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Islanding Detection And Reconnection For Integrated Multi Microgrid Environment

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ABSTRACT— Multi-Microgrid (MMG) generally constitutes two or more microgrids (MGs), connected together. The MGs in turn includes renewable energy resources. The variable and nonlinear loads connected to the MMG, deviates the balance between sources and loads, which create many power quality problems. These problems are based on voltage such as dips, swells and harmonics. In this regard, a novel device like Distribution Power Conditioner (DPC) is proposed to mitigate these concerned power quality issues. The DPC in addition to voltage magnitude compensation provides harmonic mitigation. This is achieved by adapting active power filtering with proposed control technique. A novel control technique based on (Identity Vector Template Generation (IVTG)) approach is proposed to improve its performance in providing harmonic compensation and compared with conventional control techniques like PI, SRF theory with varying load conditions in the MMG.

KEYWORDS—*Multi Microgrid; Solar; Power quality; Harmonics, WECS*

I. INTRODUCTION

Distribution generation (DG) is observed to act in the direction to benefit the utilities with decentralized approach. A microgrid is developed in this regard, with the concept of power generation at distribution. The application of MG is further enhanced to multi microgrid (MMG) to provide optimal service to the consumer. Hence, a Multi Microgrid (MMG) is a combination of more microgrids. Multi Microgrids utilize freely available renewable energy sources (RES) to generate power and are installed at load end. Generally, the RESs like PV and wind are used to construct the MG in the MMG. Power quality issues have been observed in these MGs. These are caused due to the output variations from the RES generation, i.e the supply side disturbances to the loads. These common disturbances in the MG can be due to (i) disturbances arising due to environmental changes (ii) nature of loads and (iii) fuse or breaker operation. The voltage disturbances are also caused by symmetrical and non-symmetrical faults. The performance of the sensitive equipment in industries, hospitals, business centers is adversely affected by the disturbances in the source voltages. In such case, voltage sags for a short duration of few cycles may cause a great damage to the sensitive equipment. The voltage fluctuations are additionally

caused by loads. The nonlinear nature of the loads and AC loads demanding reactive power at the time of starting are few scenarios which cause harmonics. The series compensator DVR is proposed to mitigate these voltage disturbances. The primary application of DVR in the distribution system is to compensate for sags and swells in the voltages in terms of its magnitude. The first DVR entered commercial service on the Duke Power System in the U.S.A. in August 1996 [1] to compensate 50 % voltage sag for a period of 0.5 seconds. DVR has been studied widely in compensating voltage quality issues in traditional grid [2] but not for voltage compensation in the MG. The application of DVR in wind technologies for fault ride through is presented in [2]. MG protection using DVR is discussed in [3, 4] along with power quality improvement in microgrid a DVR. However using PV supported DC link was proposed in [5] but harmonics mitigation was neglected. In this regard, in order to enhance the DVR to compensate all voltage problems, it is necessary to add additional features requiring the modeling of DVR.

Active filters provide a solution to this problem in the condition of both linear and nonlinear loads. Their zone of operation is limited to installation and will not consider the complete operating zone of the entire system. In the literature, the application of APFs is mentioned differently in providing power quality compensation. In such case, the APF is providing the compensation with the support from MG (or) MMG to energize its DC link i.e for MG connected main grid [3, 4]. However, the MMG in grid free mode, has to balance power independently as there is no reference for frequency or voltage [5]. The severity in terms of power quality problems comes with the connection of linear and non-linear loads. [6]. This paper presents the solution by using a device, specified as distribution power conditioner (DPC) in mitigating all voltage quality issues occurring in MMG. The DPC in addition to voltage magnitude compensation provides harmonic mitigation. This is achieved by adapting active power filtering with proposed control technique. A novel control technique based on IVTG approach is proposed to improve its performance in providing harmonic compensation and compared with conventional control techniques like PI, SRF theory with varying load conditions in the MG. This paper presents the Multi

Microgrid (MMG) in section 2, modeling of DPC in section 3, control techniques for DPC in section 4, results and comparison in section 5.

II. MULTIMICROGRID STRUCTURE

The MMG has been developed using two different MGs, with PV and Wind Energy Conversion System (WECS) and is shown in Fig. 1.

