OPEN ACCESS

Volume: 5

Issue: 3

Month: July

Year: 2026

ISSN: 2583-7117

Published: 06.07.2026

Citation:

Ravikant Sahu, Dr. Naveen Asati, Dr. Syed Uaid "Harmonic Evaluation of Active and Reactive Power Droop Control Strategies for Cascaded type Microgrid" International Journal of Innovations in Science Engineering and Management, vol. 5, no. 3, 2026, pp. 13-27

DOI:

10.69968/ijisem.2026v5i313-27

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Harmonic Evaluation of Active and Reactive Power Droop Control Strategies for Cascaded type Microgrid

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Abstract

Distributed generation units incorporating power electronics are becoming popular owing to their zero emission features. The most important elements to evaluate the successful use and flexibility of microgrids are the control as well as coordination of such generating units. The present report operates a space vector PWM technically controlled distribution unit linked to the series with steady power sharing. The synchronisation as well as power balancing of dispersed generating devices constitutes two major problems in cascaded-type microgrids that require immediate response. To that aim, in this research, an f-P/Q drop control is suggested and its stability is also examined. This suggested drop-control is capable of independently achieving power balance under resistive and resistive loads. The clear benefit in comparison to the reverse power factor drop control is to expand the field of application. Furthermore, simulation results verify the viability of the suggested approach. The technique ensures precise power sharing even when the connection is interrupted. Where the load varies during the interruption of communication, energy sharing accuracy is decreased, yet the suggested approach is better than the traditional drop control method. Furthermore, the accuracy of the power sharing base on the suggested approach is not affected by the communication channel time delay as well as local loads at inverter output. The control model was simulated in MATLAB using a series connection of two or three inverters. A comparison study is performed on THDs using SPWM and SVPWM methods in the output voltage. The active forces are also compared to improved power supply..

Keywords; Cascaded-type microgrid, droop control, power balance, MATLAB, SPWM and SVPWM.

INTRODUCTION

Microgrid provides an efficient method for securely integrating dispersed energy resources that may be used in both grid-connected and insular modes. By its configuration, the microgrid may be split into two categories: parallel as well as cascaded. The former was thoroughly examined. The droop control is being used extensively to achieve parallel type microgrid power sharing as well as extended to additional applications that include a storage system's state-of-charge (SOC) balancing, a cost-effective distribution system for distributed generators (DGs) and a PWM system drive system for droop control. Furthermore, the cascaded microgrid type is a novel one just introduced. [1]

Initially, the cascaded converter is used on multilayer inverters and first expanded to microgrid applications for greater voltage and better usage. The cascaded form is extremely useful in particular for PV grid linked application and battery management. The power balance of all modules is important in an islanded cascaded-type microgrid. In order to establish power balance, a reverse drop control is suggested, which may also be utilised in the DC microgrid. For the AC microgrid, a novel inverse power factor drop control is suggested for power balancing. The technique is nevertheless only relevant in instances of resistive-inductive loads by a researcher. But this technique is utilised for inductive resistive loads as well as capacitive resistive loads. [2] This study offers an F-P/Q droop control in the cascaded-type microgrid in order to overcome constraints.

Frequency synchronisation and the power sharing across all DGs under resistive as well as resistive loads may be accomplished autonomously. The stability of the system suggested is theoretically shown. The control model was simulated in MatLab using a series connection of two or three inverters. A comparison study is performed on THDs using SPWM and SVPWM methods in the output voltage. The active forces are also compared to improved power supply.

Microgrid

The design of the electricity system is evolving as big, centrally linked power plants are converted into horizontally distributed, small power generation and distribution system via vertical networks. The motivating force for this change is climate pressure, fossil fuel prices and energy security. Conventional high-capacity power plants are powered by highly polluting fossil fuels and contribute significantly to greenhouse gas emissions. Therefore, because of the cheap cost and environmental advantages of renewable DGs such as solar photovoltaic and fuel cells, the battery storage system is quickly expanding. [3]

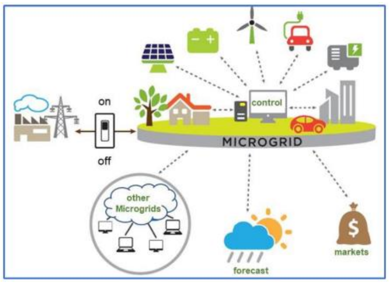


Figure 1: Microgrid concept

In addition, for the efficient and flexible use of these DGs the idea of microgrid has been suggested. By definition, a microgrid is a collection of linked loads and DGs which have well defined electrical frontiers. It may be linked or disconnected from the grid so that it can function in both the grid and insular mode, providing a more flexible and dependable energy system. Whilst micro-grids enhance the overall supply system's dependability and efficiency, voltage and current regulation and energy balancing in such a hybrid system are the difficult jobs because renewable DGs, such as wind and solar, are naturally intermittent.

The literature has a variety of microgrid definitions and functional categorization systems. A wide definition created by the Microgrid Exchange Group for the U.S. Department of Energy, an ad hoc team of research and implementation specialists, includes the following: [4]

‘‘A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.”

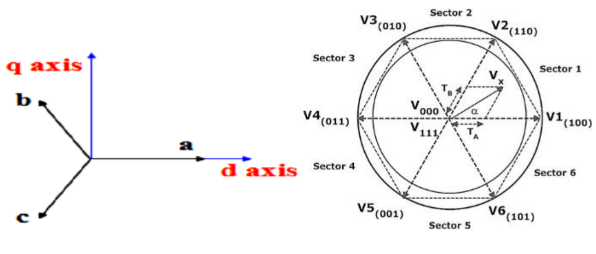
This description comprises three requirements: 1) to allow the distribution system component consisting of a microgrid to be identified as distinct from the rest of the system; 2) to control the resources connected to the micro Grid in conjunction instead of with distant resources; as well as 3) to enable the microgrid to work regardless of whether it is linked to the larger grip. The term makes no reference to the size or kind of technologies that may or should be utilised for the distributed energy resources. [5]

