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단위 역률을 갖는 대용량 하이브리드 멀티레벨 PWM 정류기

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High Power Hybrid Multilevel PWM Rectifier with Unity Power Factor

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Abstract - This paper presents a high power hybrid multilevel PWM rectifier with unity power factor. The features and advantages of the proposed PWM rectifier can be summarized as follows: 1) It realizes the high power high voltage AC/DC power conversion, 2) It uses no transformer which is bulky and heavy, 3) It has hybrid structure so that switching devices can be effectively utilized, 4) It produces high quality AC current even in high power high voltage applications, 5) The input power factor remains unity by simple modulation index control. The multilevel rectifier is analyzed by using the circuit DQ transformation whereby the characteristics and control equations are obtained.

1. Introduction

The three phase PWM rectifier has been widely studied and used as an excellent AC/DC power converter. The PWM rectifier has superior advantages over phase controlled rectifier(PCR) such as sinusoidal input current, adjustable power factor, better DC output voltage etc. In high voltage and high power application, however, such features of the PWM rectifier may be deteriorated because of lack of high frequency switching devices endurable to high voltage and/or high power.

Nowadays, one of the practical solutions to cope with high voltage and/or high power application is to employ so called multilevel PWM converter. Up to date, three major types of multilevel structure have been reported: diode-clamped type, flying-capacitor type, cascade type. Considering the multilevel converters as a rectifier, 1) the diode-clamped type has drawback of DC voltage unbalancing problem, 2) the flying-capacitor type needs large number of capacitors and the complicated control, 3) the cascade type has simple modular structure of proven technology but it is supposed to have separate DC sources, and thus isolation transformers, to synthesize multilevel output[1-3]

This paper proposes a new high power hybrid multilevel PWM rectifier without bulky and heavy transformers. It will be seen that the DC voltages required to make multilevel output may be built up from AC utility source while the input power factor remains unity. Moreover, the proposed rectifier has hybrid structure. So, for example, GTO, i.e., high power low speed switch, is involved in high power low frequency module and IGBT, i.e., low power high speed switch, in low power high frequency module. This paper reveals the advantages and characteristics of the rectifier.

2. Hybrid Multilevel PWM Rectifier

2.1 System Description

Fig. 1 shows the proposed hybrid multilevel PWM rectifier. The rectifier consists of three full bridge(FB) inverters using IGBT switches and a three phase(TP) inverter composed of GTO devices. The FB inverters operated at high switching frequency may have lower power rating than that of the TP inverter operated at lower switching frequency and this hybrid structure enables the switching devices to be fully utilized with synergism.

Assuming symmetry operation, there are four effective control variables: modulation index(m_1) and control angle(α_1) for FB inverters and modulation index(m_2) and control angle(α_2) for TP inverter, where α_1, α_2 are with respect of the angle of utility source voltage.

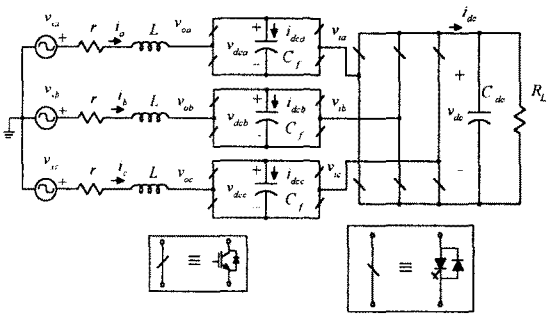

Fig. 1. Hybrid multilevel PWM rectifier.

2.2 Operating Principle

Fig. 2 represents operating principle with per-phase fundamental equivalent circuit and

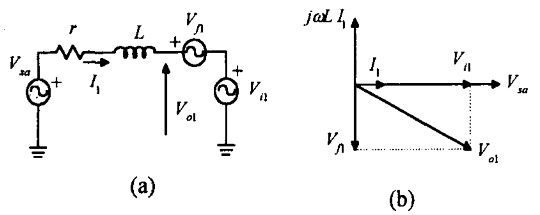

Fig. 2. (a) per-phase fundamental equivalent circuit, (b) phasor diagram.

the corresponding' phasor diagram where V_{sa}, V_{f1}, V_{i1} and I_1 denote utility voltage, FB inverter AC side voltage, TP inverter output voltage and phase current, respectively.

