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Implementation of Robust Complex Extended Kalman Filter with LabVIEW for Detection in Distorted Signal

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Abstract: This paper presents the PC-based LabVIEW as a software to develop the algorithm of the robust complex extended Kalman filter (RCEKF) for detection of the parameters of voltage signal in power systems. The hardware of this paper is to take sample-and-hold card and DAQ (Data Acquisition) card for extracting the datum from the outside system to the PC, and the program compute the amplitude, frequency, and phase of the voltage signal with RCEKF. For validating the performance of RCEKF in this paper, the voltage signal from function generator is applied to check the feasibility of algorithm firstly, and then this application was also used in the TPC (Taiwan Power Company) secondary substation in Sijhou, Taiwan.

Keywords: Complex Kalman filter, robust algorithm, voltage distorted signal, LabVIEW.

I. INTRODUCTION

The parameters of voltage signal include amplitude, phase angle, and frequency. The accuracy of estimation parameter is a very important issue for the application of power system. From the literature review [1,2], the using state variable types of the extended Kalman filter are real type and complex type in the application of signals estimation generally. But the former method in practical application, if signal is out of order, it will result in the value of estimated value. The pitch of measured value and estimated value will increase gradually through tracking time. In order to develop the drawbacks as above, therefore, the complex extended Kalman filter was proposed [3], and was applied in the estimation of voltage distortion signal parameter. The complex extended Kalman filter is considered only on the linear part of equation during filtering process. When the parameter is unnormal, sometimes the nonlinear will take a great influence.

According to literature review [4], if there is a unusual signal in the system, the variation quantity will result the errors between the estimated value and the optimal value. This condition will cause the variable state which does not attach the optimal solution, and it can not estimate the parameter exactly.

In order to solve this problem as above, the paper [4] proposed a robust calculation method in the model of extended Kalman filter. Thus, it can be a state estimation application of power system. This effect is pretty good by simulating verify. But the robust calculation method is composed by exponential function in innate character. It is $\exp\left(-\left|y_k - H\tilde{x}_k\right|\right)$. The application meaning is that the more difference between measured value and estimated value is, the less effect on estimation filtering is. This paper is proposed this robust calculation approach of complex extended Kalman filter in signal estimation to improve performance. The application of signal estimation is only applied on the simulation stage in literature review [3-14]. But these approaches are seldom applied in practical measurement. Thus, each algorithm does not have practical verification in practical task.

The LabVIEW [15-20] by PC-based is often applied in power system. Thus, this paper is used the graphic control software of LabVIEW to finish the program of robust complex extended Kalman filter. This program is used practical measurement as follows. Firstly, it is given the sine wave by function generator. Secondly, it is given the voltage signal of Sijhou secondary sub-station in Changhua county of TPC. From the above items, it can verify algorithm practicality in practical measurement. This paper is organized as follows. Section 1 is given a brief introduction. Section 2 is described the models and algorithms of this paper proposed robust complex Kalman filter. Section 3 is stated the used practical measurement to verify the algorithm of Section 2 proposed. Finally, we draw some specific available conclusions in this algorithm for this paper and its research direction in the future in section 4.

II. THE MATHEMATICS OF ROBUST COMPLEX EXTENDED KALMAN FILTER

Step 1:

Input time-changing signals measurement value y_k, the initial value of state variable $\hat{x}_0$, the initial value of error covariance P_0, and the measured value of error covariance R_0.

Step 2:

Begin to track at time k=0.

Step 3:

State estimates $\tilde{x}_k = \mathbf{A}\tilde{x}_{k-1}$ (1)

Step 4:

$$F_k = \frac{\partial(Ax_k)}{\partial x_k} \quad (2)$$

$$M_{k+1|k} = F_k P_{k|k} F_k^{*T} \quad (3)$$

Step 5:

Measurement error covariance

$$R_k = W_k^{-1} \quad (4)$$

$$W_k = W_k e^{-|y_k - H\hat{x}_{k-1}|} \quad (5)$$

Where, $e^{-|y_k - H\hat{x}_{k-1}|}$ is the Robust exponential function of complex style.

If it is real style, the Robust exponential function is $e^{-|y_k - h(\hat{x}_{k-1})|}$.

Step 6:

The Calculation of Kalman is shown as follows.

$$K_k = P_k H^{*T}\left[HP_k H^{*T} + R_k\right]^{-1} \quad (6)$$

Step 7:

State filtering

$$\hat{x}_k = \tilde{x}_{k-1} + K_k\left(y_k - H\tilde{x}_{k-1}\right) \quad (7)$$

Then, renews the P_k.

Step 8:

To judge time value k, we have to depend on if it is larger setting time or not. If it is less than this value, then it is progressed to trace next time point. If it is larger than this value, then it is ended this tracking.

