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Improvement of Power quality in Distribution System fed by a Fuzzy Controller based converter

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Abstract: This paper presents the distributed generating (DG) systems employed in distribution systems interfaced by design of proportional-integral controller (PI) and fuzzy logic controller (FLC) based 3-phase power converter. To maintain smooth transfer of power flow in distribution systems for different load conditions, the step-up converter must regulate its DC voltage and allows the VSI to stabilize terminal voltage. The power flow between the grid and the DG is controlled by the power /voltage control methods and phase-locked loop (PLL) algorithm is used to synchronize the grid and the DG.
Additionally, a set of simulations are performed for different load types and its working conditions by using fuzzy logic controller and compared with classic PI controllers. The system is designed and simulated using MATLAB/ Simulink Software.

Index Terms: distributed generating (DG), fuzzy logic controller (FLC), islanding mode,3-phase power converter, phase-locked loop (PLL), proportional-integral controller (PI),and voltage source inverter (VSI).

1. INTRODUCTION

Many developing countries are now widely recognised that the fossil fuels and other resources that are presently used in generation of electrical energy, may not be sufficient or suitable as a solution to the growing problems of energy demand [1].As the load demand increases the complexity of the distribution network increases thereby, maintain power flow and voltage becomes complex in the radial distribution network.

Apart from the consequent reduction in size of generating plants and complexity of distribution network, The Distributed Generation is a new trend that emerges for providing electric power as required for the demand [2]. These DG systems based on renewable energy resources [2] such as (photo voltaic, wind energy and fuel cells [1]) are well encouraged because of their low environmental impact and high technical advantages such as improvement in voltage levels and reduction in power losses, when these DG systems are installed in radial distribution lines[4].

The DG systems are installed in the grid, and then the distribution system becomes an active system with both energy generation and consumption, the DG must supply locally and its working regime .The DG operates at high performances requires a detailed evaluation of feeder [5] in which it is installed and along with the assessment of load type. Without this analysis the insertion of DG into the distribution system causes inevitable effects such as transient effects due to switching operations, changing in short-circuit levels, lower margin of stability, inversion of power flow through the system and islanding a part in the system [6].

The DG operation should be in the limits established by the international standards for the following parameters: harmonic distortion, voltage imbalance, voltage fluctuations, and fast transients, and whether the load is linear or non-linear.

The DG systems are installed in the grid by interfacing with the power converter, the power fed from DG is converted into AC and the operation of the system is done by maintaining the DC link voltages. This voltage control provides the capability to supply different kinds of loads (such as linear, non-linear it may be balanced or un-balanced loads) to the DG systems. The power flow in the DG fed system is determined by controlling the voltage amplitude and angle of displacement between the DG voltage and the grid voltage.

This paper analyses the effects caused by the DG sources inserted into the distribution system by different loads considered. Section II details the components in the system considered. Section III explains the synchronization of DG with grid. Section IV details the Fuzzy logic controller Section V shows the simulation analysis for different cases and Section VI presents the conclusion.

Figure 1 shows the diagram of the system interfacing DG systems into a specific feeder in the grid through a 3-phase power converter.

