Energy Optimization for Grid Management System with Dynamic Voltage Scheduling

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***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.**

***Keywords* — Grid-connected inverter, Instantaneous Symmetrical Component Theory (ISCT), microgrid, power quality. Fuzzy controller**

I. INTRODUCTION

Technology 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. The proliferation of power electronics devices and 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 [4]. 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 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 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. Control algorithms are developed by instantaneous symmetrical component theory (ISCT) to operate DVSI in grid-connected mode, while considering nonstiff grid voltage. The extraction of fundamental positive sequence of PCC voltage is done by $dq0$ transformation. 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. 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 *C*1 and *C*2. 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. 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.

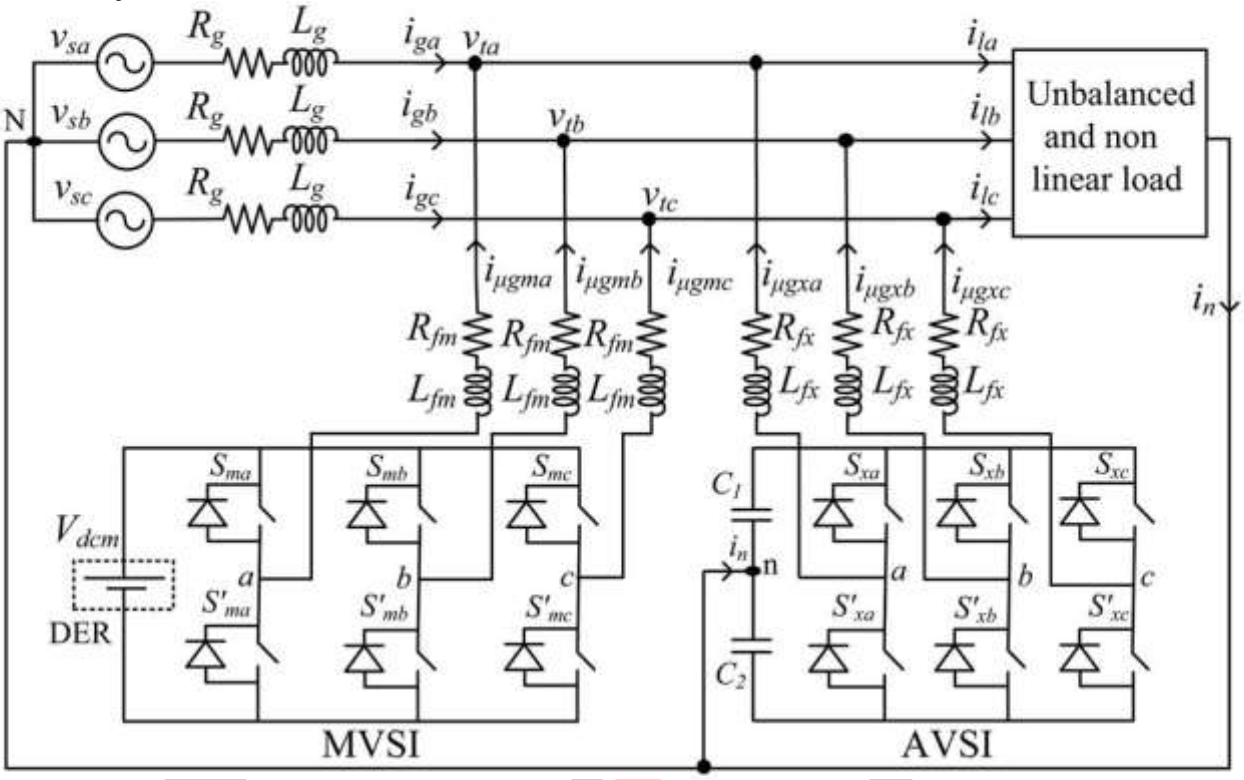

Fig.1. Topology of proposed DVSI scheme.

B. Design of DVSI Parameters

1) AVSI: The important parameters of AVSI like dc-link voltage (*V*dc), dc storage capacitors (*C*1 and *C*2), interfacing inductance (*Lfx*), and hysteresis band (±*hx*) are selected based on the design method of split capacitor DSTATCOM topology. The dc-link voltage across each capacitor is taken as 1.6 times the peak of phase voltage. The total dc-link voltage reference (*V*dcref) 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 result 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*. This energy will be equal to change in the capacitor stored energy.

C. Control Strategy of DVSI:

Control strategy of DVSI is developed in such a way that grid and MVSI together share the active load power, and AVSI supplies rest of the power components demanded by the load.

