Performance Analysis of Control Techniques for Micro Power System using Hybrid Approach

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Abstract--The hybrid combination (Photovoltaic, Fuel Cells, and Battery) has found to be best energy resources which provide a reliable micro-power system. The single-phase inverter is modelled using appropriate gate pulses and the three-phase systems are modelled by control techniques such as Sinusoidal Pulse Width Modulation (SPWM) and State Vector Pulse Width Modulation (SVPWM) for attaining AC power. In this paper, the modular approach and Multiple Input Single Control (MISC) is applied to single-phase and three-phase systems with SPWM and SVPWM respectively to achieve better output efficiency. The modular approach is introduced for the power quality problem in the micro system, and MISC maintains the constant dc-link voltage. Furthermore, the proposed method maintains the State of Charge (SOC) of the battery by controlling the converter switches. The proposed research methodology is executed in MATLAB/Simulink-R2014a (Version 8.3) tool. The simulation results demonstrate that the MISC-based three-phase AC system with SVPWM achieves better results with reduced distortion level than SPWM.

Keywords: Micro power system, Sinusoidal Pulse Width Modulation (SPWM), State Vector Pulse Width Modulation (SVPWM), Multiple Input Single Control (MISC).

1. Introduction
Energy is a highly essential requirement for all social activities that exist. Also, the energy is a huge crisis to human, as majority of the energy used on earth comes from the conventional fossil fuels [1]. The energy supply for the remote islands and the villages are supplied by means of some diesel generators. This furthers the acceleration in diesel price and shipment that influences the fuel cost. Auspiciously, the remote zones are highly abundant in locally available renewable energy sources [2]. As the diesel cost is increasing rapidly, the renewable energy resource has become a competitive resource along with the conventional energy, which encourages the wide consumption of the Renewable Energy Resources (RES) for off-grid power supply such as PV and wind battery systems and storages, etc. [3]. [4] Proposed controller which combines the Genetic Algorithm (GA) and PID controller to control the wind energy conversion system (WECS) with doubly fed induction generators.[5] Proposed a passive islanding detection technique using means of a neuro-fuzzy method for wind turbines. A micro power system engenders electricity in order to oblige a particular load. These systems support grid connected systems or independent stand-alone systems for generating electricity and its efficient storage [6]. It is a small interactive network grid consisting of micro sources, Distributed Generators (DG) units, energy storage technologies, and scattered loads [7]. The micro grid architecture insures that its electrical impact on the bulk provider qualifies the micro grid as a good citizen, i.e., it does no harm beyond what is adequate from the existing customer. Even though micro grid provides interruptible load, it serves as a small source of power, thus making it as a model citizen. The major advantage of the
micro grid is that it can be regarded as a precise entity within a power system which can be operated as a single amassed load [8].

The DGs are often interconnected with the micro grids through the power electronic interface sub-system [9]&[10]. Because of the increasing deployment of DGs in power system, managing the different DG power raised a major concern. In this case, the micro grids have become a widely accepted concept for the superior connection of DG’s in power system. While comparing with the conventional power system, the ac micro-grid has been testified mainly on the subject of power sharing of the parallel connected sources [11]. A micro power system referred to as micro grid, is a reliable short range of power generation and transmission network that could incorporate distributed power generation sources at relatively small levels, could be visualized. If disconnected from the interconnected power system, the network continues to supply electricity in the locale[12]. The DG such as the fuel cells, micro turbines, and the photo voltaic panels are smaller relative to the system’s overall capacity. The smaller size of the DG is more likely to achieve significant penetration levels. The power plants serving a high voltage transmission system cannot target a particular load and therefore lies outside the threshold of becoming a micro power system. As huge design choices and uncertainty in certain parameters exist, the designing of a micro power system becomes a tedious task [13].

The disconnection of the micro power system from the main power system leads the harmonics to flow into the main system which distorts the voltage and the current profile. Small drop in voltage, flow of zero and negative sequence components of currents to the system, and instability in terms of heavy load conditions are the general issues that occur. These problems play a vital role in reducing the overall power quality of the distributed power system. There are several control techniques available which depends on the inverter topology and its interface, DG units and the type of the storage systems[14].

