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Enhancement of Power Quality in Power Grid System using Dual Voltage Source Inverter

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Abstract: ***In power grid system power quality improvement plays an important role. Dual Voltage Source Inverter (DVSI) scheme is proposed to improve the aspects of Power and consistency of the micro grid system. Here we use Distributed Energy Resources (DER) for power exchange and unbalanced load compensation and nonlinear load in the system. Load sharing and power injections are done by grid interactive inverters in micro-grid. Based on Instantaneous Symmetrical Component Theory (ISCT), control algorithm is developed. For extraction of positive sequence voltage, dq0 transformation is done. An inverter connected to a 3- phase four- wire distribution combination is employed to test the managing strategy of the system. In this work we mainly focused on the assessment of overall performance of Proportional Integral (PI) controller and Fuzzy Logic Controller (FLC). Thus, the FLC provides increase in reliability, better performance of micro grid, less bandwidth requirements of inverters when compared to PI controller. The proposed system is validated by MATLAB simulation methods using PI controller and Fuzzy Logic Controller.***

Keywords: ***Dual Voltage Source Inverter (DVSI)-Distributed Energy Resource (DER)-Instantaneous Symmetrical Component Theory (ISCT). Proportional Integral (PI) Fuzzy Logic Controller (FLC).***

I. INTRODUCTION

Power grid technology and its implementation are expanding throughout the world; therefore, in realization power quality enhancement in power grid is more important. Power grid system involves transmission, distribution and generation of electricity**.** In grid non-conventional energy resources such as fuel cells, photovoltaic (PV) cell system, and wind energy system are used for power supply using power electronic converters [2][3]. Interactive inverters are used for power exchanging in grid from micro-grid to the load that connected in the grid system [1]. Power quality improvement plays an important role to ensure the realization of grid reliability, cost efficient and better utilization of system generation and transmission. Mostly FACTS devices are used for the harmonic filters in the grid system. These FACTS devices such as STATCOM, DVR, DSTATCOM etc., are used for the harmonic reduction. This may increase the system size and therefore increase the cost. Load sharing and power injection are done by using single interactive inverters have been used in present micro grid [4], [5]. In this proposed system Dual Voltage Source Inverters (DVSI) are used, where Voltage Source Inverter at generating side is utilized to introduce actual power and another Voltage Source Inverter at load side is used for reactive power, harmonics, non-linear and unbalanced load compensation are performed [6]. This used to understand the dual functionality of an inverter that to inject active power at generating side and unbalance and submissive energy reimbursement at load side is mainly focused [12]. This has more advantages of using DVSI which reduces power losses across the semiconductor switches. This increase reliability when compared to the single Voltage Source Inverters. DVSI can be operated at high switching frequency which reduces the size of filters and reduce the filter cost. In DVSI control algorithm is proposed by Instantaneous Symmetrical Component Theory (ISCT). For extraction of positive sequence component dq0 transformation is used [9], [11]. The effectiveness of system is validated through simulation result.

II. DUAL VOLTAGE SOURCE INVERTER

A. The proposed system topology

The configuration of DVSI structure is given in Fig.1. It involves two inverters each one is coupled to source and load of the system. These are linked to the grid at the Point of Common Coupling (PCC) by supplying unbalance and non-linear load of the system. To compensate the reactive power, harmonics, and unbalanced components in the load side inverter 2 is used at load side. The loads current are denoted as i_{l1}, i_{l2}, i_{l3} for three phase system. The main function of inverter 1 is employed to inject actual energy from the source which is connected to a dc-link to get supply. Split capacitor is use to supply power to inverter 2. Due to presence of feeder impedance, system is affected by harmonics. For extraction of positive sequence voltage, control strategy is done by ISCT and dq0 transformation.