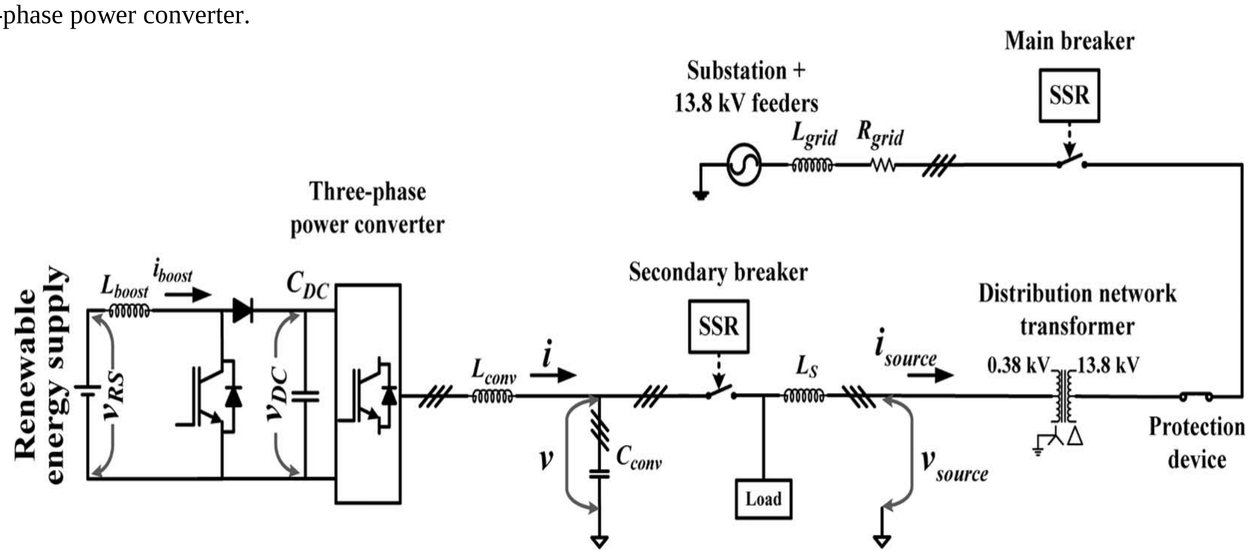


Fig: 1General Diagram of the Distributed Generation System.

1. COMPONENTS IN THE SYSTEM

A. DG System :

The DG systems based on renewable energy resources are used to generate power and these are installed directly into the grid, nearer to load in order to share the load demand with the utility. The DG system of 5000kVA capacity is connected to a specific feeder in the distribution network through a power converter. Here the DG systems represent a secondary source, while the grid system is primary.

B. Grid System :

In the simulations the complete system, considering DG and the grid is found in 1547 standards [7] developed by the Institute of Electrical and Electronics Engineers (IEEE). This standard is the primary interconnection standard; the approval of this standard should influence the electrical distribution system to operate with distributed generators and two-way flow of electric energy.

The main grid system considered is a 13.8-kV feeder connected to 69-kV radial line through a 69/13.8-kV transformer, as shown in the above Fig.1.In order to insert the DG in the distribution network, a 13.8/0.38 kV distribution network transformer is required to equalize the voltage levels in the grid.

In the simulations, the line model employed is taken into account the Bergeron's travelling wave method, used by the electromagnetic transient program (EMTP). This method is used for constructing transmission lines, which utilizes wave propagation phenomenon and line end reflections.

C. 3-Phase Power Converter:

The power obtained from different DG's can be used to fulfil the requirements for many applications. The applications differ according to the load requirements, and the conversion of DG output is done through the power electronics interface between the DG and the grid. Here a 3-phase power converter considered is a two stage converter.

1. DC-DC Converter:

The DC-DC step up converter equalize the dc-link voltages, it is used as an interface between the dc source and the dc link of the three phase power converter. The converter diagram is as shown in the Fig 2. It improves the dc voltage and supplies fast transients of energy, and thereby minimizes the disturbances in the feeder current.

This converter acts as a dc voltage source and the power it delivers is depends on the method of tracking maximum power point (MPPT)[8]of a photo voltaic array, is an essential part of a PV system.

2. DC-AC converter:

The voltage source inverter (VSI) acts as a DC-AC converter, it is used to guarantee the power quality delivered to customers and the feeder it is fed. To avoid the disturbances between the converter and the feeder, a phase –locked loop (PLL) algorithm is used.