Single renewable energy source may even cause complexity because of its intermittent nature. Several researches consider only individual energy source. Intermittent nature and availability are the two main disadvantages in single source system which leads to fluctuating output[15]. In WECS, the wind speed fluctuates and affects the output power; also, the change in solar irradiation and temperature affects the PV panel output [16]. MPPT based dc-dc converters were deployed in several researches to obtain maximum power [17]. PV, fuel cell, and battery are combined to form a hybrid source in this research, which has also been done by [17]. The proposed research is executed and the outputs are discussed in single and three phase systems. By providing appropriate gate pulse the single-phase system is modelled[18]. The three-phase inverter topology is modelled with additional modulation techniques such as SPWM and SVPWM. The aforementioned models are constructed by using MATLAB/SIMULINK software. The PV system is chosen as the primary energy resource, which is an attractive resource for generation of electricity since it is noise free, pollution free, and scale flexibility. Even though the PV system has certain advantages, they completely depend on availability of sunlight. PV system must augment additional energy resources in order to overcome the limitations of PV panel [19]. Fuel Cells (FCs) evolve as a hopeful substitution energy resource because of its advantage such as efficiency and consistency. They are the supplement which provides the extra power that could not be provided by the PV panels. The storage element is combined as the additional part for the night period as the sunlight will not be available. Batteries are generally considered as the storage mechanism. The batteries help in smoothening of the output power, enhances the startup transitions, dynamic features and the peak power capacity. Hence, the hybrid AC system is proposed in this research.

2. Related Studies
A rural electricity system was developed [20] in some of the mountainous countries wherever there was significant potential for all renewable resources. In some places, the national level utility grid is unable
to supply electricity due to its higher cost and therefore, with the inclusion of the hybrid renewable energy resource, cost effectiveness can be achieved. A mini grid which incorporates integration of a distributed generating system will improve the reliability and quality of the power. In order to integrate PV, wind and hydro power in single mini grid two combined techniques were deployed. One such example is connecting a hybrid PV wind system into a hydro dominant system by means of a micro grid. By applying hybrid charge controller, GTI, and suitable Electrical Load Controller (ELC) such kind of systems could be hybridized. According to [21] reliable and independent technique must be suggested for tracking maximum power point under partial conditions Hybrid PSO and DE was used to track MPP in power system. The proposed technique was executed in a simulation environment under three conditions. To verify the accuracy, speed, and reliability of the system these predefined conditions were used. During mismatch conditions the DEPSO system distinguished GMPPs from local MPPs. The major advantage of this study was i) DEPSO ensured purely system independent MPPT technique, ii) In order to find actual GMPP in a short time period the logical slowdown condition guaranteed reliability of the system, iii) Minimized the computational burden of the algorithm and was suitable to execute in a low-cost microcontroller. The demand for the electricity power is increasing day by day which is not met with the satisfied level and renewable energy resources such as wind, solar are used and are universal. The use of the hybrid solar system and wind renewable energy system will be considered as a best option for the various aspects. The aspects of hybrid solar and wind system are studied in this research paper [30]. The different techniques used for the renewable energy system is studied in detail and shows development of the new technologies and researches in the field of solar wind hybrid system.

An optimal allocation of Distributed Generation (DG) and recloser in concurrent mode is proposed [22] and it is developed using an improved harmony search (iHS) algorithm. Some of the real examples of micro power system which supplies power are solar battery systems and wind diesel systems. While the first handles remote load for specific applications, the latter looks into the management of an isolated village. Another example is a grid-connected natural gas micro-turbine that offers electricity and heat. [23]Proposed a technique that combines Monte Carlo (MC) and Stochastic-algebraic (SA) approaches for stochastic analyses and probabilistic evaluations in electric power systems. [24]Proposed short-term power assessment of wind and solar power for estimating the available output power of each production module. [25]Investigated an approach to estimate the reliability of large-scale and grid-connected PV systems which is also used to optimize the maintenance costs. A mathematical model using Markov method is proposed to estimate the reliability of electric power distribution system in a smart monitoring system [26]. The new formula for power flow analysis problem was developed and solution was proposed [31]. The conventional power flow analysis methods which are unable to cope were compared with the proposed methods. The optimization algorithm using the gaussian mutation and guaranteed convergence operators gives the accurate results while comparing with the conventional optimization methods such as PSO, GA and DE. The proposed system is applied to the 6 bus, 33 bus and 69 bus microgrid systems to evaluate the performance of the algorithm.

