DVSI Control Scheme With Power Quality Improvement Features in Grid Connected Applications

G Sravani[1], N Ramchander [2]
PG Scholar, Department of EEE, B. V. Raju Institute of Technology, Narsapur, Medak, India [1].
Associate Professor, Department of EEE, B. V. Raju Institute of Technology, Narsapur, Medak, India [2]

Abstract:

This paper presents a dual voltage source inverter (DVSI) scheme to enhance the power quality and reliability of the microgrid system. The proposed scheme is comprised of two inverters, which enables the microgrid to exchange power generated by the distributed energy resources (DERs) 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 has increased reliability, lower bandwidth requirement of the main inverter, lower cost due to reduction in filter size, and better utilization of microgrid power while using reduced dc-link voltage rating for the main inverter. These features make the DVSI scheme a promising option for microgrid supplying sensitive loads. The topology and control algorithm are validated through extensive simulation and experimental results.

Index Terms

Grid-connected inverter, instantaneous symmetrical component theory (ISCT), microgrid, power quality.

I. INTRODUCTION

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 microgrid [1]. In a microgrid, 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. A grid interactive inverter plays an important role in exchanging power from the microgrid to the grid and the connected load [2], [3]. This microgrid 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. Maintaining power quality is another important aspect which has to be addressed while the microgrid system is connected to the main grid.

In [8], 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 [9]. 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 microgrid real power [10]. 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 insolation periods [11]. At the same instant, the reactive power to regulate the PCC voltage is very much needed during this period [12]. It indicates that providing multifunctionalities 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 microgrid 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 sufficientrenewable 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 [13]. Also, smaller size modular inverters can operate at high switching frequencies with a reduced size of interfacing inductor, the filter cost gets reduced [14]. 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 scheme use two separate dc links. Since the auxiliary inverter is supplying zero sequence of load current, a three-phase three-leg inverter topology with a single dc storage capacitor can be used for the main inverter. This in turn reduces the dc-link voltage requirement of the main inverter. Thus, the use of two separate inverters in the proposed DVSI scheme provides increased reliability, better utilization of microgrid power, reduced dc grid voltage rating, less bandwidth requirement of the main inverter, and reduced filter size [13]. Control algorithms are developed by instantaneous symmetrical component theory (ISCT) to operate DVSI in grid-connected mode, while considering nonstiff grid voltage [15], [16]. The extraction of fundamental positive sequence of PCC voltage is done by dq0 transformation [17]. 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 SOURCE INVERTER

A. System Topology The proposed DVSI topology is shown in Fig. 1. 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.

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 [19]. 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 [20]. Section III describes the extraction of fundamental positive sequence of PCC voltages and control

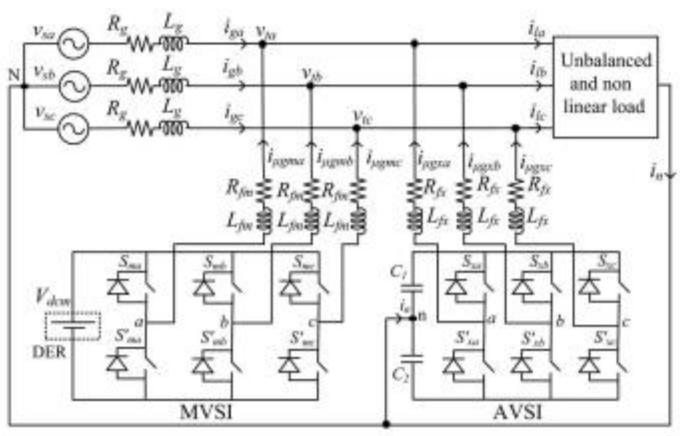


Fig. 1. Topology of proposed DVSI scheme.

strategy for the reference current generation of two inverters in DVSI scheme.

