Reactive Power Control Strategy Based on DC Capacitor Voltage Control for Active Load Balancer in Three-Phase Four-Wire Distribution Systems

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This paper proposes a reactive power control strategy for the active load balancer (ALB) in three-phase four-wire distribution systems. The proposed reactive power control strategy is based on constant DC capacitor voltage control only, which is always used in active power line conditioners. Therefore, the proposed approach does not require active and reactive calculation blocks of load currents for the reference source current calculation. The power factor of the source side currents can be adjusted under the balanced load condition using the proposed reactive power control strategy. The basic principle of the reactive power control strategy for the ALB is discussed in detail and verified via digital computer simulation using power electronic simulation (PSIM) software. A prototype experimental model is constructed and tested to demonstrate the validity and high practicability of the proposed control strategy. Simulation and experimental results indicate that balanced source currents with a predefined power factor are achieved when the proposed control strategy is applied to the three-phase four-wire distribution systems.

Keywords: active load balancer, DC capacitor voltage control, reactive power control, power factor adjustment, three-phase four-wire distribution system

1. Introduction

A wide variety of distribution systems are used worldwide for residential and commercial power supplies. Among them, three-phase four-wire wye-connected distribution systems are widely used in South Korea, Myanmar, and other countries. These distribution systems can feed three-phase and single-phase power simultaneously, as shown in Fig. 1. However, single-phase loads on a three-phase feeder result in unbalanced load conditions in the distribution systems. The unbalanced load currents result in unbalanced voltages, and affect other loads connected at the same point of common coupling (PCC). These unbalanced load conditions also cause excessive neutral current, resulting in overheating transformers, power losses, and lower system efficiencies. Therefore, load balancing is necessary in three-phase four-wire distribution systems to improve the power quality and efficiency of the distribution system.

To solve these power quality problems, several control algorithms have been proposed for active power line conditioners in three-phase four-wire distribution systems (1)–(6). Some control algorithms base their reference current calculations on instantaneous active-reactive power theory (1)–(4). The abc/dq transformation of the load currents and the decomposition of load currents by the symmetrical positive-sequence component method are also used as an alternative control algorithm (5) (6). These reference current calculation methods all require a significant number of computation steps because the active load current is derived from abc/αβ or abc/dq transformation blocks. To reduce the number of computation steps, we have proposed a simple control algorithm for the active load balancer (ALB) based on constant DC capacitor voltage control, which considerably reduced the number of active and reactive calculations of the load currents (7). However,
the proposed simple method achieved unity power factor of source-side currents under balanced load condition. Therefore, a high power rating of the ALB was required to fully compensate for the reactive power of the load currents. This power rating of the ALB must be reduced for practical applications.

In this paper, we propose a reactive power control strategy based on constant DC capacitor voltage control to reduce the power rating of the ALB. This control strategy achieved balanced source currents with a power factor of 0.9, within a limit acceptable in Japanese power distribution systems \(a\), without any calculation blocks of the unbalanced active and reactive components in the load currents. The basic principle of the reactive power control strategy based on constant DC capacitor voltage control for the ALB is discussed in detail, and then confirmed with a digital computer simulation using PSIM software. A prototype experimental model is constructed and tested to validate the feasibility of the proposed control strategy. The simulation and experimental results demonstrate that the proposed reactive power control strategy is well suited for the ALB in three-phase four-wire distribution systems.

2. Reactive Power Control Strategy Based on DC Capacitor Voltage Control for the ALB

2.1 Power Circuit Configuration Figure 2 shows a power circuit diagram of the proposed active load balancer (ALB) in a three-phase four-wire distribution systems, represented by the three-phase four-wire distribution transformer and the three unbalanced single-phase loads. The ALB, constructed of a four-leg power-switching devices with a single DC capacitor, is connected in parallel to three single-phase loads. Three legs of the ALB are each connected to a phase of the distribution transformer, and the fourth leg is connected to the neutral line. The ALB compensates for the unbalanced active and reactive currents drawn by the three single-phase loads by providing balanced source currents using a pre-defined power factor.