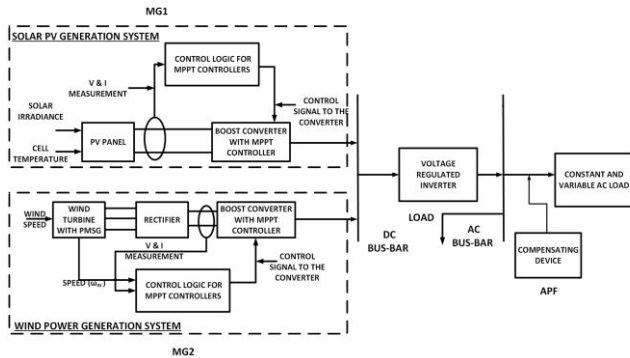


Fig. 1. MG block diagram

Various linear and nonlinear loads are connected to this MMG at the AC bus.

A. PV based MG

The MG1 based on PV generations as the power source is shown in Fig. 2. The block diagram includes PV modeling, boost converter controlled by MPPT controller and the DC bus [7].

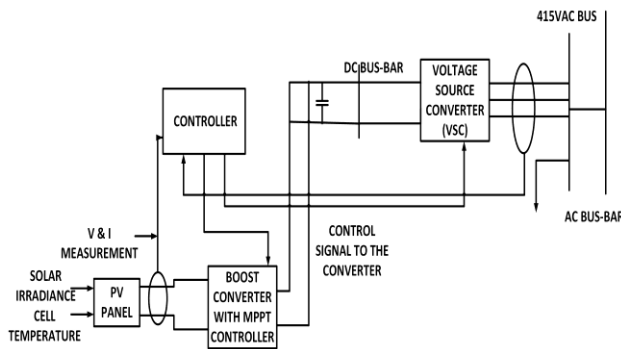


Fig. 2. Block diagram of MMG

B. WECS based MG

A wind energy conversion system (WECS) based generation as MG2 is shown in Fig. 3. The block diagram in detail is shown in Fig. 3. The components for achieving reference voltage using AC/DC conversions are similar to PV system [8].

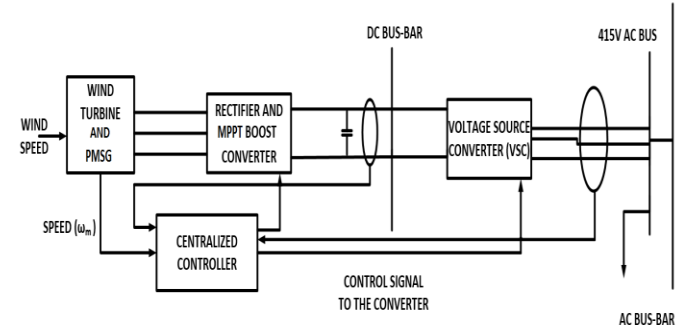


Fig. 3. Block diagram of WECS generation

C. PQ issues in the MG

Various (PQ) issues are identified from the developed the MMG owing to intermittent nature of the RES on source side, (i.e PV and Wind) and also due to loads. For clear analysis, the environmental effects of the MMG are observed using Weather Monitoring System (WMS) installed at location BITS-Pilani, Hyderabad. The data of solar irradiation and wind profile has been recorded and as a result, the changes in V, P, and Q in each MG are analyzed. It is found that the output voltage is varying continuously and also the active-reactive power unbalance is observed as shown in Fig.4 and Fig.5. Similarly, Due to the harmonic and reactive loads, many other power quality issues like sag, swell, harmonics, flicker are observed and presented. In this regard, the solution is proposed by using a compensating device, specified as distribution power conditioner (DPC) in mitigating all these concerned issues occurring in MMG [8].

