



Predictive Current Control of Voltage Source Inverters Using a Discrete-Time Model

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ABSTRACT

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In this investigation, the most popular multilevel inverter topologies and control approaches have been analyzed. The various benefits, such as low power dissipation on power switches, low harmonic contents, and low Electromagnetic Interference (EMI) outputs, Multilevel Inverter Topologies (MLIs) are finding more and more usage in medium and high-power applications. An optimization tool for the layout of a three-phase Voltage Source Inverter (VSI) using a diode-based rectifier has been created. For general-purpose industrial motor drives that use three-phase Alternating Current (AC), the Pulse Width Modulation (PWM) voltage source inverter with diode front-end rectifier has emerged as the converter of choice. This study discusses the implementation of predictive current control in a voltage source inverter. This technique makes use of a discrete-time model of the system to foresee the load current for every conceivable inverter-generated voltage vector. The voltage vector is chosen that minimizes a quality function. In this study, we use a quality function that measures the current error at the next sample interval. It is compared to hysteresis control and pulse width modulation control to see how well the suggested predictive control approach performs. The results demonstrate that the predictive strategy manages load current extremely well and outperforms traditional methods.

1. INTRODUCTION

Inverters handle the conversion of DC to ac electricity. The AC output voltage has a potent fundamental component with adjustable frequency and amplitude, an inverter receives power from a DC source [1]. Voltage-Source Inverters (VSIs) and Current-Source Inverters (CSIs) can be separated based on the kind of the source [2]. The commonest power electronic converters are VSIs, which are second only to rectifiers [3].

A controlled or uncontrolled rectifier can provide a DC-input voltage for a VSI, as well as other DC sources like a battery or photovoltaic array. If a rectifier is utilized, as shown in Figure 1, LC-DC link is used to feed the inverter, much like how choppers use them. Due to the fact that the voltage across the link capacitor cannot change instantly, it might be considered a voltage source [4]. Additionally, it serves as a container for the electric charges that are transported to and from the inverter bridge through the irregular negative input currents [5].

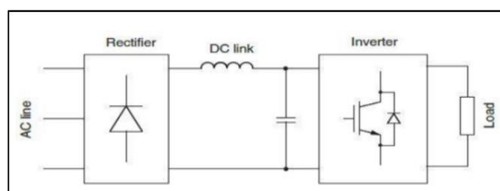


Figure 1. Voltage source inverter provided by a diode rectifier

The supplying rectifier and power system can be separated from the high-frequency component of the inverter input current, by the inductor which is its main purpose [6]. The link inductor is not fundamentally required, Unlike the capacitor. In fact, to save space and money, the inductor is sometimes removed from practical inverters. Any number of output phases can be used to construct inverters [7]. The most popular inverters in use today are single phase and three phase inverters [8]. To boost dependability for some crucial applications, it has lately been suggested to build AC motors with more than three phases. Such motors require the same number of phases in their inverters in order to operate.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

The paper [9] work presents an inclusive analysis of the OSG approach depending on most recent reference. This structure is used to study the DQ axis separation control, which is normally ignored in single-phase systems but is frequently explored for three-phase systems. We implement and analyze two separation techniques: quasi-compound proportional integral control and feed-forward control of reference current. The proposed theories and control measures were put to the test using the experimental findings.

In the study [10], the integrated (IMPPC) method proposed as a means of reducing steady-state errors in the current control system and enhancing performance of closed-loop.

Additionally, compared to the conventional MPCC, Changes in the system's parameters have less of an impact on upgraded IMPCC. The successful development and use of the traditional MPCC and the enhancement of the IMPCC were shown through simulations and experimental findings. According to the experimental findings, the enhanced IMPCC offers the advantages of quick dynamic performance, no steady-state faults, and insensitivity to changes in system parameters.

The paper [11] suggested a new synchronous reference frame (DQ) current controller, for a three-phase grid-connected inverter with a Y/out transformer. The DQ derives a dynamic model of the inverter, filter, and transformer. There is also a description of the present controller's structure. The theoretical study was supported by experimental findings on a 20kW prototype, which also showed that the suggested current controller has high current control performance [11].

In our current study, DQ frame current control based current control of VSI inverter will be used.