According to[27] several stand-alone applications existed by accepting the renewable energy resource as the suitable choice. Several aspects of IRES such as integration configuration, choice of energy storage, sizing technique and energy flow management control was included in the review,also discussed the sizing approaches of the integrated systems adapted by other researchers. Artificial Intelligence (AI) offers computational simplicity for finding the global optimum solution. The most predictive algorithms used for sizing is Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Harmony Search (HS), and Biogeography Based Optimization (BBO). These technique deals with
stochastic performance level of the renewable energy sources. [28] Described that the high investment cost of DERs along with the micro grid introduced a barricade in deploying this technology due to the consumers who were not sure about the return of their investment. As forecast errors in load, renewable generation, and the market price exist the micro grid long term revenues could not be persistent. The proposed technique evaluated economic deployment of micro grid by verifying if the micro grid revenue would pay off the venture. To evaluate and examine the uncertain data, a robust optimization model was embraced. Even when the distribution of the uncertain data was not known, the robust model provided a solution. [29] Proposed a new multi objective EEMS for optimizing the operation of a micro grid in a cost-effective approach. In order to schedule the DER’s optimally, the EEMS consisted of a short-term power forecasting module for WTs. The artificial neural network forecasted the wind speed. The forecasting error was estimated with a level of confidence and finally, the obtained wind power capacity was used by the EEMS for optimal scheduling of WTs. The EEMS optimization module used an improved bacterial foraging based fuzzy satisfactory optimization algorithm for optimizing the multi objective problems.

3. Research Methodology

3.1 Standalone Power System
In order to meet the demand of remote area applications, a stand-alone system is established which incorporated hybrid resource structure. These systems included dc-dc converter, bidirectional storage system, and an inverter. A stand-alone power system is used for providing energy at local and remote situations where it is more effective cost than connecting to the power grid. In this research, the energy stored in batteries can be used when energy requirements outdo the output from renewable energy sources such as PV cell and wind. Inverters convert DC power from batteries and PV into AC power. Figure 1 denotes the structure of stand-alone power system.

![Figure 1 Standalone power system](image)

3.2 Modelling of PV cell
A p-n junction fabricated in a thin wafer of a semiconductor constitutes a solar cell. As per the photovoltaic effect, the solar radiation received from sun is converted to electricity. General computational model of solar cell has been discussed so far by researchers and they are preferred for applications corresponding to maximum power point. Figure 2 represents the equivalent circuit of a solar cell which constitutes of diode, photo current, series and parallel resistor, and the leakage current.
The V-I characteristic equation of a PV cell is given by as,

\[ I_{PV} = I_{PH} - I_S \left[ \exp \left( \frac{q(V + R_S I_{PV})}{NRT_c} \right) - 1 \right] - \frac{V + R_S I_{PV}}{R_{SH}} \]  

Where,

- \( I_{PH} \) = light-generated current,
- \( I_S \) = cell saturated dark current,
- \( q = 1.6 \times 10^{-19} \text{C} \) the charge of electron,
- \( k = 1.38 \times 10^{-23} \text{J/K} \) the Boltzmann constant,
- \( T_c \) = working temperature,
- \( A \) = ideal factor,
- \( R_{SH} \) = shunt resistance and
- \( R_S \) = series resistance

The photocurrent depends on the solar insolation level. The working temperature can be described as,

\[ I_{PH} = \left( I_{SC} + K_i (T_c - T_{Ref}) \right) \lambda \]  

