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Study of THD for various kinds of Loads Connected to the Distribution System

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Abstract : In recent years there has been a growing interest in moving away from large centralized power generation towards distributed energy sources. Hybrid solar and wind energy generation presents several benefits for use as a distributed energy resources, especially as a peaking power source. In case of solar PV the energy is harnessed in DC form. The dc power is converted into ac form and then fed to the grid or used in isolated load. Inverters are commonly used to convert dc power into ac power. Multilevel inverters have gained popularity in recent times as ac output power quality can be improved by increasing the number of levels of inverters..In this paper an effort is made to improve the power quality (voltage sag, swell, and harmonics) of smart grid of distributed generation with the use of multilevel inverter. With multilevel inverters harmonic contents gets reduced as the number of levels of output voltages is increased approaching the sine wave. The voltage stress alsogets reduced by synthesizing the ac output terminal voltage. The output of multilevel inverter has several levels of voltages, staircase waveforms can be produced, which approaches the sinusoidal waveform with low harmonic distortion .The simulation is done in MATLAB/SIMULINK software.

Introduction

In [1] model consisting of two different distributed generating units comprising of PV array and wind power resource integrated to the grid through multilevel inverter and filter is proposed. The developed controller controls the real and reactive power supplied by the DGs at Point of Common Coupling (PCC). The controller is designed to deliver current at unity power factor at PCC. The performance of the developed controller is evaluated through MATLAB/Simpower platform. The performance of the controller is evaluated by simulating the proposed system under various conditions like varying local power demand and varying grid impedance. The simulation results are presented which indicates that voltage sags and swell and harmonics at PCC due to customer load variation and grid impedance variation is nullified by the designed controller structure and current at unity power factor is delivered to the grid.

A comprehensive simulation and implementation of 3 phase grid connected inverter is presented in [2]. In this paper the control structure of grid side inverter and the synchronization of grid connected inverter is discussed.The simulation of grid connected inverter system using PSIM simulation package and the system implementation is also presented in this paper. Distributed power generation system (DPGS) based on renewable energy sources have experience a ;large development worldwide .Due to increasing number of DPGS connected to utility network, new and stricter standards in respect to power quality safe running and islanded protection are issued as consequences, the control of distributed generation system should be improved to meet the requirement for grid interconnections. An overview of the structures for the DPGS based on fuel cells, photovoltaic and wind turbines is given in [3].In addition, control structure side converter are presented in[3] and the possibility of compensation for low order harmonics is also discussed. An overview of synchronization methods and a discussion about their important in the control is also discussed in this paper. Hybrid PV wind generation shows higher availabilities as compared to PV or wind alone. For rural electrifications researchers are focused on hybrid power system which provides sustainable power the variable voltage and frequency of the self excited induction generator (SEIG) is rectified through Vienna rectifier (three switches) to the required dc voltage level and fed to common dc bus. A hybrid scheme for isolated applications employing solar and wind driven induction generator with Vienna rectifier is proposed in [4] with fuzzy logic controller with optimized ruled based. Small distributed generation's system provides standby service during utility outages and when operated during peak load hours, potentially reduced energy cost. Renewable energy sources are being increasingly connected in distribution system utilizing power electronics converters. A novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3 phase 4 wires DG system is presented in [5] it has been shown in this paper that the grid interfacing inverter can be effectively utilized for power conditioning without affecting its normal operations of real power transfer. The interfacing inverter with the proposed approached can be utilized to inject real power generated from RES to the grid and operates as a shunt active power filter. It has been shown in this paper that the [proposed approached eliminates the need for additional power conditioning equipment to improve the quality of at PCC. Extensive MATLAB/simulink simulation approached have shown that the grid interfacing inverter can be utilized as a multifunction device. Distributed generation is emerging as a new paradigm to produce on site highly reliable and good quality electrical power. In [6] a method for the parallel operations of a inverter in an ac distributed system is proposed it explores the control of active and reactive power flow through the analysis of output impedance of the inverter and its impacts on power sharing. In [7] a pseudroop control structure integrated within a micro grid system through distributed power generation modules capable to function in off grid islanded genset connected and grid connected modes of operation is presented in [7].

