DESIGNING AN EFFICIENT BIDIRECTIONAL PWM CONVERTER USING PID CONTROL TECHNIQUE FOR MICROGRID

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ABSTRACT— Microgrid, a part of the smart grid is designed to supply electricity for a small community such as residential areas, universities or industrial sites by making use of renewable energy resources available at the consumer site, thereby making the microgrid an easy and cost effective method of supplying electricity. Power electronic devices plays a vital role in delivering the electrical energy derived from the non conventional sources to the load and also reduce the wastage of energy by supplying energy back into the system. A single phase bidirectional PWM converter is such a power electronic device which improves the efficiency of the system by operating in two modes namely, rectification mode and inverting mode.This paper aims at designing an efficient bidirectional PWM converter using PID control technique by using MATLAB/SIMULINK simulations. The results are also verified with a hardware module of PWM converter.

Key words: Microgrid, PWM converter, PID controller

I. INTRODUCTION

The existing electricity grid converts only one-third of fuel into electricity and 8% of its output is wasted across the transmission lines. Smart grid technology basically derived from traditional power grid with some additional features such as reliability, efficiency and sustainability. The conventional methods of power generation are burning of fossil fuels which affect the environment, causing an increase in greenhouse gas emissions that leads to global warming. Even though these methods of generations have exceptional scale of economy, it transmits power over long distances. As a result, it has turn into the driving force for the growing interest in alternative energy. Distributed generation is one approach to the manufacture and transmission of electric power. In this generation the power is generated locally (near load) hence the transmission loss is reduced and size and number of power line is also reduced. Therefore microgrid is an accepted concept that consists of generating units and storage elements and uses the naturally available distributed energy resources such as solar, wind, fuel cell etc.

1.1 RENEWABLE ENERGY

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/heating, motor, and rural (offgrid) energy services. Based on REN21's 2014 report, renewable contributed 19 percent to our energy consumption and 22 percent to our electricity generation in 2012 and 2013, respectively. Both modern renewable, such as hydro, wind, solar and biofuels, as well as traditional biomass, contributed in about equal parts to the global energy supply. Worldwide investments in renewable technologies amounted to more than US$214 billion in 2013, with countries like China and the United States heavily investing in wind, hydro, solar and bio-fuels.

Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits

This project deals the Microgrid connected single phase Bidirectional PWM converter which operates in Rectification and Inverting mode. This converter helps to connect renewable energy sources to loads as well as excess power are given to power grid. Double Loop PID control technique is used for controlling the converter for both modes. The designed Converter is simulated in MATLAB/Simulink software and results are verified using the Hardware.

II. MICROGRID SYSTEM

Microgrid consists of Distributed Generation (DG) resources and interconnected loads. It is a small independent power grid and can be viewed as the building block of Smart grid. It can be operated in parallel with the grid or independently provide power to the load. They achieve specific local goals, such as reliability,

carbon emission reduction, diversification of energy sources, and cost reduction, established by the community being served.

Distributed Generation takes advantage of advances in electrical generating systems, e.g., solar panels, wind turbines and cogeneration, which allow for creating and distributing electrical power outside the traditional grid system. As such these systems are smaller; more locally focused and can act in addition to or separate from the traditional grid supply. Because distributed generation systems transmit electricity over short distances, i.e., they are local, they reduce the amount of energy loss compared to the grid. On the other hand, because they rely on alternative energy technologies, they can have a large initial cost. Distributed generation systems can generate between 3kW – 10,000kW of electricity

Like the bulk power grid, smart micro grids generate, distribute, and regulate the flow of electricity to consumers, but do so locally. Smart micro grids are an ideal way to integrate renewable resources on the community level and allow for customer participation in the electricity enterprise. They form the building blocks of the Perfect Power System.
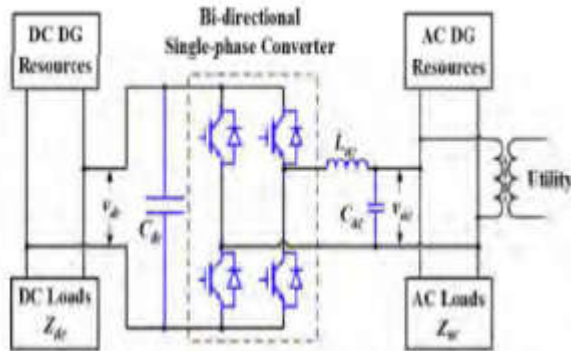

Fig.1.block diagram of Microgrid system.