The block diagram of the DC-AC converter is as shown in the Fig 3.The closed-loop controls of the output current and voltage were implemented in order to guarantee inverter voltage quality. The

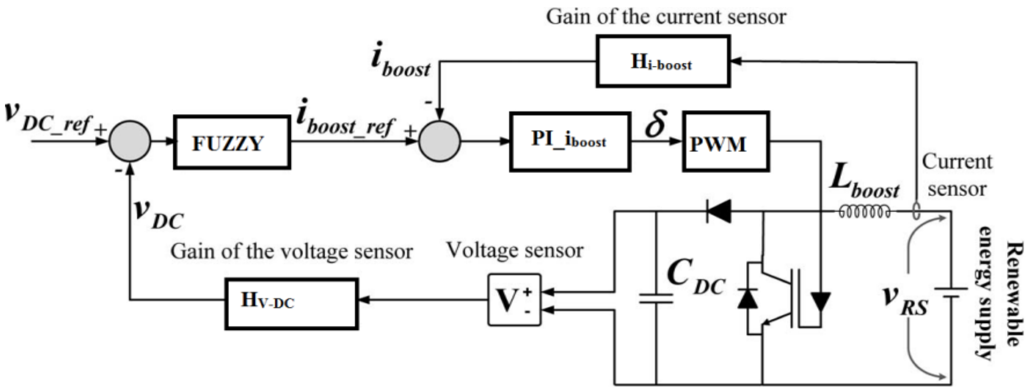


Fig: 2 Shows the Block Diagram of the DC-DC Converter.

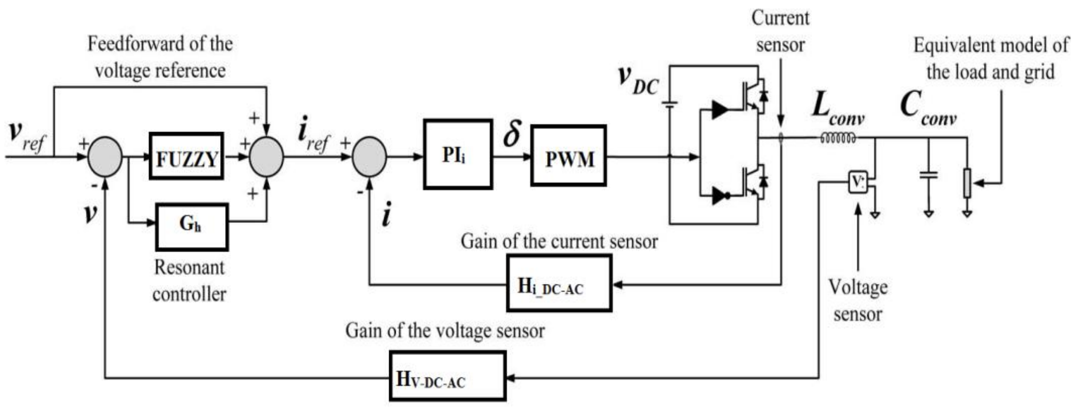


Fig: 3 Shows the Block Diagram of the DC-AC Converter.

parameters in the Table I show the required design parameters of both the converters [2].

TABLE I

DESGIN PARAMERTERS OF THE CONVERTERS				
V_{DC} - (V)	C_{DC} - (μF)	$H_{i\text{-}boost}$	$H_{V\text{-}DC}$	$H_{i\text{-}DC\text{-}AC}$
330	2,800	1/12	1/360	1/12

I. SYNCHRONIZATION ALGORITHM

To insert the DG systems into the grid it is necessary to synchronize both the systems i.e., maintaining voltage magnitude, phase angle of the voltage and the frequency are same.

There are several methods used for grid synchronization [10], among the Zero-Crossing Method and Filtering of Grid Voltages, Phase Locked Loop (PLL) technique is most widely used.PLL Technique is the state-of –the-art of extracting phase angle of the grid voltage. The general description of the PLL algorithm is as shown in the Fig 4.

