Power Quality Enhancement in a Four-Leg Inverter for Driving Mixed Loads using Iterative Hysteresis Loop Controller

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Abstract: With increasing demand of renewable energy in recent years, different kinds of voltage source inverters (VSIs) have been presented and studied to transfer the required power with highest quality to a vast range of various loads. The four-leg inverter is widely utilized in four-wire micro grids to provide high-power quality supply for the consumers. How every there are various losses associated with the switching techniques of these inverters. In this work the inverter designing is done with a suitable controller for driving mixed loads. The four leg inverter is designed with modified hysteresis loop controller for providing pulses to it. The controller output voltage and current is studied to detect the THD level in them from the control. The Active power output from the proposed Modified iterative hysteresis loop controller for a four leg neutral ground inverter was found to be 45.01 KW as compared to the output from the three leg universal bridge inverter having basic PWM control which was approximately 43.02 KW. The designed modified loop control controlled inverter has produced a voltage output with total harmonic distortion to be 2.26 %. Also the THD percent in the current waveform was found to be considerable to be approximately 6.08 %.

***IndexTerms* - Iterative control, Loop control, Hysteresis, THD, inverter.**

I. INTRODUCTION

With increasing demand of renewable energy in recent years, different kinds of voltage source inverters (VSIs) have been presented and studied to transfer the required power with highest quality to a vast range of various loads. Unbalanced/non-linear loads including single-phase loads/rectifiers in three-phase system generate zero-sequence component in voltage and current waveforms [1]. Many electric energy conversion applications such as distributed generation (DG) [2], uninterruptible power supply (UPS) [3] and etc., require three-phase four-wire systems to create a path for compensating zero-sequence component and preventing asymmetrical output voltage waveform.

The use of RERs within microgrids is one of the promising approaches to cope with the aforementioned environmental and technical problems. A microgrid can be defined as a group of Distributed Generations (DGs), loads, power electronic devices and energy storage systems, which behaves as a controllable entity. The structure of a typical microgrid is depicted in Fig. 1. It is capable of operating either in autonomous mode or in conjunction with the main grid. Microgrids are being developed to enhance energy efficiency, improve power quality as well as the resilience of the power system, reduce transmission losses, decrease consumer prices, and successfully facilitate the utilization of RERs.

II. LITERATURE REVIEW

Kim, J.-H. et al.[1] This paper suggests a multi-level four-leg PWM voltage source inverter (VSI) as a topology for the high power applications where a function is required to control a zero sequence component as well as dq components. It proposes a carrier-based PWM method for a multi-level four-leg PWM VSI along with introducing a new offset voltage. The proposed offset voltage makes it possible for the switching sequence of all the legs to be optimized for the minimization of the harmonic distortion of the output voltage independently of the number of inverter levels. The feasibility of the proposed PWM method is verified throughout the spectral analysis, simulation and experimental results.

Liu et al.[2] This paper presents a unified control strategy that enables both islanded and grid-tied operations of three-phase inverter in distributed generation, with no need for switching between two corresponding controllers or critical islanding detection. The proposed control strategy composes of an inner inductor current loop, and a novel voltage loop in the synchronous reference frame. The inverter is regulated as a current source just by the inner inductor current loop in grid-tied operation, and the voltage controller is automatically activated to regulate the load voltage upon the occurrence of islanding. Furthermore, the waveforms of the grid current in the grid-tied mode and the load voltage in the islanding mode are distorted under nonlinear local load with the conventional strategy. And this issue is addressed by proposing a unified load current feedforward in this paper.

Sinsukthavorn et al.[3] This paper presents the flexible control methodology of inverters as grid front end using an isochronous control function which is used by synchronous generators in conventional power systems to provide load sharing and control. The core of these interfacing units is power-electronics grid front end, namely, inverters. The inverter is the primary interface that provides not only their principal interfacing control function but also various utility functions.

N.-Y., Wong et al.[4] This paper presents a comparison study between the three-level four-leg NPC inverter and the three-level NPC inverter. A fast and generalized applicable three-dimensional space vector modulation (3DSVM) is proposed for controlling a three-level NPC inverter in a three-phase four-wire system. The zero-sequence component of each vector is considered in order to implement the neutral current compensation. Both simulation and experimental results are given to show the effectiveness of the proposed 3DSVM control strategy. Comparisons between the 3DSVM and the 3-D hysteresis control strategy are also achieved.