2.1. Model of a Microgrid System:

Fig..1 describes the simple diagram of Microgrid system in which a Bidirectional converter is implemented. Single phase Bidirectional PWM converter is an important component in Microgrid system that connects ac and dc subsystem. It has to operate in Inverter mode as well as Rectifier mode by utilizing dc and ac renewable energy sources. The Double loop PID control is proposed for controlling the converter.

Inner current loop is common for both modes to regulate inductor current and outer voltage loop is separately designed for each mode to regulate ac and dc voltage. The bidirectional converter should operate in the following modes:

Inverter Mode:

If the dc side renewable energy is available converter operates as the inverter feeding power to the ac loads and dc loads directly get power from renewable energy sources. In this mode the converter act as a full bridge inverter and LC filter is used to get the sinusoidal output.

Rectifier Mode:

If the dc side renewable energy is not available converter operates as the rectifier feeding power to dc loads and ac side renewable energy resources provide power to ac loads. In this mode the converter act as a rectifier and provide dc output with less ripple factor by using filter capacitor Cdc.

III. CONTROL SYSTEM DESIGN

All In recent years many control strategies have been developed for example hysteresis and predictive control (current control),fuzzy logic, sliding mode ,repetitive control and neural network (voltage control).In this methods each mode requires different control strategy which results difficulty in control system design and over all reliability of the system is reduced. Therefore the Double loop PID control is proposed because of simple design, easy implementation and excellent performance.

Before designing the control system, converter has to be modeled. The Average model of the full bridge inverter is given by the following equation (1) & (2),

$$L_{ac}\frac{di_{ac}}{dt} = V_{ab} - V_{ac} \quad \text{----------} \quad (1)$$

$$C_{ac}\frac{dv_{ac}}{dt} = i_{ac} - \frac{v_{ac}}{z_{ac}} \quad \text{----------} \quad (2)$$

Since the double loop control is used, the current loop is used to regulate the inductor current and the voltage loop is used to regulate ac and dc voltage. The current and voltage loop is designed separately. Transfer function for current and voltage loop can be obtained from the average model given by the equation (1) &

(2). Transfer function for common inner current loop,

$$\frac{i_{ac}}{v_{dc}} = \frac{1+SZ_{ac}C_{ac}}{S^2 L_{ac}Z_{ac}C_{ac}+SL_{ac}+Z_{ac}} \quad \ldots\ldots (3)$$

Transfer function for outer voltage loop,

Inverter Mode

$$\frac{V_{ac}}{i_{ac}} = \frac{Z_{ac}}{1+SZ_{ac}C_{ac}} \quad \ldots\ldots\ldots (4)$$

Rectifier Mode

$$\frac{V_{dc}}{i_{dc}} = \frac{Z_{dc}}{1+SZ_{dc}C_{dc}} \quad \ldots\ldots\ldots (5)$$

The desired output for a closed loop system is obtained by tuning PID gain values to the system inherent condition. Several methods are used to tune the PID controller in which Ziegler-Nicholas method is commonly used.

IV. PULSE WIDTH MODULATION TECHNIQUE

The advent of the transformer-less multilevel inverter topology has brought forth various pulse width modulation (PWM) schemes as a means to control the switching of the active devices in each of the multiple voltage levels in the inverter. The most efficient method of controlling the output voltage is to incorporate pulse width modulation control (PWM control) within the inverters. In this method, a fixed d.c. input voltage is supplied to the inverter and a controlled a.c. output voltage is obtained by adjusting the on and–off periods of the inverter devices. Voltage-type PWM inverters have been applied widely to such fields as power supplies and motor drivers. This is because: (1) such inverters are well adapted to high-speed self turn-off switching devices that, as solid-state power converters, are provided with recently developed advanced circuits; and (2) they are operated stably and can be controlled well.

The PWM control has the following advantages

(i) The output voltage control can be obtained without any additional components.

(ii) With this type of control, lower order harmonics can be eliminated or

minimized along with its output voltage control. The filtering requirements are minimized as higher order harmonics can be filtered easily.

The commonly used PWM control techniques are:

(a) Sinusoidal pulse width modulation (sin PWM)

(b) Space vector PWM

The performance of each of these control methods is usually judged based on the following parameters: a) Total harmonic distortion (THD) of the voltage and current at the output of the inverter, b) Switching losses within the inverter, c) Peak-to-peak ripple in the load current, and d) Maximum inverter output voltage for a given DC rail voltage

From the above all mentioned PWM control methods, the Sinusoidal pulse width modulation (sinPWM) is applied in the proposed inverter since it has various advantages over other techniques. Sinusoidal PWM inverters provide an easy way to control amplitude, frequency and harmonics contents of the output voltage.

