Improvement of Power Quality by Using Advanced Reactive Power Compensation

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***Abstract*—In the same feeder, it will decline the power quality of power supply when the quality is poor at load side, which can cause other equipment malfunction and even damage devices. Therefore, a reactive power compensation method is suggested to improve the power quality of the electric arc furnace in a distribution power system. Both the static var compensator (SVC) and an active filter can modify power factor and balance three phase currents simultaneously. The active filter can solve the problem of instantaneous state of an SVC. Then, an SVC can reduce power quantity of the active filter. Finally, field measurement data in a metal factory were analyzed. Simulation results confirmed the feasibility of correcting the power factor and balancing load currents simultaneously using the proposed method.**

***Index Terms*—Active filter, current, power quality, reactive power, static var compensator (SVC).**

I. Introduction

Many metal industries produce steel by using electric arc furnaces (EAFs). It is important to investigate their effects on the power quality [1]–[3]. Generally, there are three periods, boring-down, melting-down, and refining, during the EAF operating process. After preheated with burners, the electrodes are lowered and energized [4]. During boring-down and melting-down periods, the arc current changes dramatically because the scrap is continuously melted and irregularly collapses among the graphite electrodes. Consequently, the status of an EAF randomly varies among short circuit, open circuit, and nonlinear arc model [5].

The major disturbances from an EAF are voltage flicker, load unbalance, and harmonics [1]–[6]. An excessive level of power unbalance and negative sequence current are caused by the failure of arc re-ignition [7]. An unbalanced load could lead to produce undesired negative sequence current in a three-phase three-wire system. This negative sequence current will cause additional losses of generators, transmission lines, and transformers. There are many technologies to adapt the static var compensator (SVC) in three-phase systems that have been illustrated in literatures [8], [9]. The susceptance of each phase of the SVC can be obtained from root mean square (rms) values of voltage and current of three-phase loads. The compensation algorithm of the SVC can balance the three phase loads and improve the power factor to unity of fundamental component [8], [10].

Unfortunately, the method of symmetrical coordinates is difficult to show any power and current decomposition and their physical concepts [11]. Thus, instantaneous active–reactive power and current in the time domain cannot be discussed. One research suggests a compensation algorithm that can balance the three-phase currents by the active power of last cycle and improve the power factor to be close to unity by the instantaneous value of three-phase currents [12]. The instantaneous values of three-phase currents can be transferred to a vector on polar coordinates, which can be decomposed the instantaneous active current and instantaneous reactive current. Though the power factor can be modified by adjusting the instantaneous reactive current, but the three-phase currents cannot be balanced in the same time. The reason is that active power has unsymmetry components. This research proposes the active power is a constant that is obtained by using a load forecasting model. Finally, it combines these two methods to acquire the instantaneous three-phase compensation currents that can modify the power factor and balance three-phase currents simultaneously.

The susceptance of each phase of the SVC can be obtained from rms values of voltage and current of three-phase loads, thus, instantaneous active–reactive power and current in the time domain cannot be discussed. The instantaneous compensator can solve this problem [12]; however, the compensation current is supplied by an independent power source, which causes the price becoming expensive. Therefore, it is important for reducing the capacity of the independent power source. A research combines an SVC and the instantaneous compensator together [13]. An SVC is utilized with the instantaneous compensator to reduce the capacity of the independent power.

Furthermore, better performance is obtained by locating the shunt capacitance closer to the low–power-factor loads [14]. Therefore, it assumed that the SVC and the instantaneous compensator are installed at load terminal.

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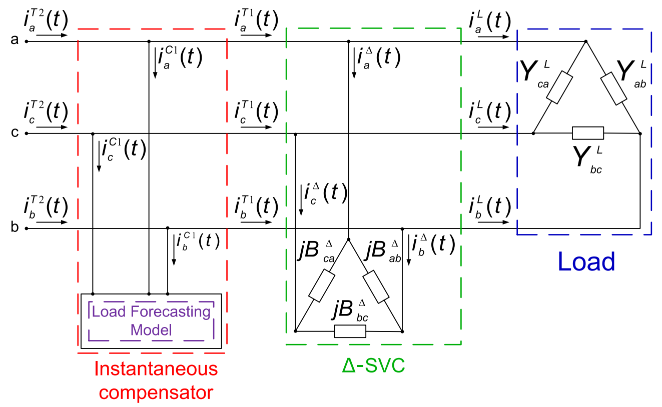

Fig. 1. Three-phase three-wire system with compensators and load forecasting technology.