2.2 Conventional Control Strategy for the ALB Figure 3 shows the reference source current calculation method used in the conventional control strategy \(a\), \(i_{aL}\), \(i_{bL}\) and \(i_{cL}\) are the three load currents, and \(v_{Ta}, v_{Tb}\) and \(v_{Tc}\) are the three terminal voltages of the distribution systems. \(i_{a0}, i_{b0}\) and \(i_{c0}\) are the reference source currents of the ALB. These reference source currents are calculated using instantaneous active power theory \(a\). The instantaneous reactive power theory can decompose three load currents into \(\alpha\beta\) load components as

\[
\begin{align*}
i_{aL} &= \frac{v_a - v_c}{v_a + v_c} \bar{p} + \frac{v_a - v_b}{v_a + v_b} \bar{q} + \frac{v_b - v_c}{v_b + v_c} \bar{q}, \quad \cdots \cdots (1) \\
i_{bL} &= \frac{v_b - v_a}{v_a + v_b} \bar{p} + \frac{v_b - v_c}{v_b + v_c} \bar{q} + \frac{v_a - v_c}{v_a + v_c} \bar{q}, \quad \cdots \cdots (2) \\
i_{cL} &= \frac{v_c - v_a}{v_a + v_c} \bar{p} + \frac{v_c - v_b}{v_b + v_c} \bar{q} + \frac{v_b - v_a}{v_b + v_a} \bar{q}, \quad \cdots \cdots (3)
\end{align*}
\]

where \(\bar{p}\) and \(\bar{q}\) are the dc and ac component of the instantaneous real power and \(\bar{q}\) and \(\bar{q}\) are the dc and ac component of the instantaneous imaginary power on \(\alpha\beta\) axis. \(p\) and \(q\) are expressed as

\[
\begin{bmatrix}
p \\
q
\end{bmatrix} = \begin{bmatrix}
v_a & v_b \\ -v_b & v_a
\end{bmatrix} \begin{bmatrix}
i_{aL} \\
i_{bL}
\end{bmatrix}, \quad \cdots \cdots \cdots (3)
\]
of the active components on the load current $I_P$. Using this effective value of the load current, the reference source currents $i_{sa}, i_{sb}$, and $i_{sc}$ are generated by the proposed reactive power control strategy. Therefore, the calculations of the active and reactive components of load currents are not necessary in the proposed method.

The basic principle of the reference source currents calculation algorithm using constant DC capacitor voltage control is discussed. The three-phase terminal voltages $v_{Ta}$, $v_{Tb}$, and $v_{Tc}$ in Fig. 2 are given by

$$v_{Ta} = \sqrt{2}V_T\cos(\omega t),$$
$$v_{Tb} = \sqrt{2}V_T\cos\left(\omega t - \frac{2\pi}{3}\right),$$
$$v_{Tc} = \sqrt{2}V_T\cos\left(\omega t - \frac{4\pi}{3}\right). \quad \cdots \cdots \cdots (4)$$

The unbalanced single-phase load currents $i_{La}$, $i_{Lb}$, and $i_{Lc}$ in Fig. 2 are expressed as

$$i_{La} = \sqrt{2}I_a\cos(\omega t - \phi_a),$$
$$i_{Lb} = \sqrt{2}I_b\cos\left(\omega t - \frac{2\pi}{3} - \phi_b\right),$$
$$i_{Lc} = \sqrt{2}I_c\cos\left(\omega t - \frac{4\pi}{3} - \phi_c\right). \quad \cdots \cdots \cdots (5)$$

Let us assume that the three-phase source currents $i_{Sa}$, $i_{Sb}$, and $i_{Sc}$ are balanced with a power factor of $\cos \theta$ after compensating the unbalanced active components with reactive power control. The three-phase source currents can then be expressed as

$$i_{Sa} = \sqrt{2}I_s\cos(\omega t - \theta),$$
$$i_{Sb} = \sqrt{2}I_s\cos\left(\omega t - \frac{2\pi}{3} - \theta\right),$$
$$i_{Sc} = \sqrt{2}I_s\cos\left(\omega t - \frac{4\pi}{3} - \theta\right). \quad \cdots \cdots \cdots (6)$$

where $I_s = (I_a\cos \phi_a + I_b\cos \phi_b + I_c\cos \phi_c)/(3 \cos \theta) = I_p/\cos \theta$ as shown in Fig. 5. $I_s$ is the theoretical rms value of the balanced source current with a power factor of $\cos \theta$ for each phase.

