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A High-Performance SPWM Controller for Three-Phase UPS Systems Operating Under Highly Nonlinear Loads

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Abstract— 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 uninterruptible power supplies (UPS) outputs. The distorted uninterruptible power supplies (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 uninterruptible power supplies (UPS). As a result, different harmonics mitigating techniques have gained a lot of attention. The main objective of this project is to develop simulation of a high-performance Pulse Width Modulation (PWM) technique based AC-DC converter system operating under highly nonlinear loads using MATLAB/SIMULINK. Here, controlled Insulated-gate bipolar transistor (IGBT) based AC-DC converter is used to supply the load instead of Diode or Thyristor Bridge. The pulse width modulation method is quite effective in controlling the root mean square (RMS) magnitude of the AC-DC converter output voltages and shape of input current. This enables automatic harmonic compensation by Rectifier itself. Therefore, the device is controlling Power Flow as well as does Power Conditioning. In this project the performance of proposed system will be analysed for different pulse width modulation techniques like sinusoidal pulse width modulation (SPWM), using MATLAB/SIMULINK.

Keywords— Harmonic Compensation, sinusoidal pulse width modulation (SPWM) technique based AC-DC Converter, different Non-linear loads, current harmonics mitigation techniques

Introduction

In recent years power quality has become an important and growing problem due to the proliferation of nonlinear loads such as power electronic converters in typical power distribution systems. Particularly, voltage harmonics and power distribution equipment problems are the result of current harmonics produced by nonlinear loads. Eminent issues always arise in three-phase four-wire systems. It is well-known that zero line may be overheated or causes a fire as a result of excessive harmonic current going through the zero line three times or times that of three. Thus a perfect compensator is necessary to avoid the negative consequences of harmonics. Though several control techniques and strategies have been developed they still have contradictions with the performance of filters.

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 uninterruptible power supplies (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 pulse width modulation (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. The solution to this problem is to design a proper inverter controller such that it generates a control signal with multiple functionalities. This signal must carry information to produce sinusoidal voltages with small steady-state RMS error, to provide fast transient response and corrective actions to reduce distortion even under highly nonlinear loads. Therefore, a major research has been conducted to design such controllers for the high-performance uninterruptible power supplies uninterruptible power supplies (UPS) Systems. The high performance controllers in general employed multi-loop state feedback control strategies to achieve the regulation specifications Moreover, the dead-beat control method and the predictive and repetitive control methods have been widely investigated and proposed among researchers. In addition, the iterative and adaptive learning control methods, the H-infinity control method the feedback linearization method, and recently the multi sampled control approach to improve the control performance have been studied and evaluated. High-quality output voltages with substantially low total harmonic distortion (THD) and fast dynamic response have been demonstrated with these methods. However, the disadvantages such as implementation complexity and the problems caused by highly unbalanced loading may limit some of the benefits of these methods.

POWER QUALITY PROBLEMS & ISSUES

A recent survey of Power Quality experts indicates that 50% of all Power Quality problems are related to grounding, ground bonds, and neutral to ground voltages, ground loops, ground current or other ground associated issues. Electrically operated or connected equipment is affected by Power Quality and determining the exact problems requires sophisticated electronic test equipment. The following symptoms are indicators of Power Quality problems:

• Piece of equipment misoperates at the same time of day.
• Circuit breakers trip without being overloaded.
• Equipment fails during a thunderstorm.
• Automated systems stop for no apparent reason.
• Electronic systems fail or fail to operate on a frequent basis.
• Electronic systems work in one location but not in another location.

The commonly used terms those describe the parameters of electrical power that describe or measure power quality are Voltage sags, Voltage variations, Interruptions Swells, Brownouts, Blackouts, Voltage imbalance, Distortion, , Harmonic resonance, Inter harmonics, Notching, Noise, Impulse, Spikes (Voltage), Ground noise, Common mode noise, Critical load, Crest factor, Electromagnetic compatibility, Dropout, Fault, Flicker, Ground, Raw power, Clean ground, Ground loops, Voltage fluctuations, Transient, Dirty power, Momentary interruption, Over voltage, Under voltage, Nonlinear load, THD, Triples, Voltage dip, Voltage regulation, Blink, Oscillatory transient etc.

The issue of electric power quality is gaining importance because of several reasons:

• The society is becoming increasingly dependent on the electrical supply. A small power outage has a great economical impact on the industrial consumers. A longer interruption harms practically all operations of a modern society.

• New equipments are more sensitive to power quality variations.

• The advent of new power electronic equipment, such as variable speed drives and switched mode power supplies, has brought new disturbances into the supply system.