The literature survey reveals that to improve the power quality of renewable energy generation the new approach of multilevel inverter is beneficial as total harmonics were reduced from system. Switches used in the proposed model are less hence switching losses are less .Model is applicable in smart grid.

Objective

The main aim of this research work is to improve the power quality of smart grid with connected inverter used in distributed generation. PV and wind power generation will be used as source of power for the smart grid under study. It is proposed that the power quality of a smart grid will be improved by using a new concept of multilevel inverter. It is expected that total harmonic distortion in output voltage waveform of multilevel inverter will be reduced as the number of levels of output voltage waveforms will be increased .However to carry out research work it is first necessary to analyze the smart grid system for various kinds of loads. Hence in this paper the smart grid under study is simulated using MATLAB SIMULINK various kinds of load (R, RL, RC and Diode) are connected and percentage of total harmonic distortion is studied. The results obtained are presented on this paper.

The power quality of smart grid is improved by using a new concept of Multilevel Inverter. It is further shown that total harmonics distortion in output voltage waveform of multilevel inverter are reduced and switching devices required for proposed model are less.

Power quality issues

The main power quality issues affected by Distributed Generation (DG) are

1. Sustained interruption:

Much of the DG's that are already in place were installed as backup generation. The most common technology used for backup generation is diesel genset. The bulk capacity of this form of DG can be realized simply by transferring the load to the backup system. However, there will be additional power that can be extracted by paralleling with the power system. Many DG installations will operate with better power quality while paralleled with the utility system because of its large capacity. However not all backup DG can be paralleled without great expense. Not all DG technologies are capable of significant improvement in reliability. To achieve improvement, the DG must be capable serving the load when the utility system cannot supply the connected load.

As taken example a homeowner may install a rooftop solar PV system with the expectation of being able to ride through rotating blackouts. Unfortunately, the less costly systems do not have the proper inverter and storage capacity to operate stand-alone. Therefore, there can be no improvement in reliability.

2. Voltage Regulation:

Large voltage changes are also possible if there were a significant penetration of dispersed, smaller DG producing reactive power at the constant power factor. Suddenly connecting or disconnecting such generation (DG) can results in a relatively large voltage change that will persist until recognized by the utility voltage regulating system this could be a few minutes, so the change should be not more than about 5 percent. Whenever fault occurs initially generators of DG will be disconnected by the circuit breakers. Depending upon the severity of the fault generators may be connected again depending upon the fault clearing time.Hence there will be low voltage across the connected load for first few seconds till the voltage regulators act accordingly. This condition can be improved by use of fast acting voltage regulators and allowing DG to absorb reactive power whenever the connected load is disconnected during the fault condition. However, there may be some instances where it will be advantageous in normal operation to have the DG produced reactive power.

3. Harmonics:

There are many who still associates DG with bad experiences with harmonics from electronic power converters. In initial days thyristor based line commuted inverter were used which would create a large problem of harmonics in DG. Nowadays switching inverters are used which have reduced the harmonics in power system significantly. However it is observed that use of switching inverters generates switching frequency which may resonate with other frequencies of the power system. The symptom is usually high frequency hash appearing on the voltage waveform. This problem is generally solved by adding a capacitor to the bus that is of sufficient size to shunt off the high frequency components without causing additional resonances.

Harmonics from rotating machines are not always negligible particularly in grid parallel operation. The utility power system acts as a short circuit to zero sequences triple harmonics in the voltage, which can results in surprisingly high currents for grounded wye-wye or delta –wye service transformers, only synchronous machines with 2/3 pitch can be paralleled without special provisions to limits neutrals current. For service transformer connections with a delta connected winding on the DG side nearly any type of three-phase alternator can be paralleled without this harmonic problem

One new distortion problem that arise with the modern inverter is that the switching frequencies will occasionally excite resonances in the primary distribution system. This creates non harmonic frequency signal typically at the 35th harmonic and higher riding on the voltage waveform. This has an impact on clocks and other circuitry that depend on a clean voltage zero crossing. An example of the above mentioned harmonics is an industrial park fed by its own substation and containing a few thousand feet of cable. A quick fix is to add more capacitance in the form of power factor correction capacitors, being careful not to cause additional harmful resonance.