From (5) and (6), the compensation currents of the ALB are calculated as

$$i_{Ca} = i_{La} - i_{Sa} = (I_a\cos \phi_a - I_p) \sqrt{2}\cos(\omega t) + (I_a\sin \phi_a - K I_p) \sqrt{2}\sin(\omega t),$$
$$i_{Cb} = i_{Lb} - i_{Sb}$$

$$i_{Cc} = i_{Lc} - i_{Sc}.$$

$$= (I_c\cos \phi_c - I_p) \sqrt{2}\cos\left(\omega t - \frac{2\pi}{3}\right) + (I_c\sin \phi_c - K I_p) \sqrt{2}\sin\left(\omega t - \frac{2\pi}{3}\right),$$

$$i_{Cc} = i_{Lc} - i_{Sc}.$$

$$= (I_c\cos \phi_c - I_p) \sqrt{2}\cos\left(\omega t - \frac{4\pi}{3}\right) + (I_c\sin \phi_c - K I_p) \sqrt{2}\sin\left(\omega t - \frac{4\pi}{3}\right), \cdots \cdots \cdots (7)$$

where $K = \tan(\cos^{-1}(pf))$, adjusting the amounts of reactive components in the compensation currents, with $pf =$ source-side power factor.

The instantaneous power $p_C$ flowing to the ALB can be calculated by

$$p_C = v_{Ta} \cdot i_{Ca} + v_{Tb} \cdot i_{Cb} + v_{Tc} \cdot i_{Cc} = \left(2I_a\cos \phi_a - I_c\cos \phi_c + \sqrt{3}I_b\sin \phi_b\right) - \sqrt{3}I_c\sin(\omega t)\sqrt{2}\cos(2\omega t) + \left(2I_b\sin \phi_b - I_a\sin \phi_a - I_b\cos \phi_b - \sqrt{3}I_c\cos \phi_c\right) \frac{1}{2} V_T\sin(2\omega t). \quad \cdots \cdots \cdots (8)$$

The mean value of the instantaneous power $p_C$ in (8) is zero, while the source currents in (6) are balanced with the same phase angle $\theta$. Thus, maintaining a constant DC capacitor voltage in the ALB will result in a balanced condition with a predefined power factor of $\cos \theta$ on the source side. Therefore, the constant DC capacitor voltage control method is ideally suited for a reactive power control strategy of the ALB in three-phase four-wire distribution systems. In practical applications, the instantaneous DC capacitor voltage is not constant because of the $2\omega$ components produced by unbalanced load conditions. Thus, the proposed method controls the constant mean value of the DC capacitor voltage.

The DC capacitor voltage $v_{DC}$ is depicted as shown in Fig. 2. The difference between the detected DC capacitor voltage $v_{DC}$ and the reference DC capacitor voltage $V_{DC}^r$ is then amplified by the proportional-integral-derivative (PID) controller as shown in Fig. 4. The output value of the PID controller becomes the input for a moving-average low-pass filter (LPF), designed to remove the $2\omega$ frequency components. The transfer function of the moving-average LPF is expressed as

$$H(z) = \frac{1}{N} \sum_{n=0}^{N-1} z^{-n} \quad \cdots \cdots \cdots (9)$$

where $N$ is the number of samples. After filtering with the moving-average LPF, the effective value $I_D$ of the source-side active current is obtained by performing constant DC capacitor voltage control. To calculate the reference source currents for the ALB, the a-phase terminal voltage $v_{Ta}$ is detected, and then the electrical angle ($\theta_T = \omega t$) is generated using a single-phase phased-lock loop (PLL). Then, $\sqrt{2} \cos(\omega t)$, $\sqrt{2} \cos(\omega t - \frac{2\pi}{3})$, $\sqrt{2} \cos(\omega t - \frac{4\pi}{3})$, $\sqrt{2} \sin(\omega t)$, $\sqrt{2} \sin(\omega t - \frac{2\pi}{3})$, and $\sqrt{2} \sin(\omega t - \frac{4\pi}{3})$ are calculated using $\theta_T$. 

