Performance of PWM Rectifier with different types of load

Mr. Rajendra Singh[1] Mr. Avinash Maurya[2]
[1,2]Department of Electrical Engineering
[1,2]Madan Mohan Malaviya University of Technology, Gorakhpur, Uttar Pradesh, India

Abstract— The paper presents the decoupled vector control of the PWM rectifier with the nonlinear DC-link voltage regulation and the load compensating feed forward. The concept of the proposed control system is based on Voltage Oriented Control with Space-Vector Pulse Width Modulation (SV-PWM). For the high-performance operation of the PWM rectifier and the satisfactory current tracing the decoupled current control has been introduced. The performance of the linear PI controller of the DC-link voltage is strictly dependent on its settings and it may introduce a disadvantageous voltage overshoot under a heavy load impact. In order to improve the transient response of the DC-link voltage control loop a load compensation has been proposed. The different approach to the control of the DC-link voltage based on the regulation of the square power of the DC voltage has been introduced.

Key words: Three Phase Controlled Voltage Source, Boost Inductors, Three lags Bridge, Capacitors, Discrete Space Vector Pulse Width Modulation Generator, Scaling gain, NOT gate

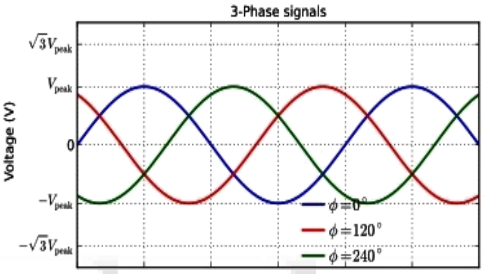
I. INTRODUCTION

Nowadays the adjustable speed drives with the squirrel-cage induction motors are intensively developed. In these drives the angular velocity and the electromagnetic torque are precisely controlled using mostly the voltage source inverters. For years most of the electrical drives with the voltage inverters have been supplied from the power distribution line through the thyristor rectifiers. Such frequency converters were supposed to provide the smooth control of the amplitude of the basic harmonic of the output voltage neglecting the influence of the line-side rectifier on the grid. The frequency converters supplied by the thyristor and diode rectifiers are characterized by the disadvantageous properties as the lack of the possibility of the regenerative braking of the induction motor, the intake of the non-sinusoidal distorted currents from the grid at the power factor different from the unity. The flow of the non-sinusoidal currents in the power distribution line causes the distorted voltage drops over the other power devices being supplied from the grid. The distorted voltages are also inappropriate for the line transformers since more heat is produced especially in case of the high power ratings.The control strategies for the AC/DC line-side converters have been adapted from the methods elaborated for the vector control of the induction motors. The classical control techniques require the strict knowledge of the values of the line and load parameters since the PI control performance is strictly dependent on the proper identification of the line chokes inductance and the DC-link capacitance.

Recently more stress has been put on the elaboration of the nonlinear control algorithms for the PWM rectifiers in order to eliminate the disadvantageous influence of the variations of the line and load parameters on the converter operation [4, 6, 9]. In this paper a method of the compensation of the load impact and the efficient control of the DC-link voltage has been proposed. The presented method has been implemented and verified on the hardware application of the DSP-based controlled PWM rectifier.

II. MATHEMATICAL MODELS OF PWM RECTIFIERS

The voltage-source PWM rectifier has the topology presented in Fig.1 [10]. The converter's bridge consists of the six fully-controllable power switches (IGBTs, MOSFETs, GTOs) connected to the three-phase grid voltages V_{as},V_{bs},V_{cs} via the three symmetrical line chokes of the resistance R_a and the induction La.



During the operation of the AC/DC line-side converter its transistors are being switched by the rectifier's control system producing the pulse-width modulation scheme based on the principles of a chosen control strategy.