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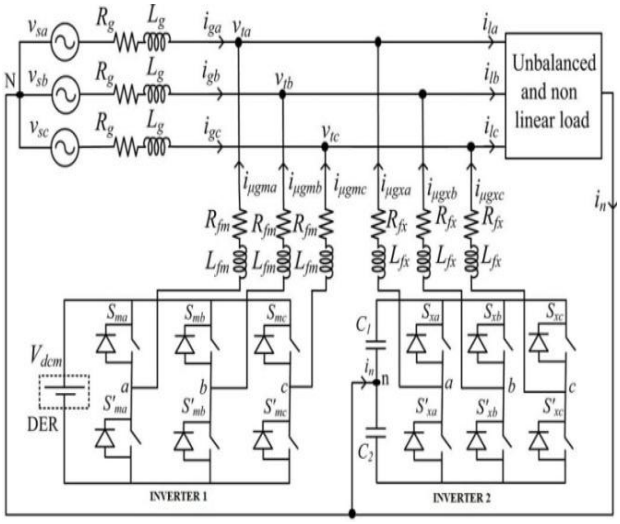

Fig.1. DVSI system topology

B. DVSI Design Parameters

1) Inverter at Source:

A three-leg topology is used for inverter1. A DC-link which is connected to inverter acts as source. At unity power factor, it supplies balanced sinusoidal current. Therefore, zero sequence switching harmonics in the output current of inverter1 will be zero. Filter requirement of inverter is reduce because of this.

2) Inverter at Load:

DC storage capacitor C1 and C2, DC-link voltage, interfacing inductance are important parameters in Inverter 2. By using the charges in DC-link voltage values of DC capacitors are chosen. From [1] let the total load rating is S kVA. To maintain the energy demand during transient formation Inverter 2 need to exchange the real power. From its reference value it results in deviation of capacitors voltage. We assume that n cycles for voltage controller i.e., nT seconds, here T is the periodic time of network. Change in capacitor power is equal to Maximum power exchange on inverter 2

Therefore

$$\frac{1}{2} \quad C1 \quad (Vd_{cr}^2 - \quad Vd_{c1}^2) \quad = \quad nST \qquad (1)$$

Where Vd_{cr} is reference DC voltage and Vd_{c1} is maximum permissible DC voltage across capacitor C1.This is similar to C2.

III. ICONTROL STRATEGY

A. Instantaneous Symmetrical Component Theory:

Instantaneous current in three phase is defined by i_a, i_b, i_c, therefore power in variant instantaneous symmetrical component are then defined by

$$\begin{bmatrix} i_{a0} \\ i_{a1} \\ i_{a2} \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (2)$$

Where $a=c^{j120'}$

Here ia0 is refer to a real quantity which is zero if line current is balanced and ia1, ia2 are complex conjugate.

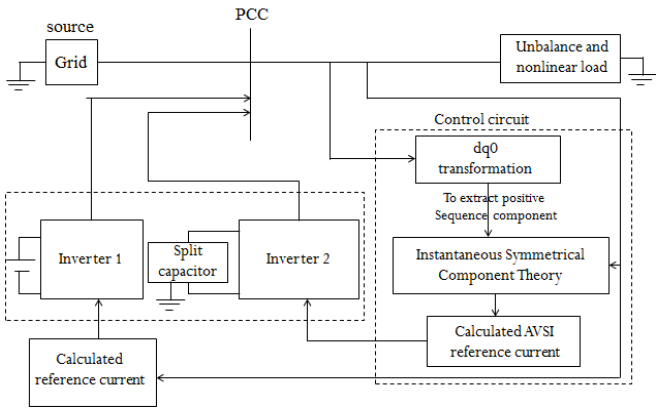

Fig.2. Block Diagram of DVSI Scheme

ISCT was developed preliminary for unbalanced and nonlinear compensation by active power filters for load compensation is based on following conditions,

Let i_{sa}, i_{sb}, i_{sc} are load current in phase a, b, c.

First condition is that neutral current must be zero after compensation

$$i_{sa}+i_{sb}+i_{sc}=0 \qquad (3)$$

The phase angle and current are used to control the reactive power deliver from the source, which is given as

$$< (v^+_{sa}(t))=<(i^+_{sa}(t))+\boldsymbol{\Phi}^+ \qquad (4)$$

Finally the foundation need to supply average load strength (P_l)

$$V^+_{sa}i_{sa}+ V^+_{sb}i_{sb}+ V^+_{sc}i_{sc} = P_l \qquad (5)$$

By solving these equation we get

Reference current as follows:

$$i_{refa}= \left(\frac{v^+_{sa}+\beta(v^+_{sb}-v^+_{sc})}{\Sigma j=a,b.c\ v^+_{sj}}\right)P_l \qquad (6)$$

$$i_{refb}= \left(\frac{v^+_{sb}+\beta(v^+_{sc}-v^+_{sa})}{\Sigma j=a,b.c\ v^+_{sj}}\right)P_l \qquad (7)$$

$$i_{refc}= \left(\frac{v^+_{sc}+\beta(v^+_{sa}-v^+_{sb})}{\Sigma j=a,b.c\ v^+_{sj}}\right)P_l \qquad (8)$$

