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Power quality improvement through dual voltage source inverter of grid connected Renewable Energy Sources

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ABSTRACT: *The power quality plays an important role in the micro-grid system. This paper presents a dual voltage source inverter (DVSI) scheme to improve the reliability and power quality of the micro-grid system. In this system we are using distributed energy resources (DERs) for power exchange and also to compensate the local unbalanced and nonlinear load. The control algorithms are developed based on instantaneous symmetrical component theory (ISCT) to operate DVSI in grid sharing and grid injecting modes. The proposed scheme increasing reliability, lower bandwidth requirement of the main inverter, lowers the cost due to reduction in filter size, and better utilization of micro- grid power while using reduced dc-link voltage rating for the main inverter. These features make the DVSI scheme a promising option for micro-grid supplying sensitive loads. The topology and control algorithm are validated through extensive simulation results.*

KEYWORDS: *Grid connected inverter, instantaneous symmetrical component theory (ISCT), micro-grid, power quality.*

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I. INTRODUCTION

In recent years, electric utilities' ability to deliver reliable clean power has become increasingly more difficult. In their rush to meet renewable energy portfolio standards, solar and wind farms have created serious grid stability challenges. This strain on utilities, in combination with the increase in electronic equipment used in industrial facilities means power quality events are only increasing. A grid interactive inverter plays an important role in exchanging power from the micro-grid to the grid and the connected load. This micro-grid inverter can either work in a grid sharing mode while supplying a part of local load or in grid injecting mode, by injecting power to the main grid. Technological progress and environmental concerns drive the power system to a paradigm shift with more renewable energy

Sources integrated to the network by means of distributed generation (DG). These DG units with coordinated control of local generation and storage facilities form a micro grid. In a micro grid, power from different renewable energy sources such as fuel cells, photovoltaic (PV) systems and wind energy systems are interfaced to grid and loads using power electronic converters.

Maintaining power quality is another important aspect which as to be addressed while the micro grid system is connected to the main grid. The proliferation of power electronics devices and the electrical loads with unbalanced nonlinear currents has degraded the power quality in the power distribution network. Moreover, if there is a considerable amount of feeder impedance in the distribution systems, the propagation of these harmonic currents distorts the voltage at the point of common coupling (PCC). At the same instant, industry automation has reached to a very high level of sophistication, where plants like automobile manufacturing units, chemical factories, and semiconductor industries require clean power. For these applications, it is essential to compensate nonlinear and unbalanced load currents.

Load compensation and power injection using grid interactive inverters in micro grid have been presented in the literature. The main focus of this work is to realize dual functionalities in an inverter that would provide the active power injection from a solar PV system and also works as an active power filter, compensating unbalances and the reactive power required by other loads connected to the system.

In a voltage regulation and power flow control scheme for a wind energy system (WES) is proposed. A distribution static compensator (DSTATCOM) is utilized for voltage regulation and also for active power, injection. The control scheme maintains the power balance at the grid terminal during the wind variations using sliding mode control. A multifunctional power electronic converter for the DG power system is described in.
This scheme has the capability to inject power generated by WES and also to perform as a harmonic compensator .Most of the reported literature in this area discuss the topologies and control algorithms to provide

load compensation capability in the same inverter in addition to their active power injection. When a grid-connected inverter is used for active power injection as well as for load compensation, the inverter capacity that can be utilized for achieving the second objective is decided by the available instantaneous micro grid real power. Considering the case of a grid-connected PV inverter, the available capacity of the inverter to supply the reactive power becomes less during the maximum solar in isolation periods. At the same instant, the reactive power to regulate the PCC voltage is very much needed during this period. It indicates that providing multi functionalities in a single inverter degrades either the real power injection or the load compensation capabilities.