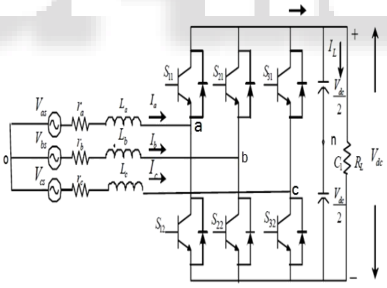


Fig. 1: Three-phase voltage-source PWM rectifier

In order to reach the sufficient quality of the line currents in case of the voltage-source PWM rectifier the high switching frequency has to be provided. The switching signals are denoted as S_{11}, S_{21} and $S_{31}$for the particular phases respectively. The relationship between the converter input voltages V_{conva}, V_{convb}, V_{convc} and the DC-link voltage V_{dc} depends on the instantaneous states of the power switches and can be described in a form of equations (1).

$$Va = \frac{S_{11} \cdot V_{dc}}{2}, \qquad V_b = \frac{S_{21} \cdot V_{dc}}{2}, \qquad V_c = \frac{S_{31} \cdot V_{dc}}{2}$$

A set of diffential equations can describe the dynamic model of PWM rectifier

$$\begin{bmatrix}\frac{\mathrm{dia}}{dt}\\ \frac{\mathrm{dib}}{dt}\\ \frac{\mathrm{dic}}{dt}\end{bmatrix}=\begin{bmatrix}-\frac{\mathrm{ra}}{\mathrm{La}} & 0 & 0\\ 0 & -\frac{\mathrm{ra}}{\mathrm{La}} & 0\\ 0 & 0 & -\frac{\mathrm{ra}}{\mathrm{La}}\end{bmatrix}+\frac{1}{L}\begin{bmatrix}\mathrm{Vas}- & \mathrm{Va}\\ \mathrm{Vbs}- & \mathrm{Vb}\\ \mathrm{Vcs}- & \mathrm{Vc}\end{bmatrix}$$

According to Park transform,

$$\begin{bmatrix}\frac{\mathrm{did}}{dt}\\ \frac{\mathrm{diq}}{dt}\end{bmatrix}=\frac{1}{\mathrm{La}}\begin{bmatrix}-R & -\omega R\\ \omega R & -R\end{bmatrix}\begin{bmatrix}\mathrm{id}\\ \mathrm{iq}\end{bmatrix}+\frac{1}{\mathrm{La}}\begin{bmatrix}\mathrm{Vd}\\ \mathrm{Vq}\end{bmatrix}-\frac{1}{\mathrm{La}}\begin{bmatrix}\mathrm{Vd}\\ \mathrm{Vq}\end{bmatrix}$$

The control design of a PWM rectifier is often performed in a synchronous frame rotating with the angular velocity corresponding to the grid pulsation ω. Thus the mathematical model of the voltage-source PWM rectifier in the *d-q* coordinates can be formulated in the set of the differential equations (2).

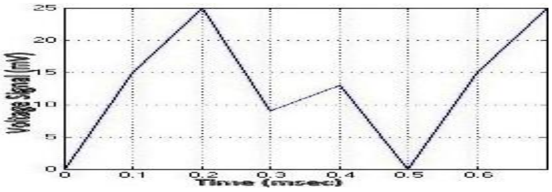
$$\frac{d}{dt}V_{dc}=-\frac{V_{dc}}{R_L C_d}+\frac{3}{2C_d}S_d i_{ad}$$
$$\frac{d}{dt}i_{ad}=-\frac{R_a}{L_a}i_{ad}+\omega i_{aq}-\frac{1}{2L_a}S_d V_{dc}+\frac{1}{L_a}e_{ad}$$
$$\frac{d}{dt}i_{aq}=-\frac{R_a}{L_a}i_{aq}-\omega i_{ad}-\frac{1}{2L_a}S_q V_{dc}$$

Assuming that the power conversion is lossless the power balance of the PWM rectifier can be described by the nonlinear differential equation (3).

$$\frac{3}{2}e_{ad}i_{ad}=V_{dc}C_d\frac{d}{dt}V_{dc}+\frac{V_{dc}^2}{R_L}$$

III. VOLTAGE ORIENTED CONTROL OF PWM RECTIFIERS

The Voltage Oriented Control technique for the AC/DC line-side converters originates from Field Oriented Control for the induction motors. It provides the fast dynamic response since the current control loops are applied. The properties of the control systems based on the VOC strategy are different depending on the involved PWM technique. The hysteresis pulse-width modulation method provides the on-line current tracking thus the influence of any disturbances is minimized and the better robustness of the control system is achieved.