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*Fig. 5. Phasor diagrams of the proposed reactive power control strategy*
Using the calculated values and the effective value \( I_p \), the reference source currents for each phase are calculated as

\[
\begin{align*}
\tilde{i}_{ca} &= \sqrt{2} I_p \cos(\omega t) + K \sqrt{2} I_p \sin(\omega t), \\
\tilde{i}_{cb} &= \sqrt{2} I_p \cos(\omega t - \frac{2\pi}{3}) + K \sqrt{2} I_p \sin(\omega t - \frac{2\pi}{3}), \\
\tilde{i}_{cc} &= \sqrt{2} I_p \cos(\omega t - \frac{4\pi}{3}) + K \sqrt{2} I_p \sin(\omega t - \frac{4\pi}{3}).
\end{align*}
\]

where \( K = \tan(\cos^{-1}(pf)) \) as shown in Fig. 5. Thus, the source side power factor can be controlled by changing the value of \( K \). The proposed reactive power control strategy uses only DC capacitor voltage control, which is a part of the conventional control strategy in (4), for the reference source currents calculation.

Figure 3 shows the complete control diagram of the proposed reactive power control strategy for the ALB. The compensation reference signals for the ALB are expressed as

\[
\begin{align*}
\tilde{I}_{ca} &= \tilde{i}_{ca} - \tilde{i}_{cb}, \\
\tilde{I}_{cb} &= \tilde{i}_{cb} - \tilde{i}_{cc}, \\
\tilde{I}_{cc} &= \tilde{i}_{cc} - \tilde{i}_{ca}, \\
\tilde{I}_{cn} &= -(\tilde{I}_{ca} + \tilde{I}_{cb} + \tilde{I}_{cc}).
\end{align*}
\]

To avoid the steady-state error, the PI controllers in the dq coordinates are used to generate the compensation currents \( I_{ca}, I_{cb}, I_{cc} \) of the ALB, as shown in Fig. 6 (10). For example, in the a-phase compensation current control, the error signal between the a-phase reference compensation current \( \tilde{i}_{ca}^* \) and the a-phase compensation current \( \tilde{I}_{ca} \) is delayed by \( T_{s}/4 \), where \( T_s \) is one cycle (period) of the a-phase terminal voltage. The error signal corresponds to the \( \alpha \)-component, and the delayed signal through the \( T_{s}/4 \) delay block corresponds to the \( \beta \)-component. Using \( \theta_T \), the electrical angle of the a-phase terminal voltage generated by the PLL, the \( \alpha \)- and \( \beta \)-components are transformed into \( \tilde{i}_{ca} \) and \( \tilde{i}_{qb} \), respectively. \( \tilde{i}_{ca} \) and \( \tilde{i}_{qb} \) are amplified by the PI controller in the dq coordinates. The amplified values are retransformed again into a-phase modulation-wave, \( \hat{v}_{bc} \). This modulation-wave is used for Q1 and Q2 gate signals generation. Finally, using the same control strategy generates gate signals for all power switching devices Q3, Q4, Q5, Q6, Q7, Q8 of the ALB.