PWM Technique

Pulse width modulation (PWM) switching methods have proven prominent in the power electronics and drive systems field. PWM is widely utilised for applications such as motor speed control, audio amplifier converters and so on. PWM is used for adjusting the motor voltage. There is no one PWM technique for all applications. Different pulse width modulation (PWM) methods have been created, for many industrial applications, in accordance with improved technology in solid state power electronic devices and microprocessors. For these reasons, since the 1970s, considerable research has been undertaken on PWM methods. The primary purpose of PWM is to regulate the output voltage of the inverter and to minimise the harmonic content of the output voltage. The modulation of pulse width (PWM) methods are primarily utilised for the control of voltage. These methods are more efficient and control switching device drives. The different PWM techniques include modulation of a single pulse width, modulation of multiple pulse widths, phase shift controls, modulation of sinusoidal pulse widths, harmonic injection modulation, modulation of pulse width of space vectors, hysteresis of the delta, selective harmonic removal and current controlled pulse width modulation. For current source inverters, the hysteresis controller is utilised, while all the rest of the PWM methods are used for voltage source inverters. Sinusoidal and Space Vector PWM are the most often utilised methods. The output voltage is controlled and the harmonics are reduced.[6]

SVPWM

The Space Vector Pulse Width (SVPWM) approach is another way of increasing the output voltage relative to SPWM. This technique is utilised for speed drives that are changeable. Compared with SPWM, this method may raise the fundamental to 27.3 percent. The rotating synchronous reference framework is used by SVPWM. The SVPWM consists of a unique sequence of switching on the top three switches of a three-phase inverter. The voltages in the abc reference frame will be converted into a stationary DQ reference frame consisting of horizontal and vertical axes depicted in figure for the space vector PWM. [7]



(a) (b)

Figure 2: (a) Relation between abc and stationary dq reference frame; (b) Basic switching vectors and sectors

The SVPWM's primary goal is to approximate the Vref reference voltage vector by utilising the eight patterns. In SVPWM by utilising sectors, the reference vector position can be recognised and switches may be controlled according to detected sectors. The patterns and areas of change are described. [8] The voltages in dq reference frame and angle (α) can be given by the following equations

$$\begin{matrix} Vd \\ Vq \end{matrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix}$$

$$|Vref| = \sqrt{V_d^2} + \sqrt{V_q^2}$$

$$\alpha = \tan^{-1}\left(\frac{Vq}{Vd}\right) = \omega t = 2\pi f t$$

Where f=fundamental frequency. The SVPWM can also extend to 3 and 5 levels whose space vector representation is shown in the figure below[9]

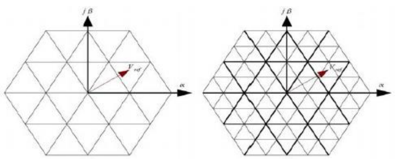


Figure 3: SVPWM's space vector representation

Here described SVPWM for 2 inverters, but this may reach 3 and 5 levels by utilising the representation of space vectors as shown in the picture. However, it may require some sophistication to calculate switching time, sector identification, to expand it to many levels. The SVPWM method is used for various applications, including direct torque control and field oriented control of the Permanent Magnet Synchronous Engine (PMSM), power factor correction, RFI filter as well as AC drive control. [10]

OBJECTIVES OF THE DISSERTATION

Microgrid is a future trend of integration in distribution systems of renewable generating units that typically consist of many inverter-based distributed generators (DGs). Again the idea of droop was taken from the traditional power system, where synchronous generators are controlled. The droop idea was utilised in hierarchical control architecture for microgrids. The major goals of the study are as follows:

1. Reducing harmonics and stabilising flow.
2. To establish a power balance autonomously under resistive and resistive loads
3. The obvious benefit of expanding the application range is to evaluate the reverse power factor drop management.

The control model was simulated in MATLAB using a series connection of two or three inverters. A comparison study is performed on THDs using SPWM and SVPWM methods in the output voltage. The active forces are also compared to improved power supply.

PWM TECHNIQUES

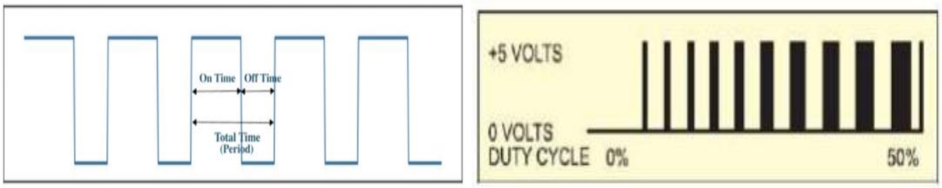
PWM (Pulse Width Modulation)

Inside the inverter, PWM is the most effective method of control. By applying a continuous DC voltage to the inverter's input, the PWM technique generates AC voltage at the required frequency. To do this, the on and off times of the inverter's switching components must be regulated. In order to improve the inverters' output, several modulation methods are used. Techniques based on pulse width modulation (PWM) have the benefit of reducing lower order harmonics and being simple to apply and regulate. We study and contrast the THD performance of SPWM and THPWM. [11]

PWM (Pulse Width Modulation) is a digital technology that allows you to vary the amount of power sent to a device. It uses a digital source to produce analogue signals. A PWM signal is a square wave that alternates between on and off states. A PWM signal's behaviour is determined by its duty cycle and frequency.

The time it takes for this signal to accomplish a one-and-off cycle is measured in periods. The frequency is the inverse of the period, and that it is the number of times a periodic alteration is accomplished per unit time. It establishes the rate at which the PWM finishes one cycle, i.e., the rate at which the signal flips from high to low states.[12]

Pulse width modulation technique worked by rapidly switching the motor's power supply ON and OFF. The DC voltage is transformed to a square wave signal that alternates between fully on (almost 12v) and zero, providing a series of power "kicks" to the motor. PWM (pulse width modulation) is a speed control technology that can solve the problem of a motor's poor beginning performance. PWM (pulse width modulation) is used to control the speed of a motor in a similar way. Instead of providing a variable voltage to a motor, it is provided with a constant voltage (such as 12v) that immediately starts it spinning. After that, the voltage is turned off, and the motor coasts. The motor speed can be regulated by continuing this voltage on/off cycle with a varied duty cycle. In DC motor speed control, pulse-width modulation (PWM) or duty-cycle modification methods are often utilised. During a PWM period, the duty cycle is defined as the fraction of digital 'high' to digital 'low' plus digital 'high' pulse-width.[13]



(a) (b)

