An Improved alpha-beta Transformation Method of Voltage Sag Detection

Lin Peng, Minyou Chen, Minglin Wang

State Key Laboratory of Power Transmission Equipment& System Security and New Technology
(Chongqing University), Shapingba District, Chongqing 400044, China

Keywords: power quality; alpha-beta transform; voltage sag; real-time performance

Abstract. Voltage sag is one of the most serious power quality problems which impacts many electric equipments. Rapidly and accurately detecting the characteristics of the voltage sag is crucially important for voltage sag compensation. Used in the detection of voltage sag, traditional alpha-beta transform method which has good real-time performance and high accuracy brings time delay, so it cannot satisfy the requirement of compensation. In this paper, an improved alpha-beta transform method of voltage sag is proposed, which can achieve the purpose of testing considering the effects of harmonic without the filter. The improved alpha-beta transform method for voltage sag detection not only has good real-time performance but also has high accuracy. The simulation results verify the validity of the method.

1. Introduction

With the development of modern power system, the advent of the Microgrid and the update technology of electrical equipment lead to serious power quality problem. Voltage sag is the most commom power quality problems [1] [2]. The main reasons of the voltage sags [3] [4] are grounding short circuit, the start of the large capacity motor and lightning. In the industrial production voltage sag causes great economical loss, therefore, it is necessary to study the voltage sags. Rapidly and accurately detecting the characteristics of voltage sag is the precondition of compensation.

The characteristics of voltage sag include magnitude, duration time and phase-angle value. At present, a variety of voltage detection methods have been put forward, such as the RMS calculation method which brings half a cycle delay and cannot detect the begin-end time of voltage sag. The peaking voltage detection method [5], which has half a cycle’s time delay is easily influenced by noise signal. So it can’t be used separately. Fundamental component detection method can detect the voltage sag amplitude, but it cannot satisfy the requirement of real-time performance. The defect voltage algorithm, single-phase voltage transform average method and the wavelet transformation method can not only detect the voltage sag value but also can detect phase-angle value, however these detection method will bring bigger begin-end time error. The most widely used method in the dynamic voltage restorer (DVR) is instantaneous voltage dq transformation method, which is only applicable to the three-phase symmetrical fault. In fact, voltage sag most happened to the single-phase short fault. The alpha-beta transform is to convert the single-phase instantaneous voltage from the stationary coordinate system to the rotating coordinate system. The data using in this method doesn't have simultaneity. The wavelet transform is easy to appear short time disturbance and seriously influences the accuracy of detection. At present, a few articles have been proposed to improve the disadvantages[6][7][8][9], however, these method all cannot satisfy the dynamic voltage restorer’s(DVR) compensation requirements because of the time delay brought by filter.

In this paper, a new approach to voltage sag detection based on improved alpha-beta transform which considered the influence of harmonic has been proposed. It uses derivative to structure voltage which can reduce time delay and has high accuracy. It can better satisfy the demands of DVR to compensate. The simulation results by contrast show that the voltage sag detection based on improved alpha-beta transform method used to single-phase voltage sag detection has superiority both in real-time performance and precision of detection.

2. Improved alpha-beta transform algorithm

The basic principle of the improved alpha-beta transform method is to convert the single phase voltage U into synchronous dq rotating coordinate system. The transformation equation from single-phase voltage to dq coordinate is:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} \cos wt & \sin wt \\ -\sin wt & \cos wt \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} \tag{1}$$

In the above equation sin(wt) and cos(wt) is sine and cosine signal in the phase with a phase voltage. According to the formula (1), the voltage of the dc component can be get from the rotating coordinate system. The alpha-beta coordinate system and dq coordinate system is shown in the figure 1 below:

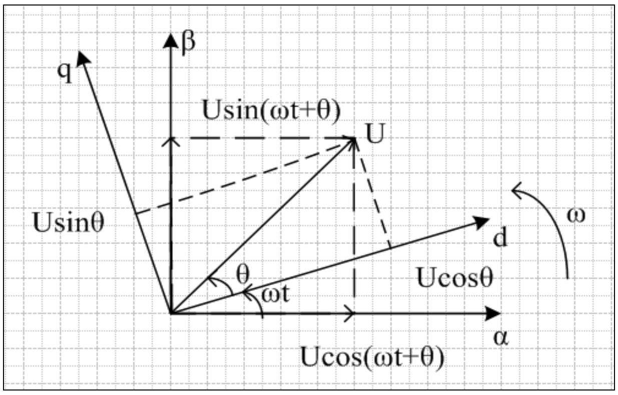


Fig.1 Conversion between alpha-beta coordinate and dq coordinate

Taking into account the harmonics, u_β is structured by the single-phase voltage sag data shown as follow:

$$u_\beta = \sqrt{2} U_{sag} \sin(wt+\theta) + \sqrt{2} U_k \sum_k \sin(kwt+\theta_k) \tag{2}$$