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POWER QUALITY STANDARDS

Power quality is a worldwide issue, and keeping related standards current is a never-ending task. It typically takes years to push changes through the process. Most of the ongoing work by the IEEE in harmonic standards development has shifted to modifying Standard 519-1992.

IEEE 519

IEEE 519-1992, Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, established limits on harmonic currents and voltages at the point of common coupling (PCC), or point of metering .

The limits of IEEE 519 are intended to:

1) Assure that the electric utility can deliver relatively clean power to all of its customers;

2) Assure that the electric utility can protect its electrical equipment from overheating, loss of life from excessive harmonic currents, and excessive voltage stress due to excessive harmonic voltage. Each point from IEEE 519 lists the limits for harmonic distortion at the point of common coupling (PCC) or metering point with the utility. The voltage distortion limits are 3% for individual harmonics and 5% THD. All of the harmonic limits in IEEE 519 are based on a customer load mix and location on the power system. The limits are not applied to particular equipment, although, with a high amount of nonlinear loads, it is likely that some harmonic suppression may be necessary.

IEEE 519 Standards for Current Harmonics

• *General Distribution Systems [120V- 69 kV]*

Below current distortion limits are for odd harmonics. Even harmonics are limited to 25% of the odd harmonic limits. For all power generation equipment, distortion limits are those with $I_{SC}/I_L<20$. I_{SC} is the maximum short circuit current at the point of coupling “PCC”.I_L is the maximum fundamental frequency 15-or 30- minutes load current at PCC. TDD is the Total Demand Distortion (=THD normalized by IL) General Sub-transmission Systems [69 kV-161 kV]. The current harmonic distortion limits apply to limits of harmonics that loads should draw from the utility at the PCC. Note that the harmonic limits differ based on the I_{sc} /I_L rating, where I_{SC} is the maximum short circuit current at the PCC, and I is the maximum demand load current at the PCC.

Sinusoidal PWM (SPWM)

The stationary or synchronous-frame space-vector PWM (SVPWM)-based controllers are the primary choice of many Researchers and the applications currently used in industry, today However, the classical sinusoidal PWM (SPWM) method is still preferred by many manufacturers because of its implementation simplicity, easy tuning even under load, flexibility, and most importantly the advantages of controlling each phase independently. The independent regulation of each phase provides easy balancing of three-phase voltages which makes heavily unbalanced loading possible. Also, it avoids problems such as transformer saturation. Although the classical SPWM method is quite effective in controlling the RMS magnitude of the UPS output voltages, it is not good enough in compensating the harmonics and the distortion caused specifically by the nonlinear loads. For example, the total harmonic distortion (THD) is greater than 5% limit even with good filtering. It becomes more severe at high-power UPSs where the switching frequency has to be reduced due to the efficiency and heating problems. This study proposes a multiloop high-performance SPWM control strategy and a design that overcome the limitations of the classical RMS control. It adds inner loops to the closed loop feedback control system effectively that enables successful reduction of harmonics and compensation of distortion at the voltages. The experimental setup using the proposed controller achieves 3.8% THD under the nonlinear load having a crest factor of 3 and absorbing power equal to the rated power of the UPS.

The Influence and Design Consideration of UPS Output Virtual Resistance on Parallel-Connected UPS System

The important characteristics of parallel-connected uninterruptible power supply (UPS) systems are excellent power-sharing quality and stability. In this paper we use the output active and reactive power to adjust the output voltage amplitude and phase to achieve the load sharing. Because of the difference of output filter inductor's resistance and distance of connection wire of each machine in the paralleled UPS system, the equivalent output impedance of each UPS inverter is different. These output impedance difference can cause circulation current and decrease the load-sharing quality. In order to solve this problem, virtual resistance is introduced to each inverter. In this paper the influence of the virtual resistance on paralleled UPS system and how to choose the virtual resistance is analyzed. Experimental studies using DSP controlled parallel-connected three-phase four-wire UPS system are presented to show the effectiveness of the proposed design.

To the paralleled UPS systems, an appropriate load-sharing or current-sharing control scheme is needed. Many existing current-sharing control strategies can be used, e.g., instant current control method, output droop scheme, active and reactive power control etc.

The instant current sharing control method using instantaneous current sharing command to correct the UPS inverter output current was studied. The voltage regulation as well as the current sharing precision is proved to be very well. However, the noise immunity and signal delay of current command due to layout of the paralleled UPS's must be dealt carefully.