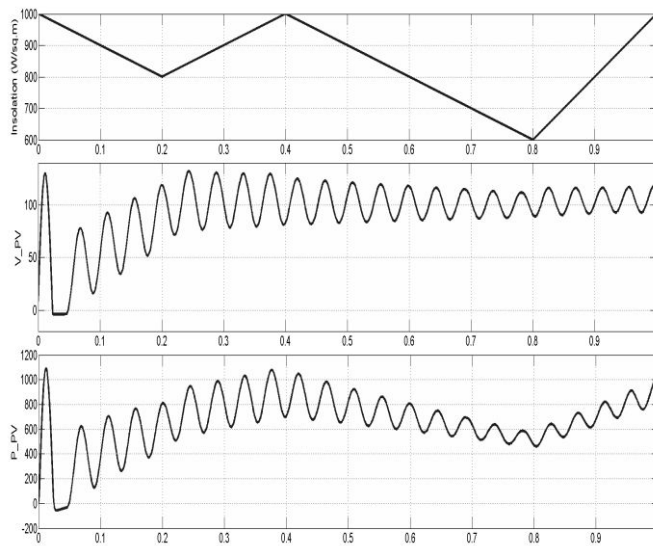


Fig. 4. Output V, P responses due to change in solar insolation

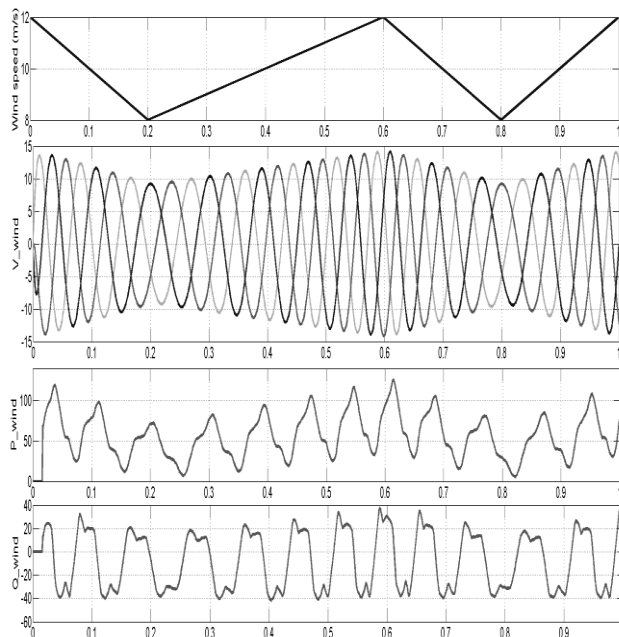


Fig. 5. Output V, P, Q responses due to wind speed

III. DISTRIBUTION POWER CONDITIONER (DPC)

All the voltage related issues in MG are mitigated by the DVR [8]. A specified control is required for proper operation of DVR system. DVR detects the presence of voltage sags/ swells and operates to mitigate the voltage dip/rise. The control technique is applied to generate Pulse Width Modulation (PWM) control signals to IGBTs switches to develop the required voltage to be injected. The generation of PWM signals, in turn, is based on the control logic applied for inverter switching. Thus the VSI generates a required three phase 50 Hz sinusoidal voltages and injects into the system [9]. The DVR

provides compensation to the voltage problems in terms of magnitude only. However, the harmonics are also observed with varying loads at the load side.