3. THE AIM AND OBJECTIVES OF THE STUDY

The aim of the study is to develop and simulates a circuit with current control for a VSI inverter using a DQ-comparator.

To achieve this aim, the following objectives are accomplished:

1. Keeping the switching frequency fixed regardless of the current error derivative.
2. To provide harmonic performance that is as close as feasible to centered space vector open-loop modulation, a three-phase VSI must choose the three nearest space vectors during a single switching cycle.
3. In a three-phase system, compensating for interactions between phase legs without direct monitoring of the switching voltages in those legs.

4. MATERIAL AND METHODS

Ramp comparison, hysteresis control, and predictive current control are the three primary methods used to regulate current in hard switched inverters. Predictive current control has the ability to provide the most accurate current control with the least amount of distortion and harmonic noise, but it is also the most complicated to install and is often matched to a particular load. In addition, there are additional issues in a real system due to mistakes induced by processing delays [12, 13]. For loads with both known and unknown back-EMF, this work proposes strategies for directly constructing a predictive current controller in a microprocessor. Because of their simplicity, these algorithms may be easily integrated into a working system, mitigating the effects of sampling delays and discretization mistakes [14]. The method given is confirmed by simulation. The majority of inverters used in industry, especially three-phase devices with medium and high power. when attaching single-phase inverter by a third leg, the power circuit of a three-phase VSI is created, shown in Figure 2.

Three switching variables, A, B, and C, will be given to the inverter if previously assumed, just one of the two power switches of each leg of the inverter is constantly run, disregarding the brief time intervals when both switches are off (dead time) [15, 16].

$$\begin{pmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{pmatrix} = V_i \begin{pmatrix} 0 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} \quad (1)$$

There are eight states in an inverter, where all output terminals are clamped to the negative DC bus, state 0. And where they are clamped to the positive bus in state 7. Each state of an inverter is denoted by the letters ABC, forming eight states overall [17]. It is simple to demonstrate that V_{AB} , V_{BC} , and V_{CA} are the instantaneous line-to-line output voltages.

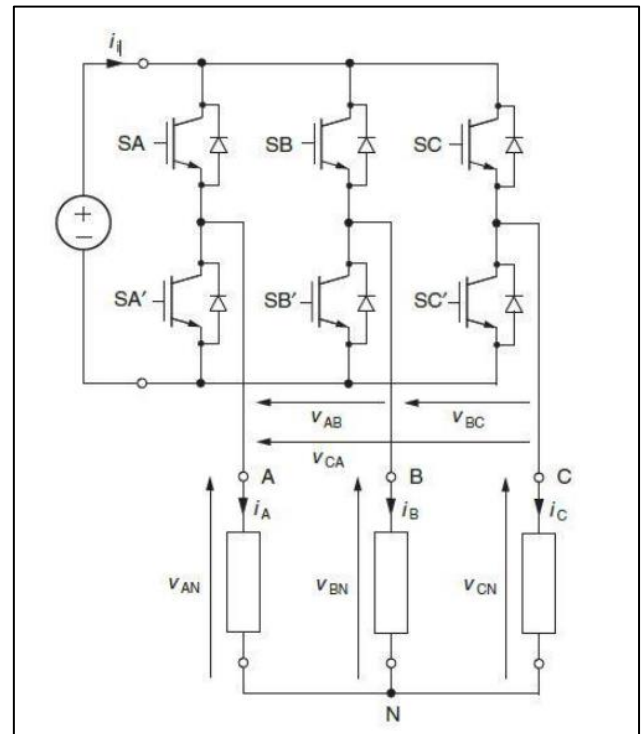


Figure 2. A three-phase voltage source inverter power circuit

Hysteresis regulators is one of the primary classes of regulators. In addition to, linear PI regulators, and predictive dead-beat regulators. That have been created over the past few decades. A succinct overview of the three-phase systems' present control methods. one of the several PWM approaches, hysteresis band current control is often used Due to its clarity of use. Additionally, the rapid response current loop is the only load parameter that the method requires knowledge of. As a result of the need to manage peak-to-peak current ripple throughout the whole fundamental frequency wave. The PWM frequency swings within a band when using a current control with a fixed hysteresis band. In PWM technique with adaptive hysteresis-band current regulation, the band can be adjusted to the load to maximize performance.

