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Virtual flux based reactive power compensation at the AC side of PWM rectifier using soft computing technique

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Abstract—This paper proposes a novel and simple direct power control of three-phase pulsewidth-modulated (PWM) rectifiers with constant switching frequency using space-vector modulation (DPC-SVM). The active and reactive powers are used as the pulse width modulated (PWM) control variables instead of the three-phase line currents being used. Moreover, line voltage sensors are replaced by a virtual flux estimator. The theoretical principle of this method is discussed. The steady-state and dynamic results of DPC-SVM that illustrate the operation and performance of the proposed system are presented. It is shown that DPC-SVM exhibits several features, such as a simple algorithm, good dynamic response, constant switching frequency, and particularly it provides sinusoidal line current when supply voltage is not ideal. Results have proven excellent performance and verify the validity of the proposed system.

Index Terms—Converter control, harmonics, power-factor correction,power quality, sensorless control.

I. INTRODUCTION

MOST three-phase rectifiers use a diode bridge circuit and a bulk storage capacitor. This has the advantages of being simple, robust, and low in cost. However, a
diode rectifier results in only unidirectional power flow, low power factor, and highlevel of harmonic input currents. Therefore, a three-phase pulsewidth-modulated (PWM) rectifier (Fig. 1) is a more interesting solution for industrial application thanks to viable advantages such as:

• bidirectional power flow;
• low harmonic distortion of line current;
• regulation of input power factor to unity;
•adjustment and stabilization of dc-link voltage;
• reduced dc filter capacitor size.

PWM rectifiers were applied by most global companies (Siemens, ABB, and others) like an ac/dc/ac converter or a dc distributed power system. Development of control methods for PWM boost

rectifiers was possible thanks to advances in power semiconductor devicesand digital signal processors, which allow fast operation.and cost reduction. It offers possibilities for implementation of sophisticated control algorithms. Appropriate control can provide both the rectifier performance improvements and reduction of passive components. Various control strategies have been proposed in recent works on this type of PWM rectifier.A well-known method of indirect active and reactive power control is based on current vector orientation with respect to the line voltage vector [voltage-oriented control (VOC)] . VOC guarantees high dynamics and static performance via internal current control loops. However, the final configuration and performance of the VOC system largely depends on the quality of the applied current control strategy. Another less known method based on instantaneous direct active and reactive power control is called direct power control (DPC).Both strategies mentioned do not perform sinusoidal current when the line voltage is distorted. Only a DPC strategy based on virtual flux instead of the line voltage vector orientation, called VF-DPC, provides sinusoidal line current and lower harmonic distortion . However, among the well-known disadvantages of the VF-DPC scheme are

• variable switching frequency (difficulties of *LC* input filter design);

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• violation of polarity consistency rules (to avoid switching over dc-link voltage);
• high sampling frequency needed for digital implementation of hysteresis comparators;
• fast microprocessor and A/D converters required.

Therefore, it is difficult to implement VF-DPC in industry. All the above drawbacks can be eliminated when, instead of the switching table, a PWM voltage modulator is applied. This paper presents a new simple method of line voltage sensorlessDPC with constant switching frequency using space-vector modulation (DPC-SVM).

II. DPC

DPC is based on the instantaneous active and reactive power control loops . In DPC there are no internal currentcontrol loops and no PWM modulator block, because the converter switching states are selected by a switching table based on the instantaneous errors between the commanded and estimated values of active and reactive power. Therefore, the key point of the DPC implementation is a correct and fast estimation of the active and reactive line power.

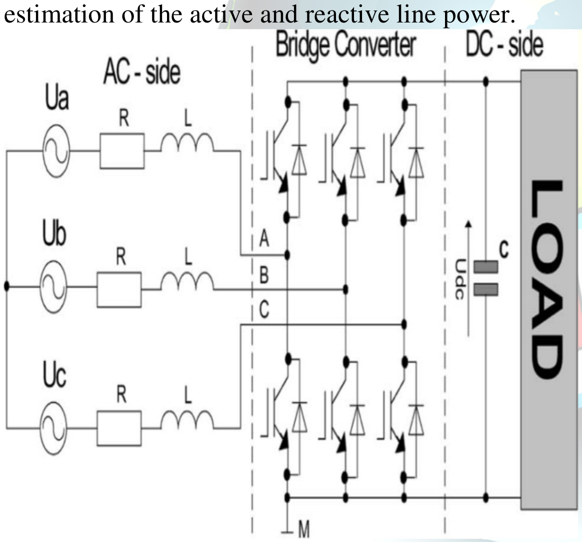

Fig. 1.PWM rectifier

A. Virtual Flux Estimator

It is possible to replace the ac-line voltage sensors with a virtual flux estimator, which gives technical and economical advantages to the system such as simplification, isolation between the power circuit and control system, reliability, and cost, effectiveness.

