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A Three Phase UPS Systems Operating Under Nonlinear Loads with Modified SPWM Controller

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Abstract: -- *This paper presents the design of a high-performance sinusoidal pulse width modulation (SPWM) controller for three phase uninterruptible power supply (UPS) systems that are operating under highly nonlinear loads. The classical SPWM method is quite effective in controlling the RMS magnitude of the UPS output voltages. However, it is not good enough in compensating the harmonics and the distortion caused specifically by the nonlinear currents drawn by the rectifier loads. The distortion becomes more severe at high power where the switching frequency has to be reduced due to the efficiency concerns. This study proposes a new design strategy that overcomes the limitations of the classical RMS control. It adds inner loops to the closed-loop control system effectively that enables successful reduction of harmonics and compensation of distortion at the outputs. Simulink is used to analyze, develop, and design the controller using the state-space model of the inverter. By using SPWM Controller THD of the system can be reduced along with Magnitude of RMS voltage.*

Keywords --- *Uninterruptible power supply (UPS), nonlinear load, sinusoidal pulse width modulation (SPWM) control, RMS Voltage, Total Harmonic Distortion (THD), MATLAB Simulink*

I. INTRODUCTION

The increased use of rectifiers in critical loads employed by the information technologies, and medical and military equipment mandate the design of uninterruptible power supplies (UPS) with high-quality outputs The highly nonlinear currents drawn especially by high-power single-phase rectifier loads greatly distort the UPS outputs. 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. 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. 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. The inductive element here is needed to remove the switching frequency harmonics from the current waveform that are generated by the PWM operation of the inverter. The inductance value can be reduced if the switching frequency is increased. But, in practice, it has an upper limit at high power inverters due to the efficiency concerns and the switching device limitations. So, for the selected switching frequency and the power level, an optimum filter with a smallest inductance can be designed, but the distortion cannot be completely avoided, and the regulations and the customer specifications may not be satisfied. Despite several UPS topologies reported in literature, Figure 1 present a high level UPS block diagram used in this work. Main aspects of this UPS topology are: i) the load has two options to be directly powered, ii) DC power for the inverter stage is controlled on a rectifier stage, iii) the load is an external agent for the UPS system, being in principle, an unknown factor for the inverter controller

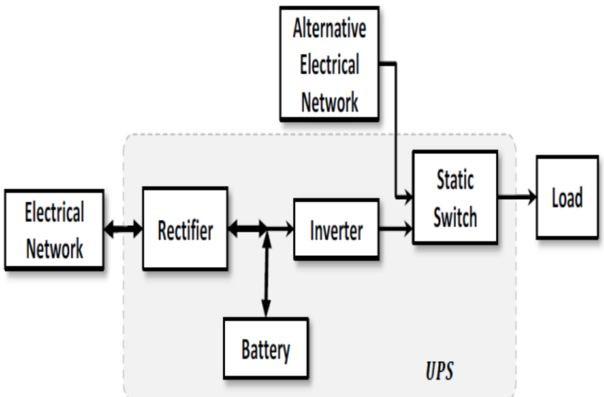

Fig: 1. Functional Model of UPS

The main purpose of this study is to achieve a high power quality on inverter stage, thus a three-phase inverter circuit

1. DC voltage. From the inverter stage point of view, DC power can be considered perfectly controlled by the rectifier stage. In this way, it could be represented as a battery bank.
2. DC/AC converter. This block describes a three-phase two level converter that will be triggered with a SPWM scheme.
3. LC output filter. This second order low-pass filter is added to eliminate high switching frequency from the DC/AC converter.
4. Output transformer. This block has several functions: i) offers a galvanic isolation for the load, ii) increases synthesized voltage from the DC/AC converter to load voltage rating, iii) its leak impedance is used as part of the output filter, iv) provides a neutral point to connect single phase loads. Static switch. This component allows fast electrical switching between the alternative source and the voltage synthesized by the inverter