1) Reference Current Generation for Auxiliary Inverter: The dc-link voltage of the AVSI should be maintained constant for proper operation of the auxiliary inverter. DC-link voltage variation occurs in auxiliary inverter due to its switching and ohmic losses. These losses termed as Ploss should also be supplied by the grid. An expression for Ploss is derived on the condition that average dc capacitor current is zero to maintain a constant capacitor voltage [15]. The deviation of average capacitor current from zero will reflect as a change in capacitor voltage from a steady state value.

2) Reference Current Generation for Main Inverter: The MVSI supplies balanced sinusoidal currents based on the available renewable power at DER. If MVSI losses are neglected, the power injected to grid will be equal to that available at DER (Pμg). The following equation, which is derived from ISCT can be used to generate MVSI reference currents for three phases (a, b, and c) This controller has the advantage of peak current limiting capacity, good dynamic response, and simplicity in implementation.

A hysteresis controller is a high-gain proportional controller. This controller adds certain phase lag in the operation based on the hysteresis band and will not make the system unstable. Also, the proposed DVSI scheme uses a first-order inductor filter which retains the closed-loop system stability. The entire control strategy is schematically represented in Fig. 2. Applying Kirchoff's current law (KCL) at the PCC in Fig. 2

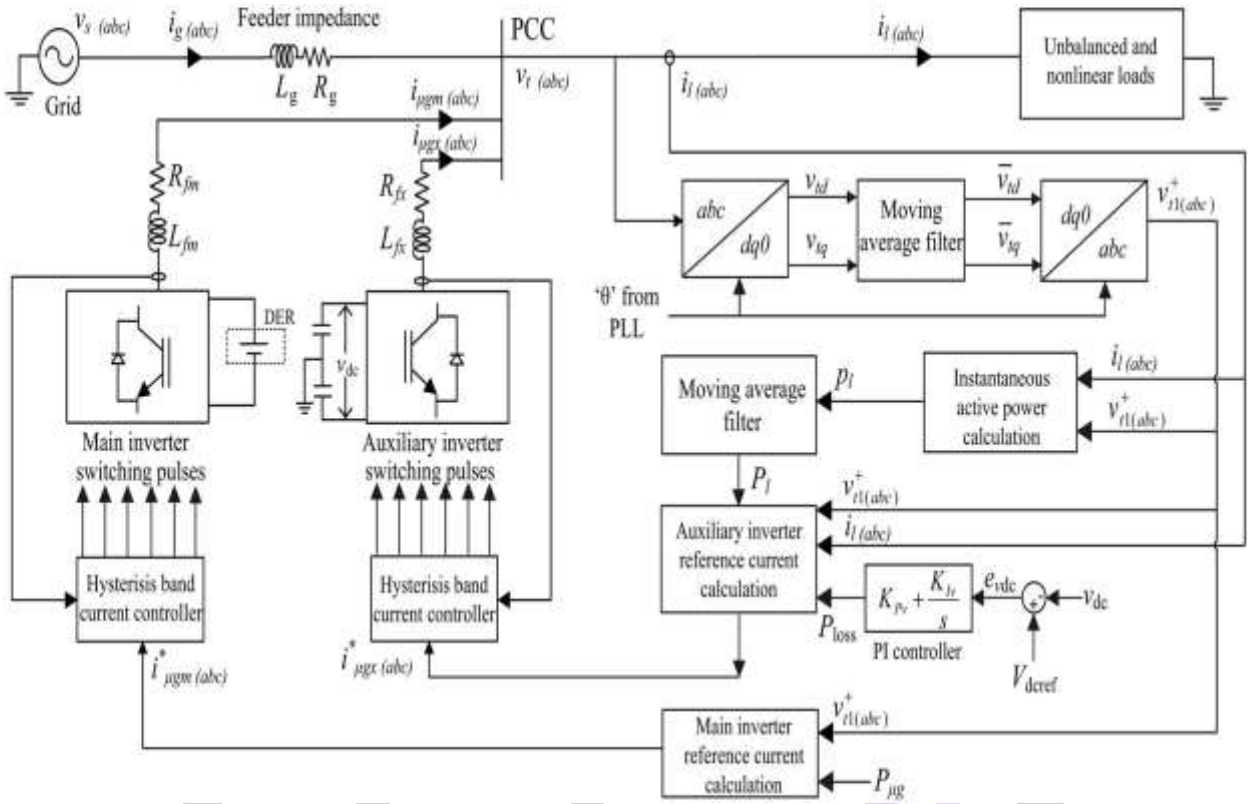

Fig 2. Schematic diagram showing the control strategy of proposed DVSI scheme.