Figure 4: (a) Pulse Width Modulation; (b) PWM Technique

For a 0% duty cycle, the average DC voltage is zero; for a 25% duty cycle, the average DC voltage is 1.25V (25 percent of 5V). When the duty cycle is 50%, the average voltage is 2.5V, and when it is 75%, the average voltage is 3.75V, and many more. The highest duty cycle, which itself is identical to a DC waveform, is 100%. Researchers can change the average voltage across a DC motor and therefore its speed by changing the pulse width. The following equation gives the average voltage:[14]

$$y' = D.\ Ymax + (1 - D)\ Ymin$$

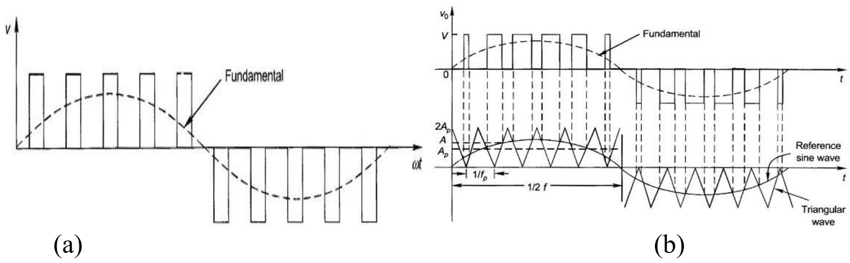
But usually minimum equals zero so the average voltage will be:

$$y' = D.\ Ymax$$

Conventional Sine PWM

The voltage source inverter makes advantage of the SPWM control method. In this method, triangle signals are compared to sine waves; if the sine wave has a larger amplitude, a pulse is generated for the positive half cycle, and if the sine wave has a smaller amplitude, a pulse is generated for the negative half cycle. The number of pulses per half-cycle is determined by the carrier signal, whose frequency is twenty times that of the sinewave. Carrier signals operate at a significantly higher frequency than radio waves.

"In Sinusoidal Pulse Width Modulation the pulse-width instead of being uniform as in the waveform of Fig. 3.3 is a sinusoidal function of its angular position with respect to a reference sine wave resulting in a reduction in the harmonic content. The control function consists of a sinusoidal wave obtained from an oscillator of variable amplitude A and of fundamental output inverter frequency f = 1/T as well as a triangular wave of fixed amplitude Ap and frequency fp with a direct component of amplitude Ap" as shown in Fig. 3.4.



(a) (b)

Figure 5: (a) Sinusoidal Pulse Width Modulation waveform; (b) Output voltage of SPWM

At the end of each half cycle, the output voltage undergoes a reversal in polarity, resulting in a biassed triangle waveform. By contrasting the sinusoidal and triangle waveforms, we may create gated pulses at times when the sinusoidal signal is more positive than the triangular one.

As can be seen in the diagram, the number of gate pulses (sinusoidally modulated) every half-cycle is

$$N = \frac{f_p}{2f} = \text{integer}$$

From this, we may infer that the thyristors' turn-on and commutation angles are set by the crossings of the two signals mentioned above.

When a high-frequency triangle waveform is superimposed over the required modulated waveform, we get the sinusoidal PWM waveform. If the signal voltage is less than or greater than the voltage of the carrier waveform, the DC bus will produce a negative or positive voltage as its output.

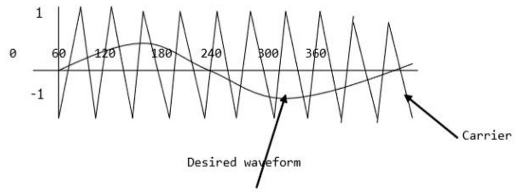


Figure 6: sinusoidal PWM waveform

"The sinusoidal amplitude is given as A_m and that of the carrier triangle is give as A_c. For sinusoidal PWM, the modulating index m is given by A_m/A_c."

Modified Sinusoidal Waveform PWM

Power is regulated and the power factor is improved using a pulse-width modulated (PWM) waveform. The basic idea is to change the PWM converter such that the grid's delayed current is transferred to the voltage grid. Therefore, power factor optimization and power efficiency are both enhanced.[15]

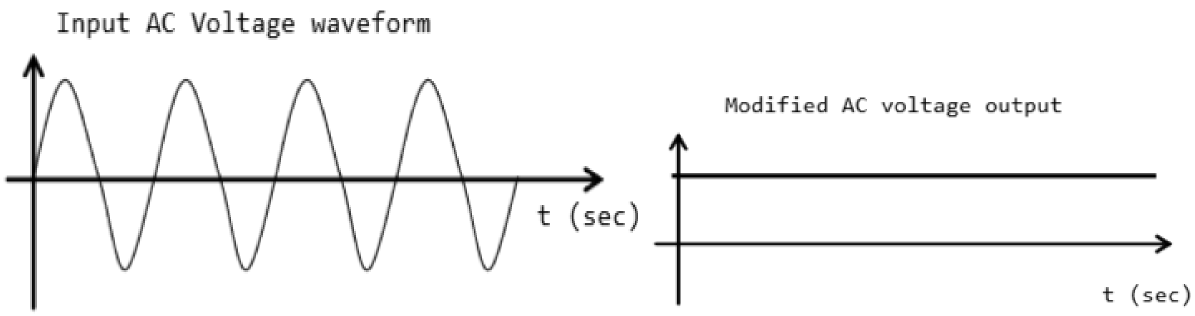


Figure 7: modified sinusoidal PWM waveform

Types of Pulse Width Modulation Techniques

PWM approaches are distinguished by pulses of constant amplitude. The width of these pulses is controlled, though, to control the output voltage and minimize the harmonic content. Single-pulse modulation, Multiple pulse modulation, and Sinusoidal pulse width modulation are the different PWM approaches. These strategies are briefly described below:

Single pulse width modulation

There is just one pulse each half-cycle in single pulse-width modulation control, as well as the width of the pulse is varied to regulate the output voltage. The gating signals are produced by the following:

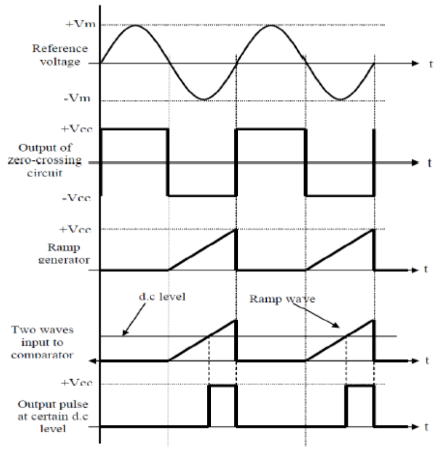


Figure 8: The generation of gating signals of single pulse width modulation

The reference signal is converted to a square wave signal using a single pulse-width modulation. As shown in Fig., this process is achieved by connecting the reference signal to a zero-crossing circuit that considers the positive part of the input signal to be the positive part of the output signal (square wave) and the negative part of the input signal to be the negative part of the output signal.