Nonlinear loads are shown in Figure 2 where nonlinear inductive and capacitive loads are presented in their three-phase form. Nonlinear behavior is represented by a diode rectifier block, but could be an SCR or TRIAC as well. In these cases normally an inductance is added in series to minimize input d/dt.A nonlinear load represents a large harmonic pollution for UPS inverter. This highly distorted current significantly affects the output-voltage waveform. In addition, the capacitive nonlinear load produces a large current peak at connection when the capacitor is discharged. Pre-charge schemes are usually implemented to avoid that as shown in Figure 2 allowing the capacitor to be charged through a limited current.

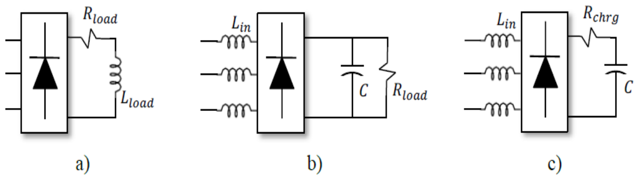

Fig: 2 Non-linear loads, a) Inductive type, b) Capacitive type, c) Capacitive pre-charge circuit.

Pulse Width Modulation (PWM) is a popular technique used for controlling the width of the gate pulse by various mechanisms. The DC-AC inverters usually operate on pulse width modulation technique (PWM). The traditional inverter output voltage changes according to changes in the load. The PWM inverter irrespective of the output load keeps the output voltage of the inverter at the rated voltage. The pulse width and switching frequency adjusted according to the value of the load to provide constant rated output. SPWM are the most popular and widely used modulation techniques. In SPWM the width of each pulse is varied in proportion to the amplitude of the sine Wave. The gating signals for the inverter are generated by comparing a sinusoidal reference signal with a triangular wave carrier. It is obtained by taking repeating sequence (triangular wave) as the control signal and comparing it with reference wave (sinusoidal signal). The frequency and amplitude of the reference or modulating voltage is varied to get the desired output voltage.

II. BASIC OPERATION PRINCIPLE OF TYPICAL THREE-PHASE FOUR-WIRE TRANSFORMER ISOLATED UPS SYSTEM

The single-line diagram of a typical three-phase four-wire transformer isolated UPS system is given in Fig. 3 The three phase thyristor-based controlled rectifier converts the mains voltages into a constant dc and also provides standalone charge to the batteries. Then, a six-switch PWM voltage source inverter (VSI) creates balanced three-phase sinusoidal voltages across the load terminals at the utilization frequency and magnitude The LC low-pass filter removes the harmonics generated by the PWM switching. The Δ-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 load-side voltages. This section obtains the state-space model of the inverter stage of a three-phase UPS in order to design the controller for the inverter. The developed model is also used to study the controller performance for the lowest THD of the output voltage while maintaining the stability and a good dynamic response under all load conditions. The advantage of the multi loop control system proposed here is that the loops can be optimized for the best performance relatively independent of each other.

For example, the outer voltage loop is tuned first for the best voltage regulation, and then the inner loops can be optimized relatively independently for the best THD of the output voltage while effectively managing and maintaining the stability. Finally, the selection of the switching frequency is critically important in the elimination of the harmonics and the distortion at the voltages. The high switching frequency allows a larger voltage loop bandwidth which enables the controller to produce corrective actions to compensate for the fast changing oscillations at the voltage waveform effectively.

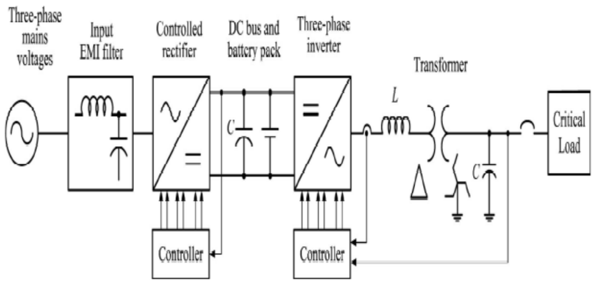

Fig. 3 Single-line diagram of a typical three-phase four-wire transformer isolated UPS system.