### 2.4 Required Power Rating of ALB

The required power rating \( S_C \) of the ALB with four-leg switching devices is discussed. Figure 7 shows the equivalent circuit of the ALB in three-phase four-wire distribution systems. Each leg of the ALB is represented by a current source. From the equivalent circuit, it is seen that the neutral-leg current should be included in the required power rating calculation of the ALB. The power rating \( S_C \) of ALB is given by

\[
S_C = V_T(I_{Ca} + I_{Cb} + I_{Cc} + I_{Cn}). \tag{12}
\]

where \( V_T \) is the rms line-to-neutral voltage and \( I_{Ca}, I_{Cb}, I_{Cc} \) and \( I_{Cn} \) are the rms compensation currents of the ALB. From (7) and (11), the rms compensation currents are given by

\[
\begin{align*}
I_{Ca} &= (I_\alpha \cos \phi_a - I_p)^2 + (I_\alpha \sin \phi_a - K I_p)^2, \\
I_{Cb} &= (I_\beta \cos \phi_b - I_p)^2 + (I_\beta \sin \phi_b - K I_p)^2, \\
I_{Cc} &= (I_\phi \cos \phi_c - I_p)^2 + (I_\phi \sin \phi_c - K I_p)^2, \\
I_{Cn} &= (\frac{-I_\alpha \cos \phi_a + \frac{1}{2} I_\beta \cos \phi_b + \frac{\sqrt{3}}{2} I_\beta \sin \phi_b + \frac{1}{2} I_\phi \cos \phi_c}{2} - \frac{\sqrt{3}}{2} I_\alpha \sin \phi_a + (\frac{1}{2} I_\beta \sin \phi_b + \frac{\sqrt{3}}{2} I_\phi \cos \phi_c) + (\frac{1}{2} I_\beta \sin \phi_b + \frac{\sqrt{3}}{2} I_\phi \cos \phi_c)^2) \frac{1}{2}. \tag{13}
\end{align*}
\]

The first squared terms in (13) represent the compensation currents for the active components and the second squared terms represent the compensation currents for the reactive components. From the second squared terms in (13), the amplitudes of \( I_{Ca}, I_{Cb}, I_{Cc} \) depend on the value of \( K \), the adjustment for the amount of reactive components in reactive compensation currents.

Table 1 shows distribution transformer parameters and load conditions of the simulated and experimental three-phase four-wire distribution systems investigated in this study. For the simulation, the rating of the transformer is three-phase, 380 V, 21.5 kVA, 60 Hz; for the experiment, the transformer rating is three-phase, 200 V, 6 kVA, 60 Hz.

Figure 8 shows the calculated results for the power rating of the ALB with various values of \( K \) and source side power factors using the load conditions in Table 1. The terminal voltage \( V_T \) of the transformer is 115 V in the calculation. The loads were 0.9 pu for a-phase, 0.5 pu for b-phase and 0.2 pu for c-phase in the transformer rated at 6 kVA.
3. Simulation Results

To confirm the validity of the proposed reactive power control strategy for the ALB, a digital computer simulation was implemented using PSIM software. The rating of the distribution transformer was three-phase, 380 V, 21.5 kVA, and 60 Hz as shown in Table 1. A line-to-neutral voltage (the terminal voltage) of 220 V was used to simulate Korea’s three-phase four-wire distribution systems. The base power rating was 7.1 kVA for each single-phase. The a-phase includes two different load conditions to simulate load variation. The unbalanced load percentage is calculated as the ratio of negative-sequence to positive-sequence values in accordance with the International Electrotechnical Commission standard. Table 2 shows the circuit constants in the simulation.

![Fig. 8. Relationship between power rating of the ALB, the value of K and source side power factor](image)

![Fig. 9. Simulation results of the proposed reactive power control strategy with heavy- to light-load variation](image)

in Fig. 2, \(v_{Ta}, v_{Tb}, v_{Tc}\), are the a-phase, b-phase, and c-phase terminal voltages, respectively. The a-phase load current \(i_{La}\) was varied from 0.9 pu to 0.2 pu, while the b-phase and c-phase load currents, \(i_{Lb}\) and \(i_{Lc}\), were held constant. The power factor was set to 0.9 in the control algorithm in accordance with the Japanese guidelines. Before and after the load current variation, the three source currents \(i_{Sa}, i_{Sb}, \) and \(i_{Sc}\) were balanced, as shown in Fig. 9. The power factor \(\cos \theta\) was 0.9 under the heavy-load condition and 0.91 under the light-load condition. A slight difference in the power factor occurred because of the filter capacitor effect of the ALB.