Study on Dual-DSP-Controlled Three-phase Series-Parallel Compensated Line-Interactive UPS System (Delta-Conversion UPS)

A three-phase series parallel compensated line interactive UPS system consisting of two voltage-source inverters controlled separately by two digital signal processors studied in this paper. According to international IEEE standards, a UPS system can be classified into three of **a** kind, i.e. Passive-standby, line interactive and double-conversion. Why this kind of UPS system is often called "delta conversion", which is a member of the line-interactive UPS family in nature, may lie in a little power handled by both inverters in standby mode and the quasi-feedback PWM technique it adopted. “delta-inverter" can be controlled either as a fundamental sinusoidal current source or as non-sinusoidal voltage source to compensate reactive and harmonic currents deriving from inductive and non-linear loads Compared to double-conversion counterpart, "delta-inverter" is a small kilo volt ampere in any modes, while a little reactive and harmonic current now through “main inverter” in standby by mode

Direct current control of an active power filter for harmonic elimination, power factor correction and load unbalancing compensation

An active power filter is designed, simulated, implemented, and tested. It can work in different modes: active power filtering, power factor correction, and load unbalance compensation. It is based on a current controlled voltage-source inverter with fixed carrier PWM. The control algorithm generates the source reference currents based on the controlled DC link voltage. The dimensioning criteria of the inductive and capacitive power components are discussed. The implementation is validated with simulated and experimental results obtained in a 5 kVA prototype.

A High-Performance SPWM Controller for Three-Phase UPS Systems Operating Under Highly Nonlinear Loads Discussion and Conclusion

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. The controller is implemented in the TMS320F2808 DSP by Texas Instruments, and the performance is evaluated experimentally using a three-phase 10 kVA transformer isolated UPS under all types of load conditions. In conclusion, 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.

References

[1] S.Khalid & Bharti D wivedi, *"Power Quality Issues, Problems, and Standards"*, IEEE transactions on power quality, May 2011, vol.1, no.2, page no.09 to 16

[2] F. Botter´on and H. Pinheiro, *"A three-phase UPS that complies with the standard,"* IEEE transactions. Ind. Electron , Aug. 2007, vol. 54, no. 4, page no. 2120–2136.

[3] S. Jiang, D. Cao, Y. Li, J. Liu, and F. Z. Peng, *"Low THD, fast transient, and cost-effective synchronous-frame repetitive controller for three-phase UPS inverters,"* IEEE Trans. Power Electron, 2012. vol. 27, no. 6, page no. 2294–3005.

[4] Ke Dai, Peiguo Liu, Jim Xiong, and Jian *Chen "Study on Dual-DSP-Controlled Three- Phase Series-Parallel Compensated Line-Interactive UPS System (Delta-Conversion UPS)"* IEFE 2003 page no-1803-1817

[5] Wei Yu, Dehong Xu, Kuian Ma *"The Influence and Design Consideration of UPS Output Virtual Resistance on Parallel-Connected UPS System"* IEEE ©2009 page no-978-1-422-2

[6] Q.-C. Zhong, F. Blaabjerg, J. Guerrero, and T. Hornik, *"Reduction of voltage harmonics for parallel-operated inverters equipped with a robust droop controller,"* in Proc. IEEE Energy Convers. Congr. Expo., Phoenix,AZ, 2011, page no. 473–478.

[7] N. M. Abdel-Rahim and J. E. Quaicoe, *"Analysis and design of a multiple feedback loop control strategy for single-phase voltage-source UPS inverters,"* IEEE Trans. Power Electron., Jul.1996. vol. 11, no. 4, page no. 532–541,

[8] H. Deng, R. Oruganti, and D. Srinivasan, *"A simple control method for high performance UPS inverter through output impedance reduction," IEEE* Trans. Ind. Electron. Feb. 2008. vol. 55, no. 2, pp. 888–898.

[9] N. M. Abdel-Rahim and J. E. Quaicoe, *"Analysis and design of a multiple feedback loop control strategy for single-phase voltage-source UPS inverters,"* IEEE Trans. Power Electron. Jul.1996. vol. 11, no. 4, pp. 532–541.

[10] F. Botter´on, H. Pinheiro, H. A. Grundling, and J. R. P. H. L. Hey, *"Digital voltage And current controllers for three-phase PWM inverter for UPS applications,"* in Proc. 36th Annu. Meeting IEEE Ind. Sep./Oct. 2001, vol. 4, pp. 2667–2674.

[11] Bunyamin Tamyurek, *"A High-Performance SPWM Controller for Three-Phase UPS Systems Operating Under Highly Nonlinear Loads"*, Aug. 2013, vol. 28, page no. 3689- 3701.
Techniques," *Proc. Of Power Quality Conference*, '04, Chicago, IL.