4. Voltage Sag:

The most common power quality problem is voltage sag. During voltage sag, DG might act to counter the sag. Large rotating machines can help support the voltage magnitudes and phase relationship although not a normal feature, it is convincible to control an inverter to counteract voltage excursions.

The DG influence on sags at its own load bus is aided by the impedance of the service transformer which provides some isolation from the source of the sag on the utility system. However, this impedance hinders the ability of DG to provide any relief to other loads on the same feeder .DG larger than 1MW will often be required to have its own service transformer. The point of common coupling (PCC) with any load is the primary distribution system. Therefore, it is not likely that DG connected in this manner will have any impact on the voltage sag characteristic seen by other loads served from the feeder.

Fig. 1.1 shows the various steps involved in developing the proposed model.

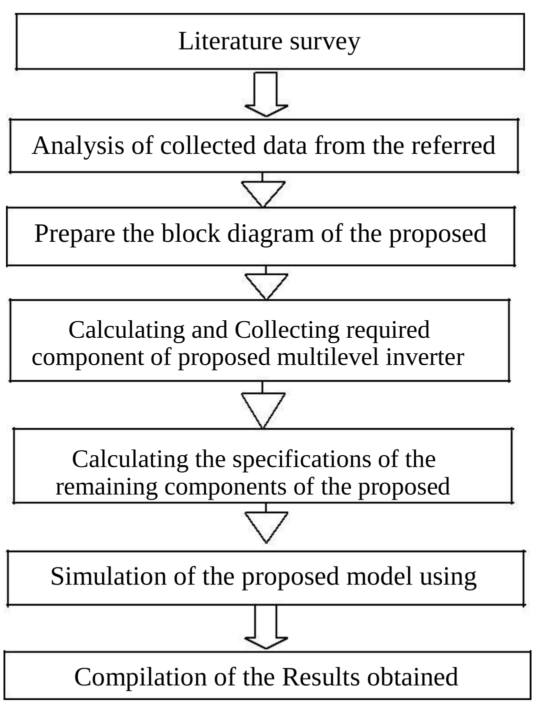

Fig. 1.1 Flow chart for development of the proposed model.

Explanation:-

The literature survey of proposed work is done by collecting data from various IEEE papers and analysis is done. Proposed system block diagram has been prepared and data required for proposed multilevel inverter model is collected and calculated. Also calculating the specification of the remaining component of the proposed model. Simulation of the proposed model will be done using MATLAB software and finally compilation of the results done.

Proposed System

The proposed multilevel inverter circuit consists of Level Module, H-Bridge inverter; input dc voltage and RL load. This load may be an isolated RL type or a grid.

Block Diagram Explanation:

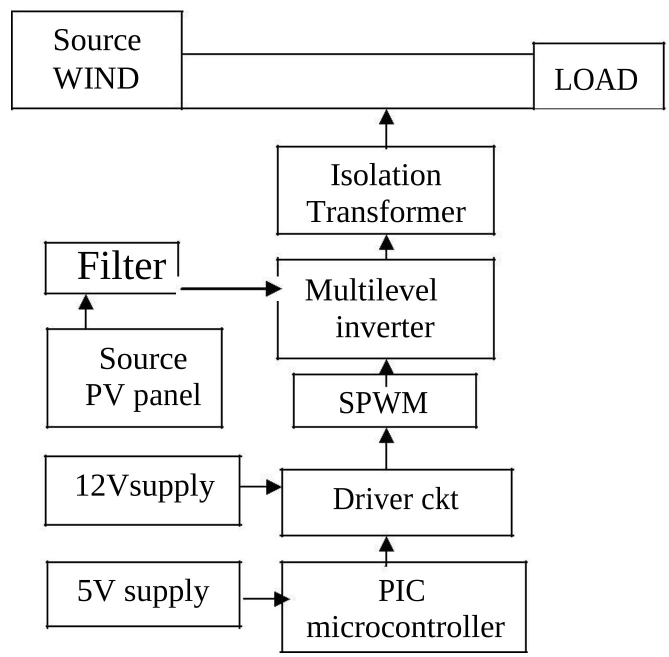

Fig 1.2 Block diagram of proposed system

The two types of DG's being used in the proposed power system are Wind Energy and Solar Energy. The output of wind generator is ac hence it is directly connected to the load. The output of solar photovoltaic cell is dc hence it is supplied to the load through inverter.