The main criterion for assessing the quality of the voltage delivered by an inverter is the Total Harmonic Distortion (THD). The goal is to see if the low order harmonics amplitude will decrease when the number of level increases. The inverter is usually followed by a low pass filter since higher frequency harmonics are easy to filter. This means that the performance of multilevel inverters can be improved by cancelling or reducing lower order harmonics. Lower order harmonics generate the most important currents when an inductive load is used.

The THD is a ratio between the Root Mean Square (RMS) of the harmonics and the fundamental signal. For An inverter that has a fundamental output voltage V1 and
Harmonics V2, V3,. . . , we define the THD as follows:

$$\text{THD} = \frac{\sqrt{\sum_{K\geq 2}^{N} V_K^2}}{V_1}$$

III. MATLAB/SIMULINK RESULTS OF MODIFIED SPWM CONTROLLER

Three phase UPS system has been simulated in MATLAB with Modified SPWM Controller .When the System is operating with Nonlinear Loads by using Modified SPWM Controller it can generate the pulses and we can reduce the output RMS Magnitude voltage Regulation and THD of the system.

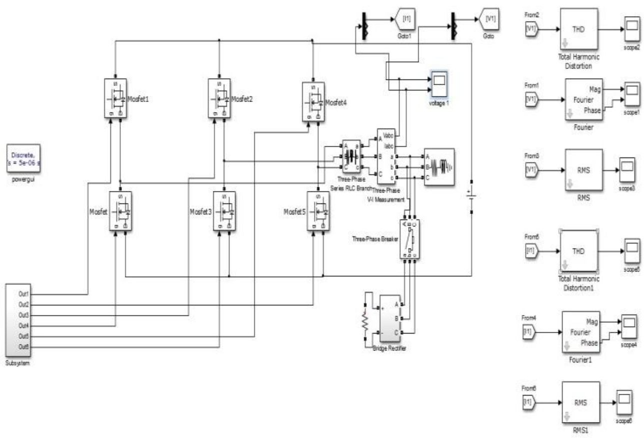

Fig: 4. Matlab/Simulink Model for Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

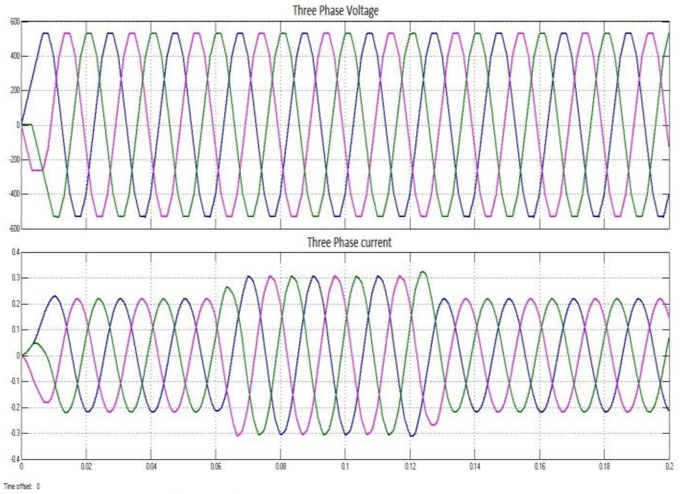

Fig: 5. Voltage & Current wave forms for Modified SPWM Controller for Three Phase UPS Systems Operating under Nonlinear Loads