III. OBJECTIVE

The work on was focused on attaining following key objectives:

- We need to design three phase inverter model in MATLAB/SIMULINK environment which is able to meet the power requirements of different types of loads simultaneously.
- The inverter having four leg and a neutral point for efficient operation while driving loads
- An efficient controller is to be designed for improving the power profile as well as reducing the distortion level in voltage as well as current waveforms. The controller designing and implementation has to be very simple and in accordance while driving the system being fed by renewable energy resources.

- Control can be considered better and reliable only when it is able to produce suitable power with reduced distortion when it is driven under varying input parameters of solar system as well as wind energy system. Therefore at last the system is to be integrated with the hybrid renewable energy resources to recognize its efficiency and reliability

IV. METHODOLOGY

A PV energy conversion system consists of a PV module, a dc-dc device, an electrical converter, and ideally an energy storage system (ESS). The PV module is established by PV cells that are series and parallel connected to generate the specified rated power. The cells are made in monocrystalline or polycrystalline structure relying to the purity of semiconductor [5–7]. The polycrystalline cells that give limited potency around 13–14% are less economical comparing to the monocrystalline that the efficiency will increase up to 20. This circuit shown in Fig 1 includes a photocurrent source, a diode, and serial and shunt resistors that are referred to as one-diode or five-parameter model [8-10]. The calculations of the one-diode model are depended to the output current:

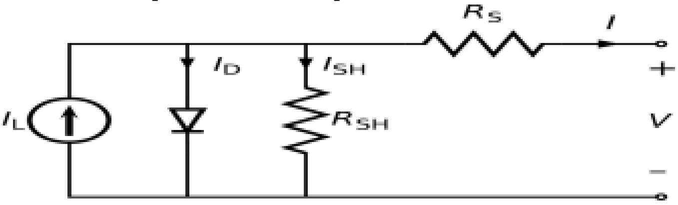

Figure 1: Electrical Equivalent of PV Cell

I_o=I_PV-I_D (V)-I_SH (V) (4.1)

Where (V) shows the dependency of diode current and resistor current to the terminal voltage whereas they're independent from irradiation value.

ID is current of the diode.

IPV is the photovoltaic Current in normal condition (25°C and 1000 W/m2 irradiance).

The wind turbine (WT) converts wind energy to mechanical energy. The power output of a wind turbine can be expressed as shown in Figure 3.2 and the aerodynamic torque is given by:

P_w=0.5C_p ρAV_w^3 (4.2)

T_w=P_w/ω_W (4.3)

Where PW = Wind Turbine Power (in Watt)

P= Air Density (in Kg/m3)

A= Rotor Area (in m2)

VW = Velocity of wind (in m/sec)

ω = Turbine rotor speed (in rad/sec)/

CP = Power Co-efficient, It is the function of tip speed and blade pitch angle.

In this research work two scenarios are simulated as discussed below in section 4.3 and 4.4.

4.1 Solar-Wind Renewable Energy Grid System

Grid connected wind-solar hybrid renewable energy system is simulated and analyzed in this research work. The overall block diagram of the system under discussion is shown in Fig. 2. A conventional inverter is used for interfacing the renewable energy system with the grid. Here, inverter not only acts as an interfacing system for real power flow to the grid, but acts as a power quality improving device also. Control methods used for the system plays an important role in the performance of the inverter.

The PV and wind system produces dc output voltage. For grid-connection of these two sources, different power electronic interfaces are required. The DC-shunted grid-connected hybrid PV /wind power system is used in this work. In the system under study, the output of DC sources are connected to DC/DC boost converter and the dc link voltage is regulated. AC output voltage of wind energy system is rectified using uncontrolled rectifier in the first stage and then a DC/DC boost converter is used to control DC link voltage.

