Journal of Engineering Science and Technology
Special Issue on SU18, February (2019) 13 - 21
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A DIRECT POWER CONTROL FOR THREE-PHASE AC-DC CONVERTER

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Abstract

This paper presents the application of the Direct Power Control (DPC) in developing a regulated voltage DC power supply utilizing three-phase AC to DC converter. Power electronic converters are widely used in the high voltage direct current (HVDC) transmission system. However, the major drawback of using power switches like diode and thyristor is the input currents are non-sinusoidal due to the present of prominent low order harmonic current components. One of the effective control strategies for the AC to DC converter is DPC. The main idea of this method is the direct control of active and reactive power. The optimum switching state for the converter is determined from a switching table which is developed by using the Matlab function. The steady state and dynamic performances of AC to DC converter are analysed before and after the implementation of the DPC method where the three-phase input currents and voltages are measured before going through the Clarke transformation. The current and voltage produced in αβ-frame are used to estimate the input instantaneous active and reactive power. The active and reactive power errors including the sector position are fed into the switching table algorithm. It can be concluded that after using DPC method, the converter's three-phase inputs current are almost sinusoidal thus the current total harmonic distortion can be reduced to less than 5%. The operation is maintained at unity power factor by supplying zero reference reactive power to the DPC.

Keywords: AC-DC converter, Direct power control, Rectifiers, Space vector, THD.

1. Introduction

High Voltage DC Transmission (HVDC) is used to transmit massive electricity in the form of dc over long distance overhead transmission lines or submarine cables. HVDC is preferred over the conventional High Voltage AC Transmission (HVAC) for very long distance when considering the cost, power losses and many other factors. One of the main components in HVDC is AC to DC (ac-dc) converter. Ac-dc converter is commonly used in electrical power system transmission lines where the ac power from the power station has to be converted into the dc before being transferred via the transmission lines. Subsequently, various controls strategies have been proposed for ac-dc converters with the same main goals such as to achieve high power factor operation and almost sinusoidal line current waveforms with low total harmonic distortion.

The control strategies are developed base on the control methods used in electric motor drive applications. Voltage Oriented Control (VOC) and Direct Power Control (DPC) which imitate the principle operation of FOC and DTC respectively have been proposed by several researchers to operate the PWM ac-dc converters [1-2] VOC guarantees high dynamic and static performance via internal current loop and is constantly being developed and improved. Consequently, the final configuration and performance of the VOC system are largely depending on the quality of the applied current control strategy [3]. The successful operation of DPC is highly dependent on the effectiveness of the active and reactive power control loops performing their task. In DPC, there are no internal current control loop and PWM modulator block. The suitable converter switching states are selected by a switching look-up table based on the instantaneous power error between the commanded and estimated values of active and reactive power [4-8].

Therefore, the key point for implementing a successful DPC system is a correct and fast estimation of the active and reactive line-power. The topology of three-phase bidirectional ac-dc voltage source converter is shown in Fig. 1. The converter is connected by three-phase ac supply and for each phase the series branch of inductor L and internal resistance R has been connected after the source in order to represents the internal impedance. Later, the six IGBTs which are parallel with free-wheeling diodes are involved in rectifying the input voltages. Finally, the capacitor is connected in parallel to smoothen the output of DC voltage.

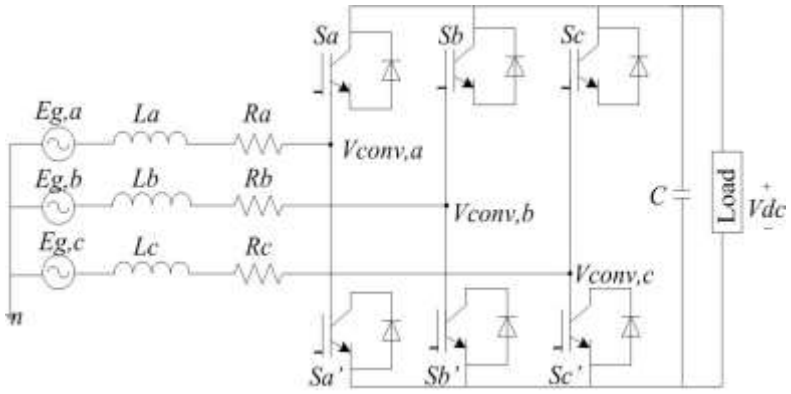

Fig. 1. Three-phase PWM rectifier system for bidirectional power flow.