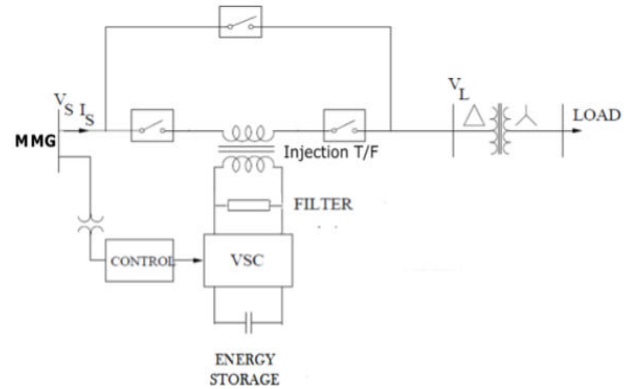


Fig. 6. DPC structure

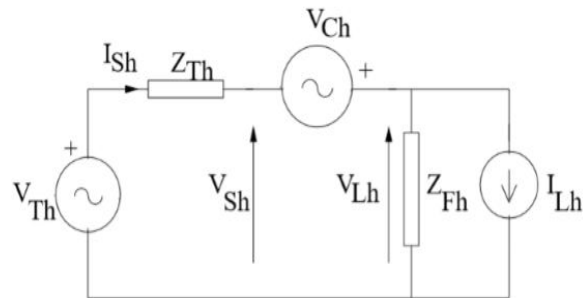


Fig. 7. DPC equivalent circuit

The filter in the DVR only removes injected harmonics caused by inverter action as shown in Fig. 6. Consequently, to enhance its performance especially when nonlinear loads are connected, the DVR is modified as distribution power conditioner (DPC) by adapting active power filtering feature to mitigate harmonics along with magnitude compensation. This is implemented in the control unit of DPC. The series power compensator is redesigned with APF technique and turned into DPC to provide harmonic compensation in addition to RPC. The equivalent circuit employed with series compensation is shown in Fig. 7. A harmonic current and voltage of I_{Lh} and V_{Lh} start flowing due to nonlinear load. The harmonic impedance is Z_{Fh} . From the supply side, the Thevenin (harmonic) voltage, current, and impedance are given by V_{Th} , I_{Sh} and Z_{Th} . As a result, the harmonic voltage injected in series is V_{Ch} . To mitigate this voltage an equal and opposite voltage to be injected by the series APF which is represented by using V_{Sh} .

IV. DPC CONTROL TECHNIQUES

The DPC is used to provide compensation for voltage quality issues including harmonics in the MMG. In turn the APFs are driven by using self-supporting DC bus or battery energy storage system (BESS). They are used to inject required voltages in series between the sources (DGs) and load for voltage magnitude compensation or

for obtaining balanced sinusoidal voltages across the load. These objectives are selected either individually or in combination to maintain stable voltage profile in the MG. The control algorithms considered are:

- PI control
- Synchronous reference frame (SRF) theory, also known as a d-q theory.
- Identity vector template generation (IVTG) technique. (Proposed technique)

The PI controller has simple structure, easy to design and low cost. Despite these advantages, the PI controller fails when the controlled object is highly nonlinear and uncertain [7]. PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively as shown in Fig. 8. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. The flow chart of PI control is shown in Fig. 9.

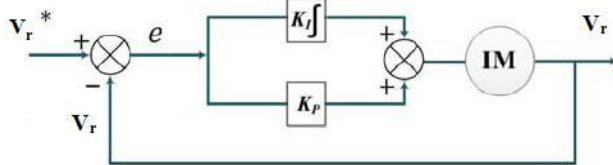


Fig. 8. PI control

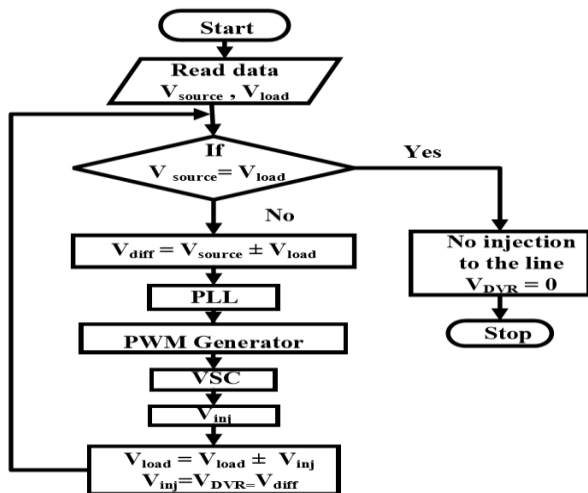


Fig.9.Flowchart of PI control

SRF control is also known d-q method and is based on a-b-c to d-q transformation [8] as shown in Fig. 10. Stationary to rotating reference frame conversions are made using PLL. The *sin* and *cos* functions help to maintain the synchronization with supply system. The flow chart of the control is shown in Fig. 11.

Using these two controls (PI and SRF), the dips and swells in the output voltage due to supply voltage

variations and also due to different loads are mitigated. The series APF controlled by SRF theory based control is compensating the output voltage to the desired sinusoidal when compared to conventional PI control. However, these two methods are found to be applicable in providing compensation by mitigating voltage disturbances in terms of magnitude and only for linear loads. However, loads that give non-sinusoidal outputs and containing harmonics also demand reactive power compensation. Hence the performance of MG is required to be assessed for nonlinear loads. In this regard, the IVTG technique is proposed which generates fundamental identity vector templates to derive reference signals as shown in Fig. 12. In the MMG, 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.

