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# Advanced SPWM Controller with 3 Phase Ups System Operating in Extream Nonlinear Load

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### **ABSTRACT:**

This paper presents the design of a high-performance sinusoidal pulsewidth modulation (SPWM) controller for threephase uninterruptible power supply (UPS) systems that are operating under highly nonlinear loads in the systemin the system. Generally, the classical SPWM method is quite effective in adjusting the RMS magnitude of the UPS output voltages for that system. However, it is not good enough in compensating the harmonics and the distortion caused specifically by the nonlinear currents drawn by the rectifier loads. It is more severe at high power where the switching frequency has tobe reduced due to the efficiency concerns. At this stage, this study proposes a new design strategy that overcomes the limitations of the classical RMS control. In this method, the inner loops to the closed-loop control system effectively that enables successful reduction of harmonics and compensation of distortion at the outputs. In this paper, the Simulink is used to design the controller using the state-space model of the inverter of the nonlinear load. Finally, the simulation results demonstrate that the controller successfully achieves the steady-state RMS voltage regulation specifications as well as the total harmonic distortion and the dynamic response requirements of major UPS standards in the system.

### **Index Terms:**

Nonlinear load, uninterruptible powers supply (UPS), sinusoidal pulse width modulation (PWM) control, RMS voltage.

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### I. Introduction:

The performance SPWM control strategy is very efficient in the nonlinear load. The increased use of rectifiers in critical loads employed by the information technologies and medical and military equipment mandate the design of (UPS) with high-quality outputs in the system[1]–[3]. The highly nonlinear currents drawn especially by highest-power single-phase rectifier loads greatly distort the UPS outputs of the system. The distorted UPS voltages cause generation of low dc voltage at the output of the rectifier loads, which causes high current flow, increased power losses, and possibly the malfunction of the critical load or the UPS of the system. The distortion is resulted mainly by the voltage drop across the inductive element of the LC filter due to the non sinusoidal current at the output of the inverter [4]–[6] in the system. In a UPS system, the inverter is responsible for synthesizing sinusoidal voltages from a dc source through the pulse width modulation (PWM) of the dc voltage in the system. In this system, the inductive element is needed to remove the switching frequency harmonics from the current waveform that are generated by the PWM operation of the inverter in the system. A major research has been conducted to design such controllers for the high-performance UPS systems [2]–[5], [7]–[12]. This study proposes a multiloop high-performance SPWM control strategy and a design that overcome the limitations of the classical RMS control [13]. The significance of the proposed multiloop controller compared to other methods is as follows:



Figure 1: Single-line diagram of a typical three-phase four-wire transformer isolated UPS system.

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1. The main execution time is less and allows higher switching frequencies of the nonlinear load.

2. The cost is low.

3. The easy tuning even under load of the system.

4. The flexibility: It means that we can modify our controller and optimize it using this system.

5. The scalability: It means that the controller is very easy to design and tunable for any power level system [13].

### II. Architectural Diagram: A.System Description:

In the architecture of given advanced SPWM system the three phase thermistor-based controlled rectifier converts the mains voltages into a constant dc and also provides standalone charge for the batteries. In this paper, a six-switch PWM voltage source inverter (VSI) creates balanced three-phase sinusoidal voltages across the load terminals at the utilization frequency and magnitude of the system.

Then the LC low-pass filter avoids the harmonics generated by the PWM switching system. The  $\Delta$ -winding of the transformer blocks the third harmonic currents at the inverter side, and the zigzag winding provides a neutral point and zero phase difference for the loadside voltages.

In this system, the load can be a three-phase or a single phase load ranging from linear to nonlinear load of the system.



Figure2:UPS inverter stage including the Δ-zigzag transformer equivalent circuit and the resistive load.

In this paper, the model is developed based on the circuit schematic given in Figure. 2. As shown in Figure. 2, in an insulated gate bipolar transistor (IGBT)-based three-phase inverter is used to create pulse-width modulated voltages across the terminals labeled as 1, 2, and 3 in the system. L is the outer filter inductor used to decrease ripple at the line current, Llk1 is the primary side leakage and L $\mu$  is the magnetizing inductance of the transformer of the given system then L\_lk2 is the secondary side leakage inductance in the diagram, C' is the filter capacitor, and finally R' is the load resistance (the prime symbol represents the parameters referred to the  $\Delta$ -side of the transformer) in the given UPS inverter stage.