Where,

- \( I_{SC} \) = short-circuit current at a 25\(^\circ\)C and 1kW/m\(^2\),
- \( K_i \) = short-circuit current temperature coefficient,
- \( T_{Ref} \) = solar insolation level in kW/m\(^2\)

The saturation current of solar cell changes with change in cell temperature which is given by as,
Where,

\[ I_{RS} = \text{reverse saturation current}, \]

\[ E_g = \text{band-gap energy of the semiconductor} \]

An ideal PV cell is free from series loss, and leakage to the ground (\( R_S = 0 \) and \( R_{SH} = \infty \)),

Figure 3 denotes the simplified circuit model of the equivalent circuit of a solar PV cell. The eqn (1) can be rewritten as,

\[ I_{PV} = I_{PH} - I_S \left[ \exp\left(\frac{qV}{AKT_c}\right) - 1 \right] \]

\[ \text{......... (4)} \]

Figure 3 Single diode equivalent circuit with \( R_{SH} = \infty \) and \( R_S=0 \)

3.3 Fuel cell

Fuel cell is defined as a chemical cell which uses chemical resources such as hydrogen and oxygen to produce electricity. The basic block diagram of fuel cell is shown in Figure 4.

Figure 4 Block diagram of the fuel cell
The basic block diagram of the proposed system is shown in Figure 4. The hydrogen and oxygen is extracted from the air and it is processed to fuel cell as an input. Proton exchange membrane is generally used in fuel cell for conversion process. Theses electrodes are generally made up off porous carbon and thin acidic fragile sheet is used as an electrolyte. During chemical reaction, hydrogen is processed through anode where it get oxidized by losing electrons and oxygen is supplied to the cathode layer. The flow of electrons amongst anode and cathode causes chemical reaction producing flow of electrical energy in the opposite direction.

The advantages of using fuel cell as a source of generating electrical energy are as follows,

1. The main advantage is that it uses water as an input source which is abundant in nature.
2. It has much higher efficiency compared to gas and diesel engine.
3. The operation of fuel cell is less noisy compared to IC and diesel engine.
4. The economic dependency on oil and gas can be reduced by using renewable gases as an input source.
5. The property of low heat transmission makes the fuel system ideal for military applications
6. Maintenance is cheaper because of very few moving parts

The advantages of hybrid solar-fuel cell power generation are as follows,

1. Since the input resource is mainly dependent on renewable sources, the hybrid system is quite operational with less emission.
2. The fuel efficiency of the system is increased
3. The performance of the battery is increased with high reliability
4. It is observed that fuel cell can operate for thousands of hours without any maintenance.

From the above advantages, it is found that hybrid power generation comprising solar-fuel is found to be efficient and effective especially in remote areas compared to other existing techniques.

3.4 Micro power system

![Flow diagram of Proposed System](image)

Figure 5 Flow diagram of Proposed System

Figure 5 describes the overall flow diagram of the proposed research method. The major aim of the research work is to achieve new advancements in micro grid by deploying several control techniques.
The micro power system works on the renewable energy resource combination such as the solar, fuel cell, and the battery. As the single renewable energy system leads to intermittent power fluctuations, the hybrid system is chosen. The SPWM and SVPWM are the control measures deployed in this research for controlling the gate pulse of the three-phase inverter. Furthermore, an advanced control technique, Multiple Input Single Control (MISC) is deployed for maintaining constant Dc link voltage. The research can be divided into four stages. They are given as follows.

a) Single phase AC system
The circuit topology of the single-phase ac system is described in the below Figure 6. The converter uses four switches to regulate the power flow.

![Circuit topology of single phase AC system](Image)

Figure 6 Circuit topology of single phase AC system (Converter)

As shown in Figure 6, the converter comprises with two input sources \( V_1 \), \( V_2 \) and a battery system denoted by \( V_B \) acts as both storage device and source. The DC output obtained from the source is fed into the input of the converter and output obtained will be in terms of single-phase AC or three phase AC depending on the requirement. The operating modes of the single-phase AC system are as follows,

- **First mode of Operation**
In this mode of operation, the input sources \( V_1 \) and \( V_2 \) supplies the load to the source through \( S_4 \) and \( D_3 \). The control strategy can be achieved by regulating any one of the input sources as its reference and other is used for regulating the output by varying duty ratio.