The switching signals for Hysteresis current control are obtained by comparing the current error with a preset tolerance band. Based on a comparison between the actual phase current and the tolerance zone surrounding the reference current connected to that phase, this control is implemented [18].

On other hand, the phase current interactions that are frequent in three-phase systems have a negative impact on this form of band management. Since each phase current relies on its corresponding phase voltage as well as the voltage of the other two phases, this is mostly caused by interference between the commutations of the three phases. During the

fundamental period, switching frequency may change depending on the load conditions, causing irregular inverter functioning.

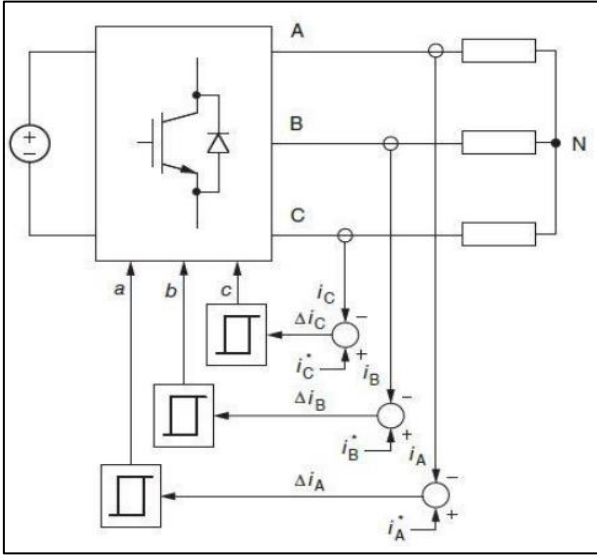


Figure 3. Hysteresis current control schema

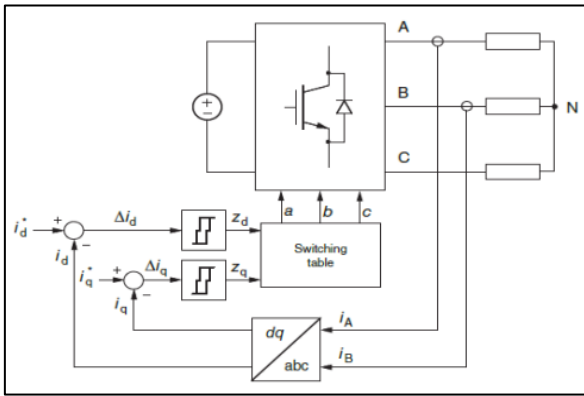


Figure 4. The hysteresis current control scheme in space vector

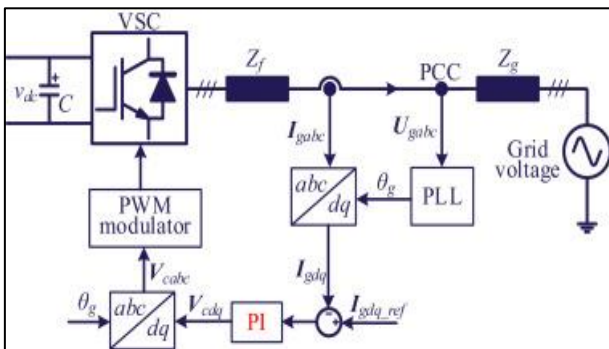


Figure 5. Diagram of a proportional and integral controller used to manage current in a three-phase voltage source converter

4.1 Hysteresis regulators

An inverter's output currents (i_A , i_B , and i_C) are measured and contrasted with the corresponding reference current waveforms (i_A , i_B , and i_C). Current controllers provide

switching variables, A, B, and C, for the inverter by applying current errors, Δi_A , Δi_B , and Δi_C . Figure 3 shows the space vector scheme [19].

Two current controllers can be used in place of three controllers, one controller for each phase of the inverter. The space vector Components (i_d and i_q), and \vec{i}^* of output currents are calculated and compared with corresponding components, i_d and i_q , of the reference current vector, \vec{i}^* based on the park transformation provided by (2) and applied to the output currents of an inverter. Figure 4 for the d-component controller shows the three-level outputs of the present controllers, z_d and z_q . The Table 1 illustrates the Hysteresis current control switching in the below.