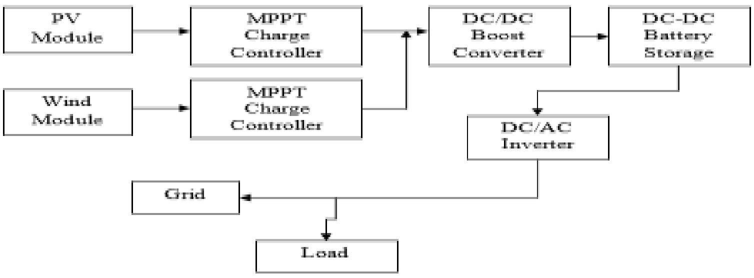

Figure 2: Block diagram of Solar-Wind RE System

V. RESULTS

The work has focused on driving the mixed types of loads being non liner load, unbalanced load and balanced load. The four leg neutral ground three phase inverter is being proposed instead to three leg inverter. The inverter control has been varied in order to attain the enhancement in power output from the system. The control is also verified for the total harmonic distortion levels in voltage as well as current outputs from the designed controller to analyze the type of feeding to the loads. The system sis made efficient by integrating the designed converter with the solar wind hybrid system. The chapter here discusses the various output waveforms of the electrical parameters and gives a comparative analysis of the systems in the following three cases:

- CASE 1: Inverter with basic SVPWM control
- CASE 2: Four leg neutral ground three phase Inverter with modified iterative current hysteresis loop controller
- CASE3: Proposed system integrated with solar/wind hybrid system
- Validation

The proposed system is being simulated in MATLAB/SIMULINK environment for analysis purpose

5.1 Case 1: Inverter with basic SVPWM control

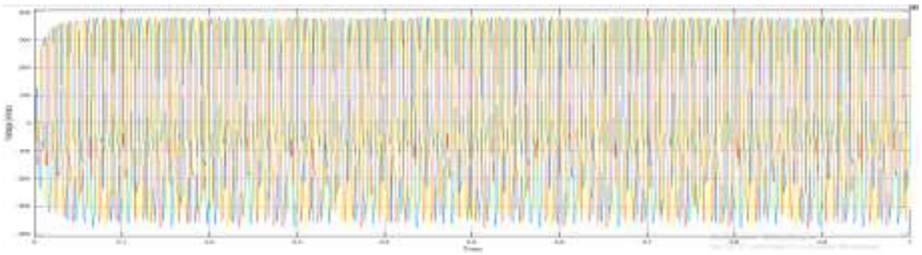

Figure 3 Voltage output from the system having inverter with basic SVPWM control

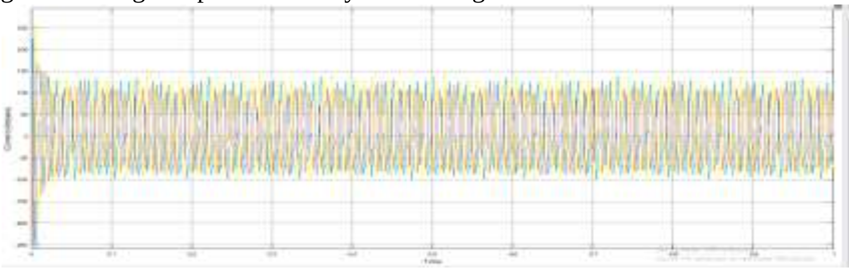

Figure 4 current output from the system having inverter with basic SVPWM control

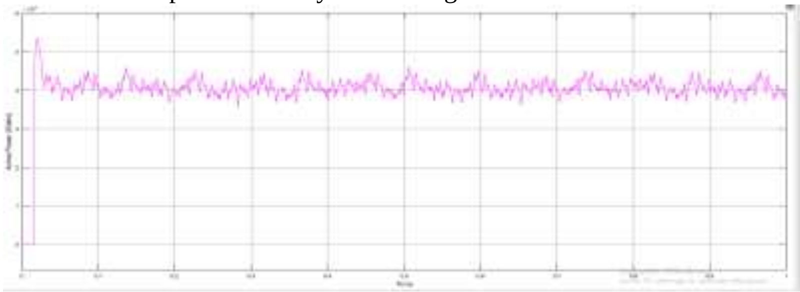

Figure 5 Active Power output from the system having inverter with basic SVPWM control