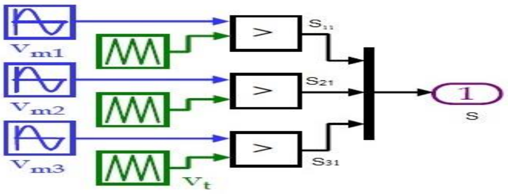
On the other hand the varying switching frequency introduces an additional stress in the power switches and requires the higher values of the parameters of the input filter. The Space-Vector PWM technique reduces the higher harmonics content in the line currents since the constant switching frequency of the power transistors is provided [3]. Fig.3 presents Voltage Oriented Control with SV-PWM for the AC/DC line-side converters.

Due to the vector transformation to the *d-q* reference frame the AC-side control variables are hence the DC signals. Thus the steady-state errors are easily eliminated via the PI controllers. The reference values of the converter input voltages are computed in the current controllers based on the values of the current tracking errors (7).

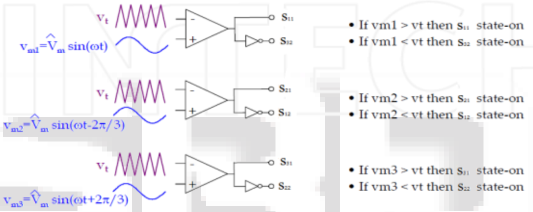
$$V_{convd}=k_p\left(i_{gdref}-i_{gd}\right)+k_i\int\left(i_{gdref}-i_{gd}\right)dt$$
$$V_{convq}=k_p\left(i_{gqref}-i_{gq}\right)+k_i\int\left(i_{gqref}-i_{gq}\right)dt$$

IV. PWM RECTIFIER CONTROL TECHNIQUE PRINCIPLE

Let us consider the electrical scheme presented on figure 18a.



It represents a DC motor fed by a six-pulse rectifier. The electrical equivalent circuit of the DC motor is described by an inductance La in series with a resistance Ra in series with an induced voltage V_a which characterizes the electromotive force, as illustrated in figure 18b.



The IGBT are modelled by an ideal model which traduces the state of the switch:

-VS = 0 when the IGBT is state-on

-IS = 0 when the IGBT is state-off

Similar to the diode rectifier, there are 13 operating phases to describe:

-1 phase of discontinuous conduction mode (P0)

All the IGBT are state-off

-6 phases of classical conduction P1 to P6 (figure 15c)

P1: S11 and S 31 state-on,P2: S 11 and S22 state-on

P3: S 32 and S 22 state-on, P4 : S 32 and S 12 state-on

P5: S 21and S 12 state-on, P6 : S 31 and S 21 state-on

-6 phases of overlap O1 to O6 (figure 15d)