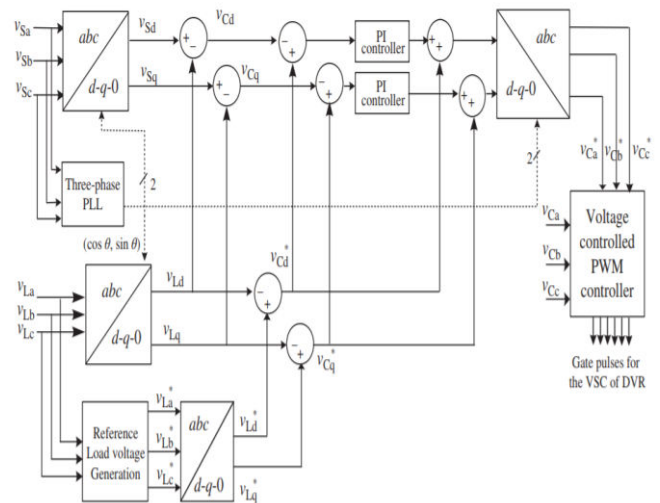


Fig.10.SRF Control

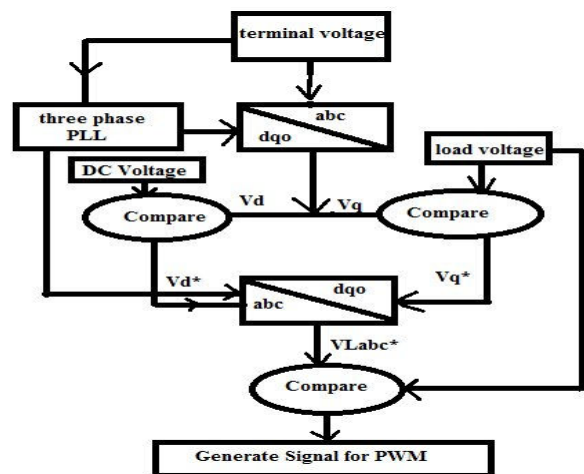


Fig.11.Flow chart of SRF Control

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 as explained in the flow chart shown in Fig. 13.

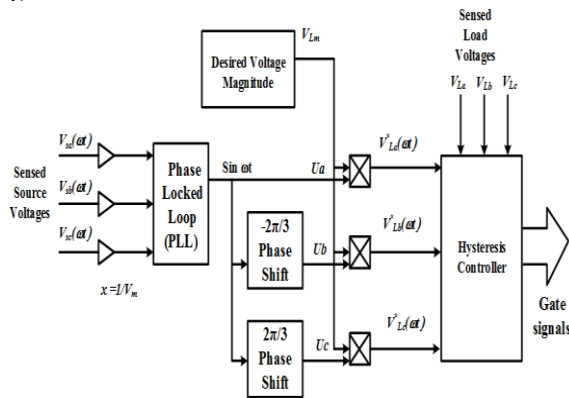


Fig.12.Proposed IVTG Control

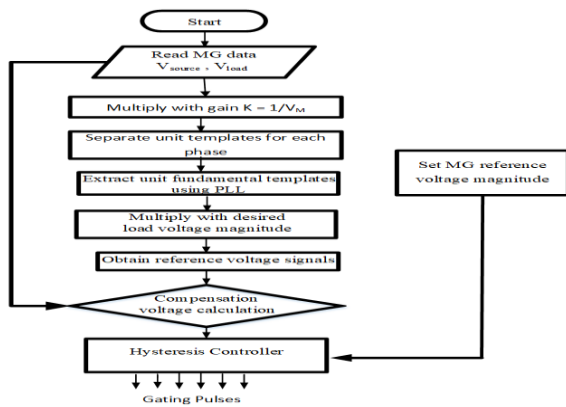


Fig.13.Flowchart of IVTG Control

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

$$V_{La}^*(\omega t) = V_{Lm} \cdot U_a = V_{Lm} \sin(\omega t) \quad (1)$$

$$V_{Lb}^*(\omega t) = V_{Lm} \cdot U_b = V_{Lm} \sin(\omega t - 120^\circ) \quad (2)$$

$$V_{Lc}^*(\omega t) = V_{Lm} \cdot U_c = V_{Lm} \sin(\omega t + 120^\circ) \quad (3)$$