In the formula (2), U_{sag} is the RMS of the voltage sag. U_k is the RMS of k times harmonic component. θ is the phase-angle value of voltage sag. θ_k is the phase-angle value of the k times harmonic. K refers to the harmonic times.

Through derivative, the Synchronous voltage u_α can be get from formula (3).

$$u_\alpha = \frac{w^2 u'_\beta + u'''_\beta}{k(k+1)w^3} + \frac{u'_\beta}{w} \tag{3}$$

By observing the formula (3), As long as the harmonic times is known, u_α can be constructed. The formula (4) can be obtained through formula (2) and formula (3) shown as follow:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \sqrt{2} U_{sag} \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} + \sqrt{2} U_k \begin{bmatrix} \sum_k \cos\left[(k-1)wt+\theta_k\right] \\ \sum_k \sin\left[(k-1)wt+\theta_k\right] \end{bmatrix} \tag{4}$$

in order to get the value of U_{sag} and θ , the dc component must be isolated from formula (5). Using the method of derivation can be directly isolated dc component, shown as follow formula:

$$\begin{bmatrix} U_d \\ U_q \end{bmatrix} = \begin{bmatrix} u_d \\ u_q \end{bmatrix} + \frac{1}{(k-1)w} \begin{bmatrix} u'_q \\ -u'_d \end{bmatrix} \tag{5}$$

The voltage sag amplitude and phase-angle value can be obtained through following formula:

$$U_{\text{sag}} = \sqrt{\frac{U_d^2 + U_q^2}{2}}$$
$$\theta = \arctan\left(\frac{U_q}{U_d}\right) \tag{6}$$

The main framework design of the improved alpha-beta transform method is shown as follow:

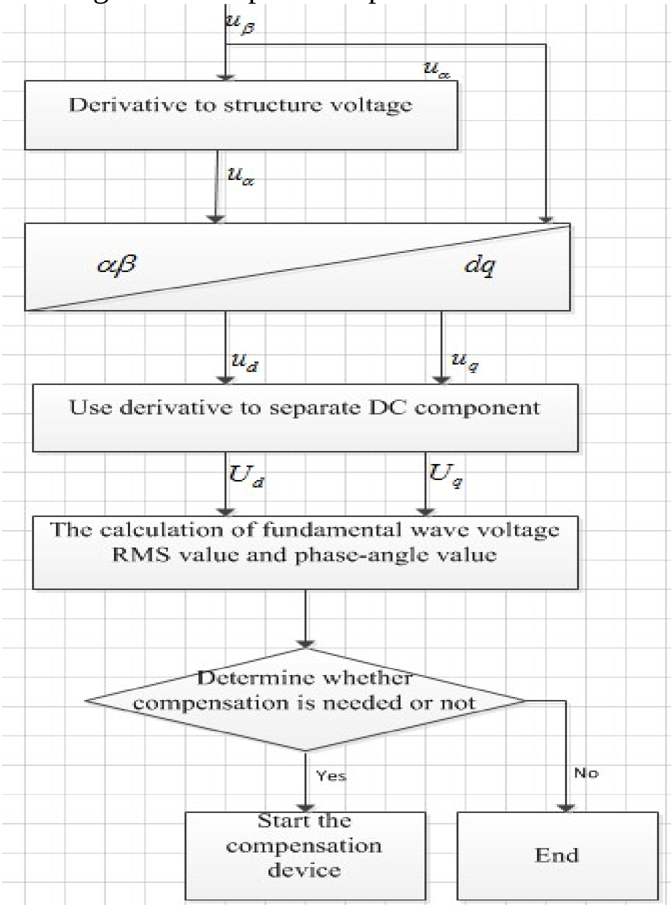


Fig.2 The improved alpha-beta transform algorithm flow chart

3. The Analysis of the improved alpha-beta transformation algorithm

First, the improved alpha-beta transformation algorithm applies to the voltage sag with harmonic. This method can get voltage sag of amplitude value and phase-angle value instantaneously.