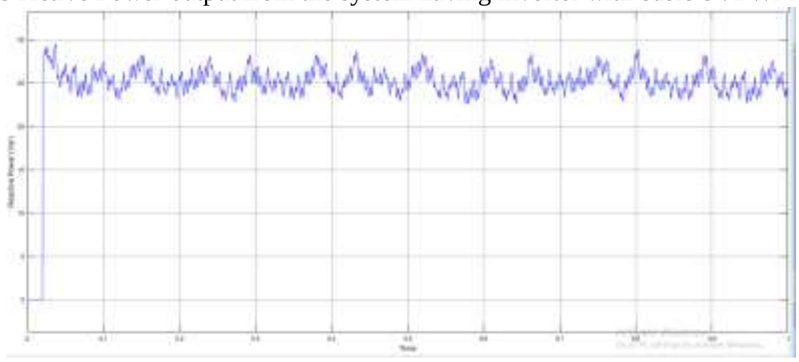

Figure 6 Reactive Power output from the system having inverter with basic SVPWM control

5.2 CASE 2: Four leg neutral ground three phase Inverter with modified iterative current hysteresis loop controller

The system inverter is changed to four leg converter in this case and iterative current hysteresis loop controller is designed for this inverter. The inverter is made to drive the mixed loads. The output wave from the proposed inverter is being shown in the figures below.

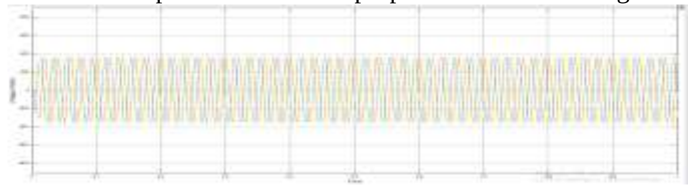

Figure 7 Voltage Output from the system with four leg inverter and modified iterative current hysteresis loop controller

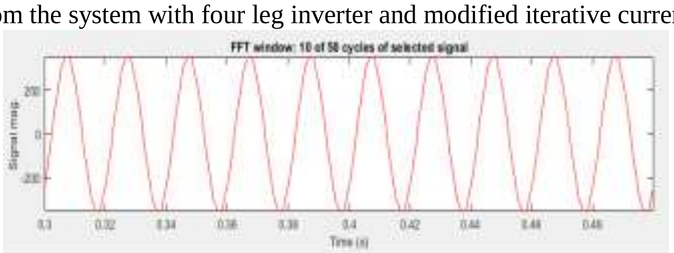

Figure 8 FFT analysis of Voltage Output from the system with four leg inverter

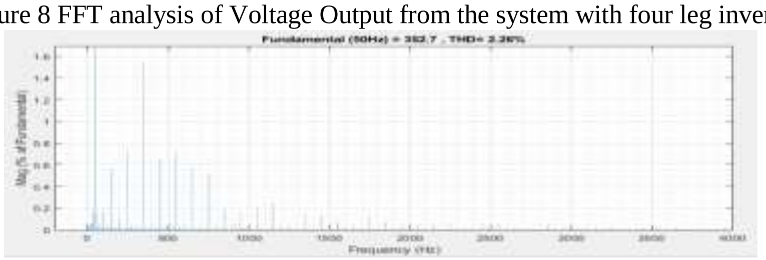

Figure 9 THD % in Voltage Output from the system with four leg inverter

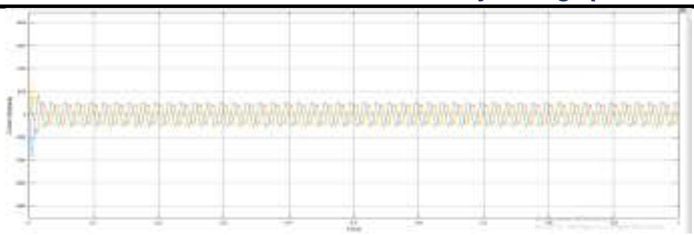

Figure 10 Current Output from the system with four leg inverter and modified iterative current hysteresis loop controller