II. Characteristics of Compensators

The power factor generally is an important penalty factor in the revenue of electricity customers. The effects of load unbalance and harmonic distortion should be considered. To solve these problems, the technology of modification power factor with the SVC in three-phase three-wire has been used [15], [16]. The susceptance of each phase of the SVC can be obtained from voltage and current signals of loads. The reactive power compensation technology can modify the power factor and balance loads simultaneously [17].

To progress the power quality more efficiently on feeding unbalanced loads, a scheme of instantaneous current compensation that can calculate the compensation current to modify the power factor and balance the three-phase currents simultaneously is proposed [12]. The method of instantaneous space vectors can compensate the reactive power effectively, but the problems of unbalanced load currents remains. Thus, it suggests a method that can mitigate the unbalanced load currents by setting the active power as a constant for each cycle. Moreover, the instantaneous compensator requires an independent power source, whose capacity can be reduce by using an SVC. The SVC does not interfere with the capability of the instantaneous compensator. Therefore, it is suggested for combining an SVC with the instantaneous compensator [13].

The instantaneous compensator and an SVC are installed at the load terminal; thus, the line resistance and reactance between the load and compensators could be ignored. It sets the active power as a constant for each cycle to solve the problem of unbalancing three-phase load. The active power can be obtained after the voltage and current data are measured within a power cycle. Because the active power would not change dramatically during two power cycles; therefore, we often expected the active power that is the same value as the last power cycle. In this research, it sets the active power for each power cycle by using load forecasting technology. The process of calculation could not be very complex because the instantaneous compensator needs an expected value every power cycle. This research combines an instantaneous compensator with the technology of load forcasting and an SVC, as shown in Fig. 1, to modify the power factor and balance three-phase load simultaneously.

III. Static Var Compensator

In a three-phase three-wire system, the compensation susceptances of an SVC can be calculated by using load currents and voltage. The diagram is shown in Fig. 1, where is an unbalanced load through a three-phase three-wire distribution system. The superscripts L and Δ represent the load and Δ-connected SVC, respectively. It assumed that the three-phase voltages are in positive-phase sequence. The fundamental component of the three-phase line currents as

$$\begin{aligned}\bar{I}_{a1}^{L} &= \bar{I}_{ab1}^{L} - \bar{I}_{ca1}^{L} = \left[Y_{ab}^{L}(1-a^2) - Y_{ca}^{L}(a-1)\right] V_{a1}^{L}\\ \bar{I}_{b1}^{L} &= \bar{I}_{bc1}^{L} - \bar{I}_{ab1}^{L} = \left[Y_{bc}^{L}(a^2-a) - Y_{ab}^{L}(1-a^2)\right] V_{a1}^{L}\\ \bar{I}_{c1}^{L} &= \bar{I}_{ca1}^{L} - \bar{I}_{bc1}^{L} = \left[Y_{ca}^{L}(a-1) - Y_{bc}^{L}(a^2-a)\right] V_{a1}^{L} \quad (1)\end{aligned}$$

where $a = e^{j(2/3)\pi}$. The line currents can be transformed to symmetrical components by the transformation matrix as

$$\begin{bmatrix}\bar{I}_0^L\\ \bar{I}_1^L\\ \bar{I}_2^L\end{bmatrix} = \frac{1}{3}\begin{bmatrix}1 & 1 & 1\\ 1 & a & a^2\\ 1 & a^2 & a\end{bmatrix}\begin{bmatrix}\bar{I}_{a1}^L\\ \bar{I}_{b1}^L\\ \bar{I}_{c1}^L\end{bmatrix}. \quad (2)$$

Substituting (1) into (2), we have

$$\begin{aligned}\bar{I}_0^L &= 0\\ \bar{I}_1^L &= \bar{V}_{a1}^L\left(Y_{ab}^L + Y_{bc}^L + Y_{ca}^L\right)\\ \bar{I}_2^L &= \bar{V}_{a1}^L\left(-a^2 Y_{ab}^L - Y_{bc}^L - aY_{ca}^L\right). \quad (3)\end{aligned}$$