The second, due to the use of a variety of power electronic devices, The voltage sag usually alongs with harmonic actually. The improved alpha-beta transformation method uses the measured data to construct u_β and then construct u_α through derivative, however the traditional alpha-beta transformation algorithm is to construct u_α through time delay. The improved alpha-beta transformation algorithm has the advantage of eliminating a quarter of a cycle time delay and it can be better able to meet the requirements of DVR to compensate.

The third, if the voltage sag alongs with high frequency harmonic component， k times harmonic component will be decomposed into the superposition of k - 1 times harmonic component after using the improved alpha-beta transformation. In order to eliminate the influence of harmonics, to ensure the detection accuracy and real-time performance, the paper adopted the derivation method instead of the original low pass filter to eliminate the time delay brought by the filter. If the value of k in the formula (3) is very big, the formula (3) can simplify into the following formula:

$$u_\alpha = \frac{u'_\beta}{w} \tag{7}$$

The formula (8) makes the calculation simple.

The fourth, in the engineer applications, the derivation method will be replaced by the differential. If the voltage data is got more in one cycle, the error will become smaller. The reason is as follows:

$$u'_\beta = \lim_{\Delta t \to 0} \frac{u_\beta(t+\Delta t/2) - u_\beta(t-\Delta t/2)}{\Delta t} \tag{8}$$

When time is very short, the formula can be equivalent to the follow formula:

$$u'_\beta = \frac{u_\beta(t+\Delta t/2) - u_\beta(t-\Delta t/2)}{\Delta t} \tag{9}$$

Assuming that the sampling frequency is T_s, then using T_s replaces Δt.

$$u'_\beta = \frac{u_\beta(t+T_s/2) - u_\beta(t-T_s/2)}{T_s} \tag{10}$$

The formula (10) can be simplified as follow equation:

$$\overline{u}_\alpha = u'_\beta / w = \frac{2}{wT_s}\sin(\frac{wT_s}{2})\cos(wt+\theta) \tag{11}$$

The error equation is:

$$\delta = \left|\frac{\overline{u}_\alpha - u_\alpha}{u_\alpha}\right| = \left|1 - \frac{\sin(wT_s/2)}{wT_s/2}\right| * 100\% \tag{12}$$

It can be seen from equation (12) that the smaller error comes from $T_s \to 0$.

The fifth, when the power system frequency changes, Δf refers to the variation of frequency, f is the original frequency of the grid. The following formula can be obtained from formula (7).

$$u_\alpha = \frac{\sqrt{2}U_{sag}(f+\Delta f)\cos[2\pi(f+\Delta f)t+\theta]}{f} \tag{13}$$

The formula (14) can be got through the measured data, when the frequency changed.

$$u_\beta = \sqrt{2}U_{sag}\sin[2\pi(f+\Delta f)t+\theta] \tag{14}$$

The formula (15) can be got from formula (13) and formula (14)

$$U_{sag} = \sqrt{\frac{u_\beta^2 + (\frac{f}{f+\Delta f})^2 u_\alpha^2}{2}} \tag{15}$$

The accepted value of frequency deviation in the distribution grid system is from 49.8Hz to 50.2Hz. So the frequency change caused by the detection error of amplitude is negligible.

4. Simulation analysis

The MATLAB software simulation is accomplished to validate the advantages of the improved alpha-beta transformation method. Between 0.3s and 0.6s period, 60% amplitude and 30 degree phase-jump happen. And 10% amplitude high frequency harmonic with 2500 Hz is added. the load's voltage waveform is shown as Fig.3.