IV. SIMULATION STUDIES

The simulation model of DVSI scheme shown in Fig. 1 is developed in MATLAB to evaluate the performance. The simulation parameters of the system are given in Table I. The simulation study demonstrates the grid sharing and grid

TABLE I
SYSTEM PARAMETERS FOR SIMULATION STUDY

Parameters	Values
Grid voltage	400 V(L–L)
Fundamental frequency	50 Hz
Feeder impedance	$R_g = 0.5\ \Omega$, $L_g = 1.0$ mH
AVSI	$C_1 = C_2 = 2000\ \mu$F $V_{dcref} = 1040$ V Interfacing inductor, $L_{fx} = 20$ mH Inductor resistance, $R_{fx} = 0.25\ \Omega$ Hysteresis band ($\pm h_x$) = 0.1 A
MVSI	DC-link voltage, $V_{dcm} = 650$ V Interfacing inductor, $L_{fm} = 5$ mH Inductor resistance, $R_{fm} = 0.25\ \Omega$ Hysteresis band ($\pm h_m$) = 0.1 A
Unbalanced linear load	$Z_{la} = 35 + j19\ \Omega$ $Z_{lb} = 30 + j15\ \Omega$ $Z_{lc} = 23 + j12\ \Omega$
Nonlinear load	3 ϕ diode bridge rectifier with DC side current of 3.0 A