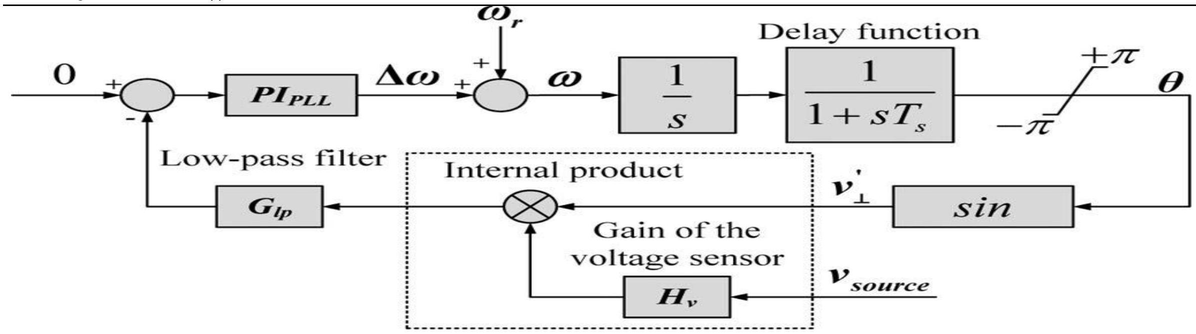


Fig: 4 show the general description of the PLL algorithm.

II. FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller (FLC) is a fuzzy –logic based control system, it is a non-mathematical decision algorithm that is based on an operator's experience. This controller analyzes analog input values in terms of logical variables that can take on continuous values between 0and 1.The First input of the Fuzzy Logic Controller is error and second input is change in error. Fig.5 shows the Fuzzy logic controller [11].

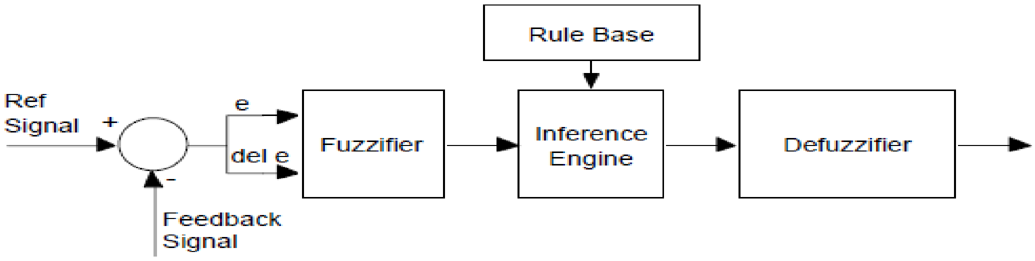


Fig: 5 Show the Structure of Fuzzy Logic Controller.

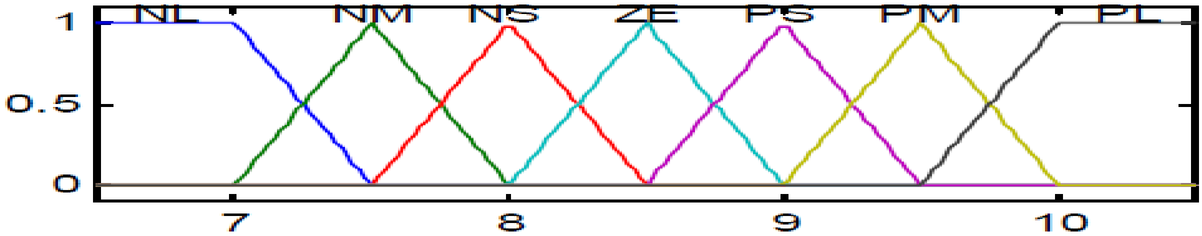


Fig: 6 Shows the Membership Functions of the Fuzzy Logic Controller.

Voltage

Del Volt	NL	NM	NS	ZE	PS	PM	PL
NL	PL	PL	PL	PL	PM	PS	ZE
NM	PL	PL	PM	PM	PS	ZE	NS
NS	PL	PM	PS	PS	NS	NM	NL
ZE	PL	PM	PS	ZE	NS	NM	NL
PS	PL	PM	PS	NS	NS	NM	NL
PM	PM	ZE	NS	NM	NM	NL	NL
PL	ZE	NS	NM	NL	NL	NL	NL

Fig: 7 show the Fuzzy Logic Rule table.