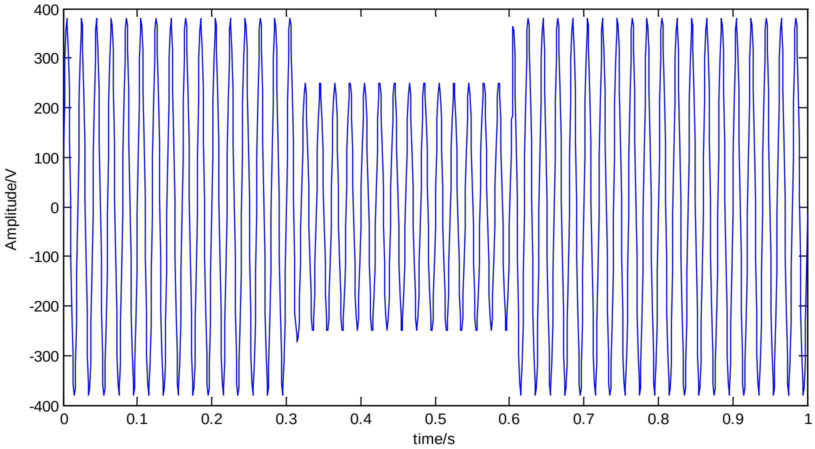


Fig.3 The load's voltage waveform

The simulation result of the improved alpha-beta transform method is shown as following Fig.4 and Fig.5. It can be seen the voltage is 380v when the system is under normal operation. Between 0.3s and 0.6s period, 60% amplitude and 30 degree phase-jump happen.

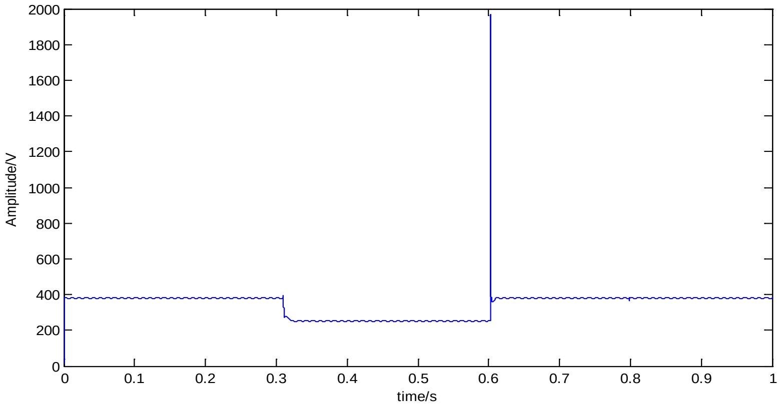


Fig.4 The alpha-beta transformation method of improved voltage amplitude sag figure

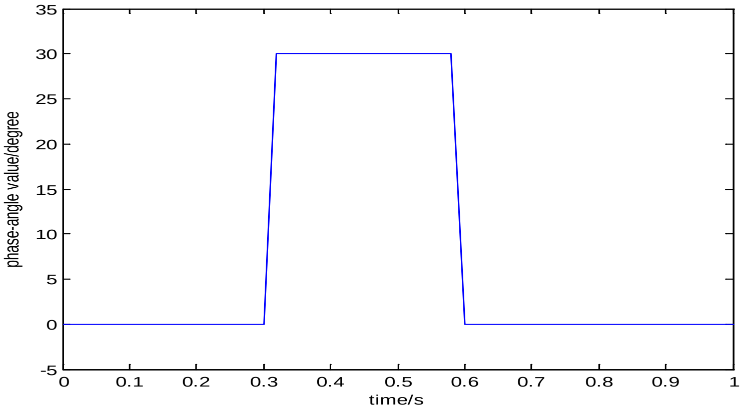
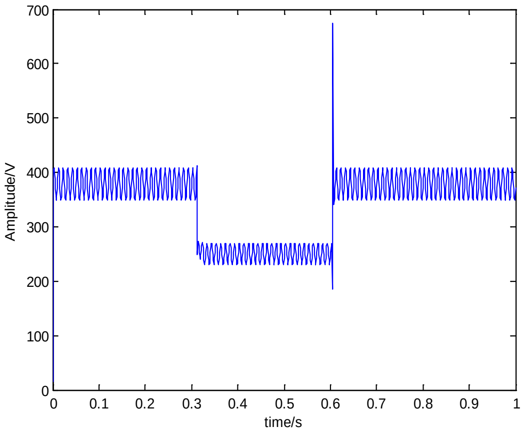


Fig.5 The alpha-beta transformation method of improved voltage phase-Angle jump figure

The simulation result of the traditional alpha-beta transformation method on the same conditions is shown as Fig.6 and Fig.7.