Therefore, the symmetric components of current of the SVC are

$$\begin{aligned}\bar{I}_0^\Delta &= 0\\ \bar{I}_1^\Delta &= j\left(B_{ab}^\Delta + B_{bc}^\Delta + B_{ca}^\Delta\right) V_{a1}^L\\ \bar{I}_2^\Delta &= -j\left(a^2 B_{ab}^\Delta + B_{bc}^\Delta + aB_{ca}^\Delta\right) V_{a1}^L. \quad (4)\end{aligned}$$

In order to reduce the negative-sequence current and to improve the power factor, results of the load currents and the SVC currents can be expressed as

$$\bar{I}_2^L + \bar{I}_2^\Delta = 0 \quad (5)$$

$$\operatorname{Im}\left[\bar{I}_1^L + \bar{I}_1^\Delta\right] = 0. \quad (6)$$

Substituting (3) and (4) into (5) and (6), the compensation susceptances of the SVC can be expressed in terms of symmetrical components of the load currents.

$$\begin{aligned}B_{ab}^\Delta &= -{}^1\!/_{3V_{a1}^L}\left[\operatorname{Im}\left(\bar{I}_{a1}^L\right) + \operatorname{Im}\left(a\bar{I}_{b1}^L\right) - \operatorname{Im}\left(a^2\bar{I}_{c1}^L\right)\right]\\ B_{bc}^\Delta &= -{}^1\!/_{3V_{a1}^L}\left[\operatorname{Im}\left(a\bar{I}_{b1}^L\right) + \operatorname{Im}\left(a^2\bar{I}_{c1}^L\right) - \operatorname{Im}\left(\bar{I}_{a1}^L\right)\right]\\ B_{ca}^\Delta &= -{}^1\!/_{3V_{a1}^L}\left[\operatorname{Im}\left(a^2\bar{I}_{c1}^L\right) + \operatorname{Im}\left(\bar{I}_{a1}^L\right) - \operatorname{Im}\left(a\bar{I}_{b1}^L\right)\right]. \quad (7)\end{aligned}$$

By observing Fig. 1, the resistor that is between loads and the compensator is ignored. When the compensation current is

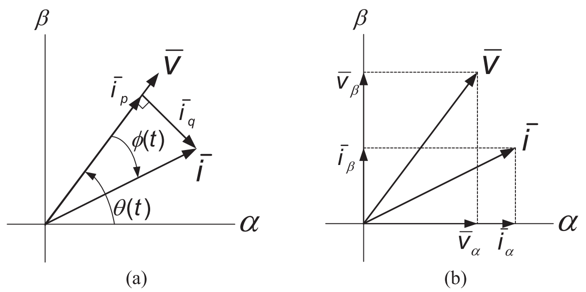

Fig. 2. (a) Instantaneous voltage and current vectors. (b) Components of instantaneous voltage and current vectors.

inductive, the instantaneous current of each phase for the SVC can be obtained by

$$\begin{aligned} i_{ab}^{\Delta}(t) &= \frac{1}{L_{ab}^{\Delta}} \int v_{ab}^{L}(t)dt \\ i_{bc}^{\Delta}(t) &= \frac{1}{L_{bc}^{\Delta}} \int v_{bc}^{L}(t)dt \\ i_{ca}^{\Delta}(t) &= \frac{1}{L_{ca}^{\Delta}} \int v_{ca}^{L}(t)dt. \end{aligned} \tag{8}$$

If the compensation current is capacitative, the instantaneous current of each phase for the SVC can be expressed as

$$\begin{aligned} i_{ab}^{\Delta}(t) &= C_{ab}^{\Delta} \frac{dv_{ab}^{L}(t)}{dt} \\ i_{bc}^{\Delta}(t) &= C_{bc}^{\Delta} \frac{dv_{bc}^{L}(t)}{dt} \\ i_{ca}^{\Delta}(t) &= C_{ca}^{\Delta} \frac{dv_{ca}^{L}(t)}{dt}. \end{aligned} \tag{9}$$