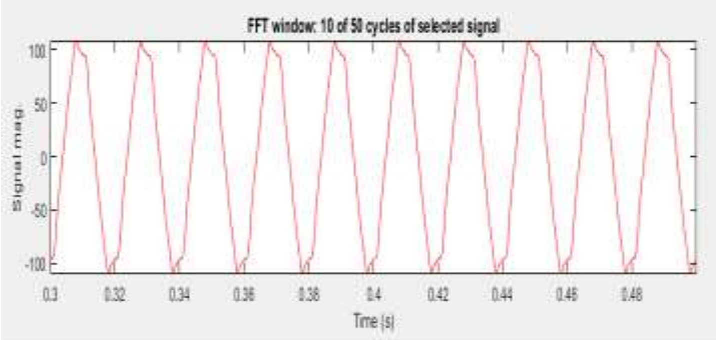

Figure 11 FFT analysis of Current Output from the system with four leg inverter

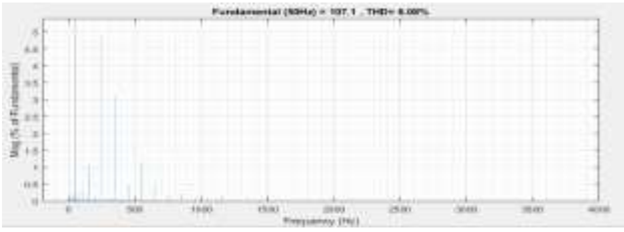

Figure 12 THD% Current Output from the system with four leg inverter

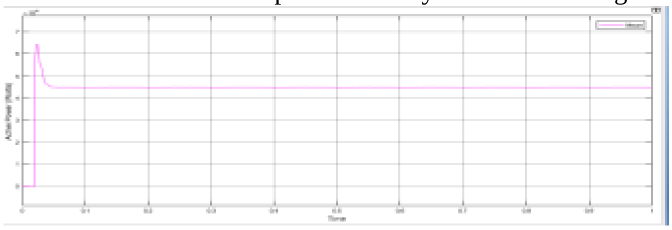

Figure 13 Active Power Output from the system with four leg inverter and modified iterative current hysteresis loop controller

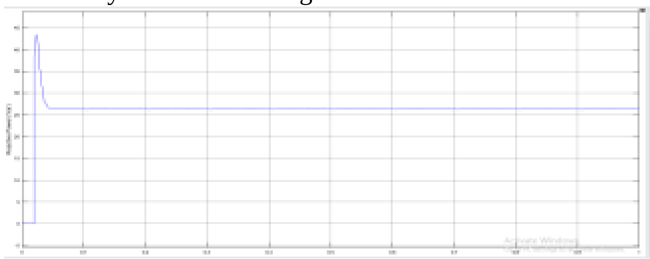

Figure 14 Reactive Power Output from the system with four leg inverter and modified iterative current hysteresis loop controller

5.3 Case 3 Proposed systems integrated with solar/wind hybrid system.

After making the proposed iterative current based hysteresis loop controller for a four leg inverter it was found that the output voltage and current waveform has considerably improved. Therefore for the DC voltage source which was acting as an input for the inverter was replaced by a solar wind hybrid system in order to study the system under practical renewable energy resource influence. This study is important to realize the reliability of the proposed controller.

This case discuss the voltage current active power and reactive power output from the four leg inverter with the proposed controller whose waveforms are been given below