1. FUZZIFIER:

Fuzzy Logic uses linguistic variables instead of numerical variables. The process of converting a numerical value into a linguistic label is called "Fuzzification". In a closed loop control system, the error (e) between the reference voltage and the output voltage, and the rate of change of error (Del e) can be named as zero (ZE), positive small (PS), negative small (NS), etc.

Figure 6 shows the member ship functions that are used to Fuzzy inputs. The membership value can take from 0 to 1 for each Linguistic label.

For each of the input and output variables, the following seven Linguistic labels are assigned to the membership functions:

NL= Negative Large
NM =Negative Medium
NS=Negative Small
ZE=Zero
PS=Positive Small
PM=Positive Medium
PL=Positive Large

Once the member ship functions are found for each linguistic label, an intelligent decision process can be made to sense what output should be, is called inference.

2. INFERENCE:

In conventional PI controllers there are control laws, where as the Fuzzy Controller contains rules. Rules are linguistic in nature and they allow the operator to develop a control design in a more familiar human environment. A typical rule can be written as Follows:

If the "error" is negative Large (NL), and the "rate of change of error" is negative Large (NL), then the output is positive large (PL).It is convenient when dealing with large number of inputs, to put rules.

The Fig 7 show the rules done for large number of input combinations. After the rules are evaluated, from each of the output membership function having a membership provides a numerical value called crisp value called "Defuzzification".

3. DEFUZZIFICATION:

DeFuzzification plays an important role in Fuzzy logic based control system. It is the last process of Fuzzy control system in which the Fuzzy inputs, to put rules.

The Fig 7 show the rules done for large number of input combinations. After the rules are evaluated, from each of the output quantities defined for the output membership functions are mapped into a crisp number.

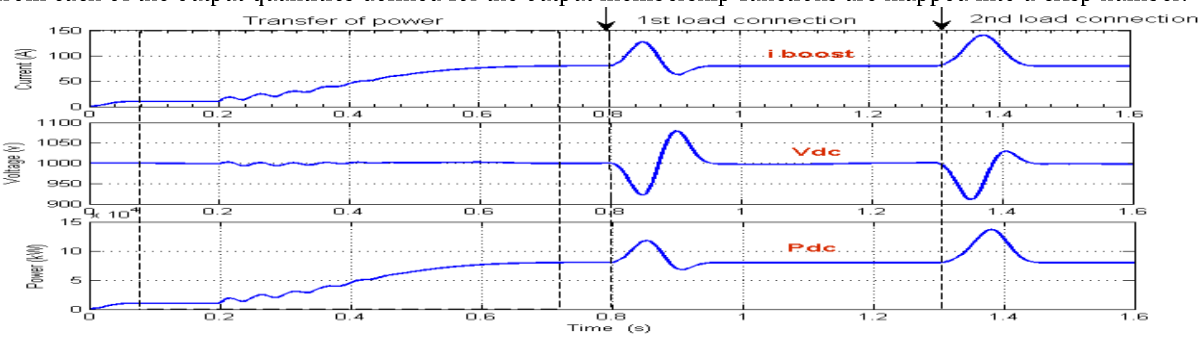
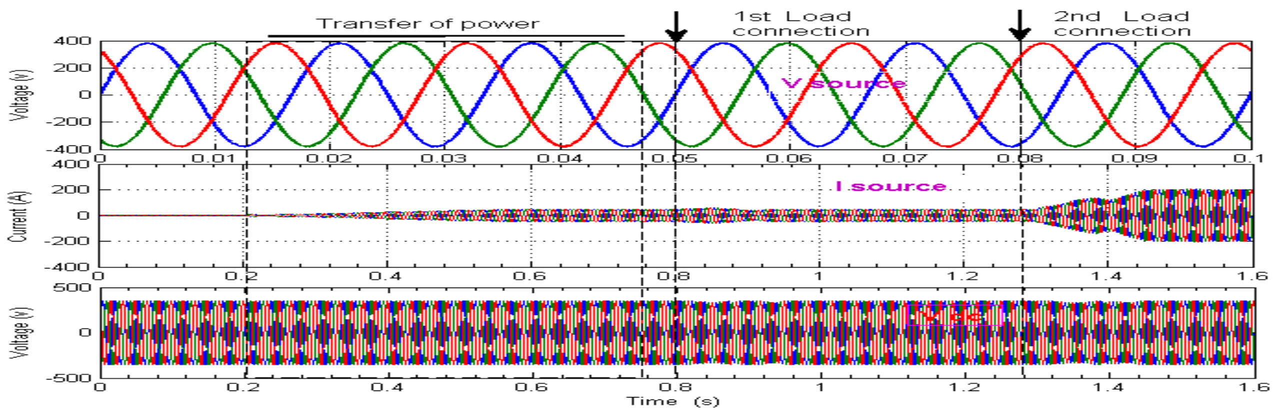