IV. Instantaneous Compensator

For a three-phase power system, the instantaneous voltage and current vector can be denoted as [11]

$$\bar{v} = \sqrt{\frac{2}{3}} \left(v_a(t) + v_b(t) e^{j\frac{2}{3}\pi} + v_c(t) e^{j\frac{4}{3}\pi} \right) = v(t) e^{j\theta(t)} \tag{10}$$

$$\bar{i} = \sqrt{\frac{2}{3}} \left(i_a(t) + i_b(t) e^{j\frac{2}{3}\pi} + i_c(t) e^{j\frac{4}{3}\pi} \right) = i(t) e^{j(\theta(t)+\phi(t))} \tag{11}$$

where $v_a(t)$, $v_b(t)$, and $v_c(t)$ are instantaneous voltage values; $i_a(t)$, $i_b(t)$, and $i_c(t)$ are instantaneous current values. Both $\theta(t)$ and $\phi(t)$ are time-varying angle values. The instantaneous voltage and current vectors in a coordinate system are shown in Fig. 2(a). The reactive current vector $\bar{i}_q$, which is

$$\bar{i}_q = i \sin\phi(t) \angle \left(\theta(t) - \frac{\pi}{2} \right). \tag{12}$$

This component must be eliminated by the compensator to let the instantaneous current vector $\bar{i}$ and the instantaneous voltage vector $\bar{v}$ be in phase. To investigate instantaneous load balancing compensation technologies, the components on the α- and the β-axes of the instantaneous voltage and current vectors should be described, as shown in Fig. 2(b).

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & 1/2 \\ 1 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \tag{13}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & 1/2 \\ 1 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix}. \tag{14}$$

The instantaneous active power $p(t)$, reactive power $q(t)$, and homopolar power $p_0(t)$ are

$$\begin{bmatrix} p(t) \\ q(t) \\ p_0(t) \end{bmatrix} = \begin{bmatrix} \bar{p} + \tilde{p} \\ \bar{q} + \tilde{q} \\ \bar{p}_0 + \tilde{p}_0 \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta & 0 \\ -v_\beta & v_\alpha & 0 \\ 0 & 0 & v_0 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \tag{15}$$

where $\bar{p}$, $\bar{q}$, and $\bar{p}_0$ are fundamental components under purely symmetrical conditions; and $\tilde{p}$, $\tilde{q}$, and $\tilde{p}_0$ are components from harmonics or unsymmetries. In a three-phase three-wire system, the components in the α- and β-axes of the instantaneous current vector can be expressed as

$$\begin{aligned} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} &= \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} 0 \\ \bar{q} \end{bmatrix} \\ &+ \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \end{aligned} \tag{16}$$

where $\Delta = v_\alpha^2 + v_\beta^2$. If the reactive power compensation is used, the reactive power is zero, and then

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ 0 \end{bmatrix}. \tag{17}$$

The next step is to balance the unbalanced currents. The fundamental active power of each cycle can be obtained by the fast Fourier transform. Then, the instantaneous active power of the load can be calculated. Finally, the compensation current to balance the three-phase currents is

$$\bar{i}_{bl}^{C} = (-1)\left[i_\alpha + j(i_\beta)\right] = -\frac{v_\alpha \tilde{p}}{v_\alpha^2 + v_\beta^2} - j\left(\frac{v_\beta \tilde{p}}{v_\alpha^2 + v_\beta^2} \right). \tag{18}$$

The compensation current of each phase can be obtained by

$$\begin{bmatrix} i_a^C(t) \\ i_b^C(t) \\ i_c^C(t) \end{bmatrix} = \sqrt{\frac{3}{2}} \times \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} 0 \\ \left(\bar{i}_{bl}^{C} - \bar{i}_q\right)^* \\ \left(\bar{i}_{bl}^{C} - \bar{i}_q\right) \end{bmatrix} \tag{19}$$

where $(\bar{i}_{bl}^{C} - \bar{i}_q)^*$ is the conjugate of $(\bar{i}_{bl}^{C} - \bar{i}_q)$.

V. Load Forecasting Model

For an autoregressive model, it uses each data within the time sequence and the last output to analyze the relationship between output and input. The term of output delay is used to be the independent variable. This method has the advantage of simplifying the system that has many variables [18]. After the autoregressive model is fixed, the least square estimator can be used to calculate the expected value of autoregressive coefficients. It assumes that the noise term can be ignored and the constant term is one of the autoregressive coefficients. Then, the function can be expressed as

$$y_t = \phi_0 + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \cdots + \phi_p y_{t-p}. \tag{20}$$

It assumes that there are *n* sample values

$$y_t^{(i)} = \phi_0 + \phi_1 y_{t-1}^{(i)} + \phi_2 y_{t-2}^{(i)} + \cdots + \phi_p y_{t-p}^{(i)},\ i = 1, 2, \ldots, n. \tag{21}$$