This paper demonstrates a dual voltage source inverter (DVSI) scheme, in which the power generated by the micro grid is injected as real power by the main voltage source inverter (MVSI) and the reactive, harmonic, and unbalanced load compensation is performed by auxiliary voltage source inverter (AVSI). This has an advantage that the rated capacity of MVSI can always be used to inject real power to the grid, if sufficient renewable power is available at the dc link. In the DVSI scheme, as total load power is supplied by two inverters, power losses across the semiconductor switches of each inverter are reduced. This increases its reliability as compared to a single inverter with multifunctional capabilities. Also, smaller size modular inverters can operate at high switching frequencies with a reduced size of interfacing inductor, the filter cost gets reduced. Moreover, as the main inverter is supplying real power, the inverter has to track the fundamental positive sequence of current. This reduces the bandwidth requirement of the main inverter. The inverters in the proposed DVSI scheme provides increased reliability, better utilization of micro grid power, reduced dc grid voltage rating, less bandwidth requirement of the main inverter, and reduced filter size. Control algorithms are developed by instantaneous symmetrical component theory (ISCT) to operate DVSI in grid-connected mode, while considering non stiff grid voltage. The extraction of fundamental positive sequence of PCC voltage is done by dq0transformation. The control strategy is tested with two parallel inverters connected to a three-phase four-wire distribution system. Effectiveness of the proposed control algorithm is validated through detailed simulation and experimental results.

II. DUAL VOLTAGE SOURCEINVERTER

2.1. System Topology

The proposed DVSI topology is shown in Fig. It consists of a neutral point clamped (NPC) inverter to realize AVSI and a three-leg inverter for MVSI [18]. These are connected to grid at the PCC and supplying a nonlinear and unbalanced load. The function of the AVSI is to compensate the reactive, harmonics, and unbalance components in load currents. Here, load currents in three phases are represented by ila, ilb, and ilc, respectively. Also, ig (abc), iµgm (abc), and iµgx(abc) show grid currents, MVSI currents, and AVSI currents in three phases, respectively. The dc link of the AVSI utilizes a split capacitor topology, with two capacitors C1 and C2. The MVSI delivers the available power at distributed energy resource (DER) to grid.

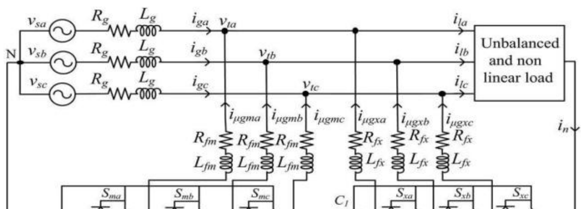


Figure : 1. Topology of proposed DVSI scheme.

The DER can be a dc source or an ac source with rectifier coupled to dc link. Usually, renewable energy sources like fuel cell and PV generate power at variable low dc voltage, while the variable speed wind turbines generate power at variable ac voltage. Therefore, the power generated from these sources use a power conditioning stage before it is connected to the input of MVSI. In this study, DER is being represented as a dc source. An inductor filter is used to eliminate the high-frequency switching components generated due to the switching of power electronic switches in the inverters. The system considered in this study is assumed to have some amount of feeder resistance Rg and inductance Lg. Due to the presence of this feeder impedance, PCC voltage is affected with harmonics. Section III describes the extraction of fundamental positive sequence of PCC voltages and control strategy for the reference current generation of two inverters in DVSI scheme.

2.2. Design of Dual Voltage Source Inverter (DVSI) Parameters

It comprises of a nonpartisan point clasped (NPC) inverter to acknowledge AVSI and a three-leg inverter for MVSI

2.2.1. AVSI

The important parameters of AVSI like dc-link voltage (Vdc), dc storage capacitors (C1 and C2), interfacing inductance (Lfx), and hysteresis band (±hx) are selected based on the design method of split capacitor DSTATCOM topology [16]. The dc-link voltage across each capacitor is taken as1.6 times the peak of phase voltage. The total dc-link voltage reference (Vdc ref) is found to be 1040 V. Values of dc capacitors of AVSI are chosen based on the change in dc-link voltage during transients. Let total load rating is S KVA. In the worst case, the load power may vary from Minimum to maximum, i.e., from 0 to S KVA. AVSI needs to exchange real power during transient to maintain the load power demand. This transfer of real power during the transient will results in deviation of capacitor voltage from its reference value.