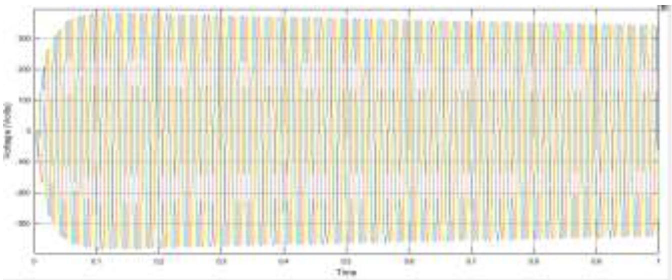

Figure 15 Voltage output from the solar-wind hybrid system

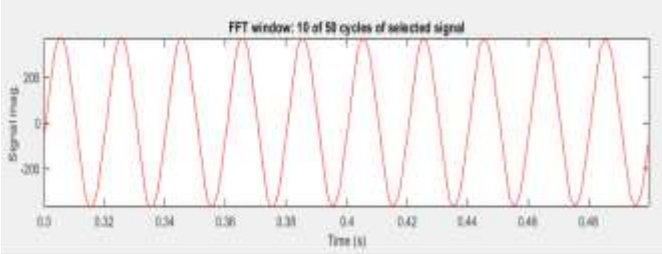

Figure 16 FFT analysis of Voltage output from the solar-wind hybrid system

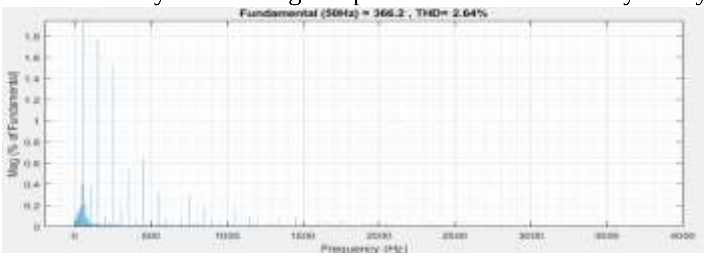

Figure 17 THD % in Voltage output from the solar-wind hybrid system

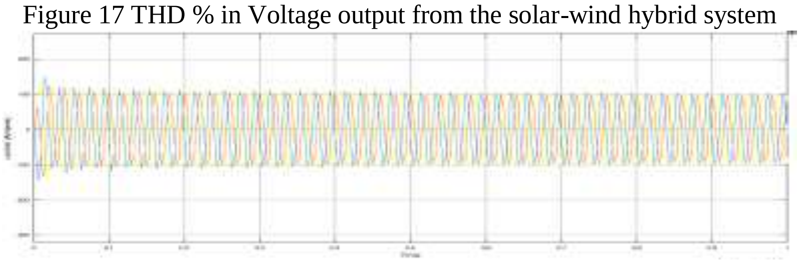

Figure 18 Current output from the solar-wind hybrid system

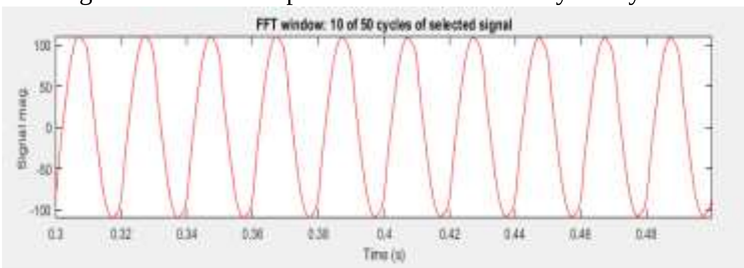

Figure 19 FFT analysis of Current output from the solar-wind hybrid system

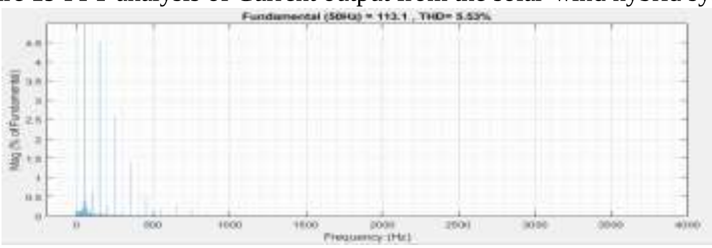

Figure 20 THD % in Current output from the solar-wind hybrid system

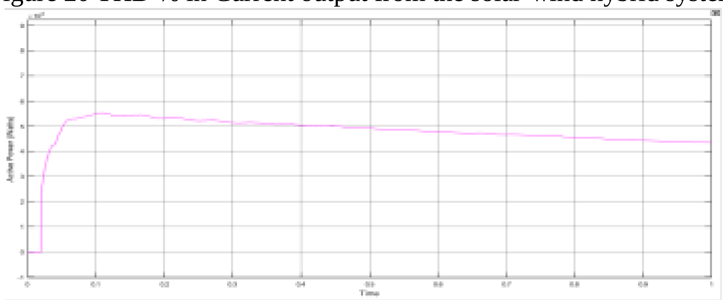

Figure 21 Active Power output from the solar-wind hybrid system

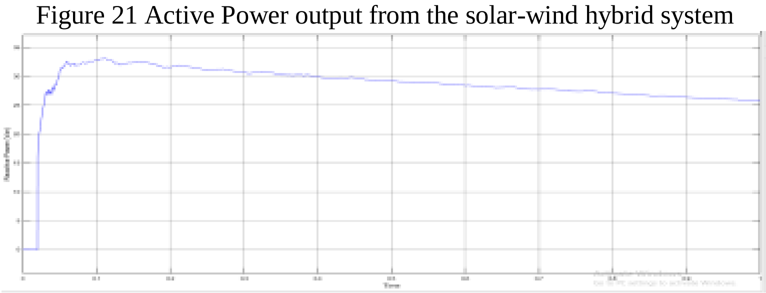

Figure 22 Reactive Power output from the solar-wind hybrid system

All the outputs from the system is being accumulated in the table below. The distortion level of the voltage as well as the current output waveform is found to be less and under the prescribed acceptable limits. Thus this control can be easily implemented with solar wind hybrid energy system also.