DC voltage controller gains	$K_{Pv} = 10$, $K_{Iv} = 0.05$

injecting modes of operation of DVSI scheme in steady state as well as in transient conditions.

The distorted PCC voltages due to the feeder impedance without DVSI scheme are shown in Fig. 5(a). If these distorted voltages are used for the reference current generation of AVSI, the current compensation will not be proper [14]. Therefore, the fundamental positive sequence of voltages is extracted from these distorted voltages using the algorithm explained in Section III-A. These extracted voltages are given in Fig. 5(b). These voltages are further used for the generation of inverter reference currents. Fig. 6(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, 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

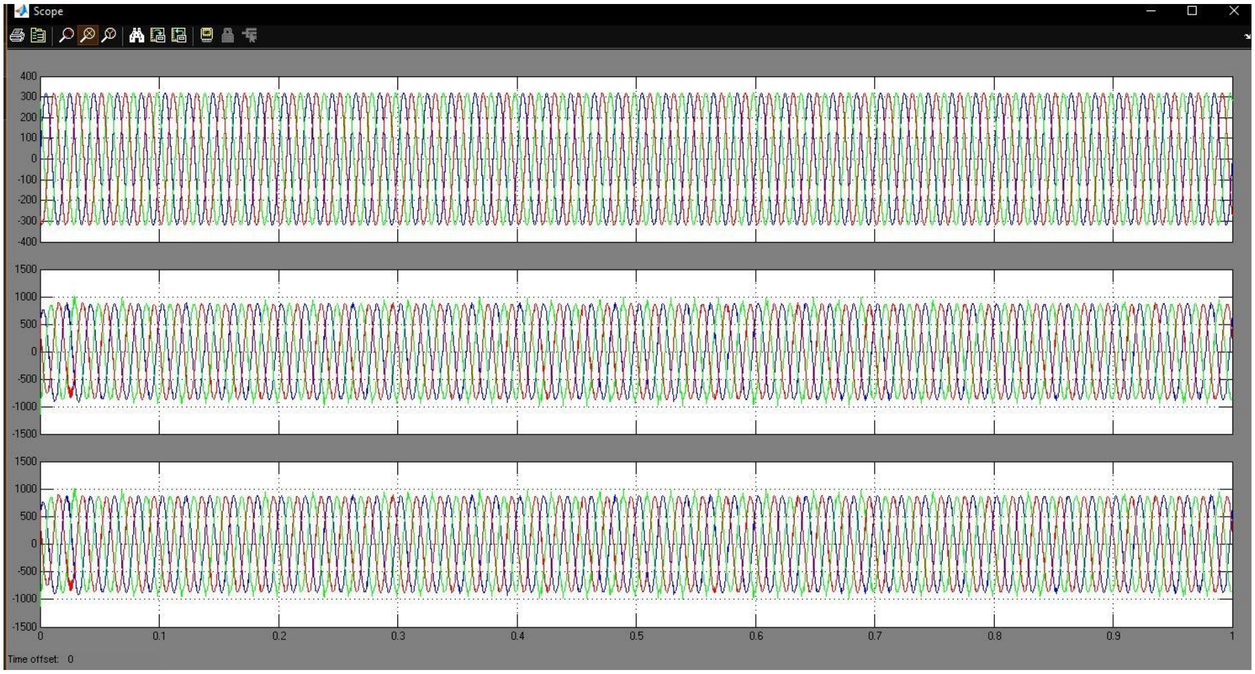
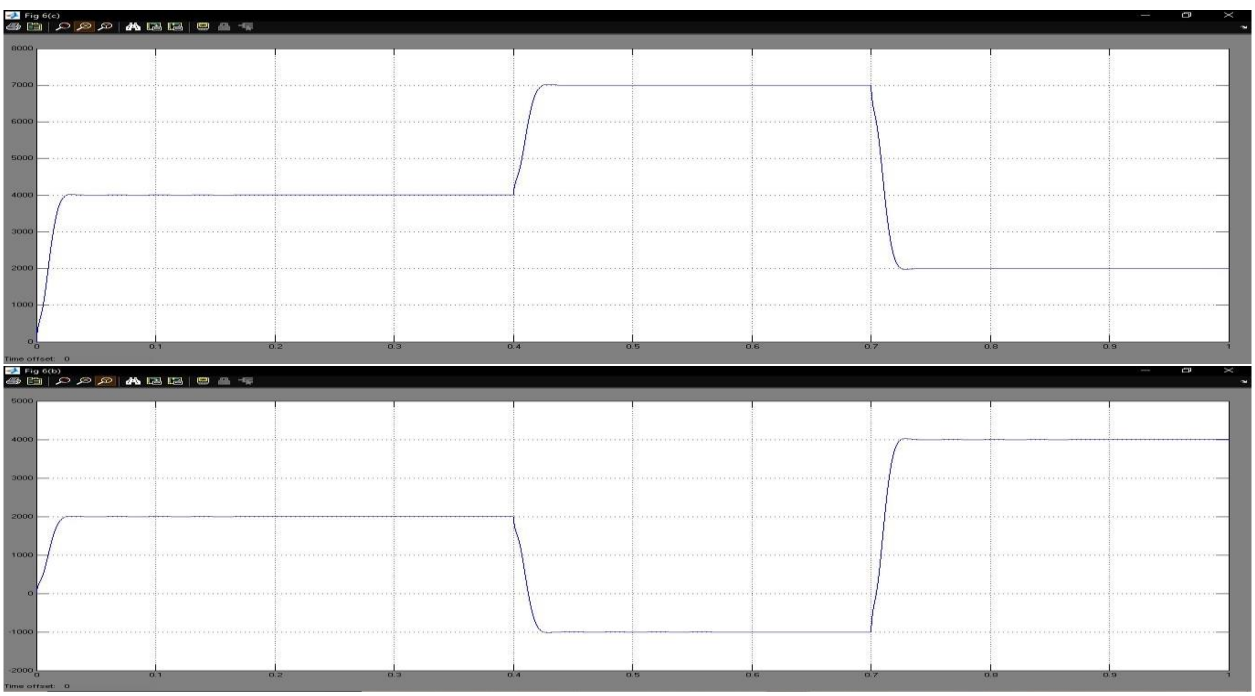