2. Development for conventional of direct power control (DPC)

The structure of direct power control implemented in three phase ac-dc converter is illustrated in Fig. 2. A total of four voltage sensors are used to measure the three-phase ac input voltage and dc output voltage while three current sensors are used to measured the three-phase input currents. Then, the currents and voltages are fed into two "abc-αβ" blocks which utilise the Clarke Transformation. The subsystem 1 and subsystem 2 from the figure have represented the Clarke transformation for both three-phase input voltage and current. The block diagrams are constructed based on the formula of Clarke Transformation: Where the three-phase input components are represented by〖 x〗_a, x_b and x_c while x_α and x_β are indicated for two-phase components. The equations can be rewritten as shown in equation (1) in order to obtain Vα and Vβ. Next, the output after the transformation which in α-β frame is then fed into another block to obtain the estimated instantaneous active power, P, and reactive power, Q as indicate in equation (2) and (3). Then, P and Q are fed into the hysteresis comparator to obtain active and reactive power errors which is given by dP and dQ respectively. Following, the angle of input voltage in α-β frame, θn, is determined by the voltage vector angle converter block. The inputs to the switching table are θn, dP and dQ. At that point, the suitable switching states of the converter will be generated by the switching table and the output voltage is kept close to the reference dc voltage by tuning the PI controller appropriately.

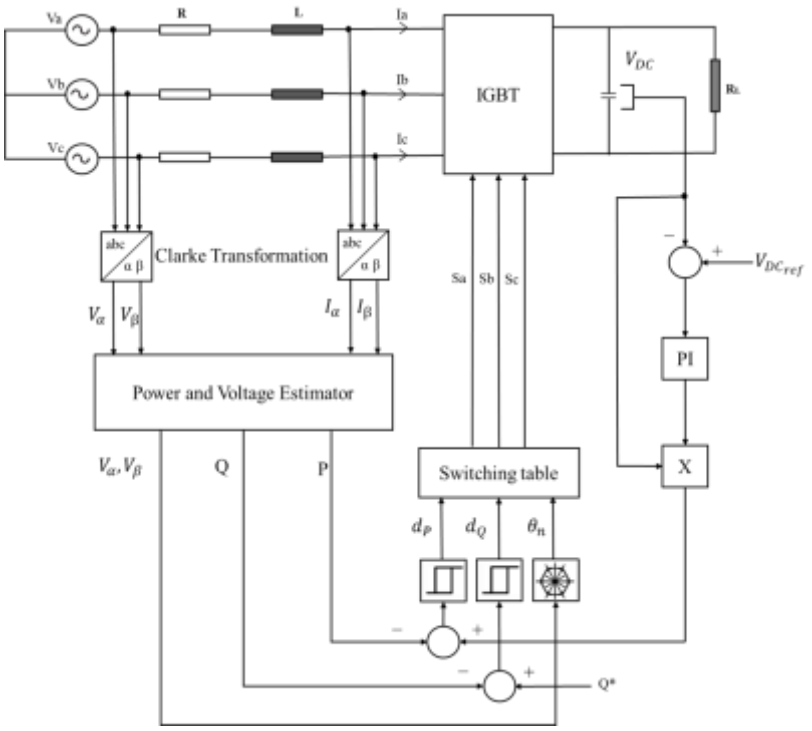

Fig. 2. Control structure of direct power control.

$$\begin{bmatrix} x_\alpha \\ x_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \tag{1}$$

$$P_{inst} = \frac{3}{2}\left[V_\alpha I_\alpha + V_\beta I_\beta\right] \tag{2}$$

$$Q_{inst} = \frac{3}{2}\left[V_\beta I_\alpha - V_\alpha I_\beta\right] \tag{3}$$

Afterward, the switching table plays an important role in the direct power control system. The input to the switching table is the instantaneous error of the active power, reactive power, and the voltage vector position. This kind of switching table is enabling for the ac-dc converter to select their switching states. Therefore, in Fig. 3 has shown the location for each sector in direct power control method (DPC). The sector selection for DPC is in αβ-plane and has been divided into twelve sectors with the angle is in the range of 0° to 30° rotates in anticlockwise [3]. Then, the instantaneous power error (d_P and d_Q) and voltage vector position (θ_n) are the inputs to the newly developed look-up table as shown in Table 1 which determines the voltage vector of the converter (V_n) while the main parameter used in the simulation is tabulated in Table 2.

