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Survey Paper on 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. Actually, the controller is implemented in the TMS320F2808DSP by Texas Instruments, and the performance is evaluated experimentally using a three-phase 10 kVA transformer isolated UPS under all types of load conditions. Finally, the experimental 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 power supply (UPS), sinusoidal pulsewidth modulation (PWM) control, RMS voltage.

I. Introduction:

The performance SPWMcontrol strategy is very efficient in the nonlinear load. Theincreased use of rectifiers in critical loads employedby the information technologies and medical and militaryequipment mandate the design of (UPS) with high-quality outputs [1]–[3]in the system.

The highly nonlinearcurrents drawn especially by highest-power single-phase rectifierloads greatly distort the UPS outputs of the system. The distorted UPS voltagescause generation of low dc voltage at the output of therectifier loads, which causes high current flow, increased powerlosses, and possibly the malfunction of the critical load or theUPS of the system.

The distortion is resultedmainly by the voltage drop acrossthe inductive element of the LC filter due to the nonsinusoidalcurrent at the output of the inverter [4]–[6] in the system.In a UPS system,the inverter is responsible for synthesizing sinusoidal voltagesfrom a dc source through the pulse width modulation (PWM)of the dc voltage in the system.

In this system, the inductive element here is needed to remove the switchingfrequency harmonics from the current waveform that are generatedby the PWM operation of the inverter in the system. a majorresearch has been conducted to design such controllers forthe high-performance UPS systems [2]–[5], [7]–[12].

This study proposes a multiloop high-performance SPWMcontrol strategy and a design that overcome the limitations ofthe classical RMS control. Thesignificance of theproposed multiloop controller compared to other methods is asfollows:

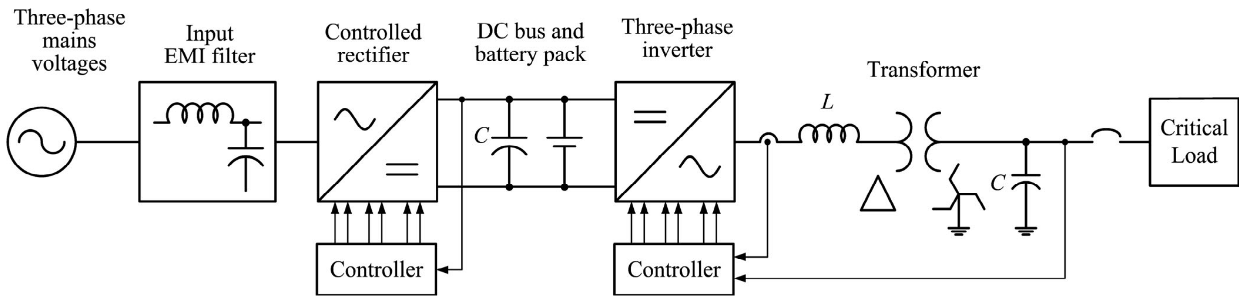

Figure 1. Single-line diagram of a typical three-phase four-wire transformer isolated UPS system.

1. The main execution time is less and allows higher switchingFrequencies 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 you can modify your controllerand optimize it using this system.

5. The scalability: It means that the controller is very easy todesign and tunable for any power level system.

II. Architectural Diagram:

A.System Description:

In the architecture of given advanced SPWM system the threephasethermistor-based controlled rectifier converts the mainsvoltages into a constant dc and also provides standalone chargeo the batteries .in this paper, a six-switch PWMvoltage source inverter(VSI) creates balanced three-phase sinusoidal voltages acrossthe load terminals at the utilization frequency and magnitude of the system. Then the LC low-pass filter avoids the harmonics generated by thePWM switching system. The Δ-winding of the transformer blocks thethird harmonic currents at the inverter side, and the zigzag windingprovides a neutral point and zero phase difference for theload-side voltages. In this system, the load can be a three-phase or a singlephaseload ranging from linear to nonlinear load of the system.