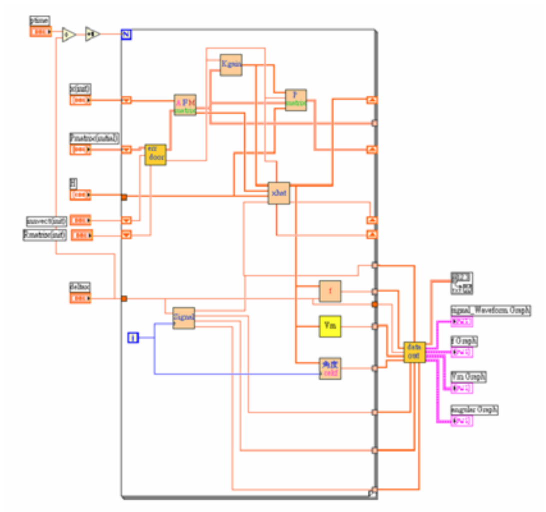

Fig. 1. The program equation of Robust Complex Extended Kalman filter.

Robust Complex Extended Kalman filter is by means of W_k of step 5 to control the Kalman Gain value. Thus, it can restrain un-exact measurement value or the parameter unusual changed to the effect of total estimation procedure. When some unusual measurement occurs, it is presented that measurement value y_k has the significant change. But the prediction of state variable hasn't detected the unusual measurement value. And it is mistaken the calculation of measurement value function which is under normal condition. Thus, when the measurement value happens to distort, the absolute value of Innovation Vector will increase. This outcome will result in the value of exponential function to reduce. Thus, it can assist to decrease the weight value. It can reduce the effect of distortion measurement value for estimation. Fig. 1 as shown is applied the software LabVIEW edited the equation of Robust Complex Extended Kalman filter.

III. NUMERICAL SIMULATION & RESULT

This paper is applied the program of Robust Complex Extended Kalman filter on LabVIEW base. It is verified practical measurement for three situations as follows. Firstly, it is given the sine wave by function generator. Secondly, it is given the voltage signal of Sijhou secondary sub-station in Changhua county of TPC. The function generator supplies the sine wave form signal in the first condition. This signal can alter the magnitude of amplitude and frequency. This paper proposed test signal frequency is 60Hz, and its amplitude is 1V sine wave form signal. It is modulated parameter by the knob of function generator. The voltage signal measurement of Sijhou secondary sub-station is at Changhua county of TPC in condition (2). Now, different application results of signals measurement are depicted as follows.

Fig. 2. The wave form of function generator by oscilloscope display.

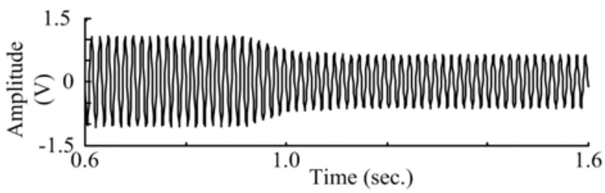

Fig. 3. The signal wave form of function generator displayed from 0.6 second to 1.6 second.

Situation 1: The measurement that function generator supplies the sine wave form signal

a.Signal amplitude change

Fig. 2 shows that function generator supplies the sine wave form. The frequency of this signal is 59.99Hz, and the amplitude is 1.05V. Its amplitude is 0.625V from 0.97 second to 1.1 second after variation. Fig.3 shows that function generator supplies the sine wave form from 0.6 second to 1.6 second. Fig. 4 shows the amplitude estimation diagram of this paper proposed method. The value of amplitude estimation is 1.041V at 0.6 second before variation. Its relative error is 0.86%. The estimation value is 0.624V at 1.8 second. Its relative error is 0.16%. Its response time of estimation is 0.7 second.

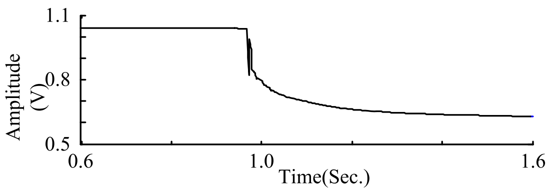

Fig. 4. The amplitude estimation diagram of this paper proposed method.

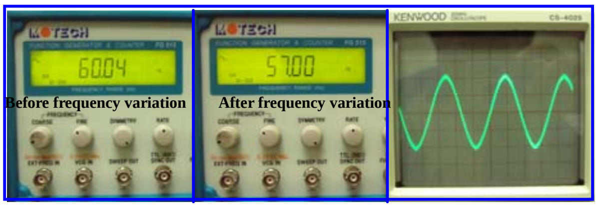

Fig. 5. The wave form of function generator by oscilloscope display.

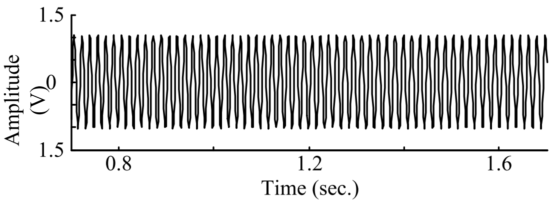

Fig. 6. The signal wave form of function generator measured from 0.7 second to 1.7 second.