The expecting values can obtain by using the regressive function and sample values

$$\hat{y}_t^{(i)} = \hat{\phi}_0 + \hat{\phi}_1 y_{t-1}^{(i)} + \hat{\phi}_2 y_{t-2}^{(i)} + \cdots + \hat{\phi}_p y_{t-p}^{(i)},\ i = 1, 2, \ldots, n. \tag{22}$$

The sum of squared error should be minimum between the sample values $y_t^{(i)}$ and the expecting values $\hat{y}_t^{(i)}$. Thus, it can be expressed as

$$\text{SSE} = \sum \left(y_t^{(i)} - \hat{y}_t^{(i)}\right)^2. \tag{23}$$

It can rewrite (23) by combining (21) and (22) as

$$\begin{aligned}\text{SSE} &= h \\ &= \sum_{i=1}^{n} \left[y_t^{(i)} - (\hat{\phi}_0 + \hat{\phi}_1 y_{t-1}^{(i)} + \hat{\phi}_2 y_{t-2}^{(i)} + \cdots + \hat{\phi}_p y_{t-p}^{(i)})\right]^2.\end{aligned} \tag{24}$$

It can calculate partial differential for (24) and set the value of partial differential is zero as

$$\begin{aligned}\frac{\partial h}{\partial \hat{\phi}_0} &= \sum_{i=1}^{n} (-2)\left[y_t^{(i)} - (\hat{\phi}_0 + \hat{\phi}_1 y_{t-1}^{(i)} + \hat{\phi}_2 y_{t-2}^{(i)} \right. \\ &\quad \left. + \cdots + \hat{\phi}_p y_{t-p}^{(i)})\right] = 0 \\ \frac{\partial h}{\partial \hat{\phi}_1} &= \sum_{i=1}^{n} (-2) y_{t-1}^{(i)} \left[y_t^{(i)} - (\hat{\phi}_0 + \hat{\phi}_1 y_{t-1}^{(i)} + \hat{\phi}_2 y_{t-2}^{(i)} \right. \\ &\quad \left. + \cdots + \hat{\phi}_p y_{t-p}^{(i)})\right] = 0 \\ &\vdots \\ \frac{\partial h}{\partial \hat{\phi}_p} &= \sum_{i=1}^{n} (-2) y_{t-p}^{(i)} \left[y_t^{(i)} - (\hat{\phi}_0 + \hat{\phi}_1 y_{t-1}^{(i)} + \hat{\phi}_2 y_{t-2}^{(i)} \right. \\ &\quad \left. + \cdots + \hat{\phi}_p y_{t-p}^{(i)})\right] = 0.\end{aligned} \tag{25}$$

Rewriting (25) can obtain as

$$\begin{aligned}\sum_{i=1}^{n} y_t^{(i)} &= \hat{\phi}_0 + \hat{\phi}_1 \sum_{i=1}^{n} y_{t-1}^{(i)} + \hat{\phi}_2 \sum_{i=1}^{n} y_{t-2}^{(i)} \\ &\quad + \cdots + \hat{\phi}_p \sum_{i=1}^{n} y_{t-p}^{(i)} \\ \sum_{i=1}^{n} y_{t-1}^{(i)} y_t^{(i)} &= \hat{\phi}_0 \sum_{i=1}^{n} y_{t-1}^{(i)} + \hat{\phi}_1 \sum_{i=1}^{n} \left[y_{t-1}^{(i)}\right]^2 \\ &\quad + \hat{\phi}_2 \sum_{i=1}^{n} y_{t-1}^{(i)} y_{t-2}^{(i)} + \cdots + \hat{\phi}_p \sum_{i=1}^{n} y_{t-1}^{(i)} y_{t-p}^{(i)} \\ &\vdots \\ \sum_{i=1}^{n} y_{t-p}^{(i)} y_t^{(i)} &= \hat{\phi}_0 \sum_{i=1}^{n} y_{t-p}^{(i)} + \hat{\phi}_1 \sum_{i=1}^{n} y_{t-1}^{(i)} y_{t-p}^{(i)} \\ &\quad + \hat{\phi}_2 \sum_{i=1}^{n} y_{t-2}^{(i)} y_{t-p}^{(i)} + \cdots + \hat{\phi}_p \sum_{i=1}^{n} \left[y_{t-p}^{(i)}\right]^2.\end{aligned} \tag{26}$$