V. RESULTS

A multi microgrid model is developed with 2 MGs, a PV generator of 1.5 kW and a wind generator 2 kW along with storage to deliver an output voltage of 3-phase, 415 V Line-Line RMS (phase to ground voltage of 338 V), 50 Hz, which is at common AC bus in MATLAB Simulink. The reference output voltage is shown in Fig. 14. Due to the changes in environmental conditions, the disturbances in source voltages is observed and the corresponding load voltage is shown in Fig. 15. In order to mitigate these two issues in the MMG, the compensating device distribution power conditioner, DPC is connected and applied with the fore mentioned control techniques. When PI control is implemented to deal, the output voltage is mitigated as shown in the Fig. 16. However, the tips of the output voltage do not get compensated well due to improper tuning of the PI control in accordance with varying supply and load conditions. Similarly, load voltage compensation is shown in Fig 17 and is further zoomed in Fig. 18. In order to overcome this problem, SRF theory is further considered and implemented. Sinusoidal voltage compensation at the edges using SRF theory control is obtained as shown in Fig. 19. i.e. DPC controlled by SRF theory based control is compensating the output voltage to the desired sinusoidal effectively when compared to conventional PI control as shown in Fig 20 and the same is verified for supply changes as shown in Fig. 21. However, these two methods are found to in providing compensation in terms of magnitude and only for linear loads. As mentioned in section 1, loads that give non-sinusoidal outputs and containing harmonics also demand reactive power compensation.

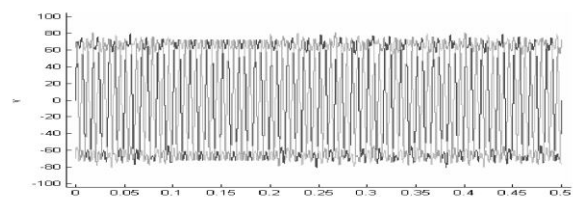
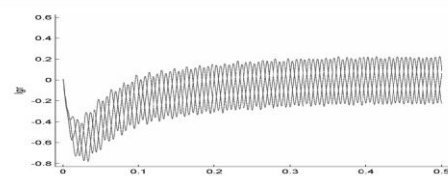


Fig.14.grid voltage& grid current



In this regard, the MG is connected to a nonlinear load containing a 3-phase full bridge diode rectifier delivering an RL load of 10 Ω + 0.15 mH combined with a series RL load of 0.4 Ω + 15 mH and thus harmonics are developed in the load voltage. A THD of 24.48% is present in the resultant voltage. When PI control is used

in the DPC, the % THD is increased to a value of 25.40 from 24.48 as shown in Fig. 22. Similarly, when SRF theory is used as a control in the series APF, % THD is further increased to 47.44 as shown in Fig. 23. Using these two controls for harmonic loads, the actual harmonic content in the load voltage is aided with the harmonics developed during injection. The injection harmonics are more in case of SRF based control due to its complex circuitry compared to PI control. Hence, % THD is raised in case of SRF theory based control compared to PI control. However, PI control is a simple conventional control that can provide compensation in terms of magnitude only.