Sources of Power:-

As the name implies, DG uses small size generator than the typical central station plant. They are distributed throughout the power system closer to the loads. The term smaller sized can apply to a wide range of generator sizes. The typical distribution system delivers electrical energy through wires from a single source of power to a multitude of loads. The,

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several power quality issues arise when there are multiple sources. The proposed model uses following two types of distribution generation namely wind turbine and Photovoltaic cell

Wind Turbine:

Wind generation capacity has been increasing rapidly and has become cost competitive with other means of generation in some regions. The chief power quality issue associated with wind generation is voltage regulation. Wind generation tends to be located in sparsely populated areas where the electrical system is weak relative to the generation capacity

.This results in voltage variation that is difficult to manage and thus it is sometimes impossible to serve loads from the same feeder that serves a wind farm. There are three main classes of generator technology used for electrical system interface for wind turbine

1. Conventional squirrel-cage induction machines or wound –rotor induction machines. These frequently are supplemented by switched capacitor to compensate for reactive power needs

2. Doubly fed wound –rotor induction machines that employ power converter to control the rotor currents to provide reactive power control

3. Non-power frequency generation that required an inverter interface.

Photovoltaic (PV) Systems:

Solar PV systems generate dc power while the sun shines on them and are interfaced to the utility system through inverters. Solar energy is one of the favorable renewable energy resources and the multilevel inverter has been proven to be one of the important enabling technologies in photovoltaic (PV) utilization. Photovoltaic (PV) power systems are getting more and more widespread with the increase in the energy demand and the concern for the environmental pollution around the world.

Multilevel Inverter

Numerous industrial applications have begun to require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power inverter structure has been introduced as an alternative in high power and medium voltage situations subsequently; several multilevel inverter topologies have been developed. A multilevel inverter not only achieves high power ratings, but also enables the use of renewable energy sources. The term multilevel began with the three-level inverter. The advantages of three-level Inverter topology over conventional two-level topology are:

• The voltage across the switches is only one half of the DC source voltage;

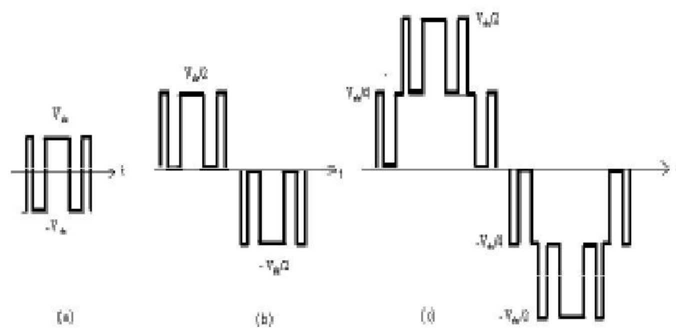
• The switching frequency can be reduced for the same switching losses;

• The higher output current harmonics are reduced by the same switching frequency.

Multilevel inverters, in case of n-level, can increase the power by (n-1) times than that of two-level inverter through the series connection of power semi conductor devices without additional circuit to have uniform voltage sharing. The general structure of the multilevel inverters is to synthesize a near sinusoidal voltage from several levels of dc voltages, typically obtained from capacitor voltage sources. As the number of levels increases, the synthesized output waveform has more steps, which produce a staircase wave that approaches a desired waveform. Also, as more steps are added to the waveform, the harmonic distortion of the output wave decreases, approaching zero as the number of levels increases.

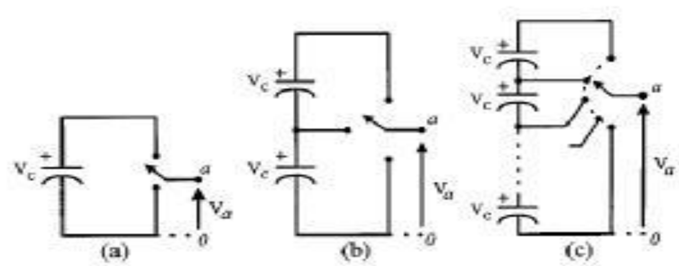
Figure.1.3: One Phase Leg of An Inverter with (A) Two Levels, (B) Three Levels, And (C) N Levels.