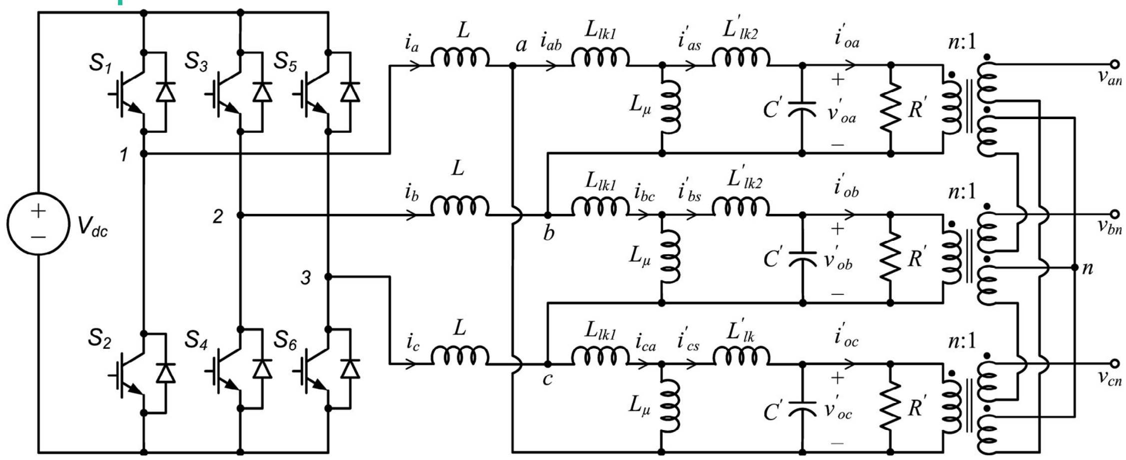

Figure2. UPS inverter stage including the Δ-zigzag transformer equivalent circuit and the resistive load.

In this paper, the model is developed based on the circuitschematic given in Figure. 2. As shown in Figure. 2, in an insulated gatebipolar transistor (IGBT)-based three-phase inverter is used tocreate pulse-width modulated voltages across the terminalslabeled as 1, 2, and 3 in the system. L is the outer filter inductorused to decrease ripple at the line current, Llk1 is the primaryside leakage and Lμis the magnetizing inductance of the transformer of the given systemthen L_lk2 is the secondary side leakage inductance in the diagram, C_is the filter capacitor, and finally R_ is the load resistance (theprime symbol represents the parameters referred to the Δ-sideof the transformer) in the given UPS inverter stage.

TABLE I
MAJOR UPS DESIGN SPECIFICATIONS

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

B. State Soace 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 μH, Lμ= 1 H, Llk1 = 820 μH, L_lk2 =100 μH, C_ = 202 μF, Vdc = 405 V,Vtri = 2487, R_ = 10 Ωfor full load and R_ = 255 Ω, the state-space model of the plant is obtained asshown in Figure. 4. In that system, the peak of the carrier waveform is obtainedbased on the type of the selected DSP and the switchingfrequency in the system.

C.Controller Design:

This sectionin this paper presents the design of the proposed inverter controller in the system.The main controller is based on the multiloop SPWM methodwhich is shown in Figure. 5, which is also shown as a block in Figure. 4 in the system.

Thecontroller topology is very identical to the classical state-feedbackmultiloop controllers [8],[9] in the system,except that all the loops are collected before they are appliedto the PWM generator in the system. The controller parameters are described as follows.

It is basedon the steady-state voltage regulation and transient responsespecifications given in Table I of the paper, first the obtained of the main voltageloop are determined as Kp1 = 2 and Ki = 0.05, as shownin Figure. 5.

Then, the Kp2 = 3 is determined for the practicallowest THD while Kd and Kp3 are adjusted to maintain a stableoperation. The proper gains for Kd and Kp3 are obtainedusing the control design tool for the lightly loaded case in themodel shown in Figure 3. The lightly loaded case is the worst casein terms of the stability in the system.