Fig. 5. Without DVSI scheme: (a) PCC voltages and (b) fundamental positive sequence of PCC voltages



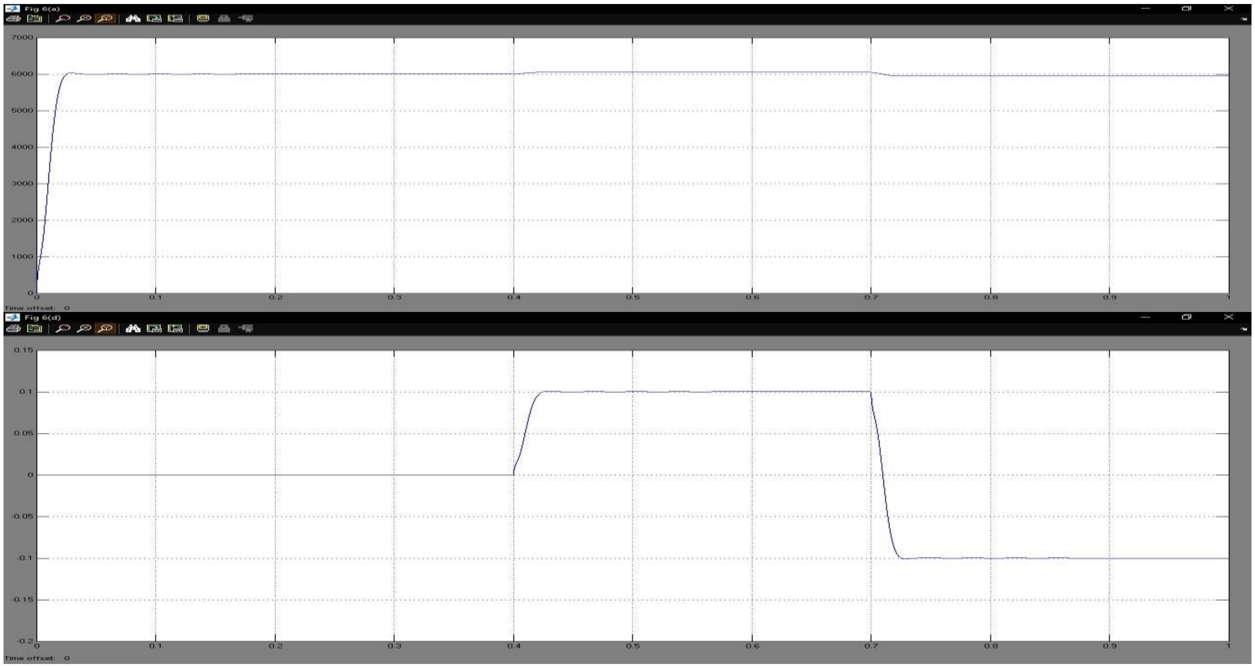


Fig. 6. Active power sharing: (a) load active power; (b) active power supplied by grid; (c) active power supplied by MVSI; and (d) active power supplied by AVSI.

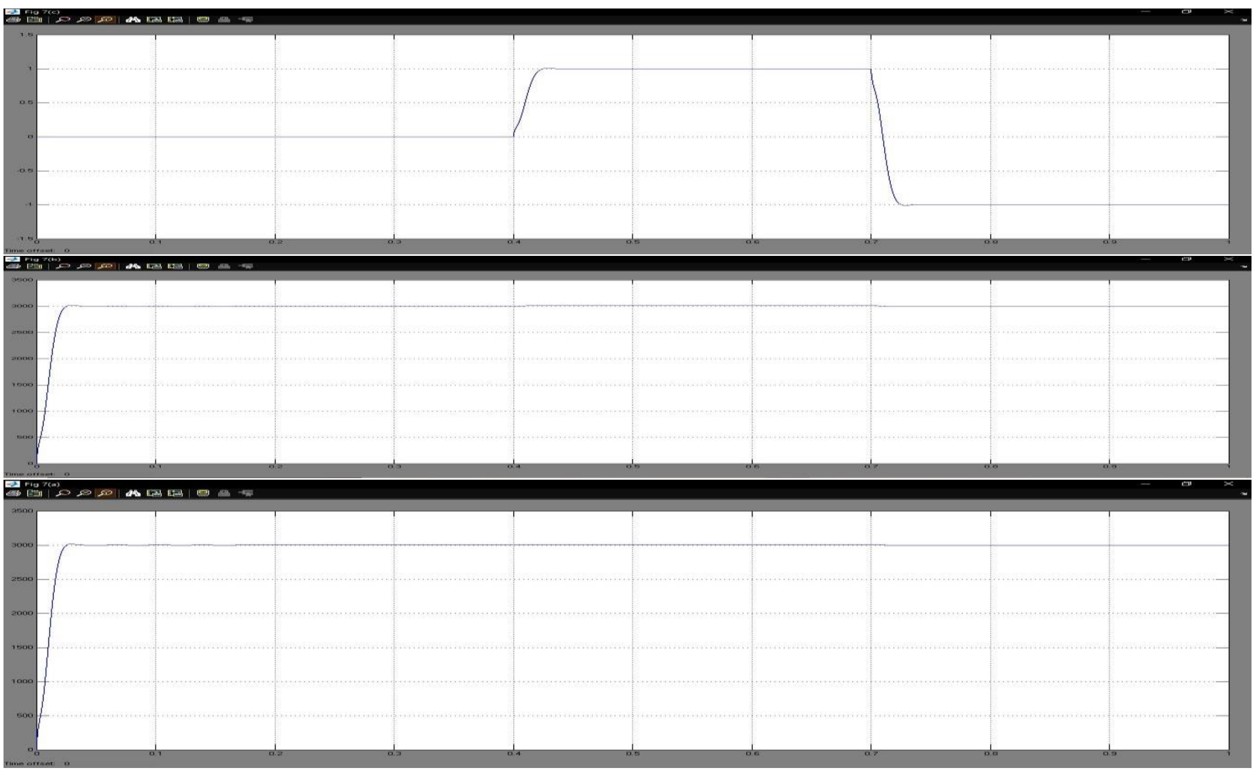


Fig. 7. Reactive power sharing: (a) load reactive power; (b) reactive power supplied by AVSI; and (c) reactive power supplied by MVSI.