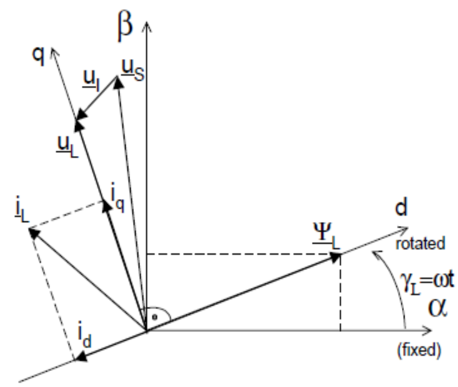

Fig. 2. Reference coordinates and vectors

Ψ_L.virtual line flux vector, u_S. converter voltage vector, u_L- line voltage vector u_I. inductance voltage vector, i_L. line current vector a virtual flux equation can presented as

$$\psi_L = \psi_S + \psi_I \quad (1)$$

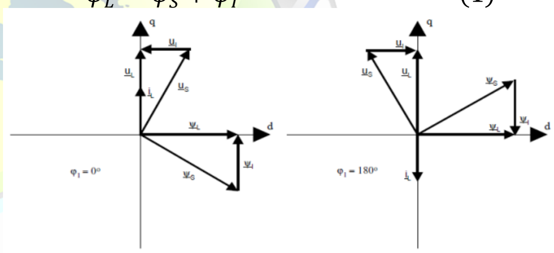

Fig. 3. Relation between voltage and flux for different power flow direction in PWM rectifier

$$u_{s\alpha} = \sqrt{\frac{2}{3}}U_{dc}(S_a - \frac{1}{2}(S_b + S_c)) \quad (2)$$

$$u_{s\beta} = \frac{1}{\sqrt{2}}U_{dc}(S_b - S_c) \quad (3)$$

Then, the virtual flux $\Psi_L$components are calculated from the) in stationary (α-β) coordinates system

$$\psi_{L\alpha}(\text{est}) = \int \left(u_{s\alpha} + L\frac{di_{L\alpha}}{dt}\right)dt \quad (4)$$

$$\psi_{L\beta}(\text{est}) = \int \left(u_{s\beta} + L\frac{di_{L\beta}}{dt}\right)dt \quad (5)$$

B. Instantaneous power estimation based on the virtual flux

The Virtual Flux (*VF*) based approach has been proposed by Author to improve the *VOC* . Here it will be applied for instantaneous power estimation, where voltage imposed by the line power in combination with the *AC* side inductors are assumed to be quantities related to a virtual *AC* motor

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$p = Re(u_L . i_L^*)$ (6) $q = \text{Im}(u_L . i_L^*)$ (7)
where * denotes the conjugate line current vector.
The line voltage can be expressed by the virtual flux as

$$u_L = \left.\frac{d\psi_L}{dt}\right|_\alpha + j\left.\frac{d\psi_L}{dt}\right|_\beta + j\omega(\psi_{L\alpha} + j\psi_{L\beta}) \quad (8)$$

$$p = \left\{\left.\frac{d\psi_L}{dt}\right|_\alpha i_{L\alpha} + \left.\frac{d\psi_L}{dt}\right|_\beta i_{L\beta} + \omega(\psi_{L\alpha} i_{L\beta} - \psi_{L\beta} i_{L\alpha}\right\}$$

and

$$q = \left\{-\left.\frac{d\psi_L}{dt}\right|_\alpha i_{L\beta} + \left.\frac{d\psi_L}{dt}\right|_\beta i_{L\alpha} + \omega(\psi_{L\alpha} i_{L\alpha} + \psi_{L\beta} i_{L\beta}\right\}$$

For sinusoidal and balanced line voltage the derivatives of the flux amplitudes arezero. The instantaneous active and reactive powers can be computed as

$$p = \omega.(\psi_{L\alpha} i_{L\beta} - \psi_{L\beta} i_{L\alpha})$$
$$q = \omega.(\psi_{L\alpha} i_{L\alpha} + \psi_{L\beta} i_{L\beta})$$