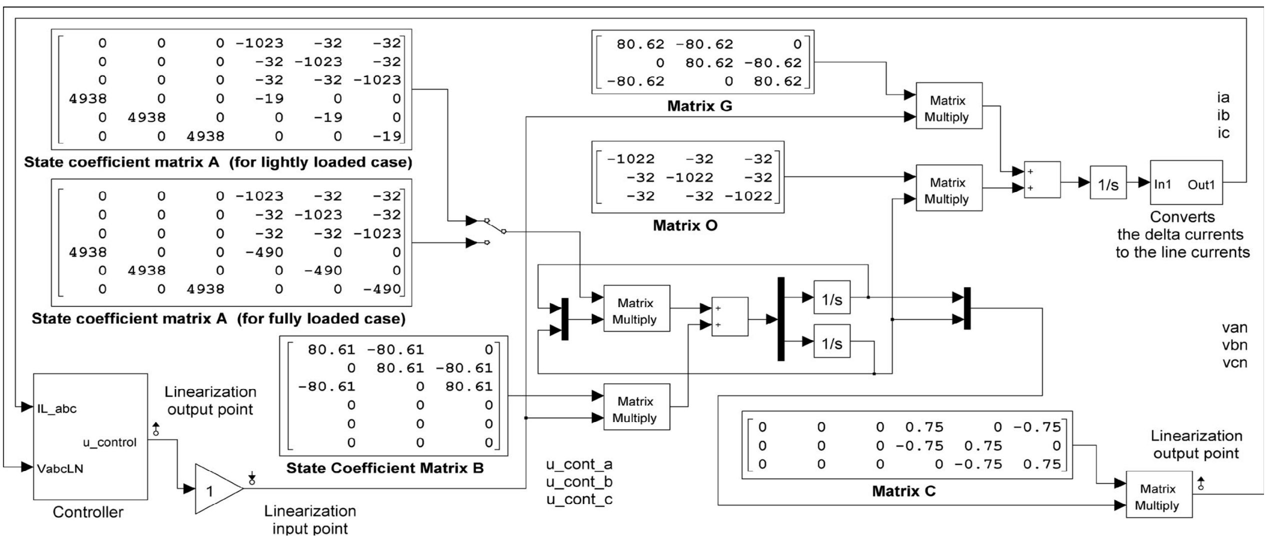

Figure 3. State-space model of the inverter power stage (the plant) including the closed-loop control system and the controller built in Simulink.

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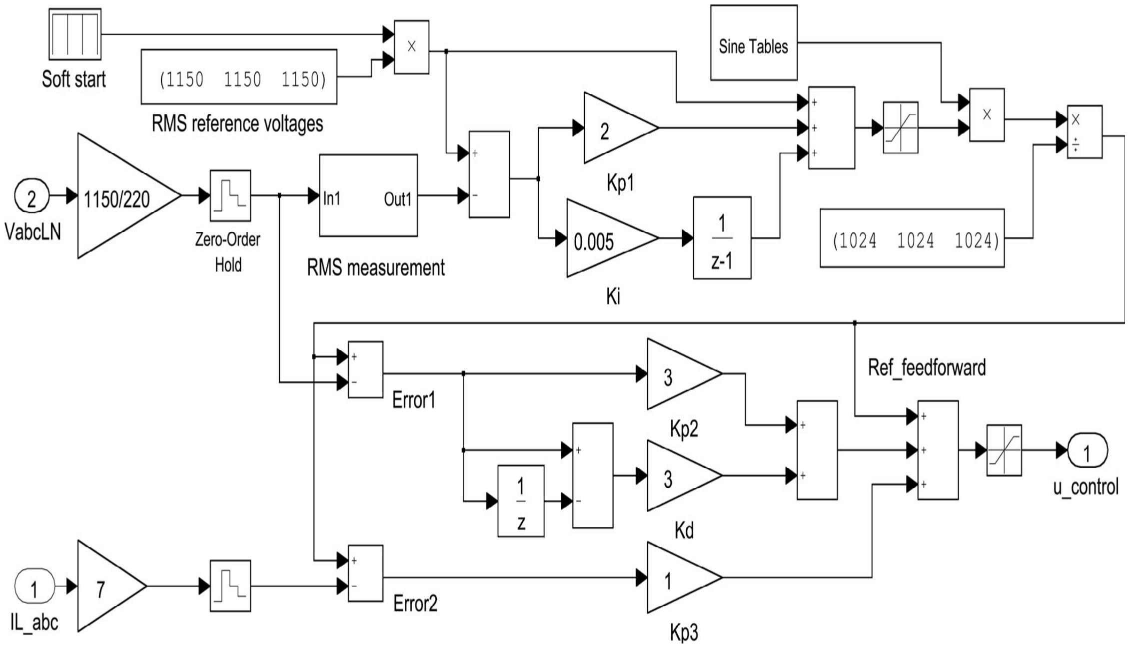

Figure 4.Simulink model of the proposed multiloop controller.