This work exhibits the twofold voltage source inverter plan, in where the power produced by the Microgrid is imbued as honest to goodness power by the Fundemental voltage source inverter then the responsive, symphonious, uneven current compensation is achieved by assistant voltage source inverter. In the DVSI arrangement, as full power is supplied by both inverters, influence incidents over semiconductor switches of both inverters are decreased. This assembles its steadfastness when diverged from a singular inverter with multifunctional capacities. The use of two separate inverters in the proposed arrangement gives extended unfaltering quality, better use of microgrid power, lessened dc system voltage rating, less information exchange limit essential of the essential inverter, and diminished channel size. Control figurings are created by flashing symmetrical part speculation to work DVSI in grid related mode, while considering nonstiff system voltage.

TABLE I
SYSTEM PARAMETERS FOR SIMULATION STUDY

Parameter	Value
Grid voltage	415 volts (L-L)
Fundamental frequency	50Hz
Fundamental impedance	R=0.5Ω, L=1.0mH
AVSI	$C_1=C_2=2000\mu F$ $V_{dcref}=1040V$
MVSI	**Fuel cell's** Nominal operating point: 1300 V and 80A Nominal stack efficiency =65% Nominal air flow = 2100(lpm) Nominal supply pressure Fuel 1.5 (bar) , air 1 (bar) Nominal Composition H2=99.95, O2=21, H2O(Air)=1
Unbalanced linear load	Nominal voltage=400V Frequency = 50Hz Real Power = 150kW $Z_{1a}=35+j19\ \Omega$ $Z_{1b}=30+j15\ \Omega$ $Z_{1c}=23+j12\ \Omega$
Nonlinear Load	3ph diode bridge rectifier with Dc side current of 3A