The fourth leg of the ALB generated the compensation current \(i_{Cn}\), closely followed by the load zero-sequence current \(i_{Ln}\). Thus, the source zero sequence current \(i_{Sn}\) was nearly zero. The DC capacitor voltage \(v_{DC}\) was well controlled to its reference value \(V_{DC}^{ref}\). The ripple of the DC capacitor voltage was 2.8% in the transient state.

Figure 10 shows the simulation results of the proposed reactive power control strategy for the ALB in Fig. 2, where a-phase load current \(i_{La}\) was changed from 0.2 pu to 0.9 pu, while the b-phase load \(i_{Lb}\), and c-phase load \(i_{Lc}\) were held constant. Before and after the load current variation, the source currents \(i_{Sa}, i_{Sb}, \) and \(i_{Sc}\) were balanced. The DC capacitor voltage \(v_{DC}\) adheres closely its reference value \(V_{DC}^{ref}\) in this light-load to heavy-load variation. The ripple in the DC capacitor voltage was less than 3.2% in the transient state and less than \(\pm 1\)% in the steady state.

4. Experimental Results

A reduced-scale experimental model of the ALB was constructed and tested to demonstrate the validity and practicability of the proposed reactive power control strategy. Figure 11 shows a block diagram of the constructed experimental model. A Δ-Y connected distribution transformer was used in the experimental setup. Electric power utilities in Japan...
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Fig. 10. Simulation results of the proposed reactive power control strategy with light- to heavy-load variation

Fig. 11. Constructed experimental model for Fig. 2

distribute 200 V for commercial supply. Therefore, a three phase transformer rated at 200 V, 6 kVA, and 60 Hz was used in the experiment instead of 380 V. The line-to-neutral voltage was 115 V for each single phase system in the secondary side. The circuit constants of the ALB are shown in Table 3.

The reference DC capacitor voltage $V^{*}_{DC}$ was 385 V in the experiment. The load conditions of the distribution system were the same as those in Table 1 excepting the rated terminal voltages.

A digital signal processor (DSP: TMS320C6713, 225 MHz) was used in the experimental setup. The line-to-neutral voltage $v_{T_{a}}$; the three load currents $i_{L_{a}}$, $i_{L_{b}}$, and $i_{L_{c}}$; the four compensation output currents $i_{C_{a}}$, $i_{C_{b}}$, $i_{C_{c}}$, and $i_{C_{n}}$; and the DC capacitor voltage $v_{DC}$ were detected. These detected signals were input to the DSP through 12-bit A/D converters, as shown in Fig. 11. In the DSP, the reference compensation currents $i_{C_{a}}$, $i_{C_{b}}$, $i_{C_{c}}$, and $i_{C_{n}}$ were calculated using the proposed reactive power control strategy in (11). The sine-triangle intercept technique was used to control the output currents $i_{C_{a}}$, $i_{C_{b}}$, $i_{C_{c}}$, and $i_{C_{n}}$. These compensation output currents were detected by the DSP for the current feedback control, where the PI controller in the dq coordinates was also constructed. A Yokogawa SL1000 high-speed data acquisition unit with a sampling rate of 5 $\mu$s was used for waveform measurements.

Figure 12 shows the experimental results for the proposed reactive power control strategy of the ALB in Fig. 11, where the a-phase load current $i_{L_{a}}$ was changed from 0.9 pu to 0.2 pu, while the b-phase load $i_{L_{b}}$ and the c-phase load $i_{L_{c}}$ were held constant. The unbalanced load percentage was 31% before the load variation and 30% after the load variation. Before and after the load current variation, the source currents $i_{S_{a}}$, $i_{S_{b}}$, and $i_{S_{c}}$ were balanced. The power factor $\cos \theta$ was 0.9 under the heavy-load condition and 0.91 under the light-load condition. A slight difference in the power factor occurred because of the filter capacitor effect of the ALB. The fourth leg of the ALB generated the compensation current $i_{C_{n}}$, which closely followed the load zero-sequence current $i_{L_{n}}$. Thus, the source zero sequence current $i_{S_{n}}$ was nearly zero. The DC capacitor voltage $v_{DC}$ adhered closely to its reference value $V^{*}_{DC}$. The ripple in the DC capacitor