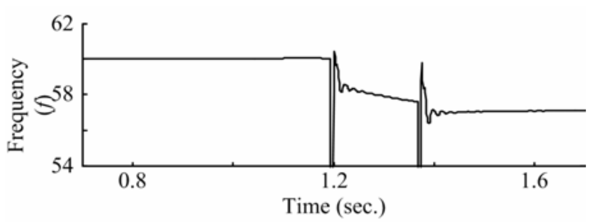

Fig. 7. The frequency estimation diagram of this paper proposed method.

b.Signal frequency change

Fig. 5 shows that function generator supplies the sine wave form. The frequency of this signal is 60.04Hz, and the amplitude is 1.05V. Its frequency variation is from 1.19 second to 1.40 second. Fig.6 shows that function generator supplies the sine wave form from 0.7 second to 1.7 second. Fig. 7 shows the frequency estimation diagram of this paper proposed method. The frequency estimation happens to oscillation suddenly during frequency changes, then it will trace to the signal frequency. The frequency estimation value is 60.032Hz at 1 second before frequency variation in Fig.7. Its value is closed to the value of Fig.6. Fig.6 displays the value 60.04Hz of function generator frequency. The relative error is 0.13% between Fig.7 and Fig.6. After frequency variation, the frequency estimation value is 57.06Hz at 1.6 second. The signal frequency of function generator is 57Hz at 1.6 second. Therefore, there is a 0.06Hz error at 1.6 second.

Situation 2: The voltage signal measurement of Sijhou secondary sub-station at Changhua county of TPC

We take a practical measurement of Sijhou secondary sub-station at Changhua county of TPC. We measured the 11.4kV BUS (Single Phase 66KV) voltage signal at the substation by means of PT (6600/115V) converting. The measured point is shown as Fig.8. Fig. 9, Fig.10 and Fig.11 are the estimation diagrams of one phase frequency, amplitude, and phase angle individual. The estimation value of frequency is 60.21Hz. The estimation value of amplitude is 160.2V. The voltage scale shown in oscilloscope is that, the amplitude is 160V after converting. Both the estimation value and the oscilloscope display value are very similar. The estimation value of phase angle is approximately -129.5°.

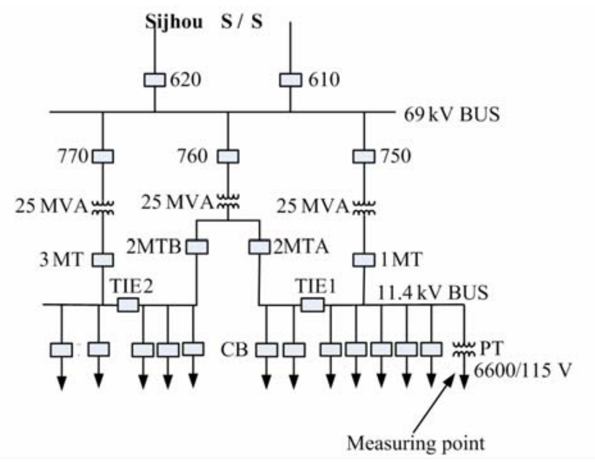

Fig. 8. The single line diagram of Sijhou secondary substation.

IV. CONCLUSIONS

It only takes the simulation of software verse signal parameter in past literature review. This paper proposes LabVIEW the software edited by means of the program of Robust Complex Extended Kalman filter. We can get state variable of system to trace the estimation parameters-amplitude, frequency, and phase angle. Thus, we can accomplish to detect if the signal is in distortion or not. We can prove the feasibility of structure that can trace the signal parameter by means of measuring the sine wave form of function generator through the practical measuring Sijhou secondary sub-station at Changhua county of TPC.

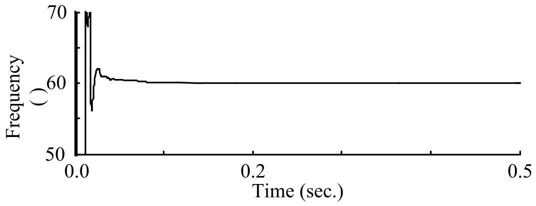

Fig. 9. The frequency estimation diagram of this paper proposed method.

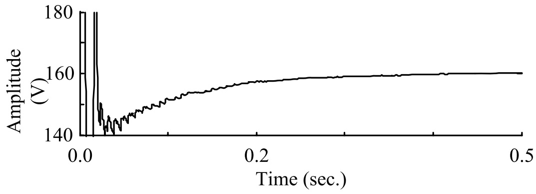

Fig. 10. The amplitude estimation diagram of this paper proposed method.

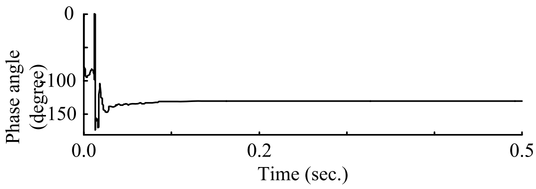

Fig. 11. The phase angle estimation diagram of this paper proposed method.

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