Table 1. DQ hysteresis current control switching

A	B	C	z_d	z_q
1	1	0	1	1
1	0	0	1	0
1	0	1	1	-1
1	1	0	0	1
0	0	0	0	0
1	0	1	0	-1
0	1	0	-1	1
0	1	1	-1	0
0	0	1	-1	-1

For $(z_d, z_q) = (0, 0)$, state 0 or state 7, "state 1 for (0, 1) and (1, 1), state 2 for (1, 1), state 3 for (1, 0), state 4 for (1, 0), state 5 for (1, 1), and state 6 for (1, 1) and (0, 1). These states produce the best control effects.

$$\vec{i} = \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \quad (2)$$

A switching table receives the signals z_d and z_q and applies them to a particular state of the inverter.

4.2 Linear proportional-integral regulators

Linear control is used by the PI regulator. The input of PI controller is the variation between the reference value and the feedback value. The output is the linear combination of the PI and the deviation. The PI controller is the most frequently used in power electronics due to its simplicity and dependability. The following is an expression for the transfer function of a traditional PI controller in the continuous domain:

$$G_{pi}(s) = K_p + \frac{k_i}{s} \quad (3)$$

where, the proportional and integral benefits, respectively, are denoted by K_p and K_i .

In a power electronic system, a the $G_{pi}(s) = K_p + \frac{k_i}{s}$ real-phase, two-level VSC is frequently employed and is regarded as the controlled plant. Figure 5 displays the control diagram for the PI controller used to control the current in VSC, where V_{cabc} is the converter voltage, v_{dc} is the DC voltage, and C is the DC capacitance, and U_{gabc} is the grid voltage of the point of common coupling, I_{gabc} is the grid current, Z_f is the impedance of the filter, which could be a simple L filter or an LCL filter, Z_g is the impedance of the weak grid, and Z_f

represents the impedance of the weak grid.

Three-phase alternate currents in the stationary frame must be converted to DC signals in the synchronous frame since the PI controller can only accomplish a zero steady-state control of the DC signal. As a result, the coordinate transformation and phase-locked loop are essential components of this control system [20].

4.3 Predictive dead-beat regulators

Dead predictive control is a method used for the determination of the necessary control action during each sample period through calculations depends on the circuit model of the controlled system, in contrast to PI controllers that collect integrated errors. For system output values to remain comparable to reference signals, equivalent circuit fidelity is crucial.

When a quick dynamic response is demanded, the deadbeat predictive current control technique is utilized. It is quite simple to program. This control does, however, have certain shortcomings, including model-assumption errors and unintended delays brought on by calculation and modulation time [21].

5. SIMULATION RESULTS

5.1 The results of current error derivative

The simulation process is depicted in Figure 6 to show the development strategy for the controller.

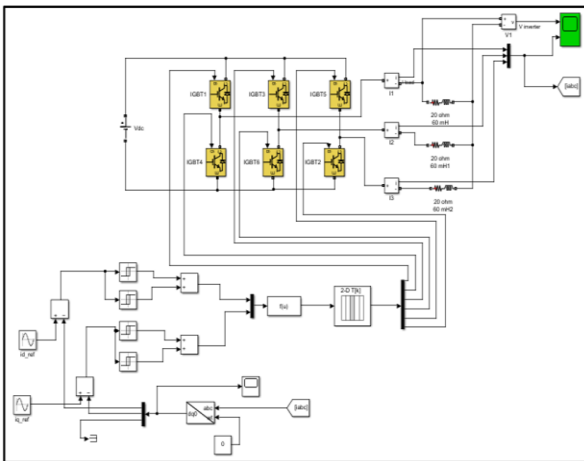


Figure 6. Simulated system

In MATLAB-Simulink, the Power Systems toolbox was used to create the three-phase VSI power circuit.

5.2 The harmonic performance

The title of the section does not correspond to objective #2 (see section 3).

In addition to the information shown in the Table 2.

