PERFORMANCE ANALYSIS OF BOOST RECTIFIER CIRCUIT WITH FULL-BRIDGE CONFIGURATION FOR AUTOMATIC SLIDING CONTROLLER

Aparna Kumari[1], Dr. Reeta Pawar[2], Dr. Anurag S.D. Rai[3]
[1]M.Tech Scholar, [2,3]Assistant Professor, Rabindranath Tagore University, Bhopal

ABSTRACT: At the present, boost type three phase rectifiers are increasingly used for industrial applications such as uninterruptible power supplies (UPS), battery chargers, motor drives. Also, such as MOSFET, IGBT are commonly used by semiconductors, operate in high frequency switching devices which are free to switch at frequencies much higher than the main frequency, allowing the controller whose dynamic response is very high. The efficient conversion of power is a problem in the modern world. The power factor, one of the most vital characteristics in the AC/DC power conversion, describes the efficiency and superiority of such process. The unity-value power factor converter does not introduce any alteration to the energy source and exploits performance of the power conversion. Many schemes and solutions that are available in the field of power factor correction (PFC) are presented in the work.

The thesis shows a power factor correction for a class of three-phase boost ac/dc power converters. Here a full-bridge boost converter has been studied for power factor control, using output sliding mode control. The sliding mode control drives the output voltage to the preferred dc level in the existence of external disturbances and internal parameter uncertainties providing a value of power factor close to unity. The controlled converters is simulated and studied for the effectiveness of the proposed control algorithms and good consistency is achieved.

Feedback control is the elementary mechanism through which many systems, like electrical, mechanical, or biological system maintain their equilibrium. Feedback control may be defined as the use of various signals that are determined by comparing the actual values of the system variables to their desired values, as a means of a control system.

Key words: - Feedback control, power converters, rectifiers, MOSFET, IGBT, power factor correction (PFC).

I. INTRODUCTION

The efficient conversion of power is an important problem that is very relevant in the modern world. It is essential to have effectual energy systems because now government is focusing on global warming, dependence on foreign oil, and the focus on renewable energy. Now a days boost type three-phase rectifiers are useful in industrial applications, such as variable speed drives, power supplies, dc motor drives, front-end converters in adjustable-speed AC drives, HVDC transmission, SMPS, in process technology like welding such as variable-speed drives and ac–dc power supplies for telecommunications equipment, aerospace, military environment and so on. The design, advancement and fruitful application of single-phase, improved quality converters in domestic, commercial and industrial environment has made possible the design and development of three-phase, improved quality converters and their widespread use in different applications. To overcome the problems of harmonic distortion and low power factor in power system several converters and control schemes have been proposed in recent years. Conventionally diode rectifiers or thyristor bridge converters were used to synthesize dc voltage from the ac voltage. A few advantages of boost topology are

- High power density
- High efficiency
- Improvement of power quality at input and output.

Hence boost type converters not only provide regulated DC output voltage but also maintain near unity power factor and low THD on current at the input. One of the main concerns in controlling the output voltage of boost converter is keeping the output voltage in a desirable value under the variations of load and parameter uncertainties.

The challenge behind the necessity of finding the most suitable control method to overcome the main problems rising and affecting the circuit performance. These problems are nonlinearity, stability, reduction of cost, reduction of EMI. Linear controllers have been used for linear systems and for the liearized version of a nonlinear system also gives good results at an equilibrium point near which the system behavior is approximately linear. Nonlinear approaches such as

- fuzzy logic control [12]
- passivity based control [13,14]
- back-stepping technique control [15]
- Lyapunov-based control [16]
- the Linearization approximation
- the Describing function concept
- the Piecewise-linear approximation
- Sliding mode control[3-4]

From aforementioned control methods sliding mode control is used because it has described the characteristics of robustness and effectiveness by some researchers [3-4], which is easy and effective to deal with the nonlinear behavior of the boost rectifier as the system order is reduced and the non-minimum phase behavior is canceled out. One of the most intriguing aspects of sliding mode control is the discontinuous nature of the control action. The main function of each of the feedback control is to switch between the two different system structures, so that a new type of system motion called sliding mode exists in a manifold $\sigma = 0$. Two main objectives are followed in order to design the efficient ac/dc power converter.

- To maintain power factor as close as possible to unity.
- To achieve a stabilized DC output voltage.

Both objectives are achieved by the SMC theory that permits not only accomplishment of high performance (power factor close to unity) [5,6] of the system but also the keeping the functionality in the presence of parameter uncertainties and external disturbances.

II. LITERATURE REVIEW

In the literature survey, I have studied about modeling of 3-ph AC/DC boost converter and to get unity value of power factor different nonlinear control technique are studied, among them I came to know that sliding mode controller (SMC) is best. The following papers describe their contributions.