III. SIMULINK MODELING OF THE PROPSED WORK

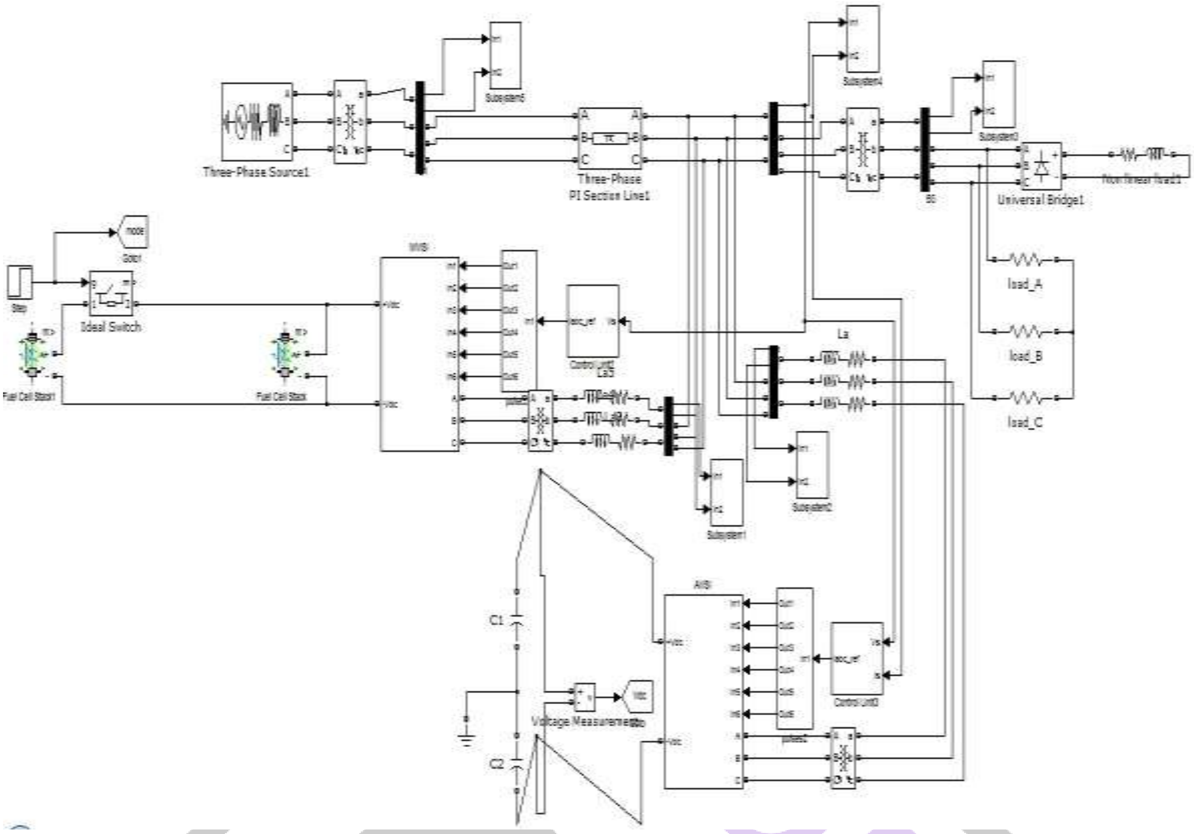

Fig 3: A Grid-Connected Dual Voltage Source Inverter model

The simulation model of Grid connected double voltage source model is shown in figure 3 which is modeled by using the MATLAB/SIMULINK software. Here in the model the double voltage source inverter is connected between the load and the grid. In the grid side the power generated is 400V and is stepped up to 33KV using the step up transformer (400/33KV), and transmitted to the load side using PI network in the system, before reaching the load it is stepped down to 400V using stepdown transformer(33KV/400V).

The 33KV voltage is tapped directly from the three phase line and is given to the MVSI (Main Source Voltage Inverter) and taking the Vs as reference and using the parkes and Inverse parke's transformation the three phase current is generated, here in the MVSI inverter switch we are using the six MOSFET switches, through these switches the gate pulses are generated. The generated Real and Reactive powers are injected to the system from MVSI. The connected ideal switch for gate pulse generation is given with the step time of 0.5seconds.

For AVSI (Auxiliary Voltage Source Inverter) also we are tapping the three phase Voltage and Current and is tapped from the three phase line and is converted using Parke's and inverse parke's transformation. Unlike in the case of MVSI here we taking the three phase current also as reference since the AVSI is concerned with the system imbalance conditions like voltage variation. Mainly Current harmonic generation, so here we considering the current also. For controlling the harmonic distortions in the systems some other control methods are used like PI controller and Hysteresis loop controller, but here we are using the Fuzzy logic controller because of its advantages, In the case of Hysteresis controller we can only predict the two states/limits of the output i.e., ON & OFF , but in the case of Fuzzy logic controller we can predict the infinite number of outputs/iterations using input signal, means we can predict the required output of the input signal by generating the error signal. As error increases, harmonic also increases in the system.

Here in the proposed system the non linear load is three phase diode bridge rectifier with DC side current of 3A. Unbalanced non linear load is three phase Resistive load with 400V nominal voltage and 150kW real power as shown in the system designe parameters table above.

IV.SIMULATION RESULTS

A. *Main Voltage Source Inverter outcomes*

The Main Voltage Source Inverter side outcomes are shown in the figure 4 and 5 respectively