Table 3. Circuit constants of active load balancer in the experiment

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated terminal voltage</td>
<td>$v_{T_{a}}, v_{T_{b}}, v_{T_{c}}$</td>
<td>115 V</td>
</tr>
<tr>
<td>Rated frequency</td>
<td>$f$</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Reference DC capacitor voltage</td>
<td>$V_{DC}$</td>
<td>385 V</td>
</tr>
<tr>
<td>Capacity of capacitor</td>
<td>$C_{DC}$</td>
<td>2200 $\mu$F</td>
</tr>
<tr>
<td>Compensation inductance</td>
<td>$L_{C_{a}}, L_{C_{b}}, L_{C_{c}}, L_{C_{n}}$</td>
<td>1.5 mH</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>$f_{sw}$</td>
<td>12 kHz</td>
</tr>
</tbody>
</table>

Fig. 12. Experimental results of the proposed reactive power control strategy with heavy-load to light-load variation (power factor is set to 0.9)
D. Reactive Power Control Strategy for Active Load Balancer

The proposed reactive power control strategy for an ALB in three-phase four-wire distribution systems under unbalanced conditions.

Table 4. Required power rating of the ALB with various source side power factors

<table>
<thead>
<tr>
<th>Source side power factor and (K)</th>
<th>Calculated power rating (kVA)</th>
<th>Simulation result (kVA)</th>
<th>Experimental result (kVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.86 (K = 0.59)</td>
<td>2.54kVA</td>
<td>2.35kVA</td>
<td></td>
</tr>
<tr>
<td>0.88 (K = 0.54)</td>
<td>2.59kVA</td>
<td>2.39kVA</td>
<td></td>
</tr>
<tr>
<td>0.90 (K = 0.48)</td>
<td>2.66kVA</td>
<td>2.65kVA</td>
<td>2.6kVA</td>
</tr>
<tr>
<td>0.92 (K = 0.43)</td>
<td>2.74kVA</td>
<td>2.72kVA</td>
<td></td>
</tr>
<tr>
<td>0.94 (K = 0.36)</td>
<td>2.83kVA</td>
<td>2.81kVA</td>
<td></td>
</tr>
<tr>
<td>0.96 (K = 0.29)</td>
<td>2.95kVA</td>
<td>2.93kVA</td>
<td></td>
</tr>
<tr>
<td>0.98 (K = 0.20)</td>
<td>3.11kVA</td>
<td>3.10kVA</td>
<td></td>
</tr>
<tr>
<td>1.00 (K = 0.00)</td>
<td>3.52kVA</td>
<td>3.50kVA</td>
<td>3.5kVA</td>
</tr>
</tbody>
</table>

three-phase, 200 V, 60Hz, 6 kVA distribution transformer base.

Conclusion

In this paper, we have proposed a reactive power control strategy based on DC capacitor voltage control for an ALB in three-phase four-wire distribution systems. The proposed reactive power control strategy uses only DC capacitor voltage control, and therefore the proposed method does not require any active and reactive load current calculation blocks. The basic principle of the proposed reactive power control strategy has been discussed in detail. Digital computer simulations and experimental results demonstrate that the control strategy achieved the balanced source currents with a power factor of 0.9, which is acceptable for Japanese power distribution system. In addition, the simulation and experimental results agree well with calculated power ratings for the ALB. These theoretical, simulated and experimental analysis demonstrate that the proposed reactive power control strategy, set to a power factor of 0.9, reduces the power rating of the ALB by 26% compared to the previously proposed control strategy with a unity power factor control strategy. Therefore, we have offered the simplest and most efficient control algorithm for an ALB in three-phase four-wire distribution systems under unbalanced conditions.
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