Fig: 8 output wave forms of the DG system.



Fig; 9 output wave forms of the Grid.

III. SIMULATION ANALYSIS

Simulation was performed by using MATLAB/Simulink software. MATLAB is a high performance language for technical computing and it integrates programming in an easy environment.

A. Connection of DG system into the grid with two Linear loads.

In this case the connection of DG into the grid system is considered and after synchronization procedure, the switch connecting both the DG and the grid system is closed at 0.2 s after minimizing the transient effects, a soft transfer of power is done at 0.2 s. The transfer of power and the minimal disturbances occurred in the grid is observed in the Figs 8 and 9.

After the power transfer, two groups of the resistive loads one Load demanding 70 kW is connected at 0.8s and another load demanding 60kW is connected at 1.3s. The variables subject to fast transients are observed in DG only, and the total harmonic distortion (THD) of the DG voltage is 1.23% only.

B. Connecting Non-Linear Load into the System.

In this case a 3-phase non-linear load demanding 50kVA from the DG is connected into the system. The output wave forms of the Load currents and voltages are zoomed out and are shown in the Figure.

with the PI Controllers the voltage imposed by the VSI is raises to 3% whereas with the use of Fuzzy controllers the voltage is 1.23%.The distortions in the voltage and the current waveforms can be clearly observed in the time interval of 1.96 to 2s as shown in the zoom of the wave forms in Fig10.

C. Islanding Mode Consideration

Islanding is the mode, obtained by isolating a part of a system from the network. This is an important aspect and in the considered network when a short circuit occurs in the grid, then the protecting devices isolate the grid from the distribution network in order to avoid disturbances, and thereby causing stability problems.

The islanding mode is clearly explained by isolating grid and performing series of events such as, First a balanced 3-phase load was connected to DG at the beginning of the simulation and the changes were observed at 1.8 s. Then another load of 75kW is connected to DG, now a small transfer of power is done by the grid. The output wave forms of the DG and the grid is observed in Fig 11.

D. Islanding and Reconnection to the Feeder

This is another important aspect, considered when DG systems are involved in the grid. Initially a balanced 3-phase load is connected at the starting of the simulations and a three phase linear load is connected at 1.25 s. The variation in the DG and the Grid powers is as shown in the Fig 12; with the power transfer is zero.