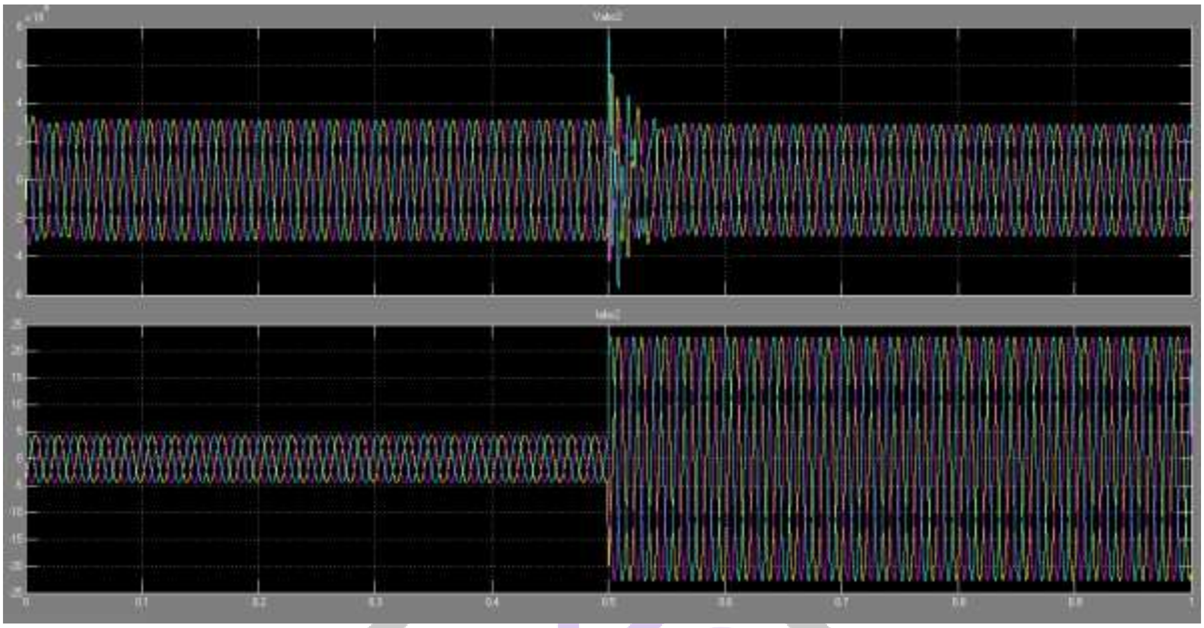

Fig 4: voltage and current outcomes of MVSI side.

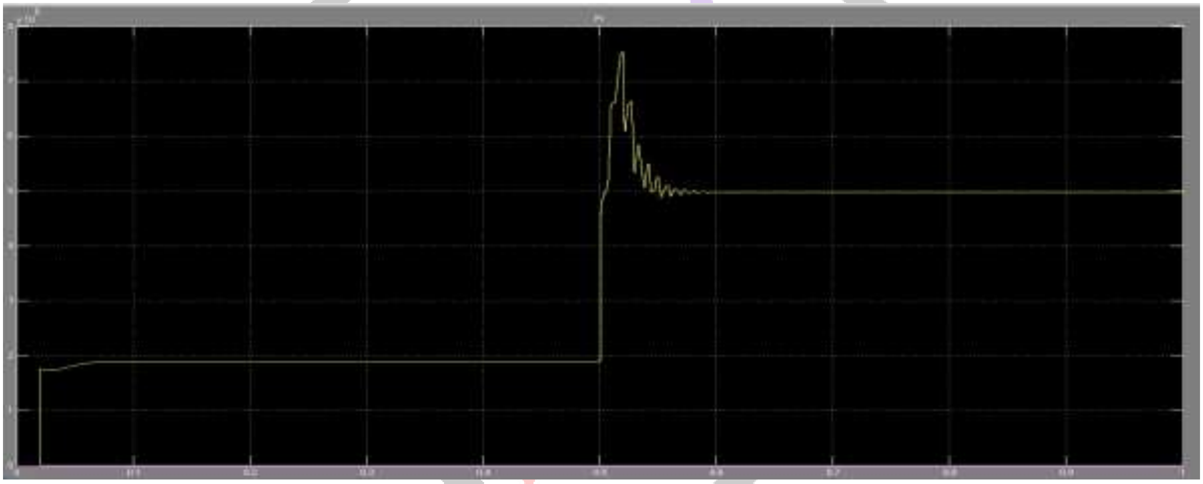

Fig 5: Power outcomes of MVSI side.

As said above the Main Voltage Source Inverter injects the Active power to the system it will increase the voltage, current and Power as shown in the figure 4 and 5 respectively as shown in the above figures. In figure 4 we can observe the current is increased to 31A from 6A and the Active power generated in the Main Voltage Source Inverter is increased to 5.5kW from 1.6kW at the time interval of 0.5 seconds and it will be constant after 0.5 seconds as shown in the figure 5 above.

This can analyzed using the subsystem 1 of the main circuit model of the work using MATLAB/SIMULINK simulation.

B. *Auxiliary Voltage Source Inverter outcomes*

The outcomes of Auxiliary Voltage Source Inverter are the main outputs of the proposed work since this work mainly concerning on the harmonic distortion/mitigation of harmonics of the system as power of the system mainly dependent on the harmonic free current and as told in this work the reactive power, harmonic distortion so on., are performed by auxiliary voltage source inverter (AVSI). So the outputs of the AVSI are the main outputs of the system.
The outputs of the AVSI are appearing in figures 6 and 7 respectively.