It should be noted that, as seen in Fig. 2(b), α_1 and α_2 are controlled in such a manner that $\alpha_2=0$ and $\alpha_2-\alpha_1=90^\circ$ and it is possible to make I_1 being in phase with V_{i1} and V_{sa} by adjusting the magnitudes of V_{f1} and V_{i1}, in turn, m_1 and m_2 respectively.

Also, the phasor diagram indicates that not only dose FB inverter absorb no active power but also compensate the reactive power required by linked reactor L. Therefore, the utility source may supply only both the active power drawn by resistor r representing loss term and the active power required by TP inverter. As a result, the rectifier remains unity input power factor.

3. Control Scheme

To figure out the characteristics and set up the control law, the hybrid multilevel PWM rectifier is analyzed using the circuit DQ transformation· technique[5] under the operating condition of $\alpha_2=0$ and $\alpha_1=-90^\circ$.

By circuit DQ transformation, all the rotating variables in the rectifier can be mapped into the stationary DQ domain and then the relationship between the transformed variables

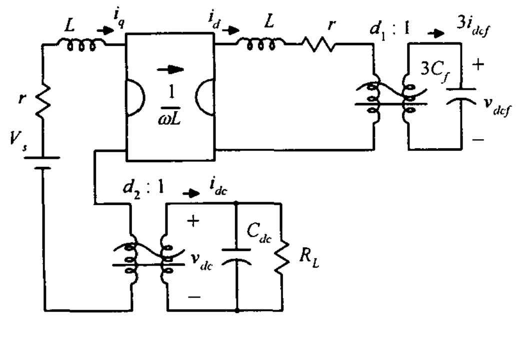

Fig. 3. Circuit DQ transformation of the hybrid multilevel PWM rectifier.

can be illustrated with the equivalent circuit as shown in Fig. 3 where $d_1=\sqrt{3/2}\cdot m_1$, $d_2=\sqrt{3/8}\cdot m_2$ and V_s is rms line-to-line source voltage.

Moreover, according to symmetry operation in FB inverters, the following approximation is assumed;

$$i_{dca} \cong i_{dcb} \cong i_{dcc} \fallingdotseq i_{dcf} \quad (1)$$

$$v_{dca} \cong v_{dcb} \cong v_{dcc} = v_{dcf}. \quad (2)$$

In steady state, the inductors seem to be short and the capacitors open since all the DQ circuit variables imply·DC values denoted by capital letters. Thus, without cumbersome equation manipulations, from Fig. 3, we obtain

$$V_{dc} = V_s \cdot \frac{D_2}{r/R_L + D_2^2} \quad (3)$$

$$V_{scf} = \frac{V_s}{D_1} \cdot \frac{(\omega L)/R_L}{r/R_L + D_2^2} \quad (4)$$

It is found from Eq. (3) that the DC voltage V_{dc} of TP inverter is independent of both D_1 and linked reactor impedance L. Also, from Eq. (3) and (4), we can get the very important condition to balance the DC voltages of V_{dc} and V_{dcf}. It should be noted that V_{dcf} must be half of V_{dc}, i.e., $V_{dcf}=V_{dc}/2$, in order to obtain 5-level output phase voltage at the terminal of the multilevel PWM converter. Therefore, D_1 should be determined by

$$D_1 = \frac{2\omega L}{D_2 R_L} \quad (5)$$

4. Simulation

To confirm the validity of the analysis and control for the hybrid multilevel rectifier, some simulations are carried out. The circuit parameters are as follows: $V_s=1100$ V, $r=0.7$ Ω, ω$L=1.885$ Ω, $C_f=500$ μF, $C_{dc}=1000$ μF, $R_L=20$ Ω. Also, the control parameters are given by $D_2=0.475$, $\alpha_2=0$ and thus $D_1=0.3968$, $\alpha_1=-90^\circ$.