- **Second mode of operation**
In this mode of operation, input voltage \( V_1 \) and \( V_2 \) along with battery source is considered for supplying the voltage to the load. The output control can be achieved through the regulation of input sources along with their reference duty cycle \( d_1 \) and \( d_2 \). The discharge power captured from the battery is used to control the output by varying the duty ratio \( d_4 \).

- **Third mode of operation**
In this mode, input source \( V_1 \) and \( V_2 \) is used for supplying the power to the load as well as providing power for charging the battery. This charging condition can be achieved when the total power generated from input source is greater than the output load power. \( d_1 \) and \( d_2 \) is used to control the input source power whereas \( d_3 \) is used to control the output voltage for charging the battery.
During these operations, if any one of the inputs fails to supply power, its corresponding duty cycle is adjusted to zero for obtaining single power source operation.

b) Three Phase AC system using SPWM

The amplitude of the gate pulse fed to the switch can be controlled by SPWM technique in a three-phase ac system. The process of generating a gate signal in SPWM technique is by comparing sinusoidal reference signal with the carrier wave signal. With respect to the amplitude of sine wave, the width of each pulse is changed. Using the frequency of reference signal ($f_r$), the frequency of inverter at the output side could be found ($f_0$). Figure 7 shows that the gate signal is produced by using unidirectional triangular carrier wave. Figure 8 shows the implementation diagram of SPWM by MATLAB Simulink

![Figure 7 Waveform of Sinusoidal PWM](image)

![Figure 8 Simulink Circuit of Sinusoidal PWM](image)

Three Phase AC system with SVPWM

![Figure 8 Simulink Circuit of Sinusoidal PWM](image)
Here, SVPWM is deployed to control the gate pulse of the switches. The reference signal is sampled periodically in SVPWM technique. The non-zero active switching vectors will be adjacent to the initial reference vector as a sampled output. To make the reference signals as average of the vectors that are used, a zero-switching vector is selected for a suitable fraction of the sampling period. The existing topology of 3 leg VSI is the outcome of the disadvantage that input lines never gets shorted and the output current always be continuous. In existing eight topologies, six topologies produce non-zero output voltage and they are the non-zero switching states. Remaining two topologies yield zero output voltage and they are known as zero switching states. The implementation diagram of SVPWM is shown in Figure 9.

The mathematical equations used for the modulation techniques are given,

\[
V' = V_\alpha + V_\beta = \frac{2}{3}[V_a + aV_b + a^2V_c]
\]

\[
V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + e^{j\frac{2\pi}{3}}V_b + e^{-j\frac{2\pi}{3}}V_c\right)
\]

\[
= \frac{2}{3}\left[V_a + \left(\cos\frac{2\pi}{3}\right)V_b + \left(\cos\frac{2\pi}{3}\right)V_c\right] + j\frac{2\pi}{3}\left[\left(\sin\frac{2\pi}{3}\right)V_b - \left(\sin\frac{2\pi}{3}\right)V_c\right]
\]

Here,

\[
a = e^{j\frac{2\pi}{3}}
\]

\[
|V| = \sqrt{V_\alpha^2 + V_\beta^2}
\]

\[
\tan \alpha = \frac{V_\alpha}{V_\beta}
\]

By equating real and imaginary parts, the equation can be formulated as,

\[
\begin{bmatrix}
V_\alpha \\
V_\beta
\end{bmatrix} = \frac{2}{3}\begin{bmatrix}
1 & \cos\frac{2\pi}{3} & \cos\frac{2\pi}{3} \\
0 & \frac{2\pi}{3} & -\sin\frac{2\pi}{3}
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\]