Multi-Pulse width modulation

Using numerous pulses in each half-cycle of output voltage helps reduce harmonic content. Figure shown below depicts the creation of gating signals for turning on and off transistors. By analyzing a reference signal to a triangular carrier wave, gating signals are created. The output frequency (fo) is determined by the frequency of the reference signal, whereas the carrier frequency (f) determines the number of pulses each half cycle.

The pulse changes from 0 to /p and the output voltage changes from 0 to Vm when the modulation index (M) changes from 0 to 1.

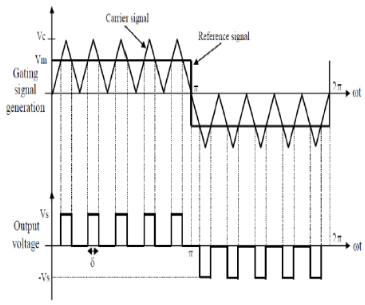


Figure 9: The generation of gating signals of multi – pulse width modulation

The Carrier-Based Pulse Width Modulation (PWM) Technique

The carrier-based PWM approach meets this need by comparing a modulating signal Vc (desired ac output voltage) with a triangle waveform V to define the on and off states of the switches on one leg of a VSI (carrier signal). In actuality, the switch S+ is on and the switch S- is off when Vc > VΔ; similarly, the switch S+ is off and the switch S- is on when Vc < VΔ.

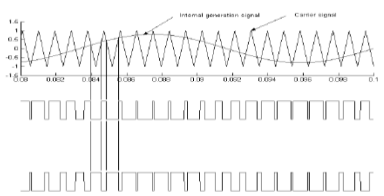


Figure 10: The generation of gating signals of Carrier-Based pulse width modulation

Waveform Distortion

Distortion of the waveform is known as a steady-state deviation from an ideal power frequency minus wave primarily distinguished by the deviation's spectral content. Following are three forms of distortion of the waveform:

HARMONICS: There are sinusoidal steady-state voltages or currents having frequencies that are integer multiples of the basic frequency. In the nonlinear characteristics of systems and loads on the power grid, harmonic distortion instigates. Computers, UPS systems, variable frequency drives (VFDs etc. are examples,

INTER HARMONICS: There are voltages and currents that have elements of frequencies that are not integer multiples of the fundamental frequency. Static frequency converters, cyclo-converters, induction motors, and arcing systems are few examples.

NOISE: There are unwanted electrical signals with a wireless spectral content of less than 200 kHz superimposed on or discovered on neutral conductors by device voltage or current.

Distributed Generators

There are two different types of generation technologies applicable for microgrid design such as renewable distribution generation (solar thermal, photovoltaic (PV), wind, fuel cell, CHP, hydro, biomass, biogas, etc.), and non-renewable distribution generation (diesel engine, stream turbine, gas engine, induction and synchronous generators, etc.). The usage of wind energy has quickly grown by approximately 30 percent per year worldwide and has become an important resource for microgrid electricity, along with solar energy. These developing technologies and well-established generating technologies are well-known and this research includes an in-depth examination of these generation systems.[16]

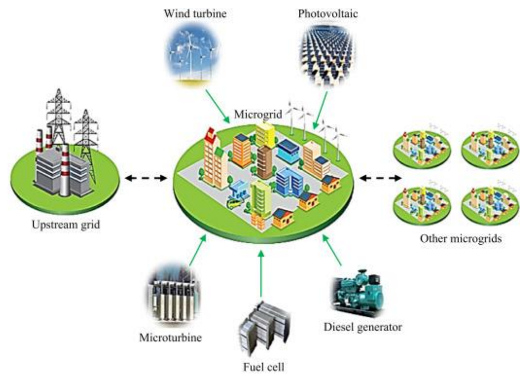


Figure 11: Distributed generation and microgrids

The production of electricity from renewable energy distribution is difficult since it is intermittent power sources. The power output relies largely on solar energy, since virtually every type of renewable energy supply has to do with a solar power system. Building a power grid with no non-renewable DGs is thus hazardous in terms of dependability. More than 80 percent of the U.S. population, comprising 37 states, has, according to a Resnick Institute study, passed renewables requirements including up to 33 percent of the energy supply projected to consumers by 2020. Moreover, some 675 billion dollars will be spent in the U.S. to build distribution infrastructure by 2030. As a result, each state stepped up its goal of standard distribution, production and generation of renewable energy. Many governments have already begun major electrification efforts with increasing demand and growing dependability problems. [17]

Energy storage Devices

The storage of energy is an essential element in legitimizing renewable energy resources as a dependable source and ensuring the success of microgrid operation. The energy storage process plays a major role in the balance between power production and energy requirements. The energy storage component needs in a microgrid are mentioned below:

- The primary objective for energy storage devices is balancing power demand between the generating end and the load side (since the sources are intermittent and transient disturbances lacks of inertia).
- The greatest energy consumption during off-peak hours is saved and all loads may be supplied when needed.
- To remove loaded microgrid components that assist fulfil unexpected and unpredictable needs
- Smooth transition circumstances from grid to island operation or vice versa.
- Adjust the minute-hour peaks to the curve of daily demand

Energy storage methods are primarily categorized as electrochemical (typically batteries and flux cells), flywheel power storage and potential energy storage systems (pumped hydro or compressed air storage). The batteries, flywheels and super condensers are best suited for microgrid use. Battery-based energy storage systems are the greatest option to guarantee the continued operation of fixed voltage and frequency while utilising renewable energy sources (RES).[18]

The alternative flywheel method is well suited as a central storage device due to its ability to absorb and release energy quickly. However, flywheel method remains too expensive for large-scale power system applications when used in an advanced design. In uninterruptible power supply applications, the storage systems compete with both batteries and flywheels with regard to high power demands, power density and efficiency. Fuel cells or traditional generators with effectively large inertia could be another option for a microgrid storage system.[19]