In the course of simulation, simple carrier based sinusoidal PWM is used for each FB and TP inverters.

Fig. 4 shows the open loop control characteristic during build-up of DC voltages where the rectifier goes to some steady state. The results in Fig. 4 show that V_{dcf} becomes half of V_{dc} as expected by analysis and the phase current is in phase with respect to AC source voltage and thus realizing unity power factor.

Fig. 5 shows the harmonic content of phase current. Note that the ripple component of 2nd order harmonic in the DC voltage of FB inverters makes little effect on the phase current because of three phase symmetry operation.

Fig. 6 shows the resultant output AC voltages of FB and TP inverters. Note that the FB inverter is operated at 2160 Hz whereas

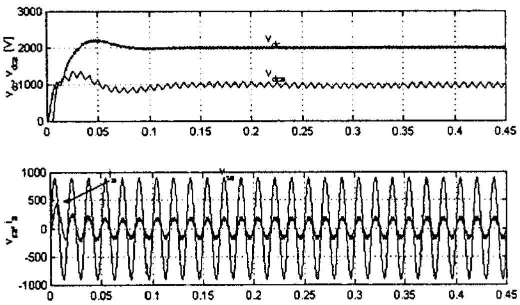

Fig. 4. Build-up of DC capacitor voltages for FB and TP inverters(top), source voltage and phase current(bottum).

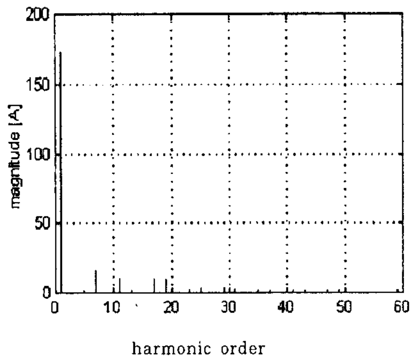

Fig. 5. Harmonic content of a line current.

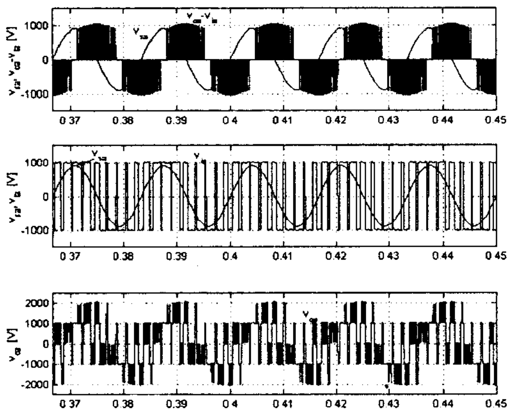

Fig. 6. AC output voltage of a-phase FB inverter(top), output phase voltage of the TP inverter(middle), the resultant output voltage of hybrid multilevel PWM rectifier(bottum).

the TP inverter at 540 Hz. Moreover, the output power of the FB inverter can be found to be 84 kVAr whereas that of the TP inverter is of 200 kW. So, the hybrid multilevel PWM rectifier realizes the benefit of hybrid structure. Actually, the FB inverters take charge of supplying the only reactive power and the TP inverter absorbs the only active power.

3. Conclusion

This paper presents a transformerless hybrid multilevel PWM rectifier. The features and advantages of the proposed PWM rectifier can be summarized as follows: 1) It realizes the high power and high voltage AC/DC power conversion owing to multilevel structure, 2) It uses no transformer which is bulky, heavy and even expensive, 3) It has hybrid structure so that semiconductor devices can be effectively utilized, 4) It producse high quality AC current even in high power and high voltage applications, 5) The input power factor remains unity by simple modulation index control.

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