Where, $\boldsymbol{\beta}=\frac{\tan\Phi}{\sqrt{3}}$

Here $\boldsymbol{\Phi}$ is the phase attitude among current and fundamental high-quality sequence voltage. For unity power factor, assume $\boldsymbol{\beta}$=0. Therefore, reference current for three phases is given by

$$i_{ref(abc)} = \left(\frac{v^+_{sa}(abc)}{\Sigma j=a,b.c\ v^{+2}_{sj}}\right)P_l \qquad (9)$$

P_l is computed as below,

$$P_l = \frac{1}{T}\int_{t1-T}^{t1}(v^+_{sa}i_{la} + v^+_{sb}i_{lb} + v^+_{sc}i_{lc})\,dt \qquad (10)$$

T1 is arbitrary time constant

Finally, reference current is generated by the compensator is

$$i_{f(abc)}= i_{l(abc)}- i_{ref(abc)} \qquad (11)$$

B. dq0 Transformation:

dq0 transformation is used for balanced voltages in the system. The reference voltages (V_{refa}, V_{refb}, V_{refc}) are first transformed into dq0 reference frame is given by

$$\begin{bmatrix} V_{refd} \\ V_{refq} \\ V_{ref0} \end{bmatrix} = C \begin{bmatrix} V_{refa} \\ V_{refb} \\ V_{refc} \end{bmatrix} \qquad (12)$$

Here,

$$C = \begin{bmatrix} sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}$$

A modified synchronous reference frame is used Ito get θ,. In reference frequency ω_0 and some frequency deviation are added to get θ. From Park's transformation, it has proved that $\theta = \omega_0 t$. Average and oscillation components arecontained in the transformed voltages, which are given as,

$$V_{refd}=\bar{V}_{refd}+\tilde{V}_{refd},\ V_{refq}=\bar{V}_{refq}+\tilde{V}_{refq} \qquad (13)$$

Where $\bar{V}_{refd}$, $\tilde{V}_{refd}$are average and oscillation components for d- axis, $\bar{V}_{refsq}$,$\tilde{V}_{refq}$are average and oscillation components of q-axis. The successive positive voltages are taken from the inverse dq0 transformation were is given by

$$\begin{bmatrix} V^{+}_{refa1} \\ V^{+}_{refb1} \\ V^{+}_{refc1} \end{bmatrix} = C^{T} \begin{bmatrix} \bar{\bar{V}}_{refd} \\ \bar{\bar{V}}_{refq} \\ 0 \end{bmatrix} \qquad (14)$$

For balanced sinusoidal voltage V^{+}_{refa1} ,V^{+}_{refb1} ,V^{+}_{refc1} are used as algorithm for the reference current generation.

C. *Proportional* Integral (PI):

PI controller, limiter, and three phase sine wave generators are used for switching signal production and reference current production. The DC link capacitor compare reference voltage with new capacitor voltage and the error signal is given to the PI controller. The By tracking the reference signal PI controller advances to zero steady error. I_{max} is considered as the result of the controller which is the highest value of supply current. The I_{max} is multiplied with source voltage to obtained the reference compensating currents. These estimated currents are, I^*_{sa}, I^*_{sb}, I^*_{sc} and real current are I_{sa}, I_{sb}, I_{sc} which are correlated at hysteresis band, that yields the error signal. The output of this hysteresis band is used to getting signal which controls converter switches. This signal is used to compensate the generated current.

D. Fuzzy Logic Circuit (FLC):

In DVSI, the DC capacitor voltage is sense and correlated with a referral value. If it has an error then obtained error is given as

$$e(c)= V_{dc,ref}(n) - V_{dc,act}(n) \qquad (15)$$

Therefore, change in error

$$ce(n)= e(n) - e(n-1) \qquad (16)$$

At nth sampling instant are taken as inputs for fuzzy processing. By tracking reference signal the error signal is handled through Fuzzy Logic Controller (FLC), to get zero steady error. The output of the FLC is reviewed as I_{max} which is highest value of supply current. I_{max} is used as generated reference current and then through them generating signals are generated. The FLC essential segments are

1. Fuzzification.
2. Interference.
3. Defuzzification.

IV. SIMULATION MODEL

In Fig. 3 the simulation model for DVSI scheme is given the simulation model for DVSI scheme is given. Using MATLAB simulation R2015a. Steady state of DVSI scheme is evaluated the grid sharing and grid injection operation by this. The voltage and current waveform with a normal load voltage of 33kV with a variation of 110% and 120% are shown in the figures 4 and 5 with respective Fault Frequency Transient analysis.