The operating states are organized in a two-dimensional table in the previous image, and the information about the operating states from MATLAB-Simulink is shown in the next Figure 7.

The Simulated system also comprises a set of control tools, energy, and the aforementioned mathematical equations.

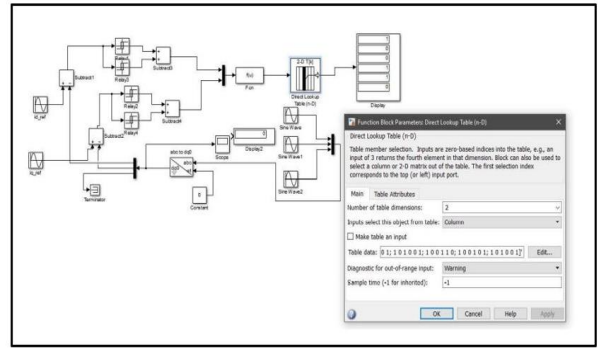


Figure 7. Operating states information

Table 2. Operating states as per the values we get from park transformation

zd	zq	a	b	c
1	1	1	1	0
1	0	1	0	0
1	-1	1	0	0
0	1	1	1	0
0	0	0	0	0
0	-1	1	0	1
-1	1	0	1	0
-1	0	0	1	1
-1	-1	0	0	1

5.3 Compensating for interactions between phase legs

The title of the section does not correspond to objective #3 (see section 3).

Clicking on the block parameters Figure 8, which stands for the General expression block, will display the circuit equations. In Figure 9 in below the Signals waves results illustrated.

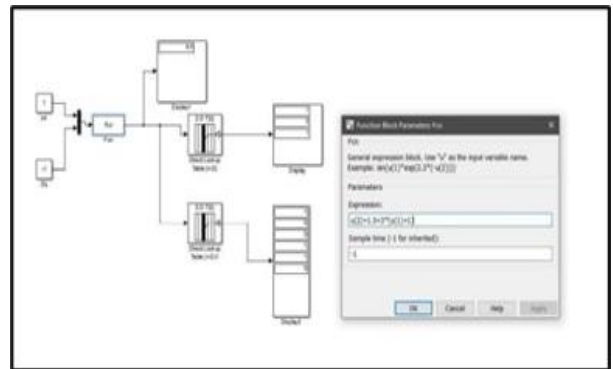


Figure 8. General expression block

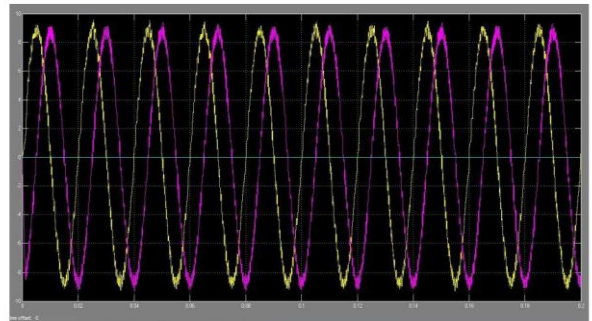


Figure 9. Signals waves results

The signals produced by the suggested system are shown in the accompanying figure, with 9.5 being the greatest signal and -9.5 representing the lowest.

The R-L load arrangement of a single-phase full-bridge inverter was tested experimentally in RT-Lab. The setups used power IGBTs as the inverter switches. When comparing the results for a single-phase full bridge inverter in RT-Lab and Matlab, it is clear that the two programs provide almost identical results. The Figure 10 show the Main circuit for single phase inverter were simulated and obtained the results in Figure 11 output current and voltage for single phase inverter.