Microgrid Loads

A microgrid system has various kinds of load and it plays a vital role for its operation, stability and control. An electrical load can be categorized as a static or motor/electronic load. The microgrid can supply various kinds of loads (such as household or industrial) which are assumed to be sensitive or critical, and demand high-level reliability. This kind of operation requires several considerations such as priority to critical loads, power quality improvement supplied to specific loads, and enhancement of reliability for pre-specified load categories. Additionally, local generation prevents unexpected disturbances with fast and accurate protection systems.[20]

The load classification is important to define the predicted operating strategy in a microgrid arrangement under the following considerations:

- The load/source operation strategy required to meet the net active and reactive power in grid-tied mode, and stabilization of the voltage and frequency in island mode.
- Improvement of power quality,
- Reduction of maximum load to enhance the DER ratings,
- Maintaining desired operation and control

Pulse Width Modulation Control

The basic magnitude of the output voltage may be adjusted by exercising control inside the inverter itself, without an external control circuit. The most effective way to accomplish this is to adjust pulsed width (PWM) within the inverter. In this system the converter is powered by the set input voltage and by changing the on and off times of the inverter components a regulated ac voltage is produced. The benefits of the PWM control system are: [21]

1 The output voltage control can be obtained without addition of any external components.

2 PWM minimizes the lower order harmonics, while the higher order harmonics can be eliminated using a filter.

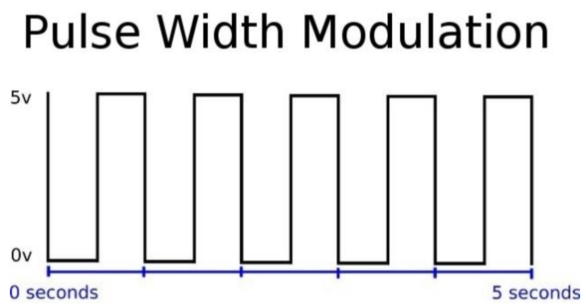


Figure 12: Pulse width Modulation

The drawback of this system is that the switching devices used in the inverter are costly because they have to have a low turn-on and turn-off periods, yet PWM is still extremely common with all industrial equipment. The PWM methods for each period are characterised by constant amplitude pulses with varying duty cycles. The width of these pulses is adjusted for inverter voltage control and the harmonic content of the inverter voltage control. The harmonic content of their respective output voltages differs fundamentally by various PWM methods and thus the choice of specific PWM technique is dependent on the allowable harmonic content of the inverter output voltage. [22]

SPWM Technique

The inverters use PWM methods for maintaining consistent output voltage regardless of load. PWM is the process of changing the pulse width with regard to the wave carrier or wave control. However, different kinds of PWM are tried and used in order to decrease the harmonic content of the inverter output. SPWM is discussed in this chapter.

When voltage source inverter is switched in either 120 degree or 180 degree mode of operation, the output waveform obtained will be a square wave. Hence, to acquire a sine wave, sinusoidal PWM is simple and efficient method. In this method, a sine wave and triangular wave which acts as carrier are compared with comparator. The resultant pulse generated is the required PWM signal. Basic principle of SPWM is shown in Fig.

Before coming to SPWM, there are some considerations to be taken. Let the sine wave amplitude be modulated be Am and the triangle carrier is Ac. The index of modulation (Am/Ac) has a larger effect on the output voltage. Due to the inductive nature, very high carrier frequency provides the benefit of decreasing harmonic components. High-frequency switching also increases the loss of switching on the inverter power electronic switches. This is why the carrier frequency is selected for optimal usage between 2 kHz and 15 kHz. Similarly, it is necessary to sustain all three waveforms symmetrically for three-phase inverters. So, the ratio of sine wave frequency fm to the carrier frequency fc is chosen in integral multiples of 3 (fm/fc= 3n, n ∈ N).[23]

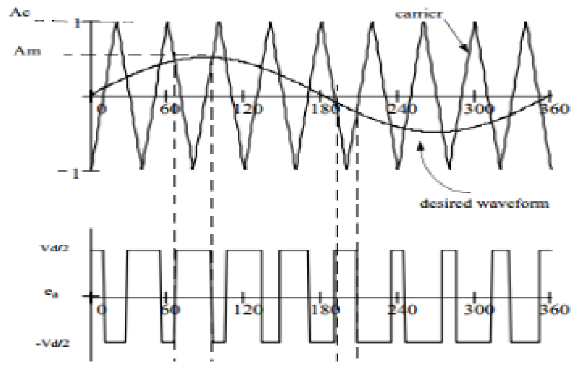


Figure 13: SPWM Technique

CONTROL STRATEGY

DROOP CONTROLLER METHOD

It is autonomous approach for controlling the frequency and voltage amplitude of the generator connected to micro grid. It takes the advantages that real power controls frequency and that the reactive power controls the voltage. The power sharing can be done by the droop control method by using the real power controller and reactive power controller. [24]

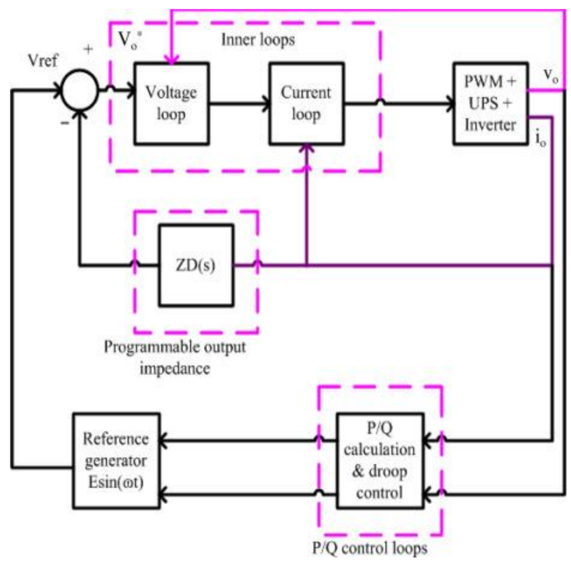


Figure 14: Droop Controller Technique

The expression defining the real power frequency control of droop characteristic are expressed as

ω (t) =ω∗− (Pj∗−(t)) (1)

βj=ω∗− ωmin/ Pj∗− Pj,max

Where (t) is the actual active power output of the Distributed generation system and βj is the slope of the P-ω droop characteristics

Where (t) is reactive power output and is the slope of reactive – voltage droop characteristics.