Assume that the voltage controller takes n cycles, i.e., nT seconds to act, where T is the system time period. Hence, maximum energy exchange by AVSI during transient will be nST. Vdcr and Vdc1 are the reference dc voltage and maximum permissible dc voltage across C1 during transient, respectively This energy will be equal to change in the capacitor stored energy. Therefore

$$\frac{1}{2}C_1(V_{\mathrm{dcr}}^2 - V_{\mathrm{dc1}}^2) = nST$$

. Here, S =5 kVA , Vdcr = 520 V, Vdc1 =0.8 Vdcr or 1.2 Vdcr, n = 1, and T = 0.02 s. Substituting these values in (1), the dc link capacitance (C1) is calculated to be 2000 μF. Same value of capacitance is selected for C2.The interfacing inductance is given by

$$L_{fx} = \frac{1.6\,V_m}{4\,h_x f_{\max}}.$$

Assuming a maximum switching frequency (fmax) of 10 kHz and hysteresis band (hx) as 5%of load current (0.5 A), the value of Lfx is calculated to be 26 mH.

2.2.2. MVSI

The MVSI uses a three-leg inverter topology. Its dc-link voltage is obtained as 1.15 *Vml, where Vml is the peak value of line voltage. This is calculated to be 648 V. Zero sequence switching harmonics will be absent in the output current of MVSI. MVSI supplies a balanced sinusoidal current at unity power factor. So, This reduces the filter requirement for MVSI as compared to AVSI .In this analysis, a filter inductance (Lfm) of 5 mH is used.

III. CONTROL STRATEGY FOR DVSI SCHEME

We have 2-control strategies are there. They are given below :

1. Fundamental Voltage Extraction
2. Instantaneous Symmetrical Component Theory

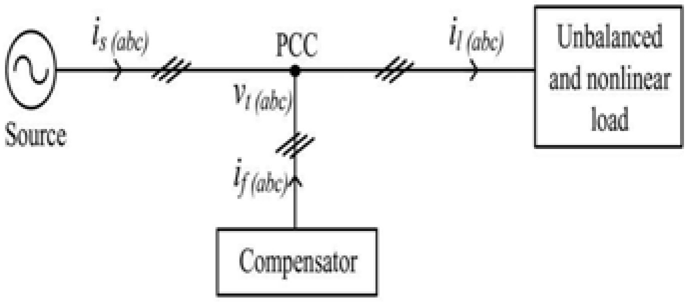
3.1. Fundamental Voltage Extraction

The control algorithm for reference current generation using ISCT requires balanced sinusoidal PCC voltages. Because of the presence of feeder impedance, PCC voltages are distorted. Therefore, the fundamental positive sequence components of the PCC voltages are extracted for the reference current generation. To convert the distorted PCC voltages to balanced sinusoidal voltages, dq0 transformation is used.

In order to get θ, a modified synchronous reference frame (SRF) phase locked loop (PLL) is used. In PLL system mainly consists of a proportional integral (PI) controller and an integrator. In this PLL, the SRF terminal voltage in q-axis (vtq) is compared with 0 V and the error voltage thus obtained is given to the PI controller. The frequency deviation Δω is then added to the reference frequency ω0 and finally given to the integrator to get θ. It can be proved that, when, θ = ω0 t and by using the Park's transformation matrix (C), q-axis voltage in dq0 frame becomes zero and hence the PLL will be locked to the reference frequency (ω0). As PCC voltages are distorted, the transformed voltages in dq0 frame (vtd and vtq) contain average and oscillating components of voltages.

3.2. Instantaneous Symmetrical Component Theory

For compensating purpose of unbalanced and nonlinear load by active power filters ISCT was developed primarily. The system topology shown in Fig is used for realizing the reference current for the compensator.



$$i_{sa} + i_{sb} + i_{sc} = 0. \qquad (6)$$

Figure : 2 Unbalanced and non-linear load compensator scheme.

The source neutral current must be zero. Therefore

The phase angle between the fundamental positive
Sequence voltage (v+ta1) and source current (isa) isφ

$$\angle v^{+}_{ta1} = \angle i_{sa} + \phi. \qquad (7)$$

The average real power of the load (Pl) should be supplied by the source
Solving the above three equations, the reference source currents can be obtained as

$$v^{+}_{ta1}\, i_{sa} + v^{+}_{tb1}\, i_{sb} + v^{+}_{tc1}\, i_{sc} = P_l. \qquad (8)$$

3.3. Advantages of the DVSI Scheme

The various advantages of the proposed DVSI scheme over a single inverter scheme with multi functional capabilities are discussed here as follows:

1) Increased Reliability:

DVSI scheme has increased reliability, due to the reduction in failure rate of components and the decrease in system down time cost. In this scheme, the total load current is shared between AVSI and MVSI and hence reduces the failure rate of inverter switches. Moreover, if one inverter fails, the other can continue its operation. This reduces the lost energy and hence the down time cost. The reduction in system down time cost improves the reliability.