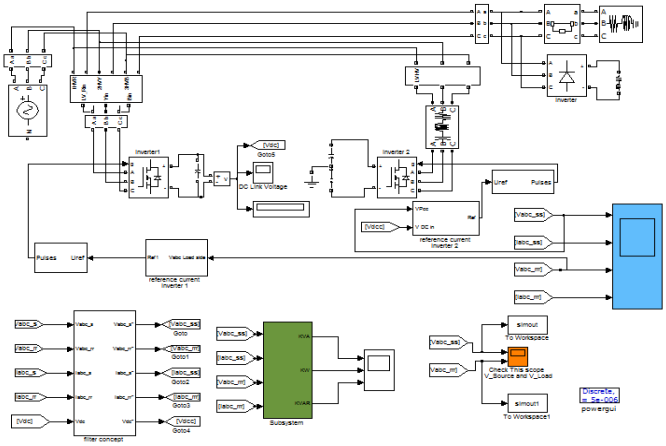

Fig.3 Simulation diagram for proposed DVSI scheme.

For various variations the current and voltage are finally compensated at the load using DVSI scheme using both PI controller and FLC for harmonic reduction.

Table 1. System Parameters

S.NO	PARAMETERS	VALUES
1	Main Supply Voltage	11KV
2	Line Frequency	60Hz
3	Line Impedance	R=1Ω , L=1mH
4	Fault Resistance	0.66Ω
5	Transition time	12/60 to 24/60
6	Filter Inductance	3.3-4.6mH
7	Filter Capacitance	4700-5600µF
8	FLC type	Mamdani
9	MF of FLC	3×3 triangular
10	Implication of FLC	Min
11	Defuzzification	centroid

A. Normal Load Condition:

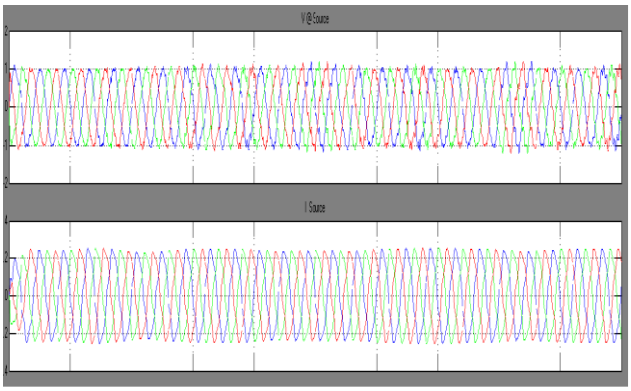

Fig.4a. Simulation waveform voltage and source current at normal load without compensation

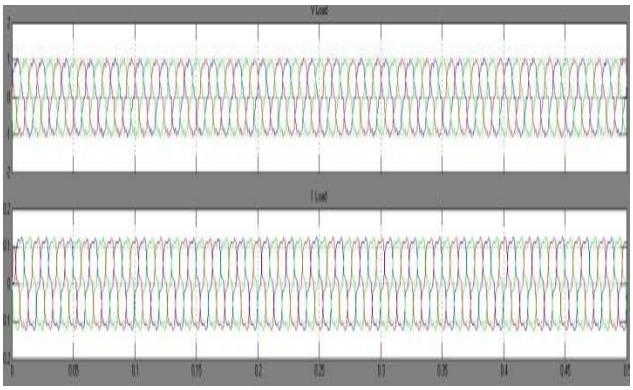

Fig.4b. Simulation wave form for biased voltage and current with PI controller

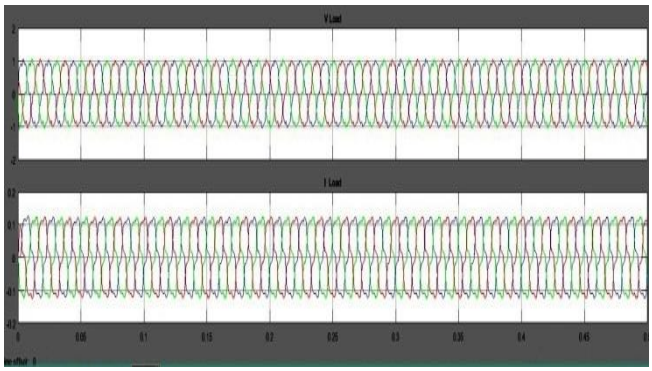

Fig.4c. Simulation wave form for biased voltage and current with FLC

Here figure 4a, 4b, 4c shows the simulation outcomes of voltage and load current without compensation for normal conditions and with PI and FLC controllers respectively and below graphs are used to explain FFT analysis of these conditions.