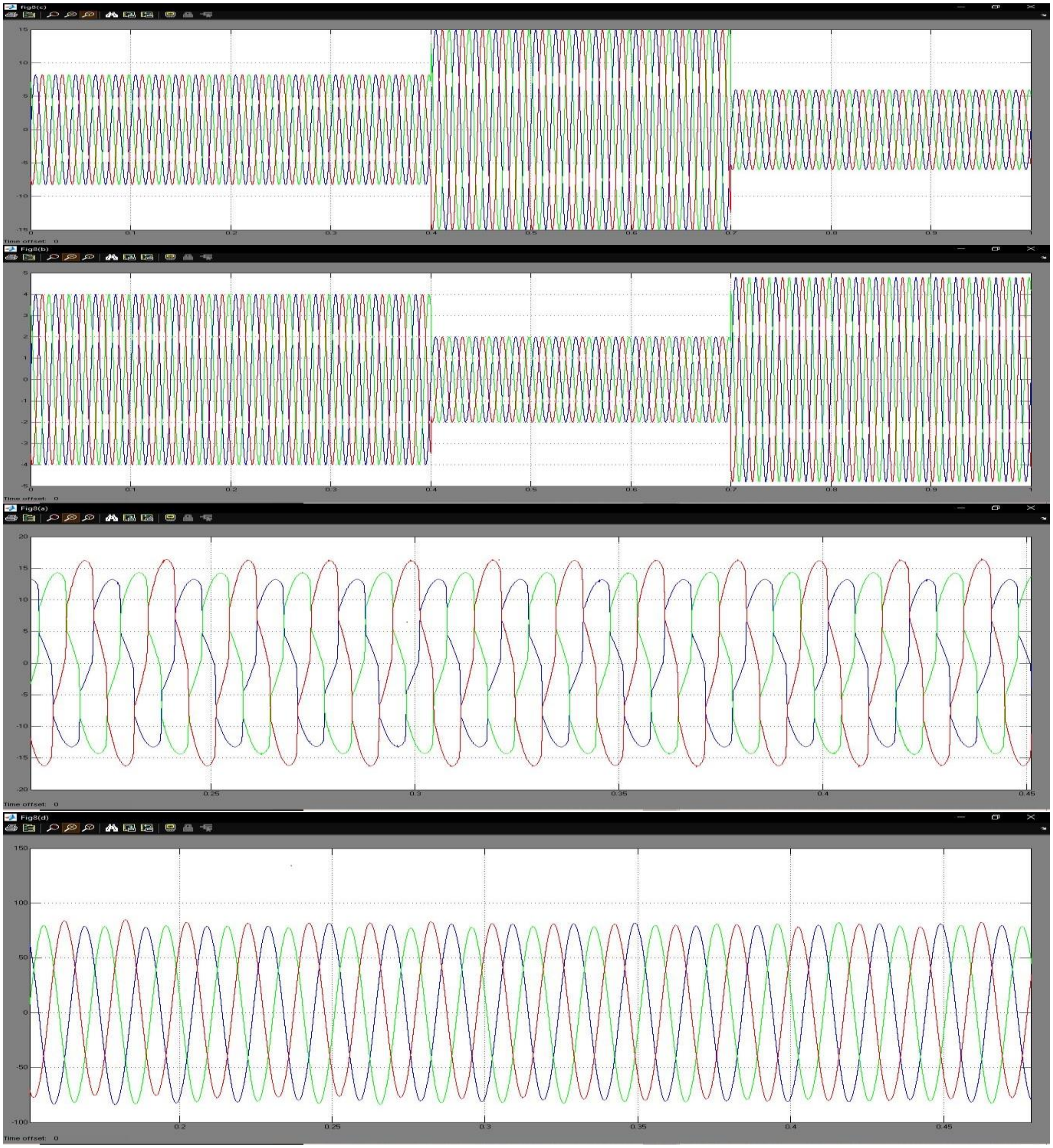


Fig. 8. Simulated performance of DVSI scheme: (a) load currents; (b) grid currents; (c) MVSI currents; and (d) AVSI currents.