2) Reduction in Filter Size:

In DVSI scheme, the current supplied by each inverter is reduced and hence the current rating of individual filter inductor reduces. This reduction in current rating reduces the filter size. Also, in this scheme, hysteresis current control is used to track the inverter reference currents. As given in, the filter inductance is decided by the inverter switching frequency. Since the lower current rated semiconductor device can be switched at higher switching frequency, the inductance of the filter can be lowered. This decrease in inductance further reduces the filter size.

3) Improved Flexibility:

Both the inverters are fed from separated clinks which allow them to operate independently, thus increasing the flexibility of the system. For instance, if the dc link of the main inverter is disconnected from the system, the load compensation capability of the auxiliary inverter can still be utilized.

4) Better Utilization of Micro-grid Power:

DVSI scheme helps to utilize full capacity of MVSI to transfer the entire power generated by DG units as real power to ac bus, as there is AVSI for harmonic and reactive power compensation. This increases the active power injection capability of DGs in micro-grid.

5) Reduced DC Link Voltage Rating:

Since, MVSI is not delivering zero sequence load current components, a single capacitor three leg VSI topology can be used. Therefore, the dc link voltage rating of MVSI is reduced approximately by 38%, as compared to a single inverter system with split capacitor VSI topology.

IV. SIMULATION AND RESULTS

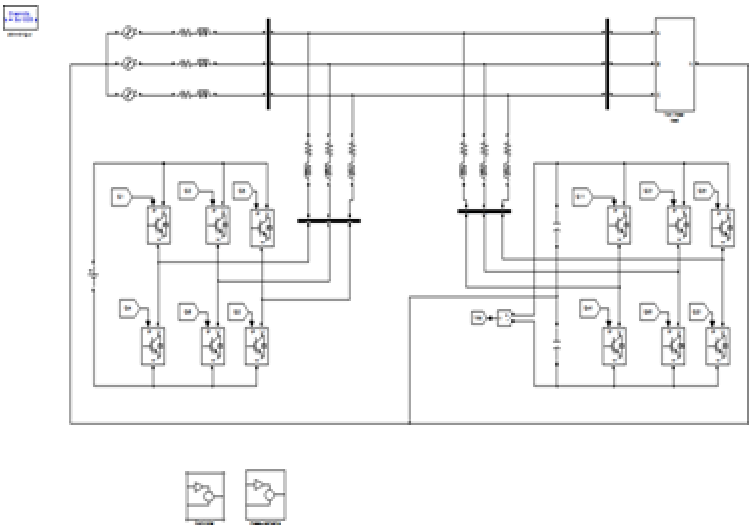


Figure : 3.Matlab/simulink diagram of proposed DVSI system

Since, MVSI is not delivering zero sequence load current components, a single capacitor three leg VSI topology can be used. Therefore, the dc link voltage rating of MVSI is reduced approximately by 38%, as compared to a single inverter system with split capacitor VSI topology.

Figure, represents active power demanded by load (Pl), active power supplied by grid (Pg), active power supplied by MVSI (Pμg), and active power supplied by AVSI (Px), respectively. It can be observed that, from t = 0.1 to 0.4 s, MVSI is generating 4 kW power and the load demand is 6 kW. Therefore, the remaining load active power (2 kW) is drawn from the grid. During this period, the micro grid is operating in grid sharing mode. At t = 0.4 s, the micro grid power is increased to 7 kW, which is more than the load demand of 6 kW. This micro grid power change is considered to show the change of operation of MVSI from grid sharing to grid injecting mode. Now, the excess power of 1 kW is injected to the grid and hence, the power drawn from grid is shown as negative active power sharing: load active power; active power supplied by grid; active power supplied by MVSI; and active power supplied by AVSI.