O1: S 11, S 31 and S 22 state-on,

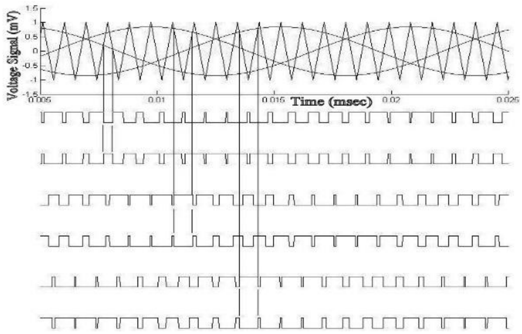
O2: S 11, S 32 and S 22 state-on

O3: S 32, S 12 and S 22 state-on

O4: S 32, S 21 and S 12 state-on

O5: S 21, S 12 and S 31 state-on

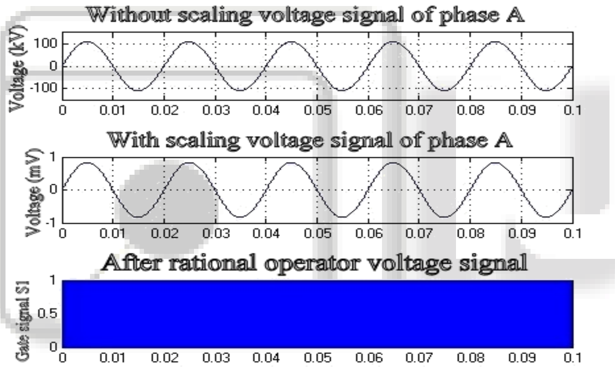
O6: S 11, S 21 and S 31 state-on



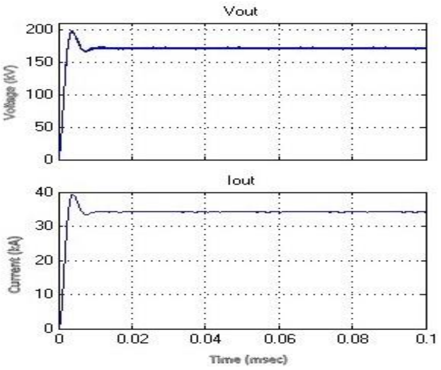
The different operating phases are illustrated in figure 15. The equations that govern an operating phase are the same whatever we work on a diode rectifier or a controlled rectifier.

V. EXPERIMENTAL STUDIES OF PROPOSED CONTROL TECHNIQUE

The experimental verification of the proposed control method has been carried out on the laboratory prototype with the power converter and the fixed-point DSP. The power unit of the proposed prototype of the AC/DC line-side converter is based on the 3.3 kW IGBT power module by EUPEC® with the electronic interface EiceDRIVER™ 6ED003E06-F [2].



For the reliable confirmation of the excellent dynamic performance of the proposed nonlinear control system of the PWM rectifier the comparative analysis has been carried out. The Voltage Oriented Control of the PWM rectifier without the load compensation and the current decoupling system from Fig.3b has been examined. The experimental results have been obtained at the same grid and load conditions as well as the computational rates of the control system. Fig.8 demonstrates the transient of the grid currents in the *d-q* coordinates and the response of the DC-link voltage control loop to the step change of the converter load.



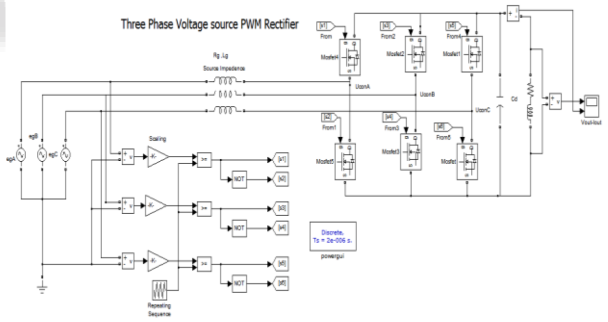
VI. CONCLUSIONS

The paper presents the real-time application of the decoupled control system of the PWM rectifier based on the Voltage Oriented Control technique. The compensation of the load current has been introduced to provide the high-performance operation of the AC/DC line-side converter.

The disadvantageous influence of the rapid changes of the converter load has been minimized by the introduction of the feed forward of the load current based on the load current sensor. The feed forward information about the actual converter load has contributed to the considerable improvement of the transient response of the DC-link voltage. The high quality of the grid currents has been provided by the application of the Space-Vector Pulse Width Modulation with the switching frequency of 5 kHz.

The operation of the proposed control method has been successfully examined on the laboratory setup of the PWM rectifier with the fixed-point digital signal processor.

VII. SIMULINK MODEL



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