The total harmonic distortion (THD) at the point of common coupling are minimized for the stand-alone and system relating the problem on reactive power sharing. The capacitive virtual impedance loop is used to control the voltage harmonics which occurs at PCC. In grid connected mode, the current control loop is applied to flow the active and reactive power for the power grid and frequency operation. In autonomous mode, power converters are used for operation in three sub-moles like convection droop mode, PCS mode and synchronization mode. The (Vg\Vdc) droop control which provides the dc link voltage at inverter output to maintain the power in micro grid. P-Vg droop control maintains the voltage limiting the constant power band. The hierarchical control consist voltage droop control and impedance control loop for VSI based MG system. These maintaining the phase angle and voltage reference of real power and reactive power. Virtual inductor is used for inverter output of power electronic devices connect to DG system which disconnect the coupling between real and reactive power. An enhanced droop control based on virtual impedance for controlling the frequency to minimize the reactive power load, unbalanced power load and distorted harmonic power load issues.[25]

Transient droop controller is used to minimize the transient voltage. Virtual inductance are connected in this controlled to avoids the harmonic voltage in grids. The droop control provides the active and reactive power influence on voltage and frequency. It supply the smooth voltage and frequency control but is mostly dependent on the specification between inverter connected distribution generation and load.[26]

PQ Control

PQ control output of the active and reactive power respectively as its reference value Pref and Qref, usually used for grid-connection mode of microgrid. In this state, microgrid voltage and frequency stability can't guarantee, load fluctuations within the microgrid, frequency and voltage disturbances borne by the large grid, each DG don't need to consider the frequency regulation and voltage regulation, directly use of large grid frequency and voltage as regulation basis, controlling the inverter according to the given reference value of active power and reactive power output, controller adopts double loop control, outer loop control needed to produce the reference signal current loop based on power target, current inner loop played the role of fine-tuning.[27]

$$\begin{cases} i_{dref} = \left(k_{p1} + \frac{k_{i1}}{s}\right)\left(P_{ref} - P_m\right) \\ i_{qref} = \left(k_{p2} + \frac{k_{i2}}{s}\right)\left(Q_{ref} - Q_m\right) \end{cases}$$

k$p1$, k$i1$, k$p2$, k$i2$ are the control parameters of the PQ controller.

In dq0 coordinate system, generally make q axis component Vq is 0.

Designed by the above formula (1) (2) PQ controller schematic is shown in Figure.

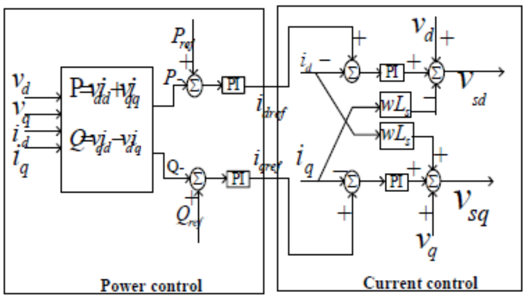


Figure 15: Structure of grid-connected PQ controller

The output voltage of current controller is modulated by the Park and SVPWM, can get a sinusoidal modulation signal, and thus completes the PQ decoupled constant power control.[28]

PQ Inverter with Droop Control

In contrast, a PQ inverter does not set frequency but monitors the frequency of the grid using a phase lock loop (PLL), and then works at that measured frequenz, by utilising a synchronous engine using its rotor speed as the frequency input for the P-f droop controller. By comparing the observed frequency with a reference value (nominal grid frequency), the inverter adjusts its power appropriately. [29]

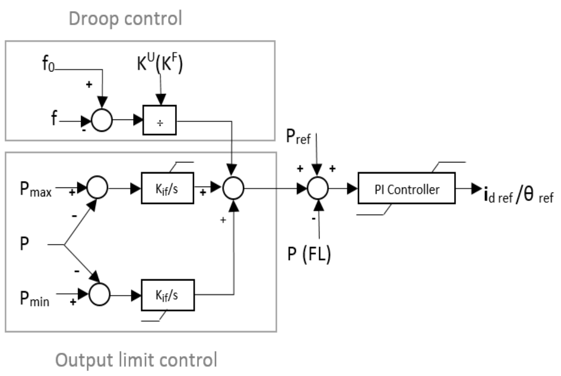


Figure 16: PQ Inverter with Droop Control

This relationship is modeled as:

$$P(f) = P_0 - (f_{set} - f)k_f$$

Where P0 is the power provided by the inverter and kf is the drop gradient, which defines the extent to which the active power P changes in response to a frequency changes f.. When using a Q-V drop the PQ inverter measures the voltage of the terminal and compares it to the reference value. By modifying the reactive component of the inverter current the reactive power is changed. This reactive power adjustment is as follows:

$$Q(V) = Q_0 - (V_{set} - V)\, k_v$$

Where Q_0 is the reactive power delivered/consumed by the inverter at set point voltage V_{set} and k_v is the gradient of the droop, which determines how much the reactive power Q will change in response to a change in voltage V.

METHODOLOGY

If the signal, received from the output of the power converter, is going to be connected to the grid it has to be synchronized with it. The inverters provide for this with help from the PWM switching information. This chapter presents the most common modulation strategies, the theory behind two-, and three levels SVPWM, and also the implementation done in Simulink and MatLab.[3]

Different PWM - approaches have the same goal: To reduce the THD of the current. Increasing the switching frequency reduces the lower-harmonics, which contributes to a lower THD, achieving the goal of a voltage output waveform with the requested rms values and frequency and a sinusoidal waveform resemblance.

Turning the switches ON and OFF creates pulses with the same amplitude but with different width. These pulses are generated in the output to replace the sinusoidal waveform. The easiest way of creating this is by using a intersection method, i.e. comparison with a saw tooth/triangle waveform (carrier wave). When the reference wave (sinus) exceeds the triangle waveform, the signal PWM (value: 1) is turned on and the signal is switched OFF when it is smaller (value: 0). [31]

The most popular technique is the Sinusoidal PWM. It has a great drawback, yet it is widely used: it has a low output voltage. Nevertheless, there are alternative ways which can better fulfill these requirements by utilising comparable carrier-based systems in various forms:

Trapezoidal modulation: triangular wave comparison and modulating trapezoidal wave.

Modulation staircase: The modulation signal is constructed as a step, the levels are determined to remove specific harmonics. For cycles with fewer than 15 pulses not advised.

Step modulation: Each step is a specific time part (in degrees) that controls the amplitude separately and eliminates harmonics. It gives modest, yet severe amplitude distortion.