III.BLOCK DIAGRAM

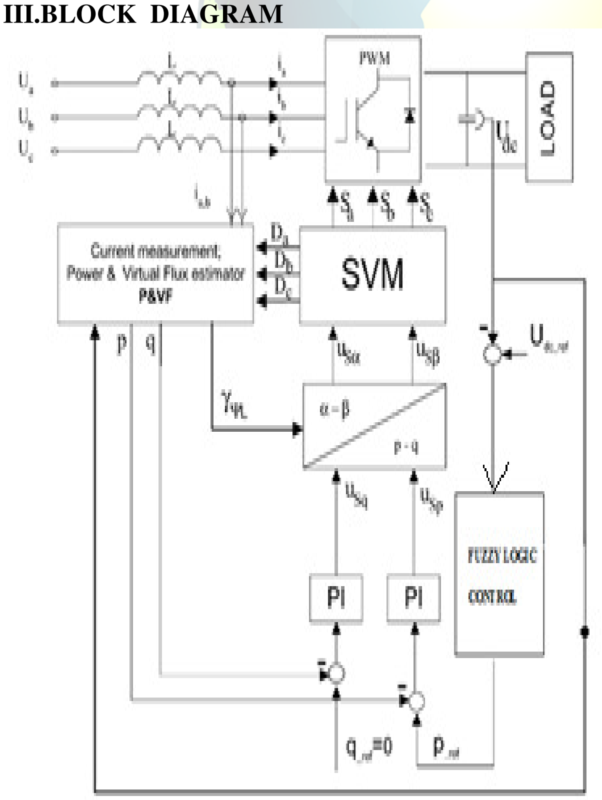

Fig.4. Block scheme of DPC using space vector modulation and fuzzy logic

IV FUZZY LOGIC CONTROL

Figure(5) shows the fuzzy logic control scheme of three phase PWM rectifiers. The dc bus voltage u_{dc} is compared with the reference valueu_{dc}^*. The obtained error $e(k) = u_{dc}^*(k) - u_{dc}(k)$ an its incremental variation $\Delta e(k) = e(k) - e(k-1)$ at the k^{th} sampling instant are used as inputs for fuzzy logic controllers.The output is the instantaneous active power p^*. The c bus voltage is controlle by controlling the active power using fuzzy controller. The main characteristics of fuzzy controllers are the following.

-Seven fuzzy sets for each set of two inputs
-Seven fuzzy sets for the output.
-Triangular membership function.
-Fuzzification using continuous universe of discourse.
-Implication using mamdani's min operator.
-Defuzzificationusiong height method.

According to the input fuzzy variables,the fuzzy logic controller determines the appropriate control output based bon the fuzzy variables.

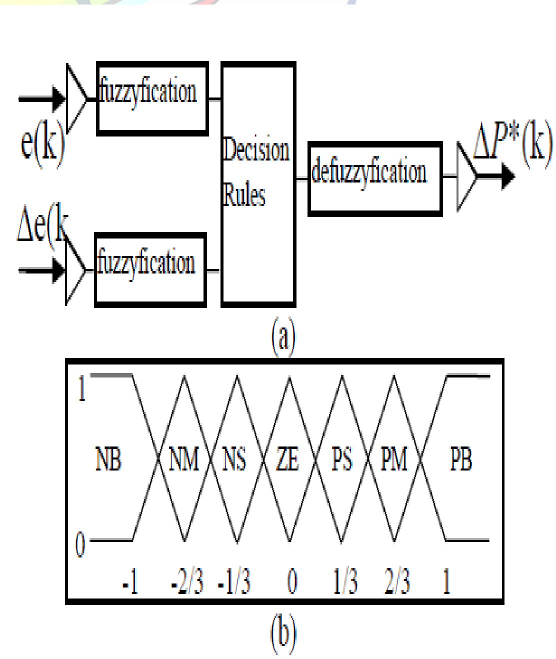

Fig5:a)Fuzzy control block b)Unitary discussion universe

The fuzzy rules used in this proposed scheme are shown in table I

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		e(k)						
		NB	NM	NS	ZE	PS	PM	PB
	NB	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NB	NB	NM	NS	ZE	PS
	NS	NB	NB	NM	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
Δe(k)	PS	NM	NS	ZE	PS	PM	PB	PB
	PM	NS	ZE	PS	PM	PB	PB	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

Table I Fuzzy Rules

The concept of DPC and VF can also be applied to new control scheme. The DPC-SVM with constant switching frequency uses closed-loop power control, as shown in Fig. 4. The commanded reactive power q_{ref}(set to zero for unity power factor operation) and fuzzy logic controller output is p_{ref}. These p_{ref} and q_{ref} values are compared with the estimated q and p values respectively. The errors are delivered to PI controllers, where the variables are dc quantities, which eliminates steady-state error. The output signals from the PI controllers after transformation described as

$$\begin{bmatrix} u_{s\alpha} \\ u_{s\beta} \end{bmatrix} = \begin{bmatrix} -sin\Upsilon_{\psi L} & -cos\Upsilon_{\psi L} \\ cos\Upsilon_{\psi L} & -sin\Upsilon_{\psi L} \end{bmatrix} \begin{bmatrix} u_{sp} \\ u_{sq} \end{bmatrix}$$

where

$$sin\Upsilon_{\psi L} = \frac{\psi_{L\beta}}{\sqrt{\psi_{L\alpha}^2 + \psi_{L\beta}^2}}$$

$$cos\Upsilon_{\psi L} = \frac{\psi_{L\alpha}}{\sqrt{\psi_{L\alpha}^2 + \psi_{L\beta}^2}}$$

are used for switching signals generation by the space-vector modulator (SVM).