Further the matrix is given by as,

\[
\begin{bmatrix}
V_\alpha \\
V_\beta
\end{bmatrix} = \frac{2}{3}\begin{bmatrix}
1 & 0 & -0.5 \\
0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\]
As the world’s population and the standard of living increases the energy demand is at its peak point. The fossil fuels and the oil resources are very much limited to satisfy the energy needs of the present population. As significance, the renewable energy usage has become highly essential. By incorporating advanced control techniques, the current research endorses an independent stand-alone hybrid power generation system. The multiple input renewable energy resource could be controlled by a Multiple Input Single Control (MISC) system. The renewable energy used in this research is solar, fuel cell, and battery. The general scheme of the MISC is derived from heighten converter. The source with high power output is generally considered as Master source, and it could be voltage or current source. The master source will always be in control of duty cycle and based on the input source, the master source fixes the duty ratio of the converter switch. As the converter scheme is based on heighten converter model the output voltage will be greater than the input voltage. Figure 10 shows the MISC heighten converter, in that S1 denotes the master source and S2 to Sn denotes the other sources that are connected to the drain of the switch in control through respective inductors.
Based on the characteristic features of the source being connected to a converter, they could be divided into voltage source or current source. The practical arrangement of MISC converter is shown in Figure 11. In the fig 10, solar is considered as master source S1. The duty cycle of the switch M1 is fixed according to the maximum power point of the solar panel. Since solar is a current source, it could be used to charge the battery or supply the load according to the needs in the micro system.
Figure 11 (a) Input current and voltage source, (b) Input current and current source, (c) Voltage and Voltage Source Inputs, and (d) Voltage and Current Source Inputs in Heighten Converter

Generally, the renewable energy resources are unidirectional in nature. Whenever the current source interfaces with the converter, the capacitor terminal will be utilized at the output. To satisfy the ripple of the input current of converter, the capacitor is required. The input capacitor will be neglected when the voltage source persists and the capacitor voltage reaches one. To operate the converter in continuous conduction mode, the ripple in the main inductor must be substantially low. The inductance value should be increased as the ripple content is decreased. Here, the exchange between the value of the ripple and the inductance is required. In order to account for power quality problems in micro power system operating at different voltage levels along with the main grid, a modular approach is presented.

4. Simulation Results

The stand-alone micro power system was simulated using the MATLAB/SIMULINK R2014a (Version 8.3) tool for both the single phase and three phase ac power output. The 1 ϕ ac system is simulated and the output waveforms are mentioned. The results obtained for stand-alone 1 ϕ ac system with MISC control and the modular approach is given as follows. Pulse width =70, Phase delay = 0 for first switch and Pulse Width = 80, Phase delay = 0 for second switch. For third switch, Pulse width = 85, Phase delay = 3.7500e-05. The fourth switch has Pulse width = 45 and Phase delay = 4.5000e-05.

The switching parameters are mentioned as follows,
FET resistance, $R_{on} = 0.1 \ \Omega$
Internal diode resistance, $R_d = 0.01 \ \Omega$
Zero internal diode inductance.

The design parameter values used for the implementation are given as follows in Table I.

| Sl. No | Parameters used | Simulation value of the parameter |
|--------|-----------------|----------------------------------|
| 1      | $R_1$           | 0.10Ω                            |
| 2      | $R_2$           | 0.10Ω                            |
| 3      | $C$             | 200µF                             |
| 4      | $L_1$           | 0.005 H                           |
| 5      | $L_2$           | 0.005 H                           |
| 6      | $F_s$           | 20 KHz                            |
| 7      | Load            | 100Ω                              |

The Figure 12 shows the voltage and current measurements of the 1ϕ system. The Figure 13 mentions the dc-link voltage. In single phase ac micro grid system, the inverter and the converter are controlled by the switches, which in turn is controlled by the pulses given.
Figure 12 (a) Single phase AC voltage measurements and (b) Single phase AC current measurements
The three-phase ac system is implemented using SVPWM and SPWM control techniques. The 3ϕ ac output waveform obtained for SPWM and SVPWM control techniques are described. 3ϕ SPWM (120 phase shift) and control of SOC with multiple frequencies for pulses is shown. The Figure 14 (a) and 14 (b) shows the voltage and current measurements with three phases and each phase individually. The initial parameters of battery are Nominal voltage (V) = 1.2 V, Rated capacity = 9 Ah, Initial state of charge = 700%.

