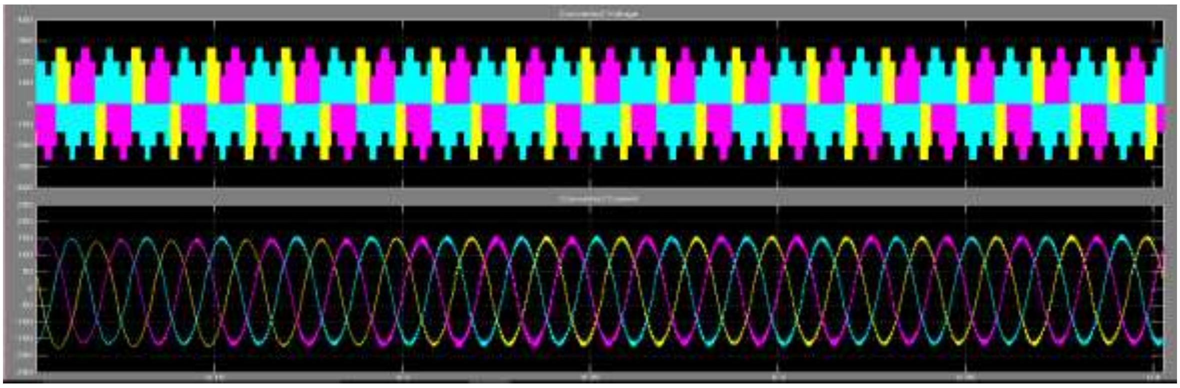

Figure 6. Simulation waveform for converter 2 with PI controller.

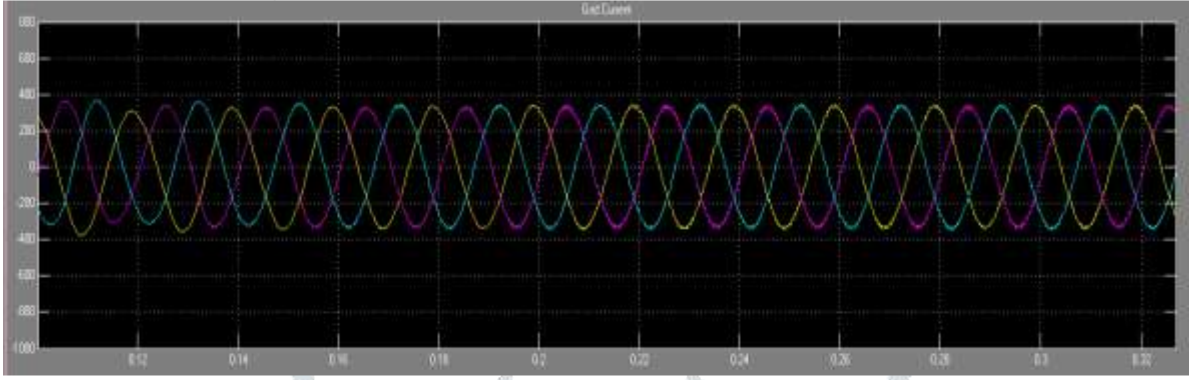

Figure 7. Simulation waveform for grid current.

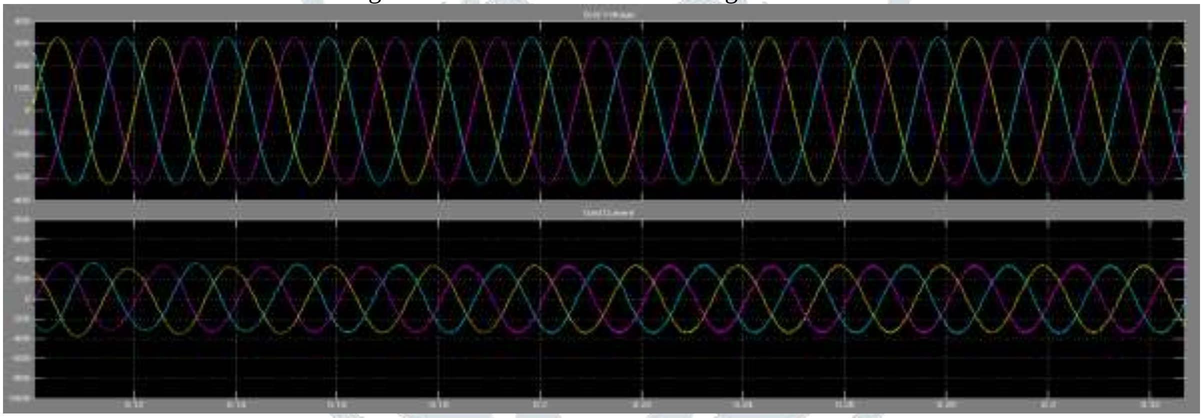

Figure. 8. Simulation waveform for the main grid voltage and the grid current when the proposed coordinated control is applied.

b. Real and reactive power of converter1 and converter2 with PI controller

Finally, the power control performance of the system is tested when the PQ reference has a step jump. It can be seen from Fig. 9 and Fig. 10. that both converters have a rapid response to PQ reference change. There is no obvious overshoot during this process and the steady-state power control error is zero.