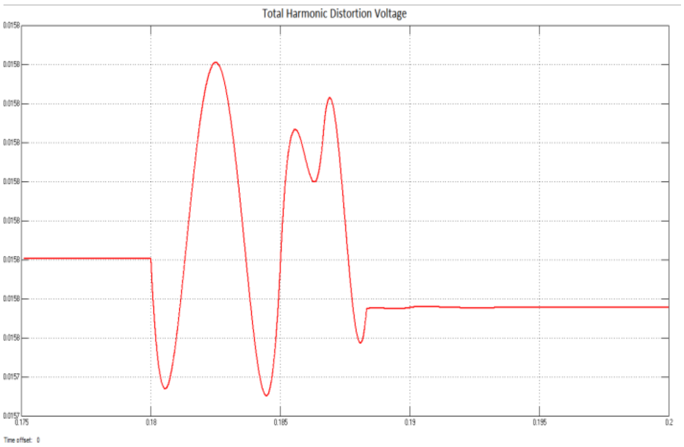

Fig: 6. Total Harmonic Distortion Voltage for Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

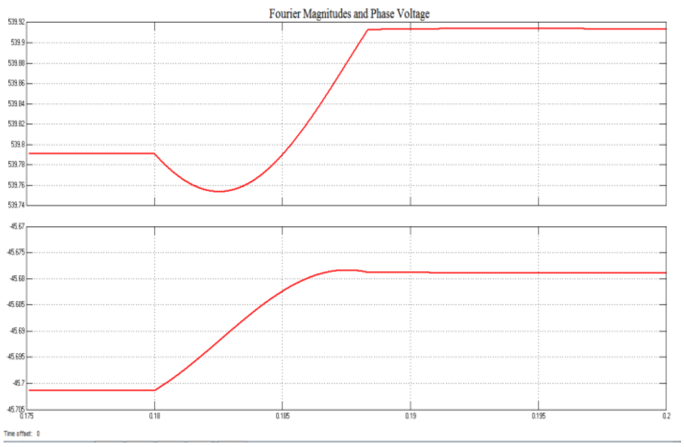

Fig: 7 Fourier Magnitudes and Phase Voltage for Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

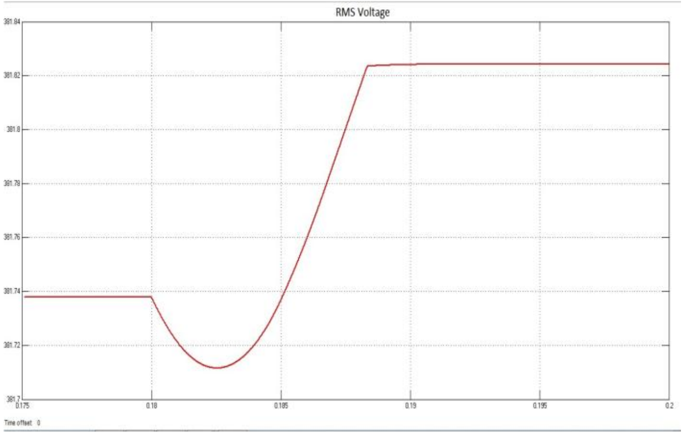

Fig: 8. RMS Voltage for Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

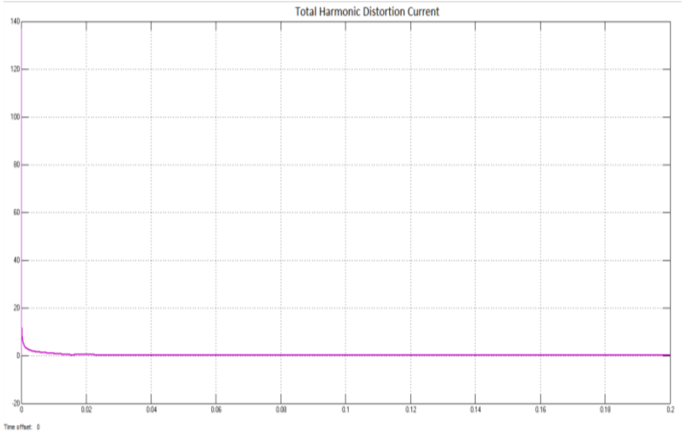

Fig: 9. Total Harmonic Distortion Current for Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