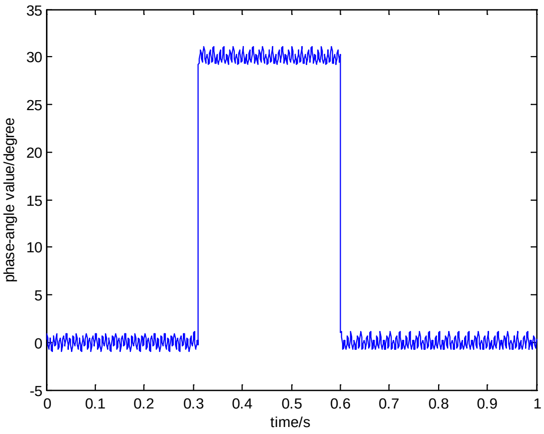


Fig.6 The alpha-beta transformation method of voltage amplitude sag figure,Fig.7 The alpha-beta transformation method of the voltage phase-angle figure

The conclusion, which can be got from Fig.4 and Fig.6, is shown as following.

1) The improved alpha-beta transformation algorithm has better real-time performance and high accuracy in the detection of magnitude drop.

2) The waveforms detected by the improved alpha-beta transformation algorithm is influenced by grid system factors smaller. Harmonic and distortion is also improved.

3) The improved alpha-beta transformation algorithm which considered the influence of harmonic derivative, significantly improved the detection accuracy, but there’s still a tiny fluctuation because of the differential algorithm, which is sensitive to noise.

The conclusion, which can be got from Fig.5 and Fig.7, is that the detection precision of voltage phase-Angle values is higher than that of the traditional transformation method. The comparison is shown as following:

Tab.1 The comparison of the starting moment of the voltage sag

method	Begin time /ms	End time /ms	Duration time /ms
Traditional alpha-beta transformation method	306.5	609.8	303.3
Improved alpha-beta transform algorithm	301.4	601.7	300.3

Tab.2 The comparison of voltage amplitude sag and phase-angle value

method	Amplitude variation /V	Average of amplitude /V	Phase variation /degree	Average of phase variation /degree

Traditional alpha-beta transformation method	[212.2,260.4]	236.3	[27.8,34.2]	31
Improved alpha-beta transformation algorithm	[225.4,231.8]	228.6	[29.4,31.2]	30.3

It can be seen from Tab.1 that the improved alpha-beta transformation algorithm can be ahead of 5.1ms to detect the begin time of voltage sag. It can be seen from Tab.2 that the amplitude and phase variation is smaller than that of traditional alpha-beta transformation method. The improved method has higher accuracy and satisfies the requirement of DVR.

5. Conclusions

The improved alpha-beta transform is used for the magnitude, duration and phase-angle jump value detection of voltage sag in this paper. When harmonics exist, the improved alpha-beta transform which considered the influence of harmonic derivative improved the accuracy of the detection. The simulation results verify that the improved alpha-beta transform is correct and effective which has shorter response time and slightly higher detection accuracy.

6. References

[1] Xiao xiang-Ning, The Power Quality Analysis and Control [M].BeiJing: China Electric Power Press, 2004:125-128.

[2] Cheng Lei, Xu Yong-Hai, Jin Wen-Long, Power Quality Problems and Management, Electric power equipment, 2003,4(1), 60-63.

[3] Melhorn. C. J, Davis. T. D, Beam. G. E, Voltage sags：their impact on the utility and industrial customers，IEEE Transactions on Industry Applications, 1998, 34(3):549-558

[4] Sawir. B, Ghani. M. R, et al, Voltage sag: Malaysian’s experience, Beijing, 2000, Vol, 2:1421-1425.

[5] Xiao Yu-Long, Study on the Detection of Voltage Sags and its Compensation Methods[D]. Tian Jin: Tianjin university, 2006.

[6] Yang Ya-Fei, Yan Xiang-Wu, Lou Yao-Lin, et al. A new method to detect voltage sag characteristic. Automation of Electric Power Systems, 2004, 28(2): 41-44.

[7] Zhao Guo-Liang, Liu Bao-Zhi, Xiao Xiang-Ning, et al. Application of Improved d-q transform without time delay in dynamic voltage disturbance identification. Power System Technology, 2004, 28(7): 53-57.

[8] Yang Shu-Ying, Du Bin, Comprehensive derivation detection algorithm based on d-q transform. Automation of Electric Power Systems, 2005, 28(2): 41-44

[9] Fitzer C, Barnes M, Green P． Voltage sag detection technique for a dynamic voltage restorer[J]． IEEE Trans on Industry Applications, 2004, 40(1): 203-212.