This concludes that the proposed Modified iterative hysteresis loop controller for a four leg inverter which is being driven by renewable energy resource can be a good choice for the driving mixed loads simultaneously ie non-linear load, balanced load and unbalanced load.

5.4 Validation

The comparative analysis of the active power outputs from the two systems having space vector modulation control and proposed modified iterative current hysteresis loop controller design for a four leg inverter has been done. It was found that the four leg inverter which was designed with the proposed controller was yielding better and more active power output as compared to the previous system. This concludes that the power available for driving mixed loads is enhanced and hence the proposed inverter having modified iterative loop hysteresis control is a better option for driving any kind of renewable energy resources which are made to feed different types of loads

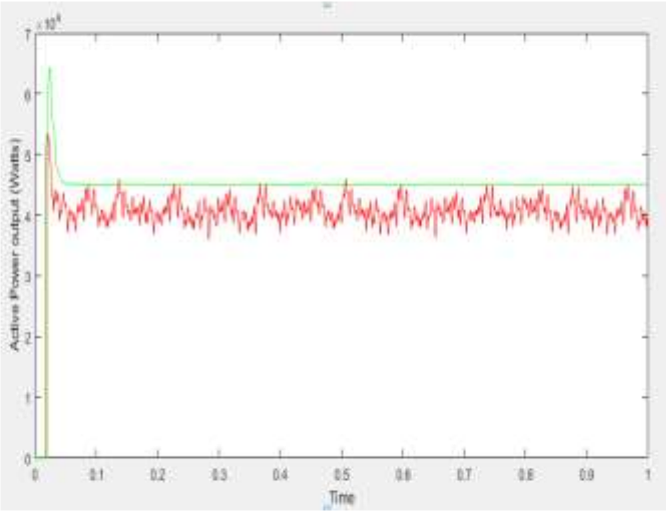

Figure 23 Comparative Analysis of Active Power outputs

The active power output from the system having proposed controller was found to be 45.01 KW as compared to the output from the system having basic PWM control which was approximately 43.02 KW. Also the output from the system is stable as compared to the previous system which is very necessary for driving loads.

VI. CONCLUSION

In this work the inverter designing is done with a suitable controller for driving mixed loads. The four leg inverter is designed with modified hysteresis loop controller for providing pulses to it. The controller output voltage and current is studied to detect the THD level in them from the control.

After the controller outputs are found to be good in all aspects the controller is also implemented with solar/wind hybrid system and the output from them is also analyzed to study the controller efficiency and reliability with renewable energy systems.

The following key conclusions were being taken out from the system under simulation;

- The Active power output from the proposed Modified iterative hysteresis loop controller for a four leg neutral ground inverter was found to be 45.01 KW as compared to the output from the three leg universal bridge inverter having basic PWM control which was approximately 43.02 KW.
- The designed modified loop control controlled inverter has produced a voltage output with total harmonic distortion to be 2.26 %. Also the THD percent in the current waveform was found to be considerable to be approximately 6.08 %.
- After studying the system for the proposed controller it was studied in integrating it with the wind solar hybrid energy system and in that case also the proposed modified hysteresis loop controller with four leg inverter model has reduced the distortion level in voltage and current waveform to be under limits.
- The THD of the voltage output waveform in the hybrid energy system using the proposed iterative hysteresis loop controller was 2.6 4% and in the current waveform it was 5.53 percent.

Thus it can be concluded that the proposed modified starches look controller design for a four leg inverter with neutral ground is the best choice while driving a renewable energy resource weather in standalone system or in hybrid system

6.1 Future Scope

Installing this solar-grid hybrid system will be actually very fruitful because it will reduce the grid dependency. On the other hand, this system promotes green energy which is very important because all the energy sources are depleting day by day. So, people must look for new renewable sources and solar power is definitely one of the best choices in this purpose. In future work an adaptive neural network based looping iterative control for improved power quality 3 phase grid integrated with nonlinear and linear loads will be designed. The expected control scheme regulates the system voltage and improves the power quality in a very effective manner.

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