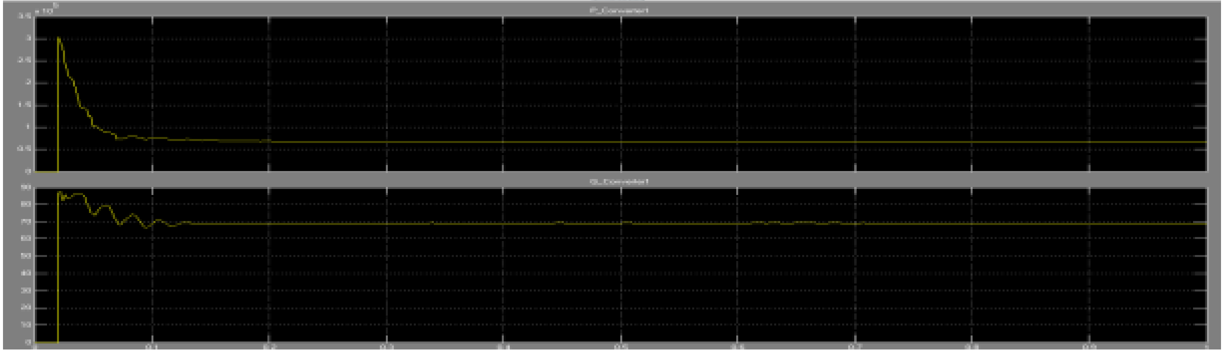

Figure 9. Active and reactive power of converter1 with PI controller.

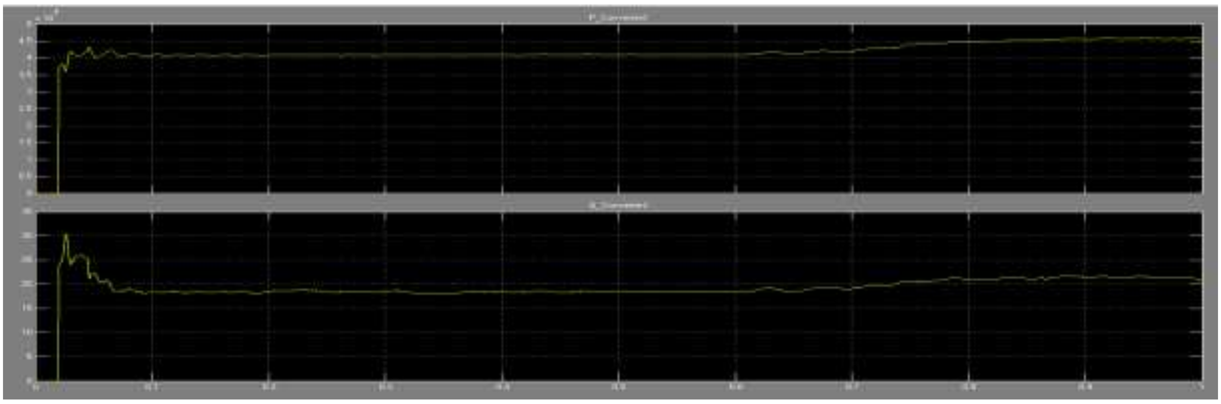

figure 10. active and reactive power of converter2 with pi controller.