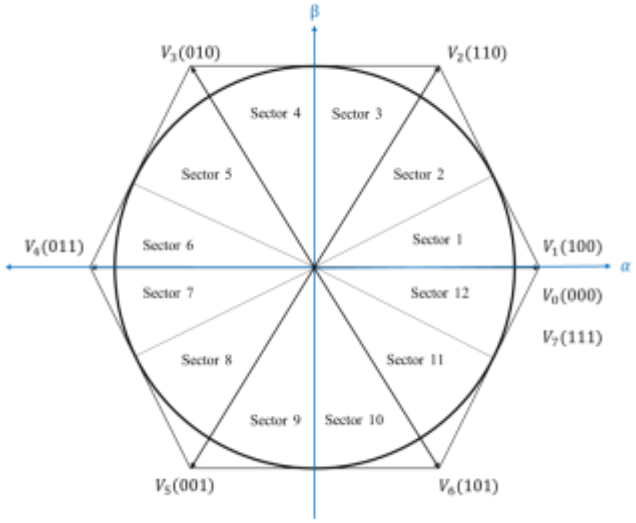

Fig. 3. Sector selection for direct power control.

Table 1. Switching look-up table for direct power control

Power error status		**Sector position (θ_n) and converter voltage vector (V_n)**											
d_P	d_Q	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}
0	0	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6
0	1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1
1	0	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5
1	1	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1	V_2	V_2

Table 2. Electrical parameters of power circuit.

Parameters	**Value**
Input phase voltage (peak), E_g	70.71 V
Source Voltage frequency, f	50 Hz
Dc-link volatage reference, $V_{dc,ref}$	150 V
Resistance of reactors, R	0.2 Ω
Inductance of reactors, L	18 mH
Dc-link capacitor, C	10.8 mF
Load Resistance, R_L	140 Ω
Sampling time, f_s	20 µs

3. Result and Discussion

An open loop rectifier as shown in Fig. 1 is constructed and simulated by using the Matlab Simulink. From the simulation, the initial result has shown the input of voltage and current waveforms in abc frame for diode rectifier. Therefore, in Fig. 4 shows the waveform for input voltage for each phase with 70.71 volts peak-to-peak.

Then, in Figure 5 shows the significant result for the input current in every phase by diode rectifier. However, it is apparent to see that the input current for the diode rectifier produced is non-sinusoidal waveforms due to the harmonics that are present in the IGBT. This circuit operates as diode rectifier during this condition.

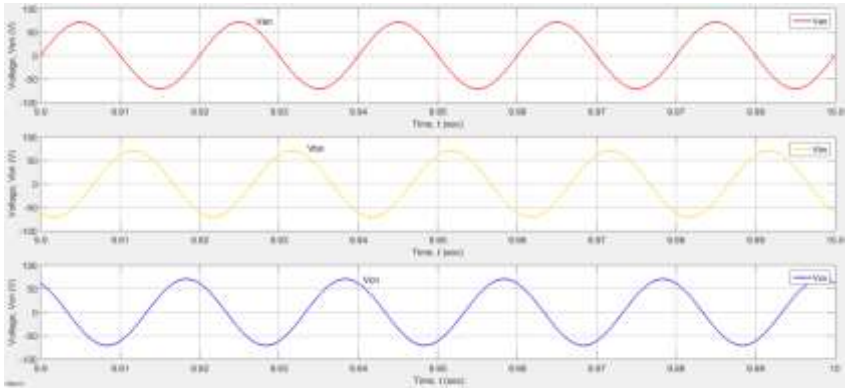

Fig. 4. Waveform for input voltages in abc frame for the diode rectifier.

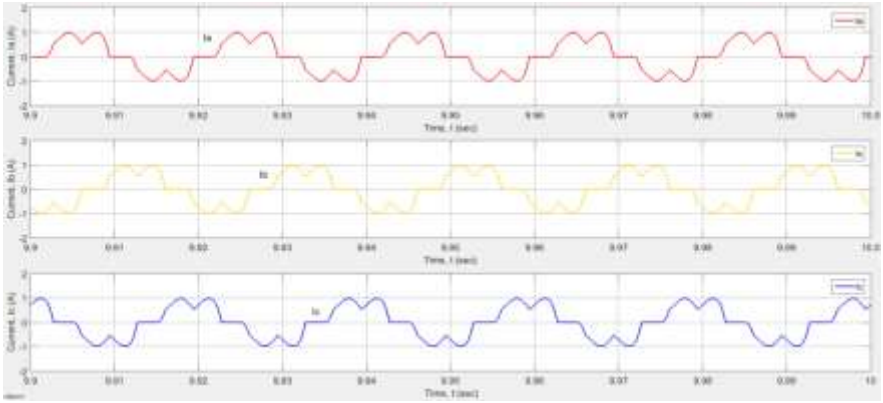

Fig. 1. The input currents in abc frame for the diode rectifier.