Fig.1.4 Output Voltage of (a) Two Level Inverter (b) Three



Level Inverter (c) Five Level Inverter

Figure.1.2 shows a schematic diagram of one phase leg of inverters with different numbers of levels, for which the



action of the power semiconductors is represented by an ideal switch with several positions. A two-level inverter generates an output voltage with two values (levels) with respect to the negative terminal of the capacitor [see Fig. 1.2 (a)], while the three-level inverter generates three voltages, and so on. The most attractive features of multilevel inverters are as follows.

1. They can generate output voltages with extremely low distortion and lower harmonics.

2. They draw input current with very low distortion.

3. They generate smaller common-mode (CM) voltage, thus reducing the stress in the motor bearings. In addition, using sophisticated modulation methods, CM voltages can be eliminated.

4. They can operate with a lower switching frequency. Various multilevel inverter topologies have been proposed during the last two decades. Specifically following three different multilevel inverter structures have been reported in the literature: cascaded H-bridges inverter with separate dc sources, diode clamped (neutral-clamped), and flying capacitors (capacitor clamped).

The inverter used in the proposed system is single phase H-bridge multilevel (7 level) inverter. The function of an inverter is to change a dc input voltage to a symmetrical ac output voltage of desired magnitude and frequency. The output voltage and frequency could be fixed or variable. A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. Single phase H-bridge multilevel Inverter are designed by using MOSFETs. IGBT can be used but it is of high cost. Same is the case with special devices such as GTO, SITH, IGT etc. SCR can also be used but it has commutation problem. Also it requires commutating circuit which is complex in nature. BJT has the problem of second breakdown. Hence MOSFET is selected as optimal device for this application.

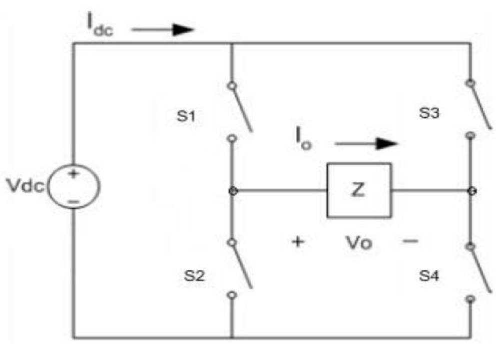


Fig 1.5Circuit Diagram of Single Phase Multilevel H-bridge Inverter

Driver Circuit:

The driver circuit forms the most important part of the hardware unit because it acts as the backbone of the inverter as it gives the triggering pulse to the switches in the proper sequence. The driver unit contains the following important units.

Optocoupler
Totem pole
Capacitor
Supply
Diode
Resistor

Controller-PIC:

PIC stands for Peripheral Interfacing Controller. PIC 16F877A is used in the proposed power system for producing switching pulses to multilevel H bridge inverter. The PIC microcontroller is driven via the driver circuit so as to boost the voltage triggering signal to 9V.To avoid any damage to micro controller due to direct 230V supply an isolator in the form of optocoupleris provided in the same driver circuit.

Filter:

In order to obtain a dc voltage of 0 Hz, we have to use a low pass filter. So in the proposed system capacitive filter circuit is used where a capacitor is connected at the rectifier output& a dc is obtained across the filter which is essentially a dc voltage with negligible ripples & it is ultimately fed to the load.

Block diagram of simulation ckt.

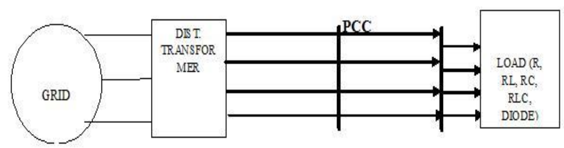


Fig.1.7 3-phase,4-wire system various load connected at PCC

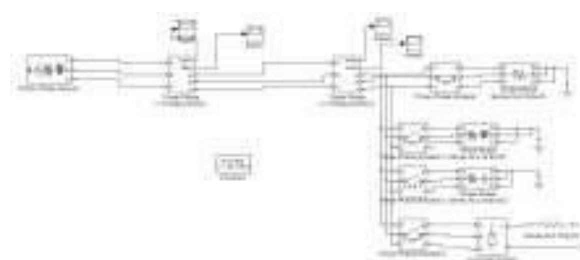


Fig.1.8 Simulation ckt.