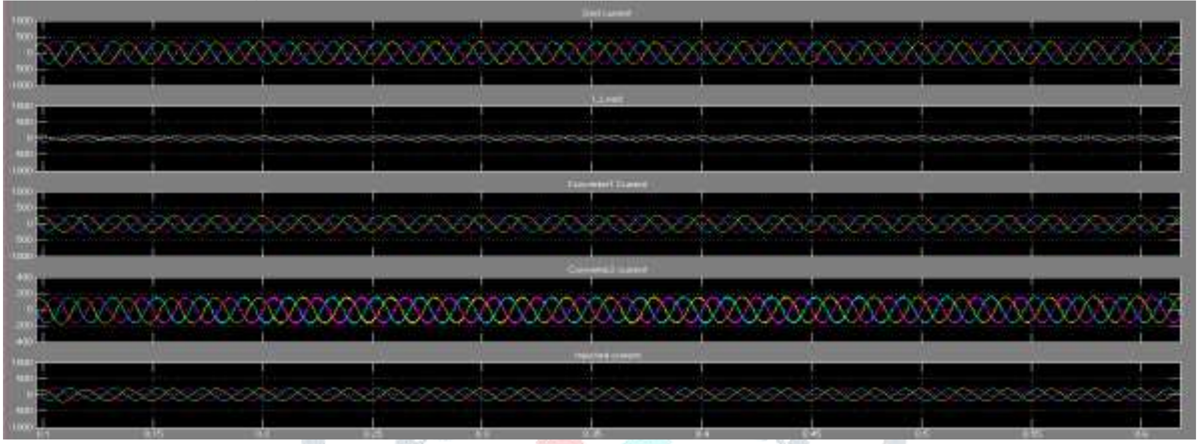

figure 11. simulation waveform for the output compensated converter (from upper to lower: gird current, i_ load, converter1 current, converter 2 current, injected current).

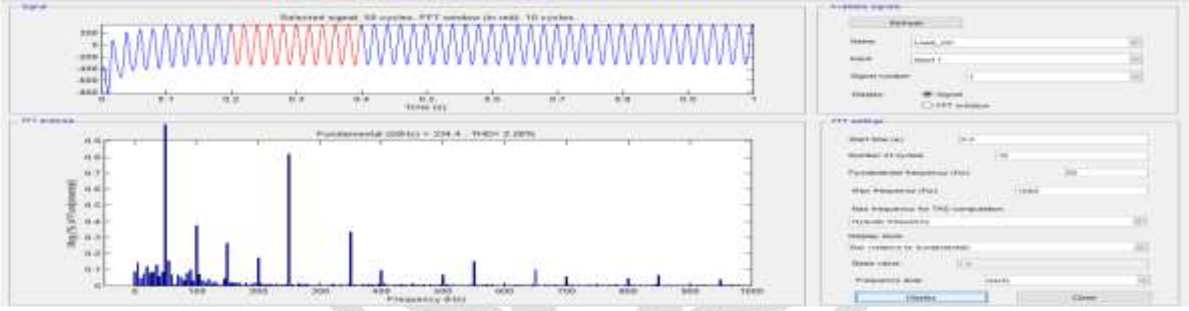

figure 12: grid current of fft analysis and thd using pi controller

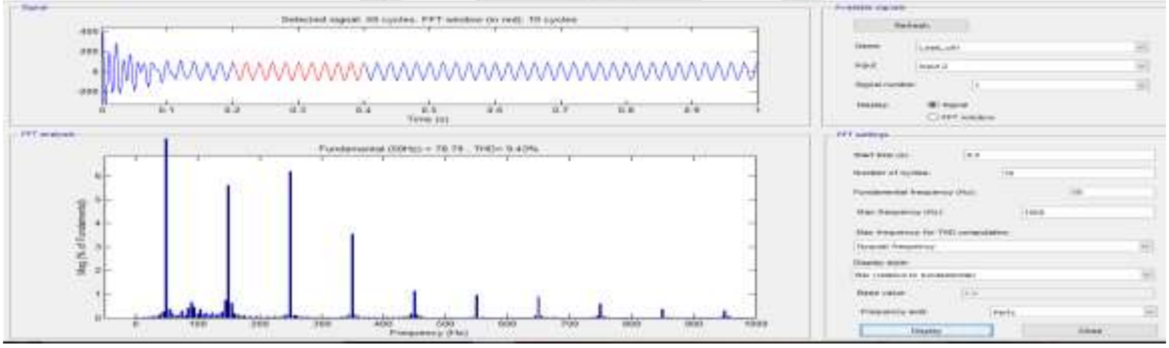

figure 13: load current (i_ load) of fft analysis and thd using pi controller.