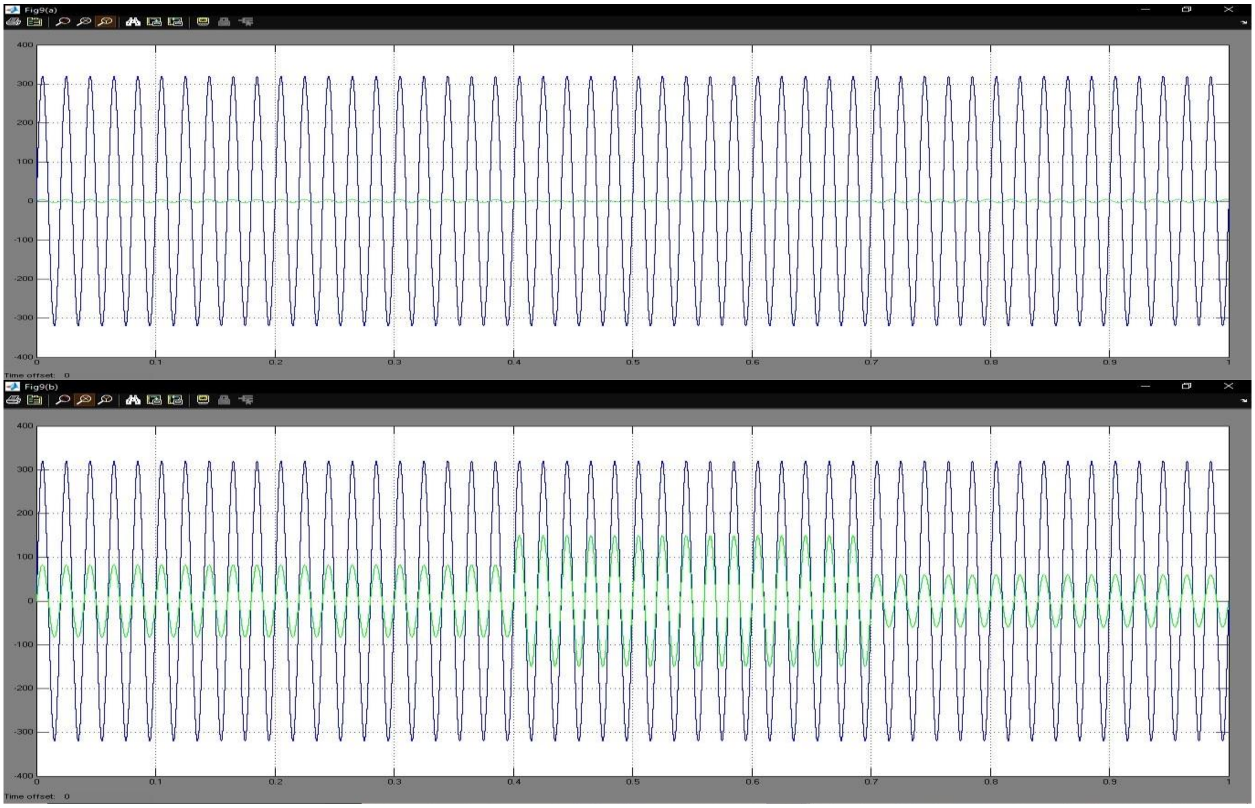


Fig. 9. Grid sharing and grid injecting modes of operation: (a) PCC voltage and grid current (phase-a) and (b) PCC voltage and MVSI current (phase-a).

VI. CONCLUSION

A DVSI scheme is proposed for microgrid systems with enhanced power quality. Control algorithms are developed to generate reference currents for DVSI using ISCT. The proposed scheme has the capability to exchange power from distributed generators (DGs) and also to compensate the local unbalanced and nonlinear load.

The performance of the proposed scheme has been validated through simulation and experimental studies. 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 microgrid. Moreover, the use of three-phase, threewire topology for the main inverter reduces the dc-link voltage requirement. Thus, a DVSI scheme is a suitable interfacing option for microgrid supplying sensitive loads.

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