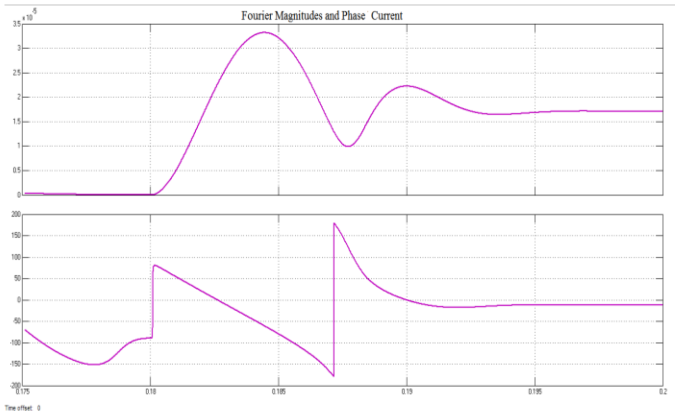

Fig: 10. Fourier Magnitudes and Phase Current for Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

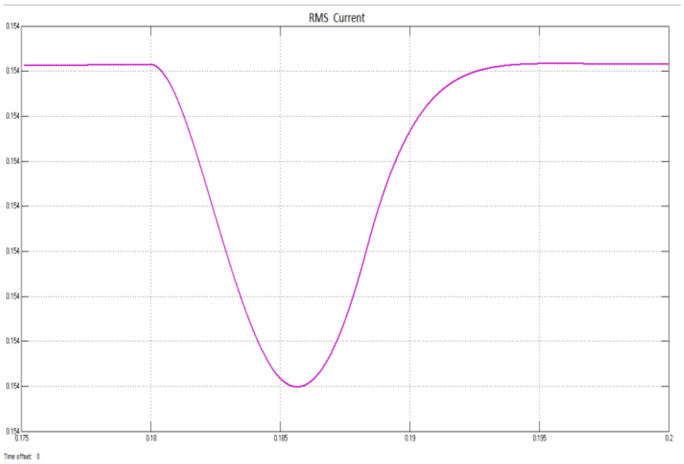

Fig: 11. RMS Current for Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

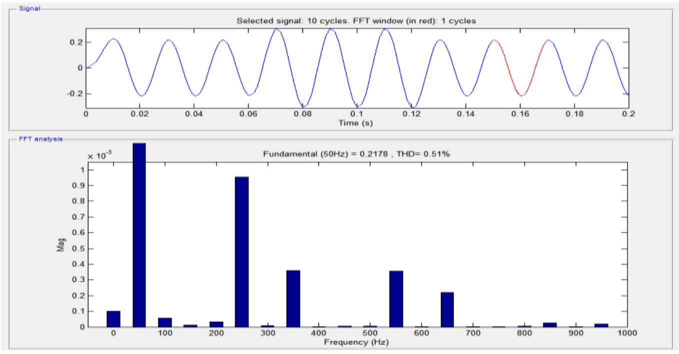

Fig: 12. THD of Modified SPWM Controller for Three Phase UPS Systems Operating Under Nonlinear Loads

IV. CONCLUSION

Therefore we can conclude that the design of a Modified SPWM controller for three-phase UPS systems powering nonlinear loads. 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. Therefore, this paper proposes a new strategy with a new design that overcomes the limitations of the classical RMS control. A THD equal to 1 % at the output voltage is achieved even under the worst nonlinear load. The load consists of three single-phase rectifiers connected between each line and the neutral and absorbing power equal to the rated power of the UPS with a crest factor up to 3. The controller performance is evaluated experimentally using a three phase 10 kVA transformer isolated UPS.A THD equal to 4.00% & 4.32% at output voltage & current for SPWM is achieved.

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