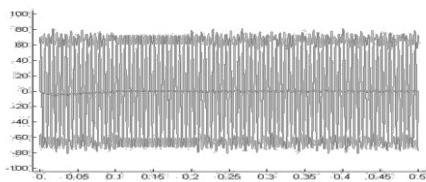


Fig.15.source voltage

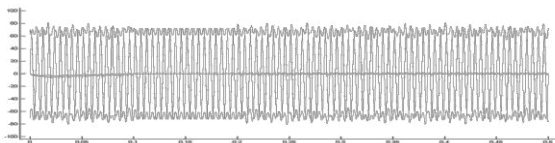


Fig.16.source current

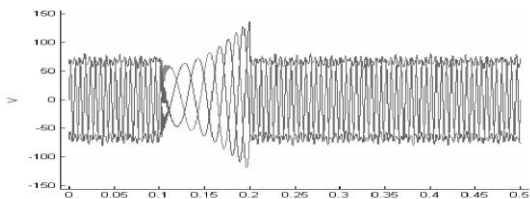
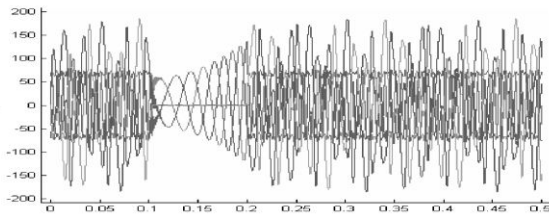


Fig.17. wind voltage and wind current

Hence the harmonics are not eliminated with PI control, more or less remains the same. In this situation, the proposed IVTG technique is considered and analyzed to provide compensation against the harmonics in the MMG. As a result, the % THD has been improved to 0.94 as shown in Fig. 22.

The simulation results prove that sag, swell, harmonics in output voltage due to supply and load changes caused by reactive, harmonic loads and RESs input parameters are compensated well with series APF

and is able to maintain its load voltage near to reference voltage in MG.

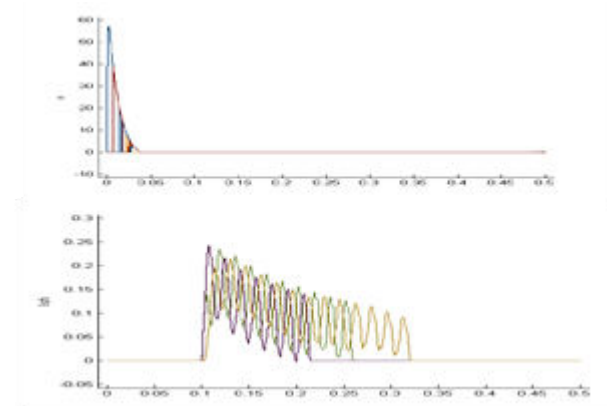


Fig.18. shunt voltage & current

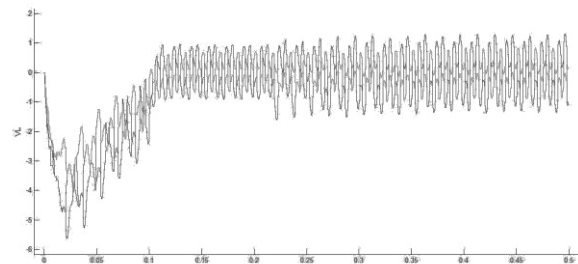


Fig.19.load voltage wave form

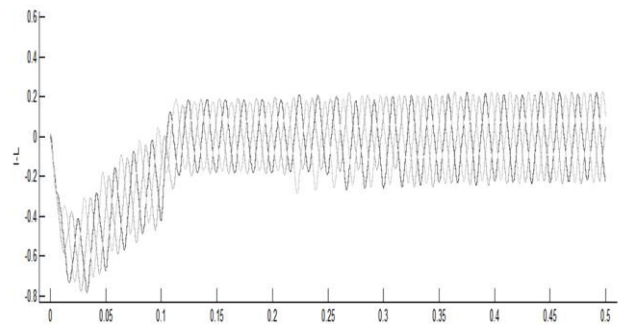


Fig.20.Load current

VI. CONCLUSION

With various power quality issues that are resulted from supply and load changes a distribution power compensator is applied to provide compensation. PQ compensation using DPC is expected to compensate all voltage problems including harmonic compensation. Hence the series compensator is enriched with active filter topology and is converted into DPC by designing appropriate filter. A controller using PI, SRF techniques that give a scaled error is applied for providing RPC using

DPC. It is observed that these two theories, are applicable in providing compensation by mitigating voltage disturbances in terms of magnitude and only for linear loads. Hence to compensate for non-linear loads, a unique technique named IVTG approach has been applied in the MMG. The simulation shows that the DPC effectively provides harmonic compensation and substantially, the performance is also satisfactory with quick response and excellent voltage regulation for all voltage disturbances.

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