Third harmonic injected PWM: The same manner as the SPWM is implemented, except the reference signal is not a sinusoidal wave. It comprises of a 1) basic component 2) Third component of harmonics. This technique provides the DC source a greater amplitude and better use. [5]

Space Vector Modulation

The idea of space vector is developed from the induction machine rotating magnetic field.

Three phase volumes are converted into two phase volumes.

Active and zero vectors may be represented correspondingly by active and zero space vectors. Typical two-level VSI space vector architecture is given in the figure. The six V1 to V6 vectors form a symmetrical hexagon of identical sections (1 to 6). Each sector is divided into 60 degrees. [33]

From Figure, Vref is the reference voltage vector which used to control the magnitude and frequency of fundamental voltage

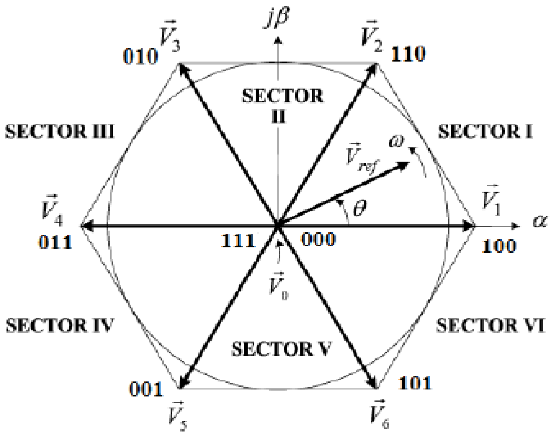


Figure 17: schema of space vector for two-level VSI

Advantages of SVPWM

- SVPWM makes efficient use of the DC link voltage, has minimal current ripple, and is straightforward to implement in hardware.
- The SVPWM maximises the use of voltage by 15 percent more than the SPWM. This quality qualifies it for use in renewable power production and other high-voltage, high-power applications.
- When comparing SVM to SPWM, we find that SVM produces less harmonic distortion in the output voltage or current.
- Compared to sine PWM, SVM makes better use of the available supply voltage.

Disadvantages of Sinusoidal PWM

As the depth of the hierarchy grows, so does the number of unnecessary transitions. As the number of possible transition states grows, so does the difficulty of their selection.

Role of SVPWM in Micro Grid

Technology evolution, environmental concerns associated with central electric power plants and deregulation of the electric utility industry are providing the opportunity for renewable energy resources to become very important in order to satisfy the on – site customer expanding power demand.

From the utility point of view application of distributed energy sources can potentially reduce the demand for distribution and transmission facilities. Clearly, distributed generating placed near loads will decrease transmittal and distribution circuit flows with two major effects: loss reduction and possible network assets replacement. [34]

Microgrids may assist the network in times of stress by reducing congestion and supporting fault recovery. The development of microgrids may help to emission reductions and climate change mitigation. This is because technologies for distributed generating units are available and are presently being developed based on renewable sources and micro sources with high emissions.

SVPWM Technique is used because of the constraint that the input lines must never be shorted and the output current must always be continuous a voltage source inverter can assume only eight distinct topologies. Space Vector PWM technique is most widely used. It controls the output voltage as well as reduces the harmonics.[35]

Advantages of SVPWM

Space vector PWM is considered a better technique of PWM implementation owing to its associated advantages mentioned below:

i. Better fundamental output voltage.
ii. Improved harmonic spectrum.
iii. Easier implementation in Digital Signal Processor and Microcontrollers.

Conventional techniques involve look up tables for achieving this optimum switching sequence.

RESULTS AND DISCUSSION

SIMULATION PARAMETERS

The simulations are carried out to validate the proposed ideas. The simulation parameters of the system comprised of three cascaded DGs are listed in Table shown below.

Name of Parameter	Value
Rated Power	200V
Frequency	50 Hz
Reactive Power	0.1 kVar
Maximum Frequency Deviation	0.5 Hz
Controlled Coefficient	5×10^{-5}
Line Inductance	1.8mH
Impedance Load (from 0 to 1 Seconds)	10+j5 Ω
Impedance Load (from 1 to 2 (Seconds)	10-j5 Ω

Simulation Results and Discussion

The simulation test results are presented in this section to show the effectiveness of the proposed SVPWM controller. Offline digital time-domain simulations were carried out in MATLAB/SIMULINK and experimental tests were conducted to verify the results of the simulations. And with the help of FFT analysis, SPWM Controller and SVPWM Controller are compared.

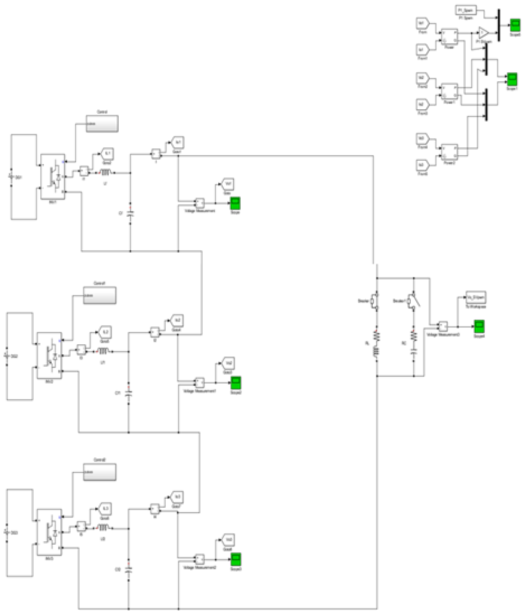


Figure 18: Proposed test system with three modules in series

The above fig 6.1 is the proposed three inverter module connected in series for output voltage generation. The below is the controller with sinusoidal PMW technique.

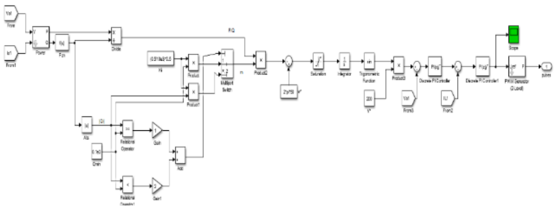


Figure 19: Proposed PQ droop controller with SPWM technique

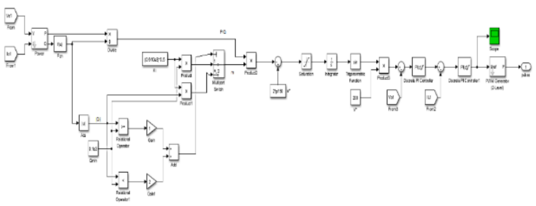


Figure 20: Proposed PQ droop controller with SVPWM technique

The above shown fig 6.3 is the controller updated with Space vector PWM technique replacing conventional SPWM technique. With the new PWM technique the output voltages of one module and all three modules in series are compared below.