Equation (26) can be expressed by matrix as

$$X^T Y = (X^T X)\Phi \tag{27}$$

where

$$Y = \begin{bmatrix} y_t^{(1)} \\ y_t^{(2)} \\ \vdots \\ y_t^{(n)} \end{bmatrix}, \quad \Phi = \begin{bmatrix} \hat{\phi}_0 \\ \hat{\phi}_1 \\ \vdots \\ \hat{\phi}_p \end{bmatrix}, \quad X = \begin{bmatrix} 1 & y_{t-1}^{(1)} & \cdots & y_{t-p}^{(1)} \\ 1 & y_{t-1}^{(2)} & \cdots & y_{t-p}^{(2)} \\ & & \vdots & \\ 1 & y_{t-1}^{(n)} & \cdots & y_{t-1}^{(n)} \end{bmatrix}.$$

Then, the regressive coefficients can be calculated as

$$\hat{\Phi} = (X^T X)^{-1} X^T Y. \tag{28}$$

This research expresses the relationship between the output and the last five power cycle values by using regressive coefficients. Moreover, it is impossible to analyze infinite sample data. Thus, the system utilizes 50 sample data to calculate regressive coefficients. The oldest data would be discarded after the system obtains a new data, which can keep the amount of data as a constant and avoid the calculation speed to be very slow.

VI. Analysis Results

This research measures voltage and current instantaneous data from an EAF in a metal industry factory. In this factory, they had already installed some compensation equipments for harmonic components; thus, the measurement data may be infected.

A. Using an SVC Only

This research utilizes fast Fourier transform to analyze voltage and current data. Then, the fundamental component can

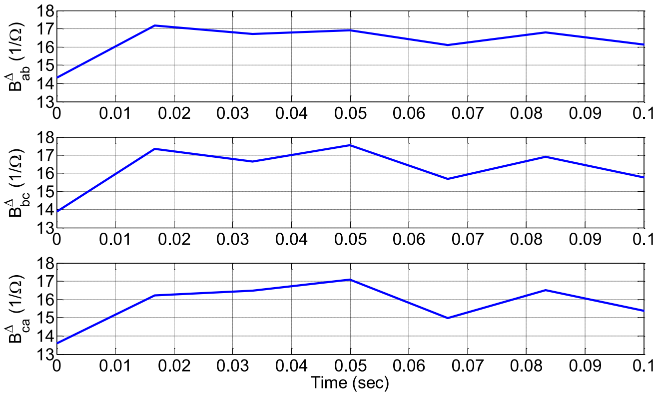

Fig. 3. Compensation susceptances of an SVC.

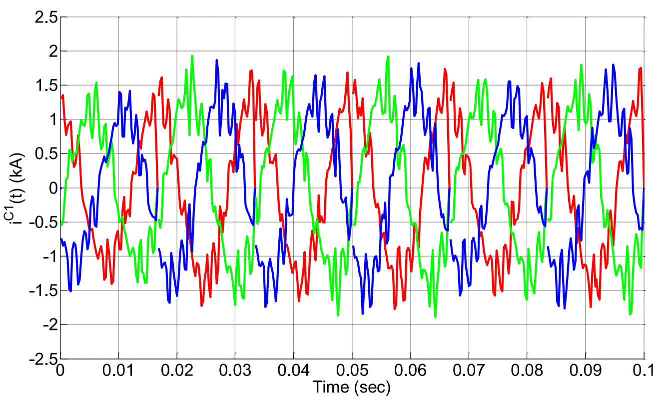

Fig. 4. Compensation current of an SVC.

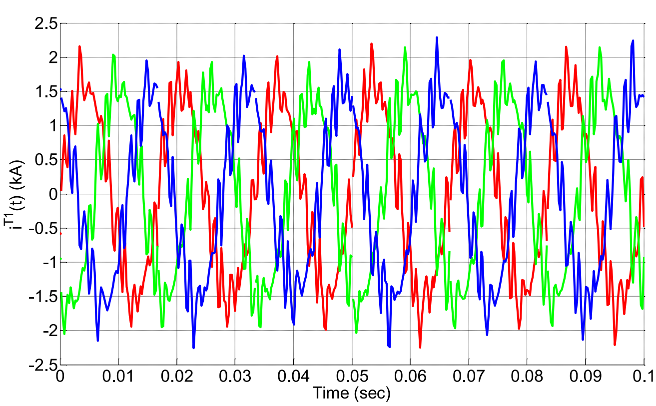

Fig. 5. Load current and compensation current of an SVC.

be employed to calculate the compensation susceptances of an SVC, as shown in Fig. 3.