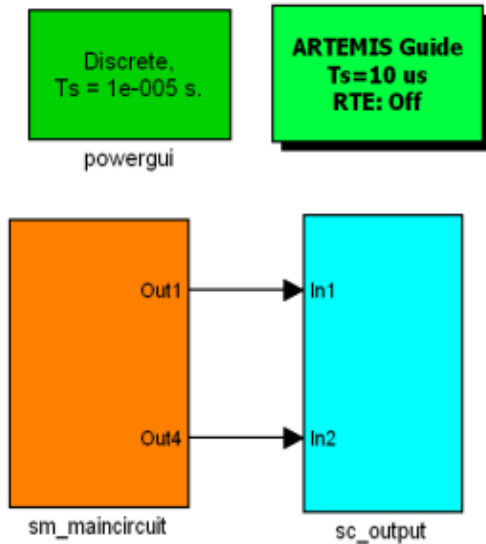


Figure 10. Main circuit for single phase inverter

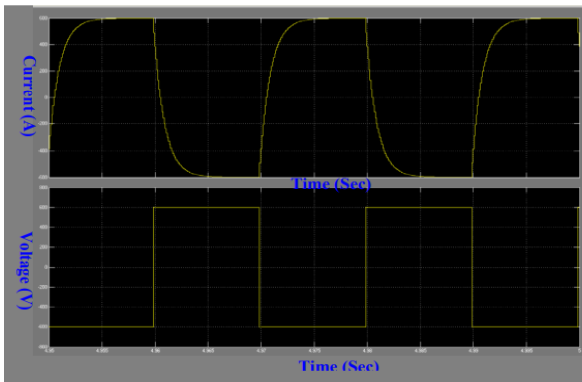


Figure 11. Output current and voltage for single phase inverter

6. DISCUSSION OF THE CONSTRAINS ON THE METHOD SUGGESTED AND FUTURE DIRECTIONS

To achieve good current regulation with little harmonic distortion, algorithms for predictive current regulation have been described that are amenable to practical application in a digital controller. The algorithms account for errors introduced by digital sampling delays and can be used in setups where the back emf is either directly measurable, as in PWM rectifier systems, or indirectly estimated from the measured current

change in the previous switching cycles, as in a variable speed motor drive setup.

Can used in either single or three phase inverter systems, are very reliable, and provide accurate current regulation, even when overmodulated or out of tune. The effectiveness of the new algorithms has been shown via both simulation and experiment. The new VSI's predictive current control algorithm is first tested for its efficacy. As discussed in results section, that the higher thyristor is activated when the current flips from negative to positive, whereas the lower thyristor generates its triggering pulse when the current flips from positive to negative. The phase current exhibits a THD of 15% due to the mistake of switching signals computation brought on by the phase delay, constrains in this work its effecting of delaying phase currents have much less distortion at the zero-crossing point to solve this issue should utilizing a new method for predication for reaching to real value for current and voltage has a zero error rate. The main benefits are that the new concept can be used across the board for power conversion, the Z-source inverter is a buck boost inverter (something the more conventional V-source and I source inverters don't offer), it can be used in situations where the input voltage varies widely, all conventional PWM control schemes can be used, and the theoretical input-output relationship remains the same, and the cost is decreased and the efficiency is increased. The average switching device power of a Z-source inverter is lower in the low boost ratio band (1/2). The dc boosted PWM inverter is the optimal setup when operating at a low voltage and requiring a boost ratio greater than 2. The recognized RHP zero in the Z-source impedance network cannot be removed by modifying the Z-source values, which is a drawback. There is a need for more research on compensation strategies. In future directions we will try to predicate the value of current control by using different neural network algorithms and comparison the results with current study.

7. CONCLUSIONS

This study proposes a real-time method for managing the load current of a three-phase VSI system based on a DQ-comparator plus DQ coordinate. The load currents need not be converted to DQ coordinates; therefore, this control approach may provide quick tracking and a simple controller for controlling the current error within the hysteresis bands in ABC coordinate. MATLAB-Simulink was used to model a circuit. To understand how the DQ-comparator performed, a modeling method was used for controller development. Results from simulations and experiments that take into account the dynamic behavior of the DQ-comparator serve to confirm the system's performance. The primary aim of these constructions is to provide a source of three-phase voltage with adjustable voltage amplitude, phase, and frequency. To provide controlled frequency and AC voltage quantities utilizing pulse width modulation (PWM) techniques the optimal spot for inverter installation to minimize fifth-harmonic interference is. Furthermore, under ideal conditions, bus 6 remains the optimal site for inverter placement due to fifth-harmonic effects. Three-phase DC/AC voltage source transformers are often used in motor drives, active filters, and unified power flow controllers in power systems and uninterruptible power supplies to supply controlled frequency and AC voltage quantities.

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