In the next analysis is shows the simulation of the three-phase input voltage of ac to dc converter using the proposed direct power control (DPC). However, there is no significant difference between before the implementation of the DPC method where it can be observed the input voltage remained unchanged. These results were obtained for purely sinusoidal supply line voltage.

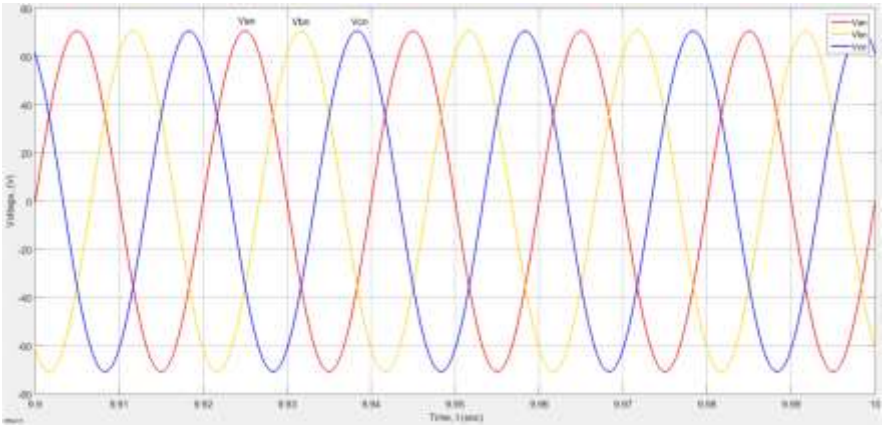

Fig. 6. The input voltages after DPC method

Meanwhile, in Fig. 7 has represented balanced three-phase line current waveforms. The implementation of the DPC scheme is able to produce almost sinusoidal line currents with a unity power factor (pf) thus leading to the lower sampling frequency. Therefore, this achievement provides for the following features and advantages such as controllable power factor and dc-link voltage, regeneration capability and excellent steady-state and dynamic performances.

Therefore by maintaining this quality of input supply for voltage and current, the converter can be controlled properly in order to achieve proper power flow regulation in the power conversion system.

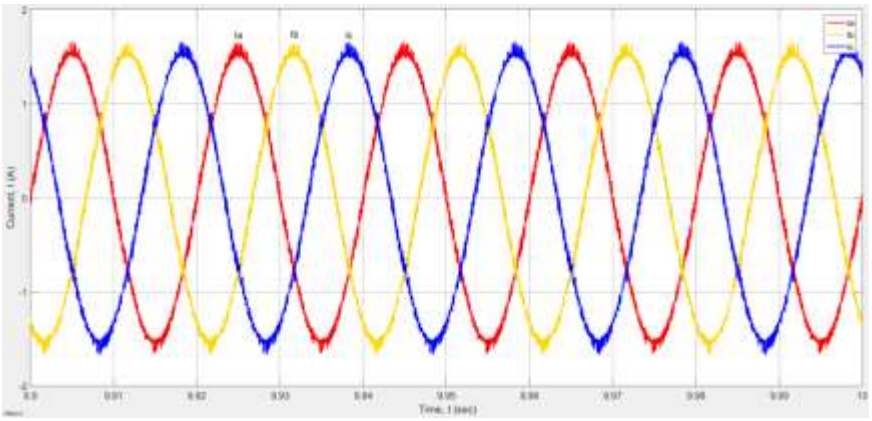

Fig. 7. The input currents after DPC method.

The result shows for the line current waveform is not being perfectly sinusoidal, thus some amount of harmonic distortion will be present consequently provided for the higher of total harmonic distortion (THD) due to the power ripple in the system. Therefore, the THD of the line current during the operation of the three-phase diode rectifier is 30.54 % as shown in Fig. 6 respectively.

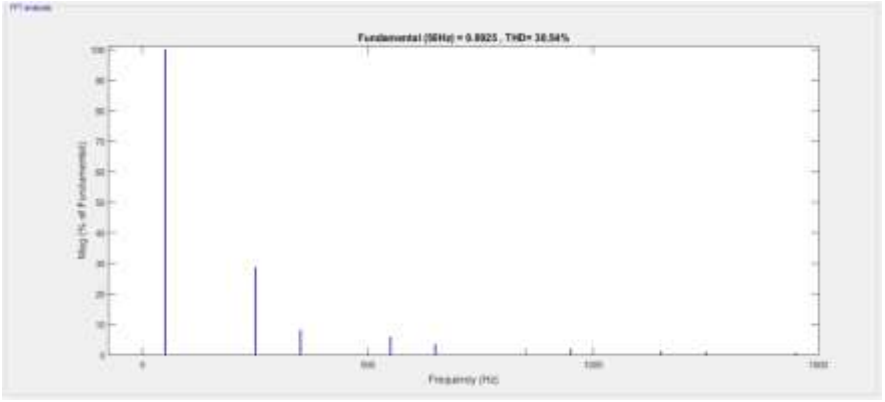

Fig. 8. Harmonic spectrum of the line current for three-phase diode rectifier.