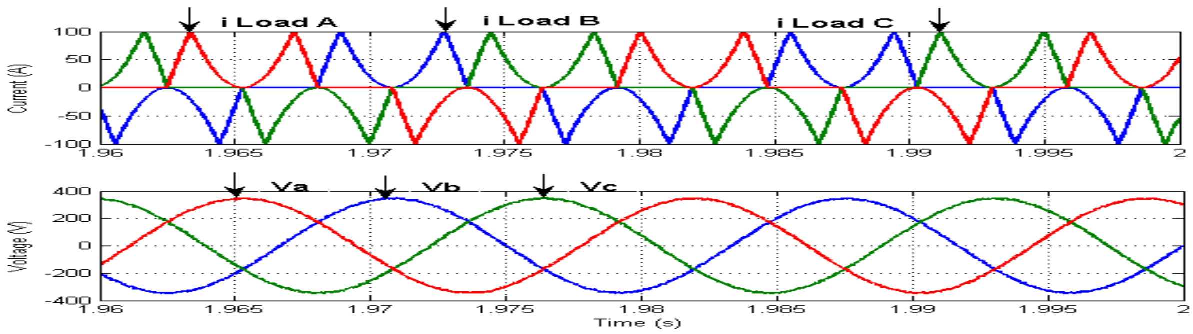
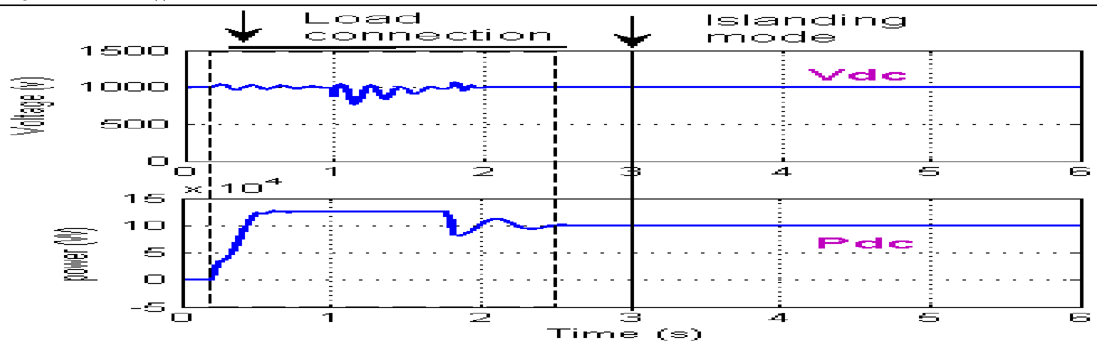
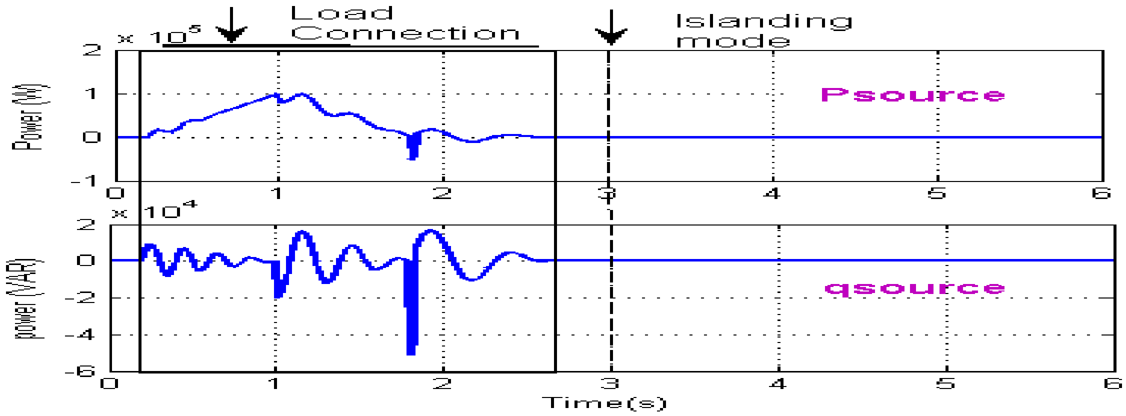


Fig: 10 Output Waveforms of the 3-phase Non-linear Load.