Jianxing Liuet.al.[1]discussed a full-bridge boost power converter topology has been studied for power factor control, using out-put high order sliding mode control. The proposed controller forces the input currents tracking the desired values which can control indirectly the output voltage while keeping power factor close to one, and ensuring minimum frequency deviation and phase difference between voltage and current.

KadaHartaniet.al.[2]proposed the space vector pulse width modulation (SVPWM) control scheme for three-phase voltage source PWM rectifier. The proposed control can stabilize the minimum of the systems storage function at the desired equilibrium point determined by unity power factor and sinusoidal current on the AC side, and constant output voltage on the DC side.

Yu Wang et.al.[3]introduced the topology of Three-Phase PWM Voltage Source Rectifier (VSR). Then the mathematical models in three-phase static and two-phase rotary coordinate system are built. Based on that theory and the voltage-oriented vector control's idea, a dual-channel closed loop control strategy with current-inner-loop and voltage-outer-loop. Active power channel is aim to make DC side voltage remain steady, and reactive power channel can regulate power factor by set current q-axis component reference. In order to prove that voltage-outer-loop is necessary, the paper builds a comparative model without a voltage loop.

R. Schaeffelet.al.[4] explained power factor correction (PFC) for a full bridge 3-phase AC/DC boost power converter. The purpose of this paper is to design and study the effectiveness of the traditional sliding mode controllers (SMC) and second order sliding mode (SOSM) controllers [12,13] that convert AC power into DC power at a desired voltage level in a 3-phase AC/DC boost power converter while driving the power factor to a unity level.

J.T.Boyset.al.[5]A voltage sourced reversible rectifier(VSRR)which achieves bidirectional power flow between a 3-phase AC supply and a DC bus voltage is described. The device features a pulse Width modulated voltage control strategy that confined unwanted harmonics to known frequency bands where they can be easily filtered out while operating at near unity power factor, with sinusoidal currents, and maintaining a constant DC bus voltage.

Cecati.C.al.c[6] proposed that active rectifiers include current or voltage sensors, and the number should be reduced to obtain low cost systems. Here a active filter with feed forward fuzzy logic control is offered and discussed. Here mathematical description of the system and design of fuzzy logic controller is introduced and analyzed.

III. MOTIVATION

The design of an efficient power converter should be considered as a difficult problem, because of mainly two reasons. They are electrical circuit (hardware topology) selection and control algorithm design and implementation. The main goal conversion of power is not only the production of electrical signals (voltage or current) but also the consideration of the effect of power converters to the energy source to provide better quality power conversion. The power factor, which reflects the efficiency and quality of the process is one of the most vital feature in the field of ac/dc power conversion. The unity-value power factor converter does not introduce any distortion to the energy source and exploits the performance factor of the power conversion. In the area of power factor correction (PFC) many schemes and solutions are introduced. Also different hardware topologies and control methods are used in this work. In order to design the efficient ac/dc power converter two main goals should be achieved.

- Power factor should be as close as possible to unity.
- Achieve a constant DC output voltage.

Both goals are addressed by the SMC theory that allows not only the achievement of the high performance of the system (with power factor closed to unity) but also its robustness, and effective to deal with the nonlinear behavior of the boost rectifier, as the system order is reduced.

IV. OBJECTIVE OF RESEARCH WORK

Due to variation of parameters like nonlinear component in the converter, line and load variation, electromagnetic interferences (EMI) the converter was deviated from the desired operating condition. The converter will not operate in steady state, if the parameter deviation increases. Many control methods are used to control and solve the above problem. Each control method has its own advantages and weaknesses due to which a particular control method is used to be the most suitable control method under specific conditions. A particular control method is demanded which has the best performances under any conditions. The DC portion of the output voltage should equal a desired constant output voltage value (V_d). The AC portion of the output voltage should be reduced to an acceptable range. The input phase currents should be in phase with their corresponding phase voltage. The phase currents should only have the frequency corresponding to the frequency of the respective phase voltage.

The thesis defines the cause by which a specific control method is selected, i.e. the sliding mode control (SMC), among all control methods. A detailed research analysis is done of the sliding mode control is implemented in some AC/DC converter topologies.

Modeling of 3-phase ac/dc converter

In this chapter we are interested in the performance improvement of ac–to–dc converters. To overcome the main disadvantages found in dc to dc converters namely low input-power factor and the considerable pollution presented in the line source the simple circuit ac–to–dc converters are used. They are generally behave as power factor pre compensators (PFPs), since they are mainly used to ensure a unity power factor functioning, thus seeming as a primary step in a power source. Three-phase single stage ac-dc Boost converter having six switches, used to obtain improved power factor and sinusoidal currents. The switches have bidirectional power flow, such as IGBTs or MOSFETs, Therefore additional series diode will be required. As there is variation in DC load the robustness must be a vital factor for rectifier controllers. Power electronic converters are nonlinear systems. In designing converters and control systems there are used both mathematical modeling of their behavior, software, capable of simulating various stages of work in order to verify the perfection of the projected solutions to design and control algorithms.