After the compensation susceptances of an SVC are known, the three-phase instantaneous current value can be calculate by using (2) or (3) for inductive or capacitative, respectively, as shown as Fig. 4. The red line, green line, and blue line is phase a, phase b, and phase c, respectively.

The current that combines load current with compensation current of an SVC are as shown as Fig. 5. In this figure, the current wave is not sinusoid because it is hard to be smooth

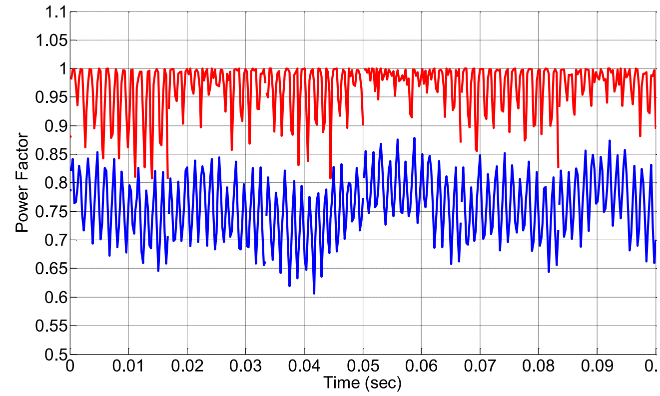

Fig. 6. Power factor with and without an SVC.

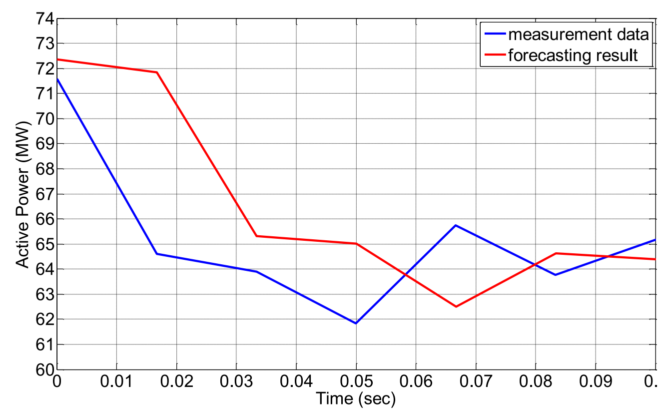

Fig. 7. Load forecasting result and the measurement data.

wave by using differential calculation. The red line, green line, and blue line is phase a, phase b, and phase c, respectively.

By observing Fig. 6, the red line and the blue line means that power factor of the distribution system with and without an SVC, respectively. An SVC can modify the power factor; however, the compensation susceptances of an SVC are calculated by using the fundamental component. In this power system, it still has other harmonic components that could infect the power factor. Fortunately, the instantaneous compensator which is suggested can solve this problem.

B. *Combining an SVC and an Instantaneous Compensator*

This research combines the instantaneous compensator with the technology of load forecasting. By observing Fig. 7, the measurement data and load forecasting result is blue line and red line, respectively. The error between the measurement data and load forecasting result is higher in the beginning but the error is about −2% to 5% after 0.1 s, as shown as Fig. 8.

The current of the instantaneous compensator is shown as Fig. 9. The red line, green line, and blue line is phase a, phase b, and phase c, respectively. By comparing Fig. 4 with Fig. 9, the peak value of the instantaneous compensator is smaller than an SVC. It means that an SVC and the instantaneous compensator support the compensation component for fundamental and

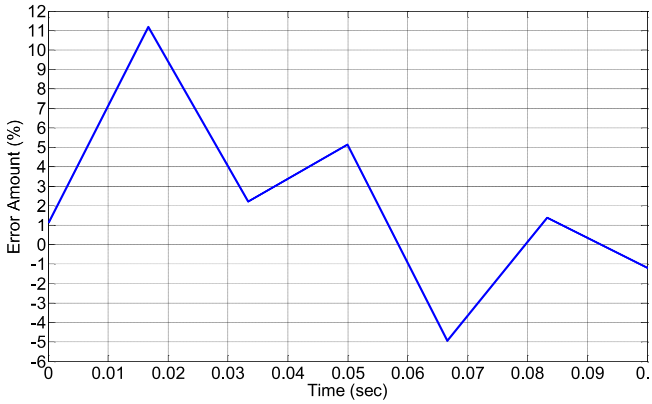

Fig. 8. Error between forecasting result and the measurement data.