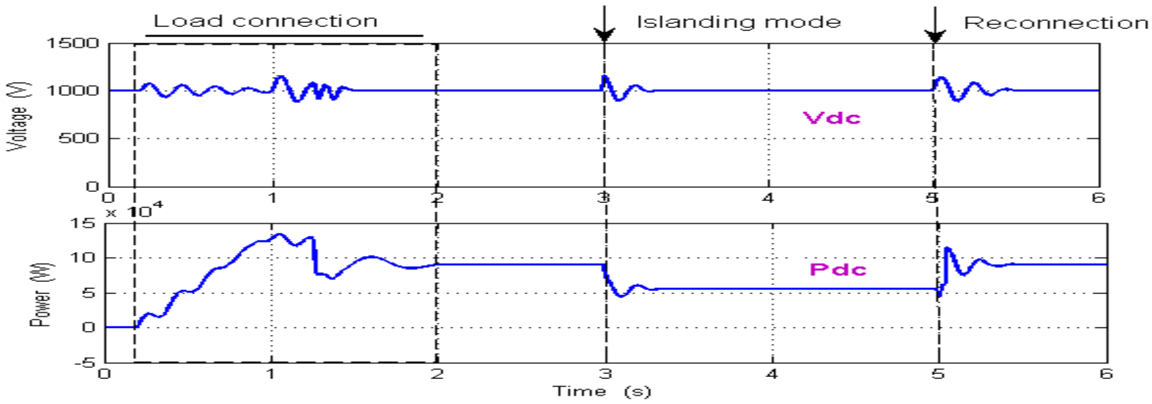


11 (a)

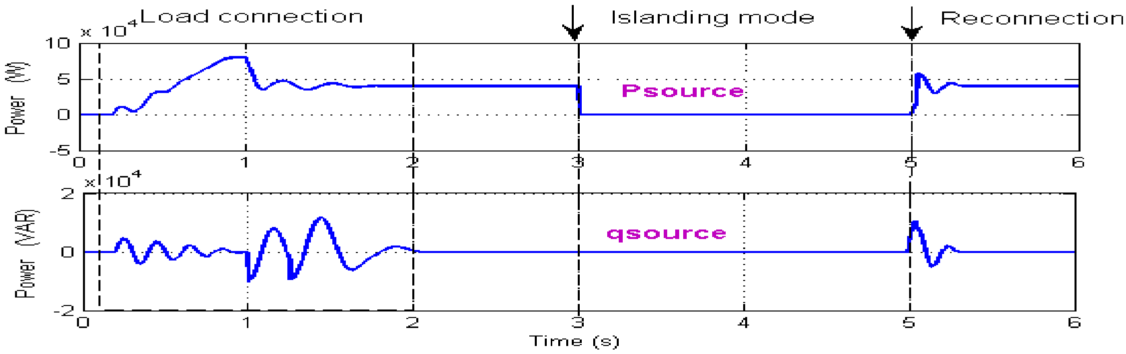


11 (b)

Fig: 11 (a) and (b) show DG and Grid output waveforms in islanding mode.



12 (a)



12 (b)

Fig: 12 shows the Islandng and Reconnection of the Grid into the Distribution Network

I. APPENDIX

Induction Machine Parameters Used in the Simulations

	Simulations	Experimental set-up
Stator resistance (r_s)	0.2761 Ω	5.43 Ω
Rotor resistance (r_r)	0.1645 Ω	6.09 Ω
Stator inductance (L_s)	2.191 mH	17.56 mH
Rotor inductance (L_r)	2.191 mH	17.56 mH
Mutual inductance (M)	76.14 mH	197 mH
Rated voltage	380/440 V	220/380 V
Rated power	20 HP	0.5 HP
Pole pairs (P)	2	2
Inertia (J)	0.1 kgm^2	0.0006 kgm^2
Rated frequency	60 Hz	60 Hz

CONCLUSION

This paper presents the method of connecting DG systems into the Grid, thereby improving the amplitude of voltage level in the distribution network. The analysis was done by considering different types of loads and connection modes.

The VSI is used to synthesize DG voltage, and the Fuzzy controller is used as a solution to produce distortion free voltage in the system for all load cases. Simulation results show the effects caused by connecting different loads in the network. With this work the THD are in the range below 2%.

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