IV. SIMULATION RESULTS

To study the operation of the DPC-SVM system under different line conditions, the PWM rectifier with the whole control
scheme has been simulated using SABER software. The simulation study has been performed with two main objectives in mind:

• explaining and presenting the steady-state operation of
the proposed DPC-SVM with a purely sinusoidal and distorted supply line voltage.

• presenting the dynamic performance of DPC.

The simulated waveforms for the proposed DPC-SVM are shown in fig.(7&8). These results were obtained for purely sinusoidal supply line voltage. Similarly, Fig. 7 shows the reactive power as zero.

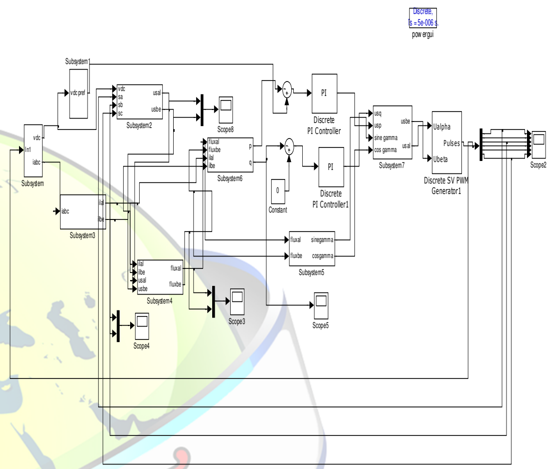

Fig. 6.Simulink model of proposed DPC-SVM.

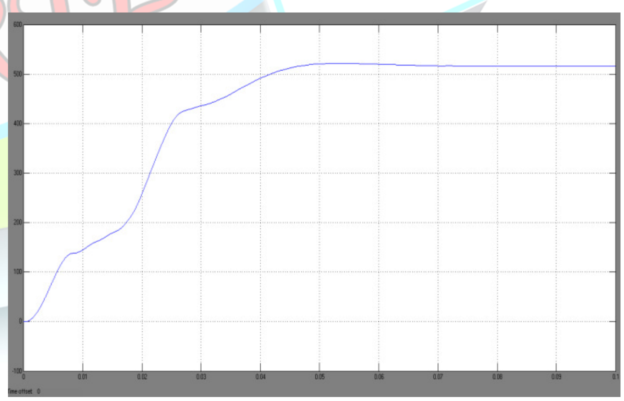

Fig.7output voltage waveform

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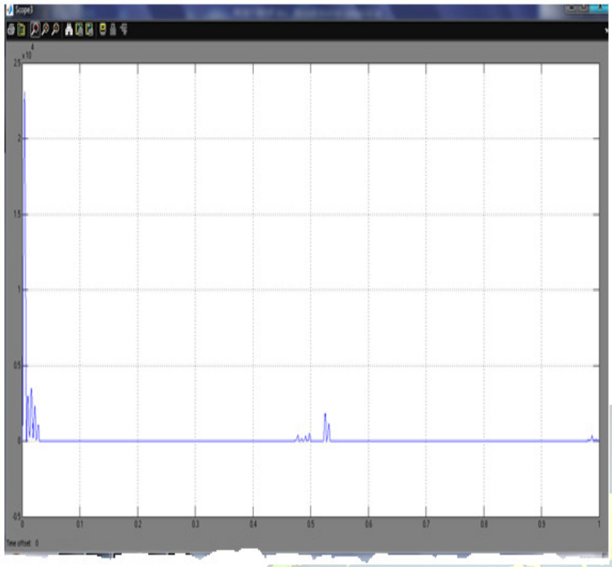

Fig.8 reactive power

V CONCLUSION

In this project, virtual flux based direct power control of three phase PWM rectifier is presented. In this direct power control the control technique was done using instantaneous active and reactive powers. The instantaneous active and reactive powers are estimate using the virtual flux. The simulation was one using MATLAB/SIMULINK. The results showed that without using voltage estimators also the power can be controlled. Space vector modulation technique was used to generate pulses.

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