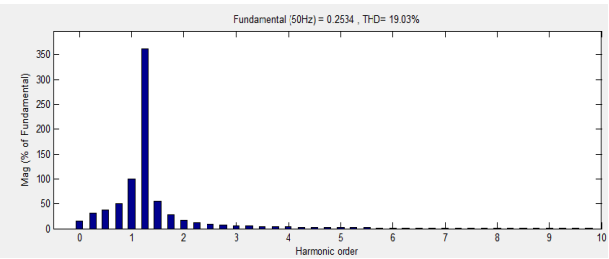

Fig.5a. FFT analysis for normal load without compensation

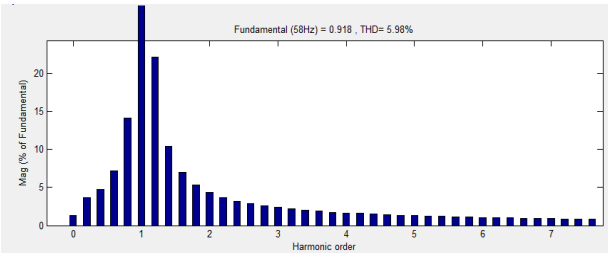

Fig. 5b. FFT analysis for normal load with PI Controller

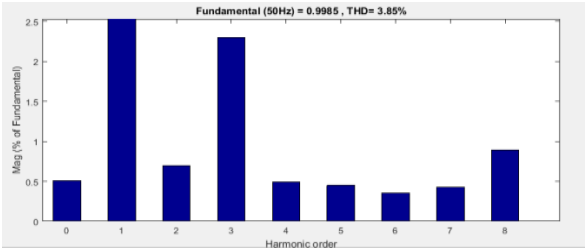

Fig. 5c. FFT analysis for normal load with Fuzzy Logic Controller

E. 110% Increased in Load Condition

The below figures show the voltage and current levels for 110% at normal condition and with PI and FLC controllers respectively.