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Control strategy:

The following are the different control strategies for an inverter,

(i) Bipolar and Unipolar PWM

(ii)Carrier based PWM

(a) Phase shifted multi-carrier modulation

(b) Level shifted multi-carrier modulation

(iii)Stair case modulation

(iv)Selective harmonic elimination scheme

(v)Space vector modulation scheme

Level shifted multi-carrier modulation :

For an N level inverter, level shifted multicarrier modulation requires (N-1) carriers, all having the same frequency and amplitude. The (N-1) triangular carriers are vertically disposed such that the bands they occupy are contiguous. The frequency modulation index is given by mf=fcr /fm and the amplitude modulation index is defined as ma =2Vm / Vcr (m-1); for 0<ma<=1 where Vm is the peak amplitude of the modulating wave and Vcr is the peak amplitude of each carrier wave. Shows three schemes for the level-shifted multicarrier modulation:

(a) In-Phase Disposition (IPD), where all carriers are in phase;

(b) Alternative Phase Opposite Disposition (APOD), where all carriers are alternatively in opposite disposition; and

(c) Phase opposite Disposition (POD), where all carriers above the zero reference are in phase but in opposition with those below the zero reference. In this paper, IPD type level shifted multicarrier modulation control strategy is employed because it results in better THD performance than the POD and APOD. For a 7-level inverter, six carrier waves with each of 0.33V amplitude and frequency of 1000Hz and one reference wave with 1V amplitude and frequency of 50Hz, required for an amplitude modulation index of 1 and a frequency modulation index of 20.

Filter: -Filter is use to reduce the harmonics and ripples, LC capacitor is used to reduce the %THD and results are taken.

Various types of load :

Resistive load: - Resistive loads are loads which consume electrical energy in a sinusoidal manner. This means that the current flow is in time with and directly proportional to the voltage. It is a load that contains no inductance or capacitance, just pure resistance. Therefore; when a resistive load is energized, the current rises instantly to its steady-state value without first rising to a higher value.

It includes loads such as incandescent lighting and electrical heaters.

Inductive Loads: - An Inductive Load is a load that pulls a large amount of current (an inrush current) when first energized. After a few cycles or seconds the current "settles down" to the full-load running current. Inductive loads can use excessive voltages to appear when switched. Examples of Inductive Loads are motors, transformers, and wound control gear.

Capacitive Loads: - A Capacitive Load is an AC electrical load in which the current wave reaches its peak before the voltage. Capacitive loads are loads that capacitance exceeds inductance. Example of a Capacitive Load is the flash of the camera.

Matlab simulation of above block diagram :

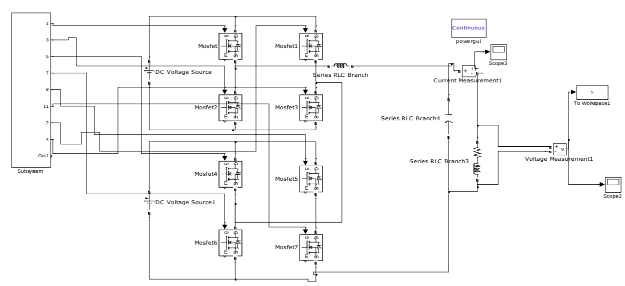

Figure.1.9(a): Five level simulation model:-

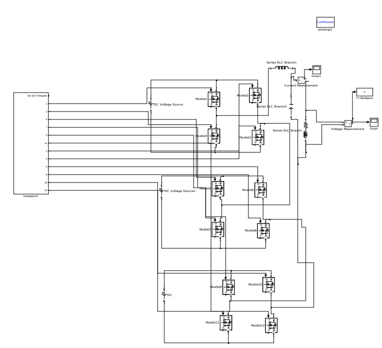

Figure. 1.9(b): Seven level inverter simulation model

Results:

The simulation results obtained after applying different types of load on grid. The THD spectrum obtained using MATLAB simulation. The simulated per phase current and voltage waveform across the load is shown in fig.1.9 (a) & 1.9 (b). Fig 1.9(a) shows current waveform of different load attached at PCC and waveform shows harmonics occurred when different load is attached and as per time of schedule various load operation occurred. R load is operate at time 0.75(s) to 0.8 (s), RL load is operate at time 0.8(s) to 0.85(s), RC load is operate at time 0.85(s) to 0.9(s) and diode as non linear load is operate at time 0.9(a) to 0.95(s). various waveform shows in fig.:

The seven level inverter operation and its results at various load condition like R, RL, RLC are studied and discussed below. The simulink output voltage and current are taken for the seven level inverter and its graph is taken and its waveform is given below.

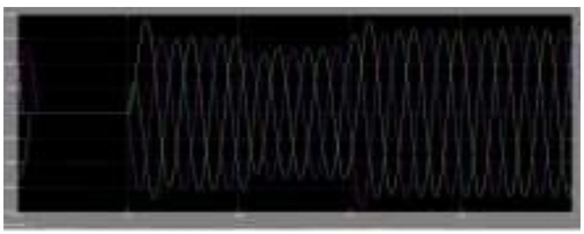

Fig.1.10 (a) Current waveform

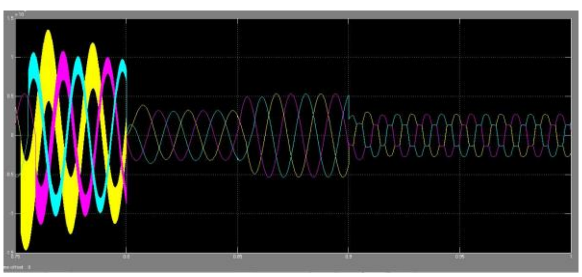

Fig 1.10(b) Voltage waveform

Fig 1.10 (b) shows voltage waveform of various load attached at PCC.

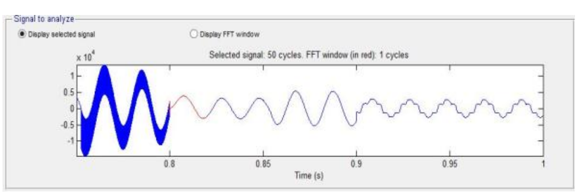

Fig.1.11 (a) Harmonic analysis of R load

Fig 1.11 (a) shows harmonic analysis of R load attached and fig 1.11 (b) shows spectrum harmonic analysis of the R load, the % THD for R load is 19.20%.

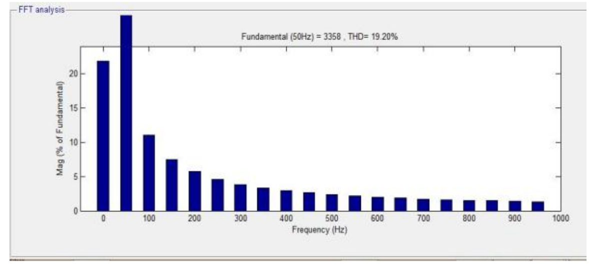

Fig.1.11 (b) FFT analysis for R load

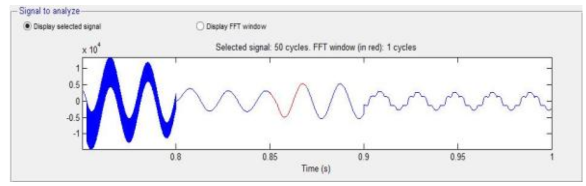

Fig.1.12 (a) Sequence 2 for RL load

Fig 1.12 (a) shows harmonic analysis of R load attached and fig 1.12 (b) shows spectrum harmonic analysis of the RL load, the % THD for RL load is 10.41%.