BOOST-TYPE three-phase rectifiers are useful in industrial applications, such as variable speed drives and ac–dc power supplies for telecommunications apparatus. A traditional rectifying technique adopts phase-control method or passive diode rectifier. They have some drawbacks, like slower dynamic respond, passive diode rectifier can absorb harmonic current from power grid and the DC-side energy cannot feedback. Three-Phase boost power converter techniques with sliding mode is used to overcome the phase-control method and passive diode rectifier's disadvantages, and has higher power factor, lower harmonic current and rapid dynamic respond. Here we design a mathematical model for 3-phase ac-dc boost converter in terms of current and voltages.

Three-phase boost rectifier model

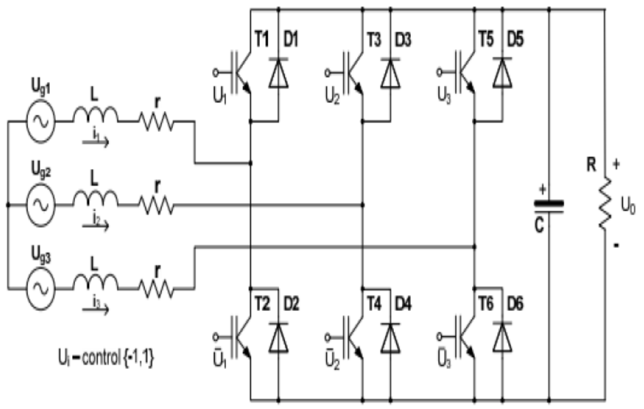

Figure - Three-Phase boost AC/DC power converters

Fig. shows a full boost converter circuit that is used to convert from 3-phase AC power into DC power. To design a math model, it is assumed that the AC voltage is a balanced three phase supply, switch is ideal and lossless, and filter is linear. The circuit consists of three main parts, storage elements, bi-directional switches, and RC filter. The Inductors are the energy storage elements used for higher output DC voltages that could be obtained by rectifier. The IGBTS with anti-parallel diode make the needed switches. The switches are bidirectional because when the switches are closed, they short the diode, therefore current can flow in either direction. The output is an RC filter which is used for smoothing and reducing the output variations to a dc voltage level [1, 8].The six on-off signals of the converter are signified by

$$s = \begin{bmatrix} s_a & s_b & s_c & s_d & s_e & s_f \end{bmatrix}^T$$

The current and voltage that come out of an uncontrolled boost power converter is not in phase and does not have the exact harmonics. Also, it does not boost the voltage to preferred levels. The estimation and correction of power factor (PF) value is very essential in the quality analysis of the designed control law

Hence the control objectives are like this

- The dc portion of the output voltage U_0 should be equivalent to some preferred constant value V_d , on the other hand the ac component has to be attenuated to a given level.
- The input phase currents should be in phase with their respective phase voltage. The phase currents should have frequency equivalent to the frequency of the respective phase voltage.
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Design of a Sliding Mode Controller

Sliding mode control (SMC) is a nonlinear control method that changes the dynamics of a nonlinear system by application of a high frequency switching control that forces the system to slide along the Cross section of the system's normal behavior. The state-feedback control law can switch from one continuous structure to another based on the existent position in the state space. Therefore sliding mode control is a variable structure control method. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so ultimate trajectory will not exist entirely within one control structure. Instead, it will slide along the boundaries of the control structures. The motion of the system as it slides along these boundaries is called a sliding mode and the geometrical locus consist of the boundaries is called the sliding surface.

Sliding Mode Control in Electrical and Mechanical Systems

As the applications of SMC are increasing day by day researchers are working to prove the efficiency of the SMC in electrical and mechanical systems. Recently many researchers have done research on the applying the SMC in electrical and mechanical systems. Some of the main fields of research on the topic are shown in Figure 3.1.