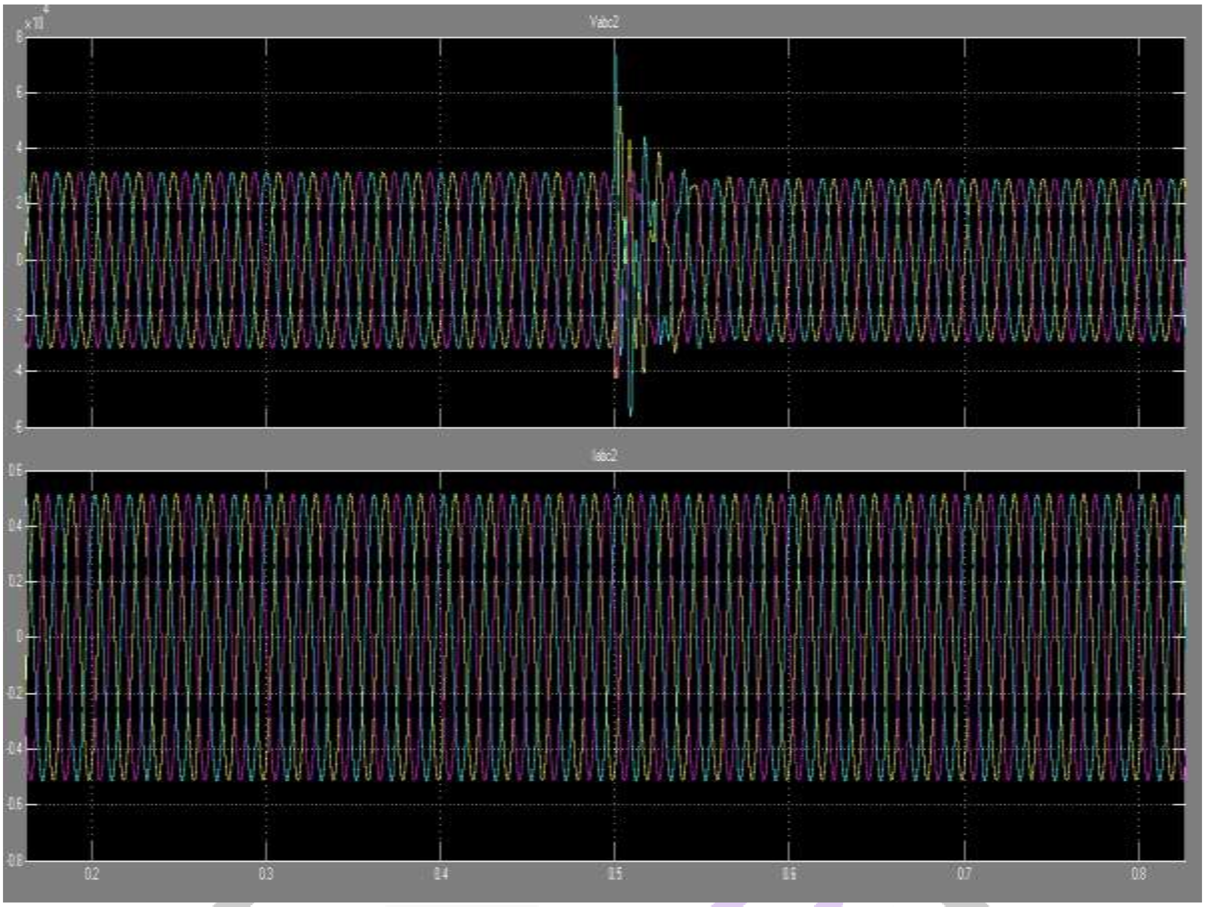

Fig 6: Voltage and Current outcomes of AVSI after Fuzzy implementation.