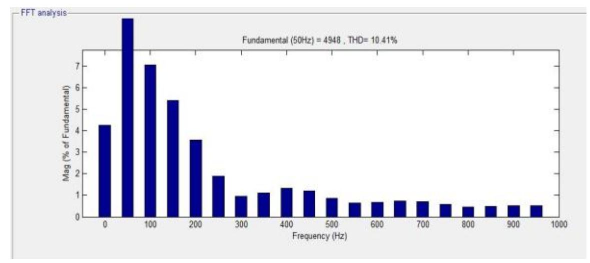

Fig.1.12 (b) FFT analysis for sequence 2 RL load

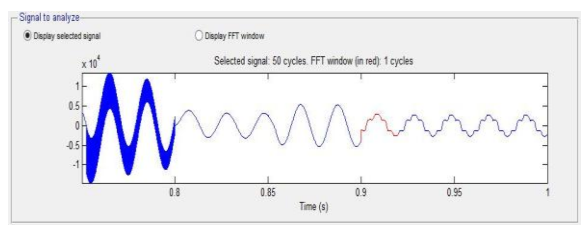

Fig.1.13 (a) Sequence 3 for RC load

Fig 1.13 (a) shows harmonic analysis of R load attached and fig 1.13 (b) shows spectrum harmonic analysis of the RC load, the % THD for RC load is 23.20%.

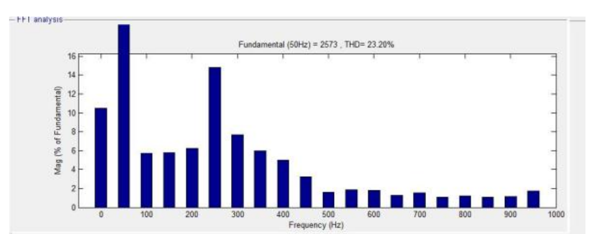

Fig.1.13 (b) FFT analysis for sequence 3 RC load

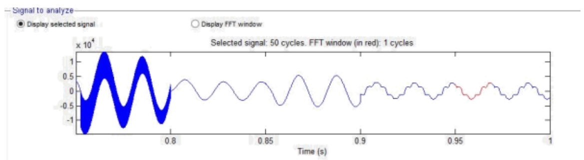

Fig.1.14 (a) Sequence 4 for Diode as non linear load

Fig 1.14 (a) shows harmonic analysis of Diode load attached and fig 1.14 (b) shows spectrum harmonic analysis of the Diode load, the % THD for R load is 19.20%.

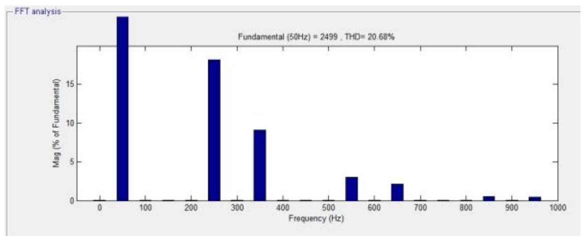

Fig.1.14 (b) FFT analysis for diode as a non linear load

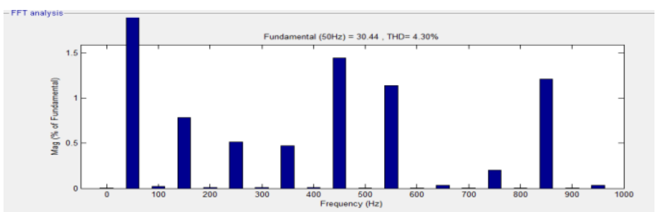

Fig 1.15 Graph for output current RLC load seven level inverter

Fig.1.15 shows the output of seven level inverter for RLC load.

Multilevel inverter	**R load**	**RL load**	**RLC load**
7 level	17.59%	4.28%	4.30%

Conclusion:

This paper presents that the harmonic analysis and improvement of power quality & performance of smart grid connected inverter used in distributed generation. Model without controller is evaluated through MATLAB/simpower platform has been carried out and results are presented. Results concluded that the % of THD for R load is 19.20%, RL load is 10.41%, RC load is 23.20% and diode as non linear load is 20.68%. The simulations indicated that harmonics is nullified and current at unity power factor is delivered to the grid. The efficiency and the performance of renewable energy sources can be increased by the development of the control structure of grid connected inverter. Seven level output concluded that seven level inverter reduced the harmonics and its design under study.

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