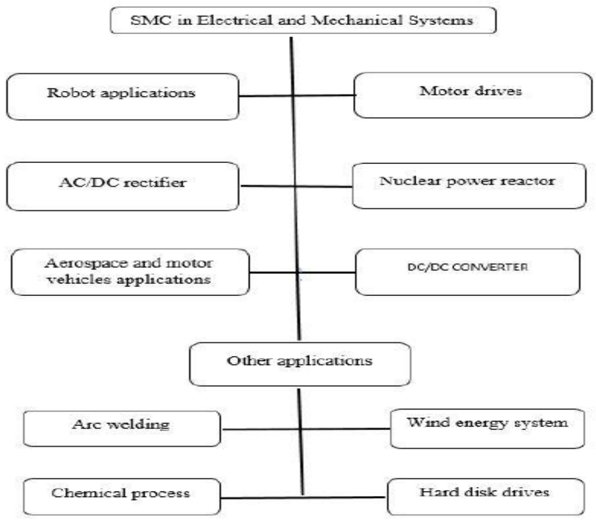

Fig. SMC in Electrical and Mechanical system

Simulation Results

The multi rate simulation of the proposed three-phase ac/dc boost power converter has been conducted with the parameters shown in Table. The system uses a control rate that is slower than the simulation rate in order to test for the controller implementation. The load resistance changes after 1.5 seconds to test for varying loads. The frequency changes after 1.0 second to test the controller's ability to handle varying frequencies. The phase voltages have different magnitudes to test the controller's ability to handle phase voltages that are not equal.

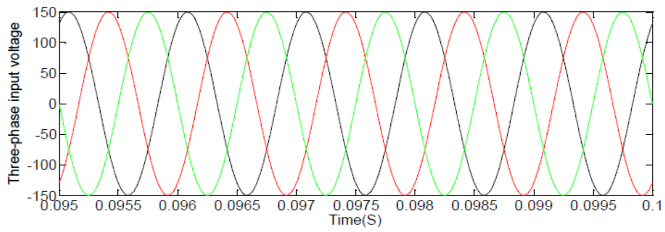

Fig - shows the relationship between 3-phase input voltages.

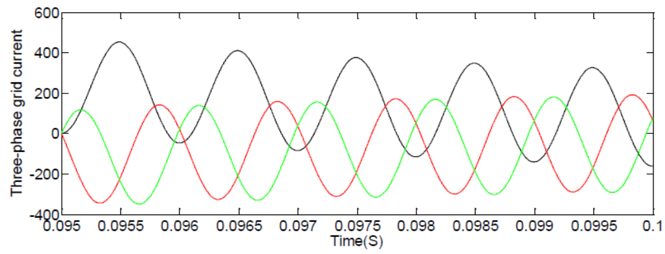

Fig - shows the relationship between 3-phase grids current

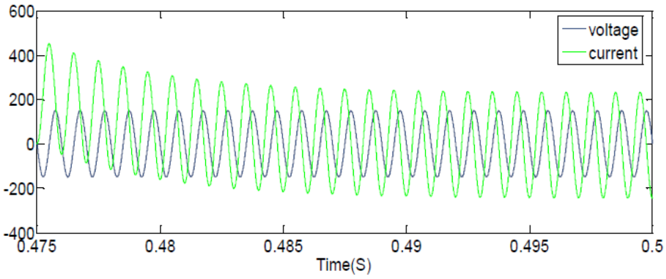

Fig - Relationship between input voltage and current

Parameter used for simulation

Parameter	Value	Description
Method	Euler	Integration method
ΔT	10^{-6}	Integration step size, sec
f_1	10^{6}	Pseudo-analog simulation rate, Hz
f_2	10^{5}	Control evaluation rate, Hz
f_3	10^{4}	Pulse width modulator rate, Hz
R	$30 \to 40$	Load resistance, Ω
R	0.02	Parasitic phase resistance, Ω
L	2	Phase inductor value, mH
C	100	Output capacitance, μF
$\{E_1, E_2, E_3\}$	$\{155,145,150\}$	Main voltage , V
F	$75 \to 150$	Main voltage frequency, Hz
$U_0(0)$	1	Initial output voltage, V
V_d	650	Desired output DC voltage, V

Table - Parameters used for simulation

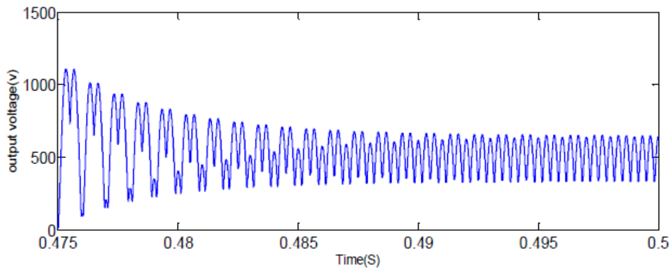

Fig - Output voltage of 3-phase boost converter with sliding mode control

V. CONCLUSION & FUTURE SCOPE

In this thesis we attempt to apply the sliding mode control concept in 3-phase boost rectifier circuit with full-bridge configuration. The mathematical formulation of power circuit under this proposed method has been done. To verify the capability of suggested method, a preliminary study of 3-phase rectifier circuit has been done using MATLAB/Simulink software. The simulation results show a good performance of proposed method at start-up during load variations, providing a desirable output voltage. However analysis of such sliding mode controlled ac/dc converter systems needs to be investigated further in detail.

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