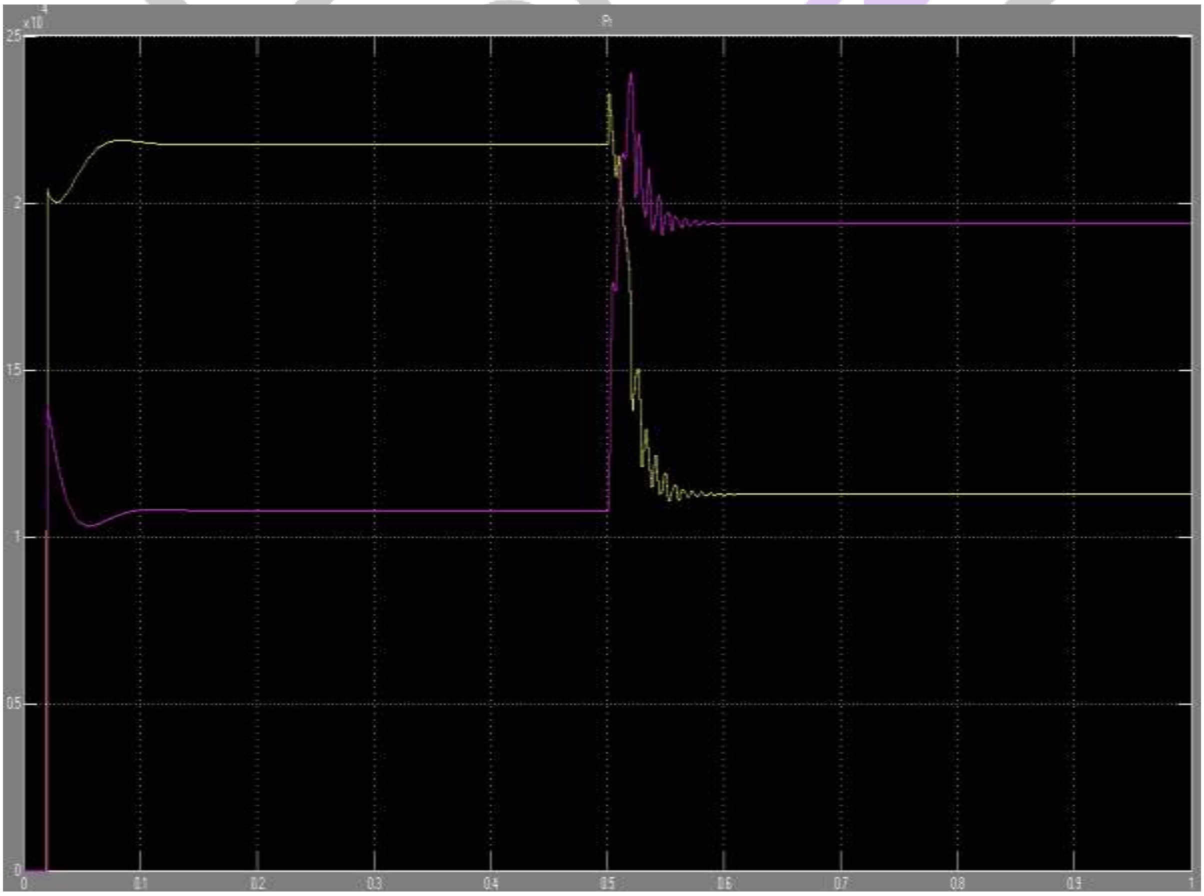

Fig 7: Real and Reactive power outcomes of AVSI after fuzzy implementation.

In figure 6 we can see that the current ie, Iabc is not distorted as in the grid side. Because of the Fuzzy logic control implemented in the AVSI to minimize the harmonics in the system which is generated due to unbalanced non linear burden at the system. So here at the AVSI the three phase current is circulating without any disturbances at 0.5 second time interval also unlike in the grid side outcomes.

In figure 7 can also see the healthy real and reactive powers flowing without distortion even after the 0.5 seconds, which is the run time interval. In figure 7 above we can observe the real and reactive powers are remain constant after the 0.5 seconds.

This can analyze in the subsystem 2 of the main circuit model of the work using MATLAB/SIMULINK simulation.

C. Graphical Representation of Harmonic mitigation Results

The graphical representation of the Harmonic mitigation results are shown in the below figures