System parameters for simulation study:

Parameters	Values
Source voltage	50 V L–N (rms), 50 Hz
Feeder impedance	R_g = 0.5 Ω, L_g = 1.0 mH
Reference DC-link voltage of AVSI	V_{dcref} = 220 V
DC-link capacitance of AVSI	$C_1 = C_2$ = 4700 μF
DC-link voltage of MVSI	V_{dcm} = 150 V
PI gains of DC-link voltage controller	K_{Pv} = 80, K_{Iv} = 0.08
Hysterisis band (h)	$\pm$ 0.15 A
Interfacing inductor (AVSI)	R_{fx} = 0.5 Ω, L_{fx} = 10 mH
Interfacing inductor (MVSI)	R_{fm} = 0.5 Ω, L_{fm} = 5 mH
Unbalanced linear load	$Z_{la} = 24 + j16\ \Omega$ $Z_{lb} = 36 + j16\ \Omega$ $Z_{lc} = 64 + j21\ \Omega$
Nonlinear load	3 ϕ diode bridge rectifier with a dc current of 2.4 A

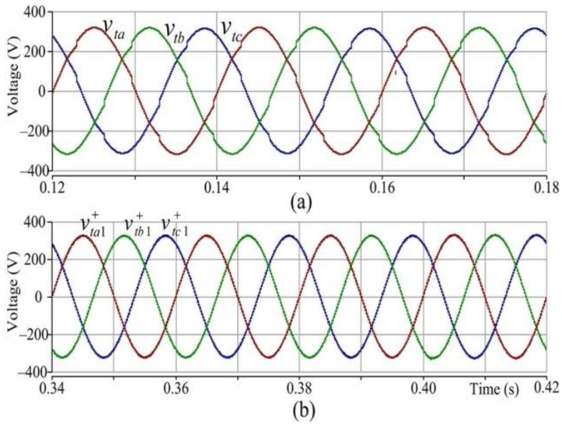


Figure:4. Without DVSI scheme: (a)PCCvoltagesand(b)fundamentalpositive sequence of PCC voltages.

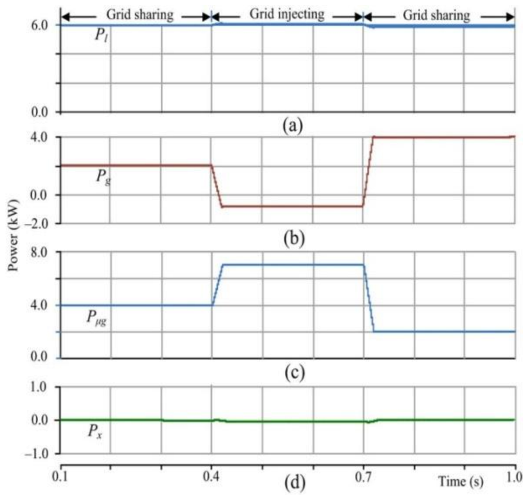


Figure:5.Activepowersharing:(a)loadactivepower;(b)activepowersupplied bygrid;(c)activepowersuppliedbyMVSI;and(d)activepowersuppliedbyAVSI.

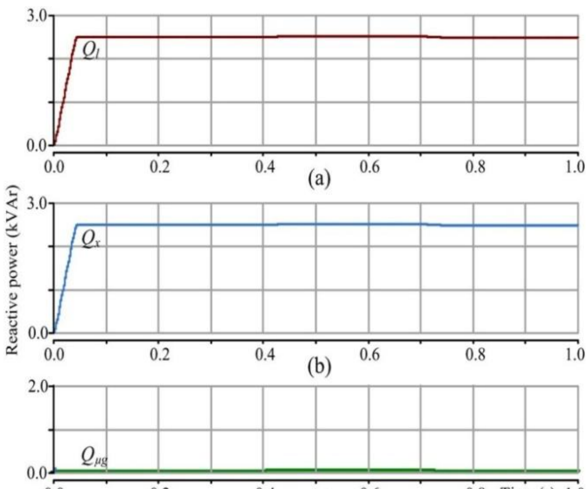


Figure:6.Reactivepowersharing:(a)loadreactivepower;(b)reactivepowersuppliedbyAVSI;and(c)reactivepo wersuppliedbyMVSI.