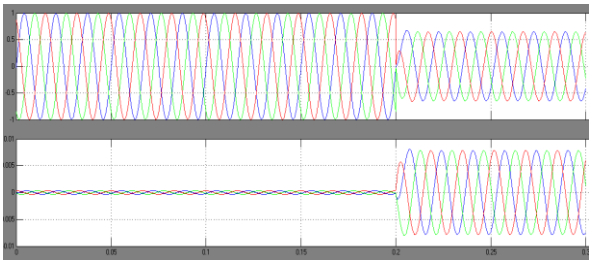

Fig.6a voltage and current for 110% variation without compensation

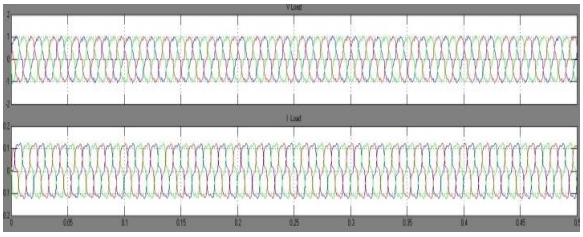

Fig.6b. voltage and current waveform for 110% with PI Controller

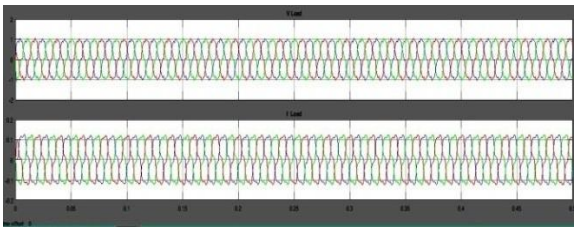

Fig.6c. voltage and current waveform for 110% with FLC

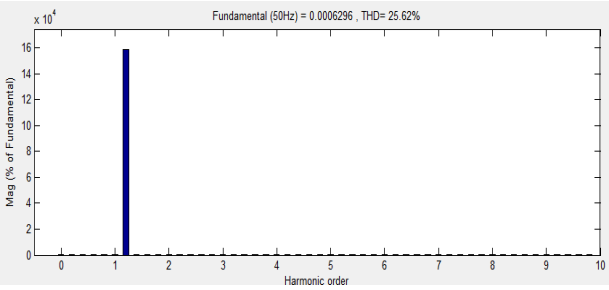

Fig.7a. FFT analysis for 110% variation without compensation

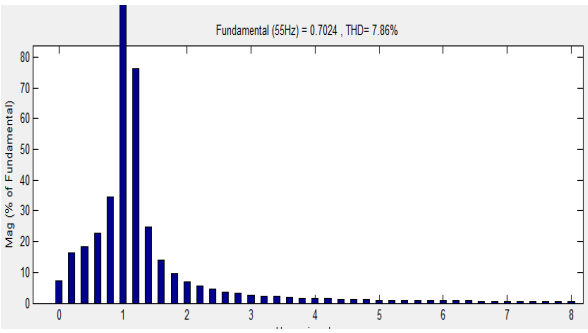

Fig. 7b. FFT analysis for 110% variation with DVSI scheme compensation

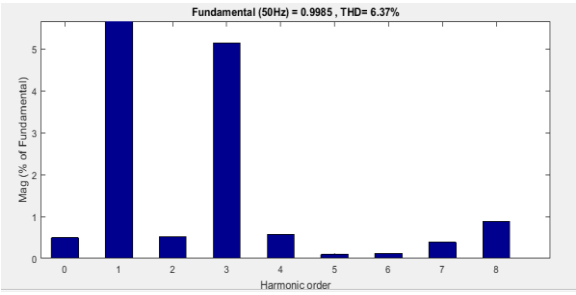

Fig.7c. FFT analysis for 110% variation with FLC

Table 2. Comparison of THD for different loads

S. NO	LOAD CHARACTERISTICS	THD(%)		
		WITHOUT CONTROLLER	PI	FUZZY
1	100%	21.89	5.09	3.85
2	110%	32.86	7.86	6.37
3	120%	39.03	9.33	8.08

C. 120% Increased in Load Condition

These figures show the voltage and current waveforms of 120% compensation.