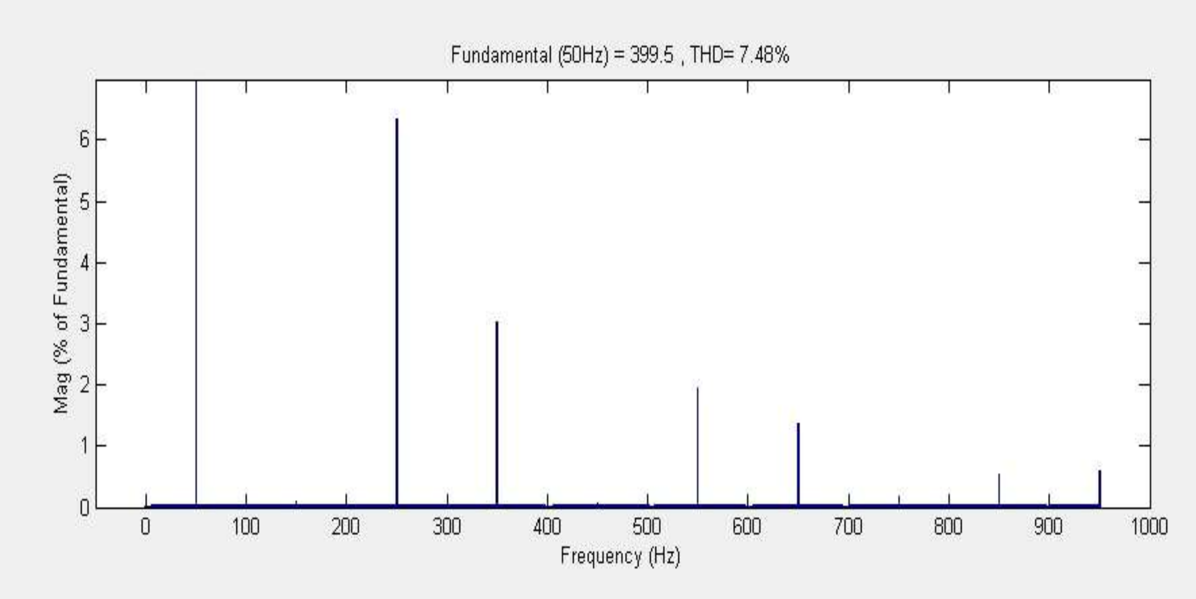

Fig 8: Graphical representation of the Harmonic mitigation before Fuzzy controller.

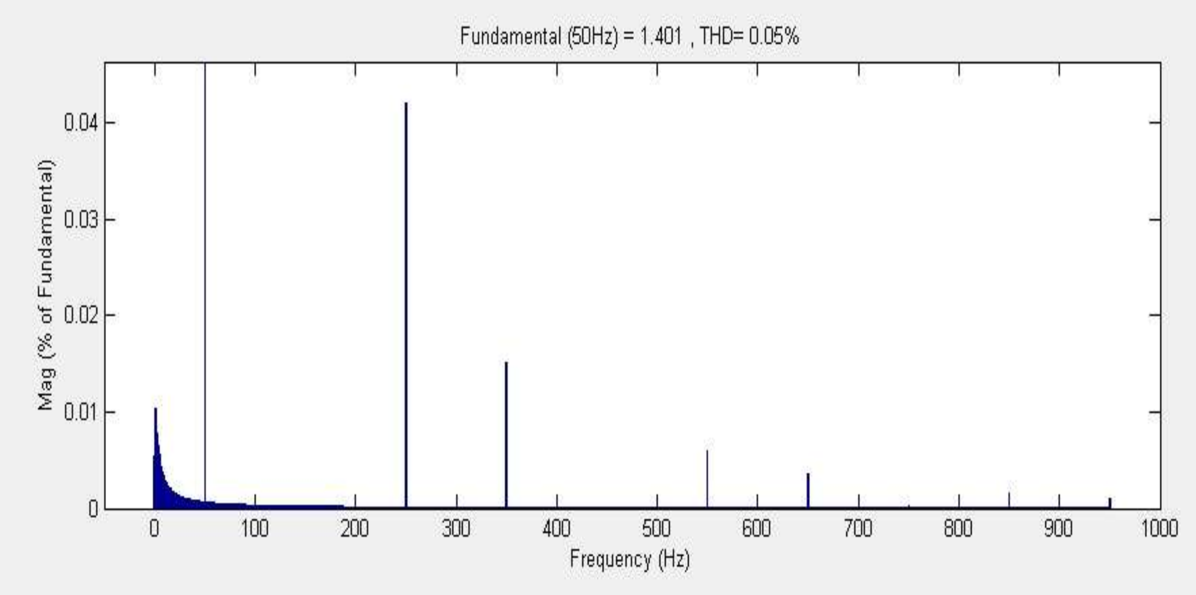

Fig 9: Graphical representation of the Harmonic mitigation after Fuzzy controller.

Figure 8 and 9 shows the graphical representation of the Harmonic mitigation before and after fuzzy controller implementation respectively. In figure 8 we can observe that the Total Harmonic Distortion (THD) is 7.48% which is not good to the system which may cause system imbalance and also subjected to decrease in the system power quality and efficiency.

Because of the much Harmonics with the absence of fuzzy controller we are implemented the fuzzy controller and we can see the graphical representation of the AVSI after fuzzy implementation and we can observe that the Total Harmonic Distortion (THD) is only 0.05% which is almost zero in figure 9. This current without harmonics can improve/enhance the system power quality using fuzzy logic controller scheme

V.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 Fuzzy logic controller for minimizing the harmonic currents in the system Thus, a DVSI scheme is a suitable interfacing option for microgrid supplying sensitive loads.

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