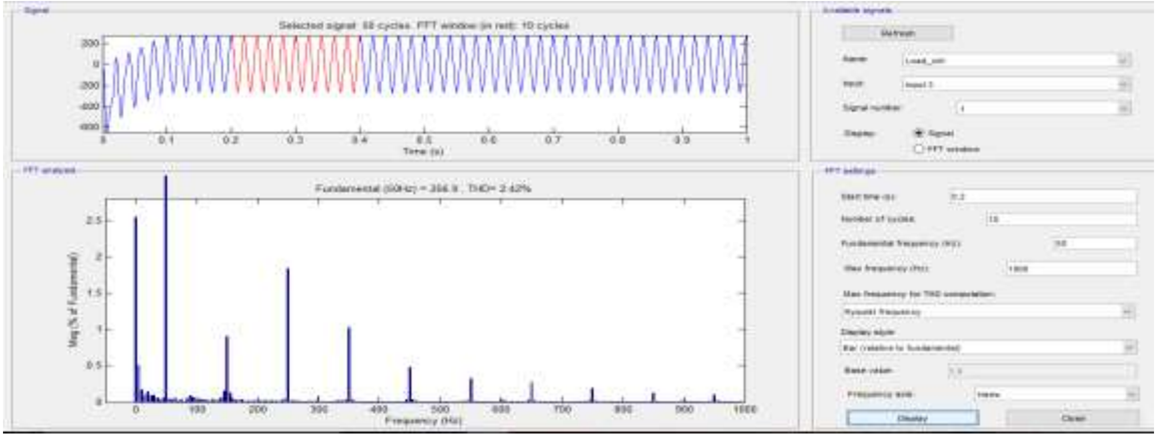

figure 14: converter1 current of fft analysis and thd using pi controller

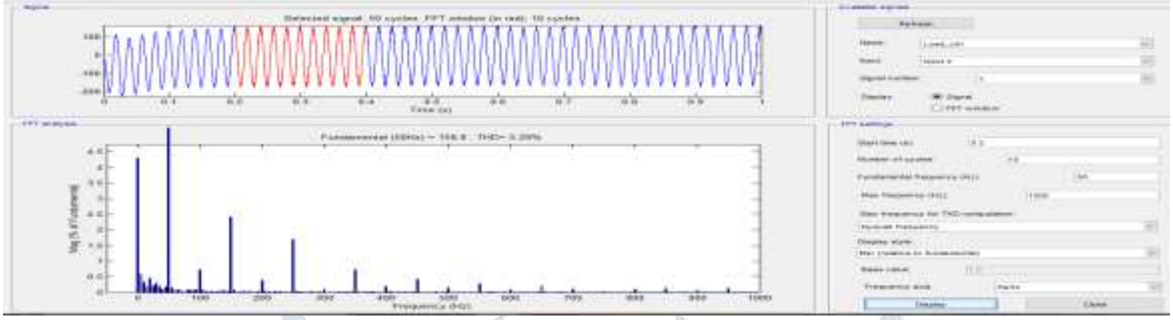

figure 15: converter2 current of fft analysis and thd using pi controller

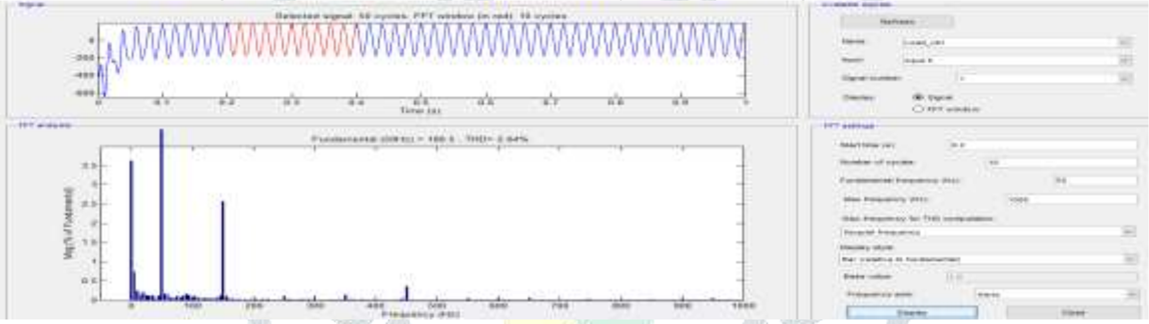

figure 16: injected current of fft analysis and thd using pi controller

CONCLUSION

The harmonic compensation by coordinated control of Dual Interfacing Converter gives better solution to the power quality issues in microgrid. The major advantage of this method is that it provides simultaneous voltage and current harmonics compensation. This paper examines a novel coordinated voltage and current controller for dual-converter framework in which the local load is specifically associated with the shunt capacitor of the primary converter. With the configuration, the quality of supply voltage can be enhanced via a direct closed-loop harmonic voltage control of filter capacitor voltage. At the same time, the harmonic current caused by the nonlinear load and the primary converter is compensated by the second converter. Accordingly, the quality of the grid current and the supply voltage are both significantly made strides. To decrease the computational load of DG interfacing converter, the coordinated voltage and current control without utilizing load current/supply voltage harmonic extractions or phase-lock loops is produced to realize to coordinated control of parallel converters.