However, International technical organizations and government agencies have introduced standard and regulation such as IEEE 519 and IEC 61000 in order to maintain the quality of input voltage and current at accepted levels. Therefore, the insight of the line current performance during steady state and unity pf operation is given in Fig. 9 respectively. The total harmonic distortion (THD) of the line current is at 3.97% which fulfills the standard requirement of less than 5%.

Note that, the harmonic frequency spectrum of line current as shown in that figure generates variable switching frequency with the current harmonics spread over a wide range frequency [1].

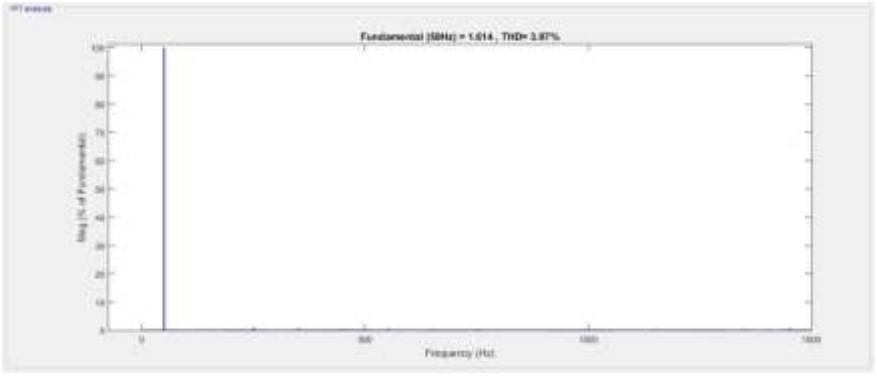

Fig. 9. Harmonic spectrum of the line current after using DPC method.

Lastly, Fig. 10 shows the output voltage, which is the dc line current. It can be seen that there is an increment in rising time and settling time before the output voltage reaches the steady state. This is due to the tuning of PI controller, which involves increasing value of *Kp* and *Ki*.

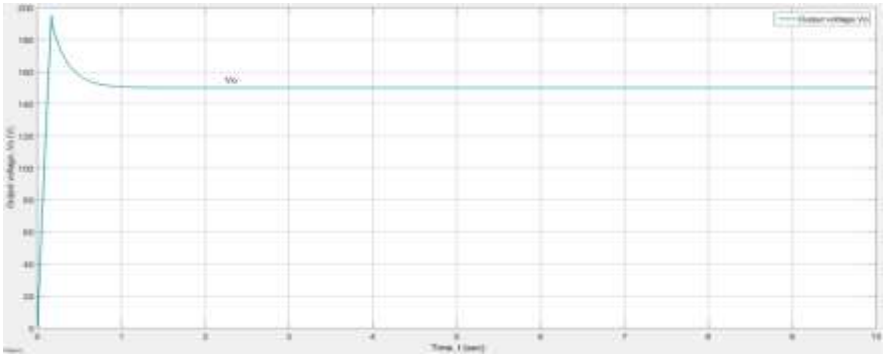

Fig. 10. The output voltage, Vo after DPC method.

4. Conclusion

The presented Direct Power Control (DPC) system constitutes a viable alternative to the pulse width modulated three-phase ac-dc voltage source converter. In the DPC method, the instantaneous active and reactive powers calculation has been used as the controlled output. The appropriate selecting for the switching states from a switching table based on the errors, which are limited by a hysteresis band are successfully simulated and presented in this paper. It has been successfully simulated in the Matlab/Simulink method. The simulation results show that the implementation of DPC is able to produce three-phase input in the line current with low total harmonic distortion factor and satisfy the unity power factor operation. Hence it can be stated that this control method is capable to improve the quality of input current of the three-phase PWM rectifiers.

Acknowledgements

The author would like to thank toward Zamalah Scheme from Universiti Teknikal Malaysia Melaka (UTeM) as providing for the continuous financial support that

enabled for the achievement of this research result and also thank Ministry of Education (KPM) for sponsoring this research work under a grant (FRGS/1/2016/TK04/UTEM/02/11/F00307).

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