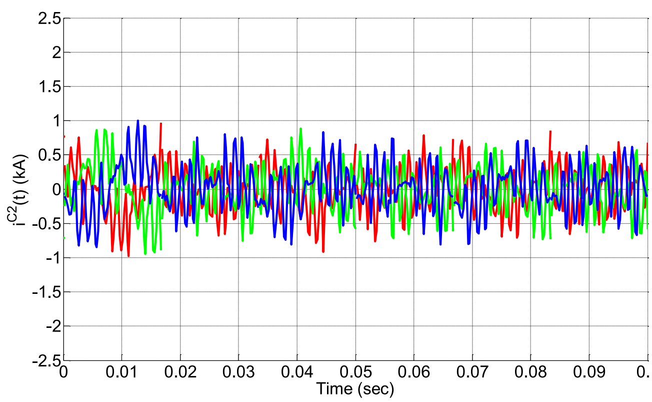

Fig. 9. Compensation current of the instantaneous compensator.

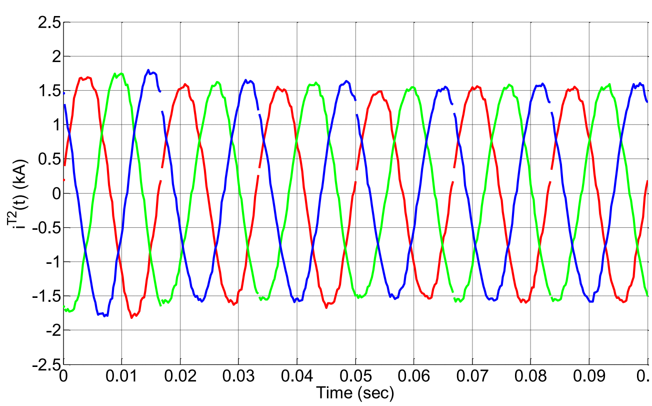

Fig. 10. Load current and compensation current of an SVC and the instantaneous compensator.

harmonic, respectively. If an SVC is removed, the capacity of the instantaneous compensator should be increased.

The load current combines compensation current of an SVC and the instantaneous compensator is shown as Fig. 10. By comparing Figs. 5 and 10, the current wave is similar to sinusoid because the instantaneous compensator can reduce harmonic components. Even the error between measurement data and the result of load forecasting would make three-phase current unbalanced; the symptom is not very heavy.

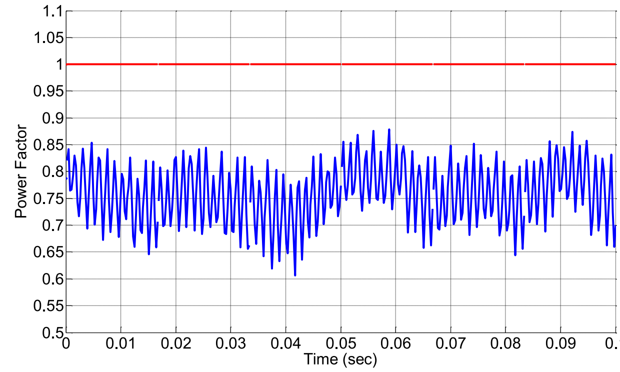

Fig. 11. Power factor with and without an SVC and the instantaneous compensator.

The power factor with and without an SVC and the instantaneous compensator is shown as Fig. 11. After the harmonic component is reduced, the power factor is very close to unity.

VII. Conclusion

The instantaneous compensator needs an independent power source to supply the compensation current, thus, the prime cost depends on capacity of the independent power source. This study suggests that an SVC is utilized to reduce the capacity of the independent power. When the instantaneous compensator is combined with an SVC, both equipments would not interfere with each other. Even it has error between the result of load forecasting and measurement data, the suggestion method can still maintain the power factor correction and reduce the current of the instantaneous compensator. Finally, it uses the proposed method to analyze measured data from an EAF in a metal industry factory. The analysis results confirm the feasibility of the compensation method that is proposed in this study.

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