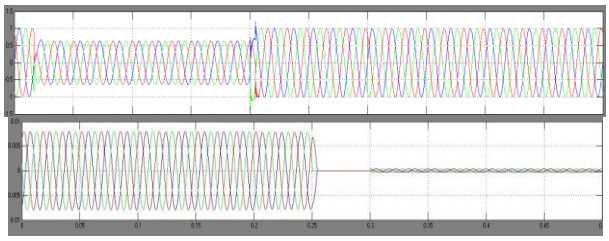

Fig.8a. voltage and current waveform for 120% variations without Compensation

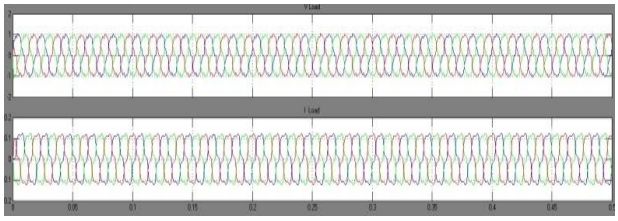

Fig. 8b. Voltage and current waveform for 120% variation with PI controller

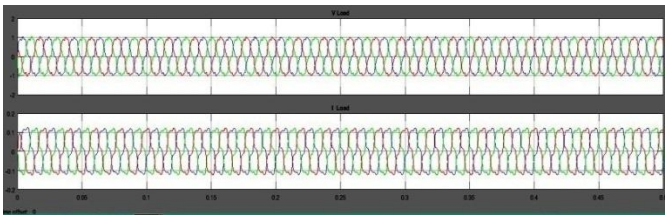

Fig. 8c. Voltage and current waveform for 120% variation with FLC

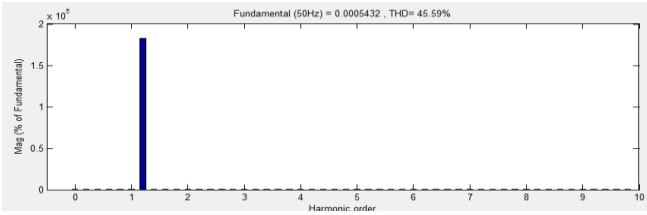

Fig. 9a. FFT analysis for 120% variation without compensation

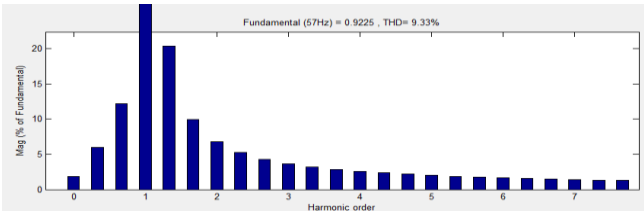

Fig.9b. FFT analysis for 120%variation with PI controller

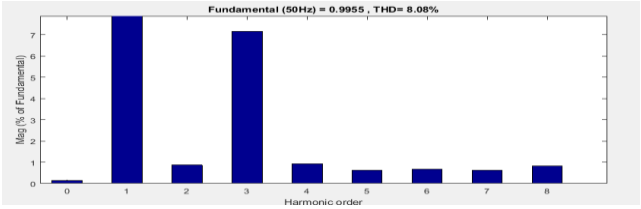

Fig.9c. FFT analysis for 120%variation with FLC

Here the table 2 shows the comparison of THD for different loads without controller and with PI and FUZZY mode. Thus, the load side inverter used at the load side is thus used for the compensation of the reactive power, harmonics and unbalanced components.

V. VARIOUS RESULTS

The DVSI operating apparatus employs voltage angle control as follows: an fault signal is attained by correlating the referral voltage with RMS voltage standardized at the load point.

Table 3. Error comparison table

S.NO	LOAD CHARACTERISTICS	THD%	
		PI	FUZZY
1	100%	76.74	24.36
2	110%	76.07	18.95
3	120%	76.95	13.93

The diverse virtual phase lock-loop (PLL) is utilized to attain the angle θ of the resource voltage. The findings abstracted from the PLL is hooked for diagnosis and referral voltage production. For various variations, the current and voltage are finally compensated at loads like 100%, 110% and 120% using DVSI scheme, with both PI controller and FLC for harmonic reduction. The above table 3 shows percentage error comparison of PI controller and FLC controller, where FLC has better results. Figure 10 and figure 11 clearly depicts the percentage of error comparison and THD comparison from where we get a conclusion of FLC has better results when compared with other modes.

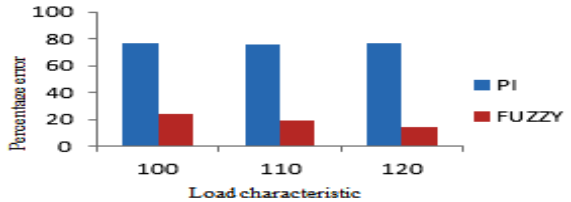

Fig.10 Percentage error comparison

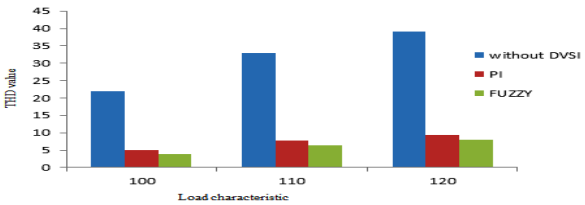

Fig.11 THD comparison

Voltage and current statistics

Table 4. Voltage and current statistics table

S NO	CHARACTERSTICS	VOLTAGE (p.u)		CURRENT (p.u)	
		PI	FUZZY	PI	FUZZY
1	100%	1	1	1	1
2	110%	0.982	1	0.98	1
3	120%	0.973	1	0.982	1

Here table 4 shows the voltage and current stability with load variations of 100%, 110% and 120% for PI and FUZZY controllers. As compared to PI controller, FLC has better results in harmonic reduction.

VI. CONCLUSION

In this DVSI scheme, power quality enhancement and durability of the micro-grid structure is propounded. ISCT is developed for the control algorithms. dq0 transformation is utilized to abstract positive series of voltages. In comparison to PI controller, Fuzzy Logic Controller has more phenomenal harmonic reduction. The proposed DVSI scheme with Fuzzy Logic Controller has many advantages such as increase in reliability, reduction harmonics and reduced system cost. The proposed scheme is validated through MATLAB simulation. Thus DVSI scheme is suitable for power quality improvement for sensitive load.

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