Sinusoidal Pulse Width Modulation

In the Sinusoidal pulse width modulation scheme, as the switch is turned on and off several times during each halfcycle, the width of the pulses is varied to change the output voltage. Lower order harmonics can be eliminated or reduced by selecting the type of modulation for the pulse widths and the number of pulses per half-cycle. Higher order harmonics may increase, but these are of concern because they can be eliminated easily by filters. The SPWM aims at generating a sinusoidal inverter output voltage without low-order harmonics. This is possible if the sampling frequency is high compared to the fundamental output frequency of the inverter.
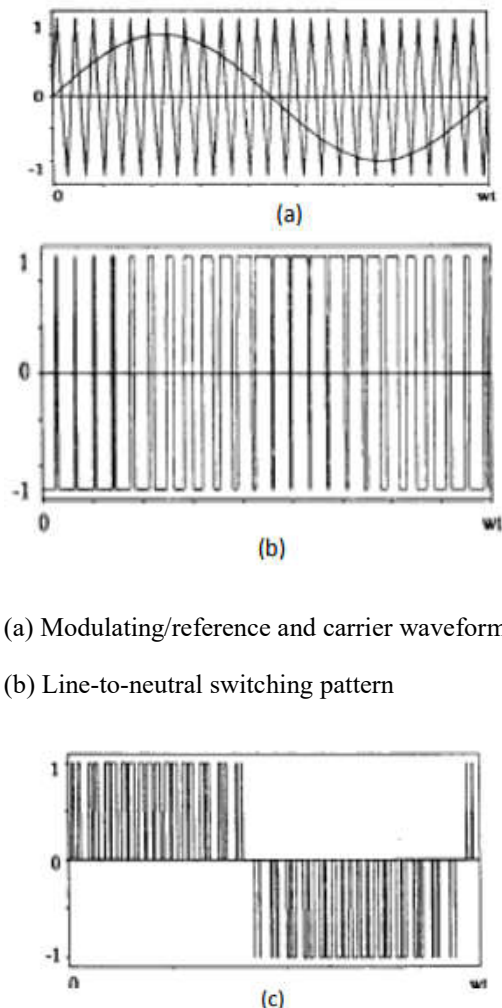
Sinusoidal pulse width modulation is one of the primitive techniques, which are used to suppress harmonics presented in the quasi-square wave.

Sampling Technique

In this method of modulation, several pulses per half-cycle are used. Instead of maintaining the width of all pulses, the width of each pulse is varised proportional to the amplitude of a sin-wave evaluated at the centre of the same pulse.

By comparing a sinusoidal reference signal with a triangular carrier wave, the gating signals are generated. The frequency of reference signal determine the inverter output frequency and its peak amplitude, controls the modulation index, M, and then in turn the RMS output voltage. Fig.3.2 shows the more common carrier technique, the conventional sinusoidal pulse width modulation (SPWM) technique, which is based on the principle of comparing a triangular carrier signal with a sinusoidal reference waveform (natural sampling)

The figure below gives the sinusoidal pulse width modulation.

(a) Modulating/reference and carrier waveform.

(b) Line-to-neutral switching pattern

. (c) Line-to-line output waveform.

Fig. 2 (a), (b), (c) Sinusoidal Pulse Width Modulation (SPWM).

By varying the modulation index M, the RMS output voltage can be varied. It can be observed

that the area of each pulse corresponds approximately to the area under the sine-wave between the adjacent midpoints of off periods on the gating signals

The amplitude of the fundamental frequency components of the output is directly proportional to the modulation depth. The second term of the equation gives the amplitude of the component of the carrier frequency and the harmonics of the carrier frequency. The magnitude of this term decreases with increased modulation depth. Because of the presence of $\sin(m\pi\ /2)$, even harmonics of the carrier are eliminated. Term 3 gives the amplitude of the harmonics in the sidebands around each multiple of the carrier frequency. The presence of $\sin((m+n)\ \pi/\ 2)$ indicated that, for odd harmonics of the carrier, only even-order sidebands exist, and for even harmonics of the carrier only odd order sidebands exist. In addition, increasing carrier or switching frequency does not decrease the amplitude of the harmonics, but the high amplitude harmonic at the carrier frequency is shifted to higher frequency. Consequently, requirements of the output filter can be improved. However, it is not possible to improve the total harmonic distortion without using output filter circuits. In multilevel case, SPWM techniques with three different disposed triangular carriers were proposed as follows:

1. All the carriers are alternatively in opposition (APO disposition)

2. All the carriers above the zero value reference are in phase among them, but in opposition with those below (PO disposition)

 3. All the carriers are in phase (PH disposition)

 4. Multi carrier modulation technique

In the proposed inverter circuit the multi carrier modulation technique is employed.