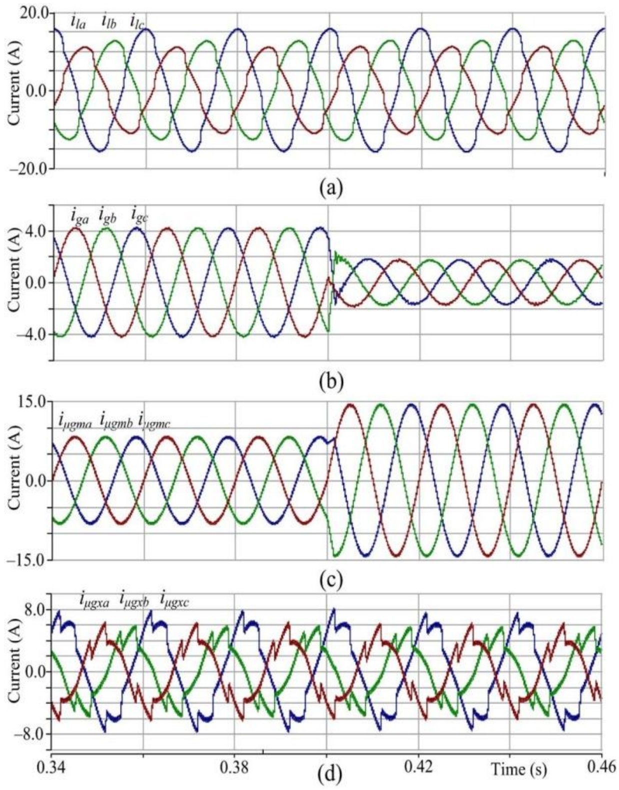


Figure:7.SimulatedperformanceofDVSIscheme:(a)loadcurrents;(b)gridcurrents;(c)MVSIcurrents;and(d) AVSIcurrents.

The distorted PCC voltages due to the feeder impedance without DVSI scheme are shown in Fig... If these distorted voltages are used for the reference current generation of AVSI, the current compensation will not be proper. Therefore, the fundamental positive sequence of voltages is extracted from these distorted voltages using the algorithm explained in Section III-A.

The plots of load currents (il(abc)), currents drawn from grid (ig(abc)), currents drawn from MVSI(iµg(abc)), and currents drawn from the AVSI (iµx(abc)),respectively. The load currents are unbalanced and distorted. The MVSI supplies balanced and sinusoidal currents during grid supporting and grid injecting modes. The currents drawn from grid are also perfectly balanced and sinusoidal, as the auxiliary inverter compensates the unbalance and harmonics

The MVSI supplies a balanced and sinusoidal currents during grid supporting and grid injecting modes. The currents drawn from grid areal so perfectly balanced and sinusoidal, as the auxiliary inverter compensates the unbalance and harmonics

These voltages are further used for the generation of inverter reference currents. Fig.5(a)-(d) represents active power demanded by load (Pl),active power supplied by grid (Pg),active power supplied by MVSI (Pµg),and active power supplied by AVSI (Px), respectively. It can be observed that, fromt=0.1to0.4s,MVSI is generating 4kWpower and the load demand is6kW.Therefore, the remaining load active power(2kW) is drawn from the grid.

During this period, the micro-grid is operating in grid sharing mode. At t=0.4s, the micro-grid power is increased to 7kW, which is more than the load demand of 5kW. This micro-grid power change is considered to show the change of operation of MVSI from grid sharing to grid injecting mode. Now, the excess power of 1kW is injected to the grid and hence, the power drawn from grid is shown as negative. Fig.6(a)(c)shows the load reactive power (Ql), reactive power supplied by AVSI (Qx), and reactive power supplied by MVSI (Qµg), respectively. It shows that total load reactive power is supplied by AVSI, as expected. Fig.7(a)(d)shows the plots of load currents (il(abc)), currents drawn from grid (ig(abc)), currents drawn from MVSI (iµg(abc)), and currents drawn from the AVSI (iµx(abc)), respectively. The load currents are unbalanced and distorted.

V. CONCLUSION

A Dual Voltage Source Inverter scheme is proposed for micro-grid systems with enhanced reliability and power quality. To generate reference currents for DVSI using ISCT Control algorithms are developed. As compared to a single inverter with multifunctional capabilities, a DVSI has many advantages such as, increased reliability, lower cost due to the reduction in filter size, and more utilization of inverter capacity to inject real power from DGs to micro grid. The proposed methodology has the capability to compensate the local unbalanced and nonlinear load and also to exchange power from distributed generators (DGs) The performance of the proposed scheme has been validated through simulation and experimental studies. Moreover, the use of three-phase, three wire topology for the main inverter reduces the dc-link voltage requirement. Thus, a DVSI scheme is a suitable interfacing option for micro grid supplying sensitive loads

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