Figure 14 (a) Combined Three Phase Voltage measurements with Voltage Waveform of Phase A, Phase B and Phase C
Figure 14(b) Combined Three-phase current measurements with Current waveform of phase A, Phase B and Phase C

Three phase SPWM (universal control) and control of SOC with multiple frequencies for pulses is simulated. The Figure 15 (a) and 15 (b) shows the voltage and current measurements with three phases and each phase individually.

Figure 15 (a) Universal control output voltage of Sinusoidal PWM for three phase with Phase A, Phase B and Phase C Voltages.
Figure 15 (b) Universal control output Current of Sinusoidal PWM for three phase with Phase A, Phase B and Phase C Currents

The three-phase ac output with the SVPWM control technique is simulated and the outputs are shown below. The Figure 16 (a) and (b) denotes the three-phase ac voltage and current waveform for three-phase and each phase individually. Figure 17 denotes the output voltage of battery

Figure 16 (a) Voltage output for three-phase State Vector PWM
Figure 16 (b) Current Outputs for three-phase State Vector PWM

Figure 17 Battery output voltage
Discussion

The major objective of various modulation approaches is to attain variable output that consists maximum fundamental component with reduced harmonics. Hence, the objective of Pulse Width Modulation (PWM) approaches is the improvement of fundamental output voltage as well as harmonic content minimization in Three-Phase Voltage Source Inverters. In this, the modular approach and Multiple Input Single Control (MISC) is applied to single-phase and three-phase systems with SPWM and SVPWM respectively to achieve better output efficiency.

In MISC-based SPWM three-phase reference modulating signals are compared against a common triangular carrier to generate the PWM signals for the three phases. It is attained simple and linear voltage values, which results in poor voltage utilization. Frequency in traditional SPWM output waves due to their fixed switching frequencies. MISC-based SVPWM, three phase system, is an advanced technique used for variable frequency drive applications. It exploits dc bus voltage more efficiently and produces less THD in the three-phase voltage source inverter. MISC-based SVPWM employs a chaotic changing switching frequency to spread the harmonics continuously to a wide band area so that the peak harmonics is reduced greatly. The inverter output with MISC-based SPWM has more harmonics and is not a smooth ac out whereas the ac output obtained by using MISC-based SVPWM has much cleaner ac output waveform. Table II shows that the performance comparison of three phase ac system with MISC-based SPWM and SVPWM. From the outputs obtained for three phase ac system with MISC-based SVPWM and SPWM, the outputs of SVPWM control technique is found to achieve better outputs than the SPWM technique. The innovation in the paper is the implementation of the multiple input single control converter based on SPWM and SVPWM which is not been developed in the existing or previous papers and is considered as novelty in this research which helps in obtaining the improved power quality with energy saving.

Table II. Comparison of three phase ac system with MISC-based SPWM and SVPWM

| Parameter      | MISC-based SPWM | MISC-based SVPWM |
|----------------|-----------------|------------------|
| THD            | 33%             | 31%              |
| DC component   | 5.2             | 2.10             |

Figure 18 Performance analysis of the proposed system
Figure 18 depicts the performance analysis of MISC based SPWM and MISC based SVPWM. From the graph, it is observed that MISC-based SVPWM gives better results compared to other existing techniques.

5. Conclusion
A stand-alone hybrid power system model by incorporating PV system, fuel cell, and battery is described in this research. The 3 dc voltage sources are combined to a single structure with a boost converter. The converter system hybridizes the Photovoltaic, Fuel cell, and the battery. By deploying control techniques, single phase and three phase ac systems were modelled. The three-phase system was modelled using SPWM and SVPWM techniques. By varying the input voltage, the output voltage can be regulated as required. The three phase output voltage for two different inverter control techniques were examined and compared in terms of total harmonic. The SVPWM technique was found to be pragmatic to yield better ac output waveform with reduced distortion level. The Multiple Input Single Control technique is deployed which upholds the constant DC link voltage. As a result, the SOC of the battery is maintained. The future work includes the further improvement of the proposed techniques using optimization algorithm.

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