MULTICARRIER MODULATION

This technique involves the carrier based PWM

CARRIER BASED PWM

These are the classical and most widely used methods of pulse width modulation. They have common characteristic subcycles of constant time duration, a subcycle being defined as the total duration Ts during which an active inverter leg assumes two consecutive switching states of

opposite voltage polarity. Operation at subcycles of constant duration is reflected in the harmonic spectrum by two salient sidebands, centered on the carrier frequency, and additional frequency bands around integral multiples of the carrier.

V. SIMULINK MODEL FOR BIDIRECTIONAL PWM CONVERTER

5.1. INVERTER MODE

The MATLAB/simulink model for Bidirectional converter in Inverter mode is given in Fig.6.1. In this the input dc voltage is continuously sensed by voltage sensor and in turn it operates the relay which is set by the rated input voltage. If dc input voltage is within the set limit the relay gives the pulse to switch A and the converter operates as a inverter and the output is a sine wave with (frequency 50Hz) less THD using LC filter. Otherwise the relay gives pulse to switch B and converter operates as a Rectifier and the output is unidirectional dc with a ripple factor less than 5%.

This table listed below gives the considered simulation parameters.

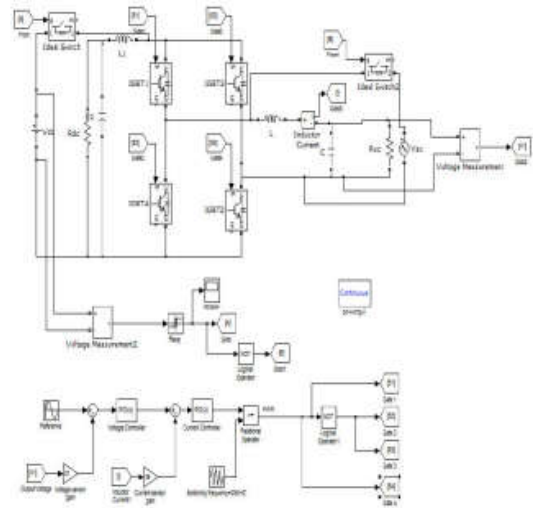| Input voltage V_{dc}	230V
V_{rms}	230V
Ac Filter Inductor	100mH
Ac Filter Capacitor	40µF
Dc Filter Inductor	500mH
Dc Filter capacitor	1000µF
Linear load	1000Ω
Switching frequency	25kHz
Voltage sensor gain	0.01(Inv)
	0.03(Rec)
Current sensor gain	0.06

Table.5.1. Simulation Parameters

Fig..3.Simulink model for Bidirectional converter in Inverter mode

For closed loop control of converter in Inverter mode the output voltage and sinusoidal reference voltage are compared and the difference is given to PID voltage controller. The output signal is again compared with inductor current; the current error signal is given to PID current controller. This control signal from PID current controller is used as the reference signal for PWM generation. The triangular wave of 25 kHz frequency is compared with reference signal and at every crossing instant the pulse is generated and used to control the switches

OUTPUT VOLTAGE FROM INVERTER MODE

The output voltage and THD analysis from the simulink model for the single phase bidirectional PWM converter in inverter mode is as shown in the fig.4
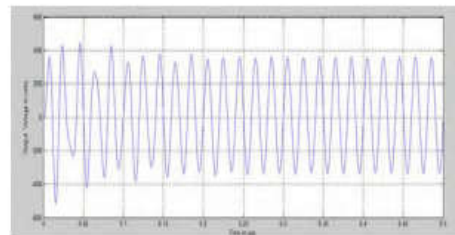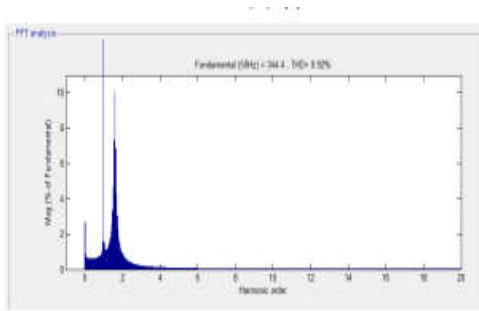