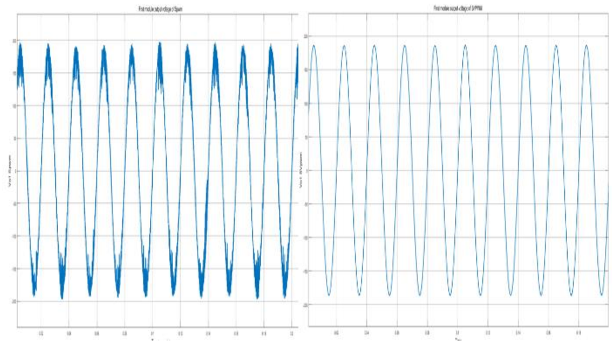


Figure 21: First module output voltage comparison between SPWM and SVPWM

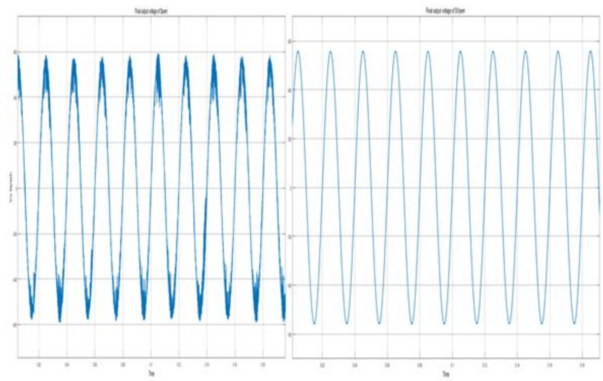


Figure 22: Final output voltage comparison between SPWM and SVPWM

The active and reactive powers comparison of the three series connected modules with same voltage generation is shown below in fig 6.6. The load is changed from RL to RC at 1sec with total simulation time of 2sec.

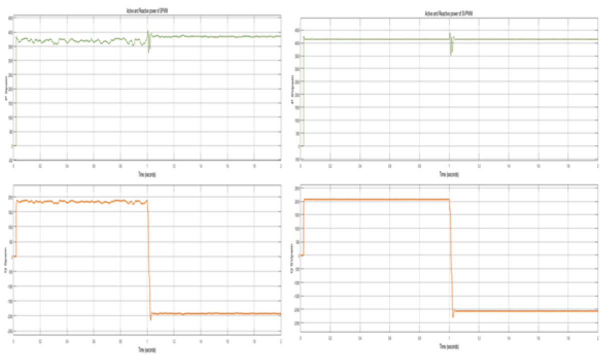


Figure 23: Active and Reactive powers comparison of Spwm and SVpwm

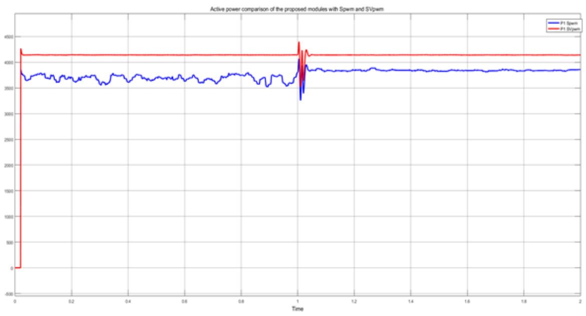


Figure 24: Active power comparison of the proposed modules with SPWM and SVPWM

The above fig. 6.7 is the active power comparison with SPWM and SVPWM control technique. The THDs of the output voltages are analyzed using FFT analysis for both the controllers.

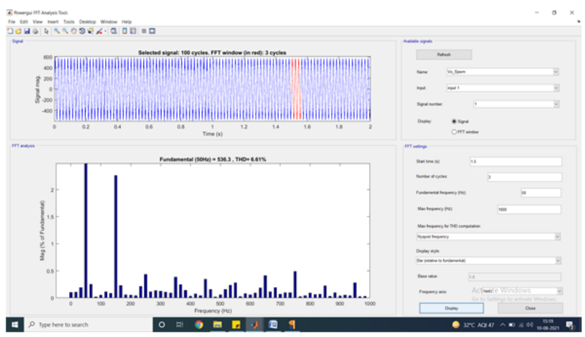


Figure 25: THD of output voltage with SPWM technique

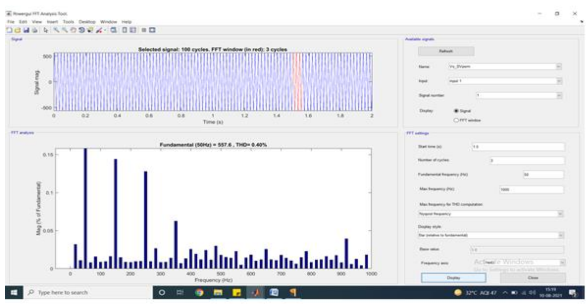


Figure 26: THD of output voltage with SVPWM technique

CONCLUSION

The preceding findings show that the SVPWM Technics Module has less active power ripple and less THD in the output voltage. It achieves a precise real-power and reactive-power balance autonomously under resistive and resistive loads. In the meanwhile, the ac bus voltage is adjustable. This article proposes a novel way to get a precise load sharing ratio across series inverters in island microgrids. In this research, the voltage drop pitch is adjusted to offset the voltage drop in line impedances by using communication connections. The technique ensures precise power sharing even when the connection is interrupted. Where the load varies during the interruption of communication, energy sharing accuracy is decreased, yet the suggested approach is better than the traditional drop control method. The exactness of the power sharing basis on the suggested approach is moreover not influenced by the latency in the communication channel and local loads. The output tension THD with SPWM is 6.61% and with SVPWM it is 0.4% which is better and much lower.

FUTURE SCOPE

The controller can be updated with adaptive controllers and sliding mode controllers for more stabilized results. The conventional DC sources can be replaced with renewable sources like PVA, Wind farm, Fuel cell, battery for renewable power sharing to the loads.

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