The experimental results also have given a better power quality profile. The simulation of this harmonic compensation method is done by using MATLAB software. The results obtained shows that the THD has been significantly reduced by using this Dual Interfacing Converter. Thus, this method of harmonic compensation proves to be a best solution for the microgrid operated both at grid connected and islanded mode of operation.

REFERENCES

[1] Jinwei He, B. Liang, Yun Wei li, C. Wang," simultaneous microgrid voltage and current Harmonics Compensation Using coordinated control of dual interfacing converters", IEEE Transactions on Power Electronics (Volume: 32, Issue: 4, April 2017
[2] P. Acuna, L. Moran, M. Riv generation, J. Dixon, and J. Rodriguez, "Improved active power filter performance for renewable power gen generation tion systems," IEEE Trans. Power Electron., vol. 29, no.2, pp. 687-694, Feb. 2013.

[3] Y. W. Li, F. Blaabjerg, D. M. Vilathgamuwa, and P. C. Loh, "Design and Comparison of High Performance StationaryFrame Controllers for DVR Implementation," IEEE Trans. Power Electron., vol. 22, pp. 602-612, Mar. 2007.

[4] B. Singh, K. AI-Haddad, A. Chandra, "A review of active filters for power quality improvement," IEEE Trans. Ind. Electron., vol. 46, no. 5, pp. 960 - 971, May. 1999. [5] C. Meyer, R. W. DeDoncker, Y. W. Li, and F. Blaabjerg, "Optimized Control Strategy for a Medium-Voltage DVR – Theoretical Investigations and Experimental Results," IEEE Trans. Power Electron., vol. 23, pp. 2746-2754, Nov. 2008.

[5] F. Blaabjerg, Z. Chen, and S. B. Kjaer, "Power electronics as efficient interface in dispersed power gen generation tion systems," IEEE Trans. Power Electron., vol. 19, pp. 1184-1194, Sep. 2004.

[6] A. Timbus, M. Liserre, R. Teodorescu, P. Rodriguez, and F. Blaabjerg, "Evaluation of current controllers for distributed power generation systems," IEEE Trans. Power Electron., vol. 24, no. 3, pp. 654– 664, Mar. 2009.

[7] J. M. Guerrero, L. G. Vicuna, J. Matas, M. Castilla, and J. Miret, "A wireless controller to enhance dynamic performance of parallel inverters in distributed generation systems," IEEE Trans. Power Electron., vol. 19, no. 4, pp. 1205-1213, Sep, 2004.

[8] J. M. Guerrero, J. C. Vasquez, J. Matas, L.G. de Vicuna, and M. Castilla, "Hierarchical control of droop-controlled AC and DC microgrids - A general approach toward standardization," IEEE Trans. Ind. Electron., vol. 55, no. 1, pp. 158 - 172, Jan. 2011.

[9] J. He and Y. W. Li, "Analysis, design and implementation of virtual impedance for power electronics interfaced distributed generation," IEEE Trans. Ind. Applicat., vol. 47, no. 6, pp. 2525-2038, Nov/Dec. 2011.

[10] Q. Zhang, "Robust droop controller for accurate proportional load sharing among inverters operated in parallel," IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1281–1290, Apr. 2013.

[11] W. Issa, M. Abusara, and S. Sharkh, "Control of transient power during unintentional islanding of microgrids," IEEE Trans. Power Electron., online early access.

[12] C.-L. Chen, Y. Wang, J.-S. Lai, Y.-S. Lee, D. Martin, "Design of parallel inverters for smooth mode transfer microgrid applications," IEEE Trans. Power. Electron., vol. 25, no. 1, pp. 6–15, Jan. 2010.

[13] N. Pogaku and T.C. Green, "Harmonic mitigation throughout a distribution system: a distributed-generator-based solution," IEE Proc. Gener. Transm. Distrib., vol.153, no.3, pp. 350- 358, May. 2006.

[14] C. J. Gajanayake, D. M. Vilathgamuwa, P. C. Loh, R. Teodorescu, and F. Blaabjerg, "Z-source-inverter-based flexible distributed generation system solution for grid power quality improvement," IEEE Trans. Energy Conversion, vol.24, pp.695-704, Sep. 2009.