Fig..4.Output voltage from Inverter mode

Fig.5.THD analysis for Inverter output

5.2. RECTIFIER MODE

The MATLAB/Simulink model for the converter in rectifier mode is given in Fig.5.2. The output signal and dc reference signal are compared and the error signal is used to generate the PWM pulses and control the switches in the converter.Fig.6 shows the dc output from Bidirectional converter in Rectifier mode.
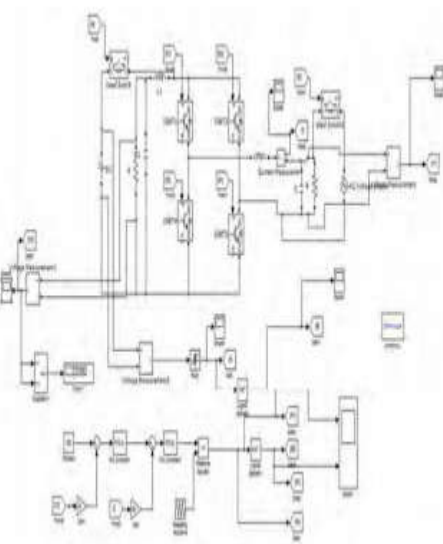

Fig .6. Simulink model for Bidirectional converter in Rectifier mode

OUTPUT VOLTAGE FROM RECTIFIER MODE

The output voltage from the simulink model for the single phase bidirectional PWM converter in rectifier mode is as shown in the Fig.
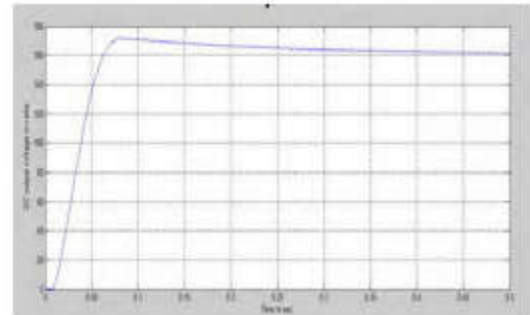

Fig..7.DC output from converter in rectifier mode

VI. EXPERIMENTAL RESULTS

The Bidirectional converter is designed using MOSFET (IRF640) and Microcontroller IC16f877a is used to control the switches in the converter and driver IC IR2110 is used for amplification and isolation between controller and power circuit. In order to avoid device failure and safety, the fabrication and experiments were done as a scaled down voltage level.

Fig.8.Experimental set up for Bidirectional converter

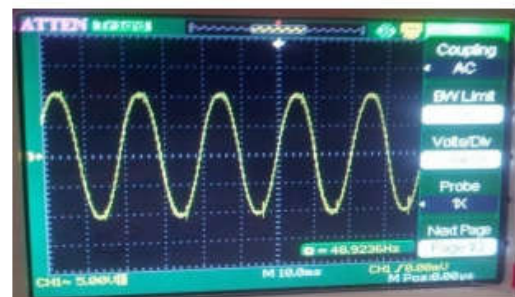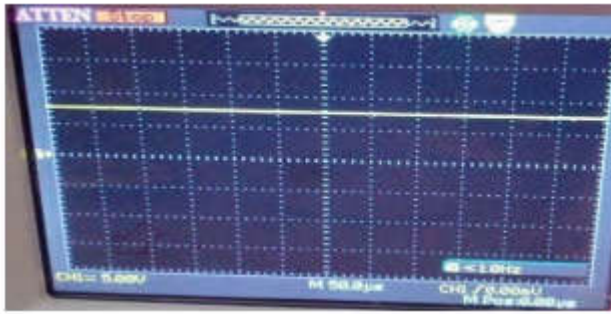## 6.1. INVERTER OUTPUT VOLTAGE

Fig..9.Inverter output voltage

6.2. RECTIFIER OUTPUT VOLTAGE

Fig.10.Rectifier output voltage

VII. CONCLUSION

This paper proposed the control system design for Microgrid connected single phase bidirectional PWM converter. Microgrid is a emerging technology provides power locally for a specific region like university, Industries, residential areas etc. It uses the renewable energy resources and is available at a reduced cost therefore the implementation is easy and cost effective. Bidirectional converter is a important component in Microgrid which connect dc and ac subsystem. The reliability of the supply is maintained even with the availability of any one renewable energy resources The Double loop PID control is designed for both mode and simulated using MATLAB/Simulink. The simulation results shows that designed control system produces inverter output with THD 0.92% and rectifier output with ripple factor 0.13%.

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