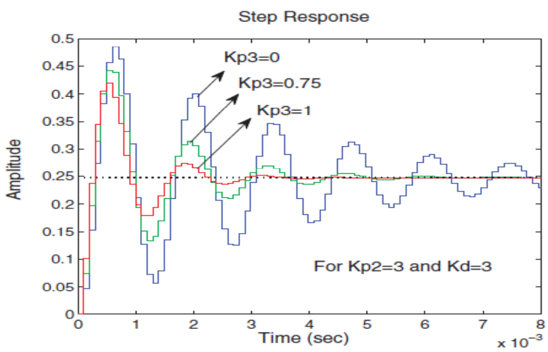

Figure 5. Step response analysis of the closed-loop control system: (a) for Kp2= 3, Kd = 0, and Kp3 = 0; (b) for Kp2 = 3, Kd = 3, Kp3 = 0 (blue), Kp3 =0.75 (green), and Kp3 = 1.0 (red).

IIIResult analysis:

A.Simulation result:

a.Proposed Multiloop Controller :

The results are evaluated based on steady-state error, transient response, and the THDof 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.

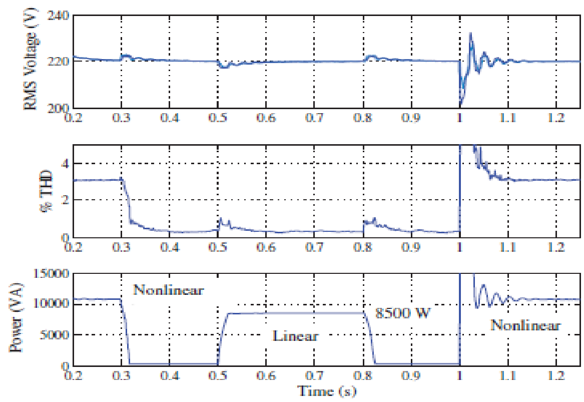

Figure 6. RMS fluctuation of top trace verses bottom trace.

b. Main Comparison of the Proposed Controllerand the PR Controller:

In order to verify the performance of the proposed controller, we selected the PR controller as the bench mark and compared the results of each system modules. The PR controller has obtainedexcellent popularity in many inverter applications mainly where an excellent reference tracking is desired in the system.

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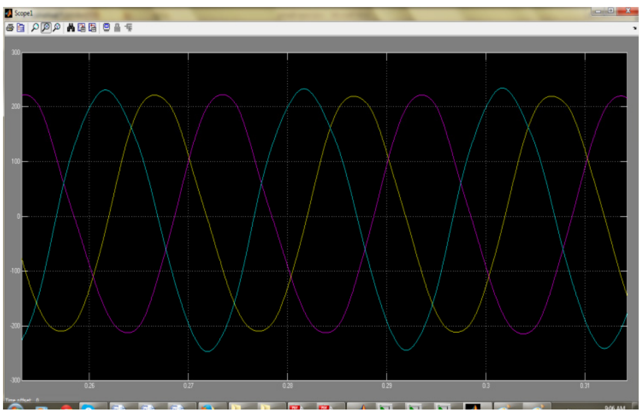
B.Experimental result:

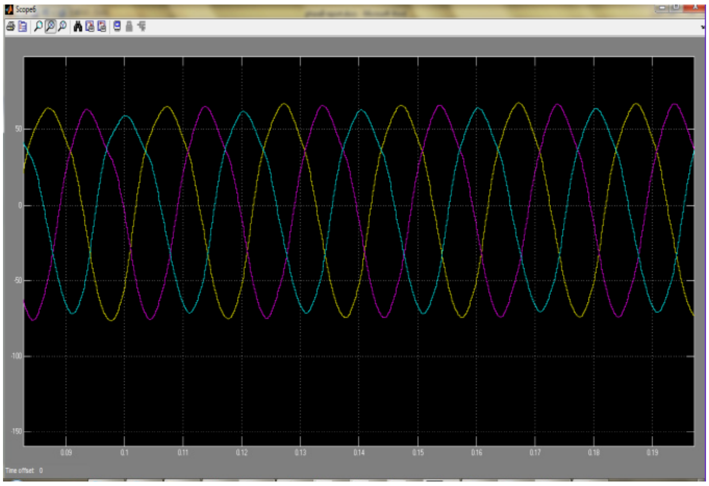
In Figure 7, we compare the results of the multiloop design against the single-loop design in order to demonstrate the performance of the proposed multiloop controller. Figure. 7compares the measured three-phase output voltages and the current of one phase for two loading conditions:

the linear full load and the nonlinear full load in the system. Figure. 7(a) and (b) show the results when only the RMS control is used (single-loop), for this case the control achieves 1.96% THD for the linear and 9.68% THD for the nonlinear load. The waveforms in Figure. 7(c) and (d) show the results when the proposed multiloop controller is used for the same loading conditions in the system.

Figure 7. Measured three-phase output voltages and the load current of one phase for the following four cases:

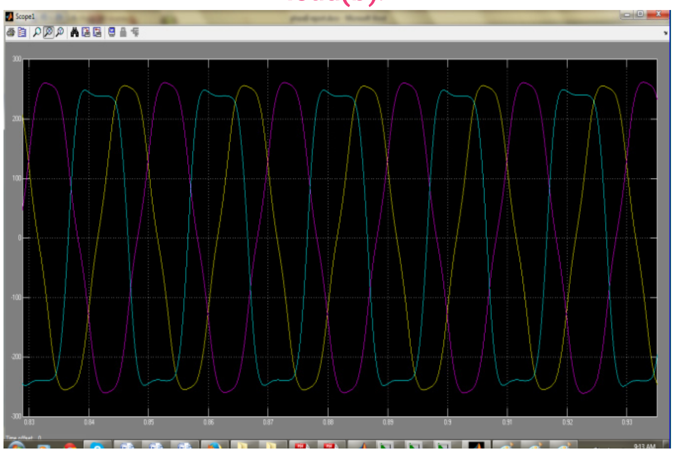


(a)

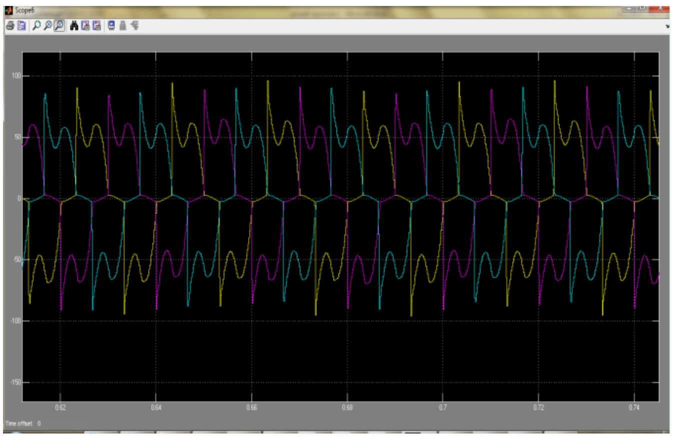


(b)

Figure 8. Measured transient response of output voltages (upper trace)(a) and currents (lower trace) when the load changes from no load to the full linear load(b).



(a)



(b)

Figure 9. Measured transient response of the output voltages (upper trace) (a)and the currents (lower trace) when the load changes from no load to the rated single-phase rectifier load placed at each phase(b).

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Conclusion:

On the overall study of this paper and related all references , this paper shows the analysis and design of a highperformanceSPWM controller for three-phase UPS systemspowering highly nonlinear loads in the system. Although the classical SPWMmethod is very successful in controlling the RMS magnitude ofthe UPS output voltages, it cannot effectively compensate forthe harmonics and the distortion caused by the nonlinear currentsdrawn by the rectifier loads in the system.

Therefore, this paper proposesa 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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