Output Power	10kVA, 0.85 power factor
-	
Output voltage(RMS)	220+2.2 V line to neutral
1 5 ( )	
Output voltage(THD)%	< 3% under the linear full load
	< 5% under the nonlinear full load
Transient Response	Comply to the ITIC standards
L .	

### **Table 1: Major UPS Design Specifications**



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# **B.** State Space Model of the Inverter Power stage :

The state-space model of the plant (three-phase inverter) is required to improve, develop and test the controller performance in the system. So, using L = 30  $\mu$ H, L $\mu$ = 1 H, Llk1 = 820  $\mu$ H, L'lk2 =100  $\mu$ H, C'= 202  $\mu$ F, Vdc = 405 V, Vtri = 2487, R'= 10  $\Omega$  for full load and R'= 255  $\Omega$ , the state-space model of the plant is obtained as shown in Figure. 3. In that system, the peak of the carrier waveform is obtained based on the type of the selected DSP and the switching frequency in the system.

## C.Controller Design:

This paper presents the design of the proposed inverter controller in the system. The main controller is based on the multiloop SPWM method which is shown in FigThe controller topology is very identical to the classical state-feedback multiloop controllers [8],[9] in the system, except that all the loops are collected before they are applied to the PWM generator in the system. The controller parameters are described as follows.

It is based on the steady-state voltage regulation and transient response specifications given in Table I of the paper, first the gains of the main voltage loop are determined as Kp1 = 2and Ki = 0.05, as shown in Figure. 5.

Then, the Kp2 = 3 is determined for the practical lowest THD while Kd and Kp3 are adjusted to maintain a stable operation. The proper gains for Kd and Kp3 are obtained using the control design tool for the lightly loaded case in the model shown in Figure 3. The lightly loaded case is the worst case in terms of the stability in the system.



Figure 3: State-space model of the inverter power stage (the plant) including the closed-loop control system and the controller built in Simulink.



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Figure 4: Simulink model of the proposed multiloop controller.



Figure 5: Step response analysis of the closed-loop control system: (a) for Kp2= 3, Kd = 0, and Kp3 = 0; (b) for Kp2 = 3, Kd = 3, Kp3 = 0 (blue), Kp3 =0.75 (green), and Kp3 = 1.0 (red).

### III) Result analysis:

The results are evaluated based on steady-state error, transient response, and the THD of the output voltage. Figure 6 shows the RMS value and the percent THD of the output voltage versus three different loads. According to Figure 6, when the linear load at 8.5 kW is applied on the system, the controller achieves 0.3% THD and when the nonlinear load at 10 kVA is applied, the controller achieves 3.1% THD. In addition, the RMS voltages are very well regulated at 220 V for each phase with an excellent transient response for the linear load but a fair response for the nonlinear load case



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Figure 6: RMS fluctuation of top trace verses bottom trace

### Acknowledgement:

We especially thanks to our department and our Institute for the great support regarding paper and their all views. I really thankful to my all staffs and my guide Prof. R. R. Bhambare. who showed me the way of successful journey of publishing paper and project work.

## **Conclusion:**

On the overall study of this paper and related all references, this paper shows the analysis and design of a high performance SPWM controller for three-phase UPS systems powering highly nonlinear loads in the system. Although the classical SPWM method is very successful in controlling the RMS magnitude of the UPS output voltages, it cannot effectively compensate for the harmonics and the distortion caused by the nonlinear currents drawn by the rectifier loads in the system. Therefore, this paper proposes a advanced strategy with a recent design that overcomes the limitationsof the classical RMS control in the system. In conclusion, the final expected results demonstrate that the proposed controller successfully achieves the steady-state RMS voltage regulation specification as well as the THD and the dynamic response requirements of major UPS standard in the system.

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