AUTOMATIC GAIN AND PHASE COMPENSATION IN RTU

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ABSTRACT

This paper introduces a new technique to extract eigenvalues of the gain and phase offsets and to compensate them automatically in transducerless sampling RTU. It discusses in detail the cause of the offsets, describes the principles of gain and phase compensation, establishes the algorithm to extract eigenvalues. The process of using the compensated measurements is also illustrated in the paper. This technique enhances the operational speed, simplifies the operational complexity, and improves the capability of transducerless sampling in RTU.

1 INTRODUCTION

In SCADA, RTU is one of the most important devices. In recent years, microprocessor based Remote Terminal Unit (RTU) is well accepted by a great number of customers for its steady performance, high reliability and installation simplicity. One of the most important tasks for a RTU is to collect real-time analog values from power system and to calculate deduced values such as virtual value of voltage and current, and mean value of power, etc. To get accurate results as fast as possible, right samples are crucial.

Inevitably gain and phase offsets will occur in most of circuits with resistance and capacitance due to parameter variances. The offsets can be normally compensated via adjusting hardware parameters manually. However, manual adjustment on hardware system has some obvious limitations, such as low efficiency, low stability and low interconvertible capability.

Another way is Automatic gain and phase compensation. Automatic gain and phase compensation is a software-based method implemented through microprocessor data processing technology. The automatic compensation have many advantages over manual method, especially high efficiency and superior stability. It makes the process of adjustment easy, convenient and efficient.

2 THE CAUSES OF THE OFFSETS

In a data processing system, there are four main steps.

1) Insulation
2) To filter
3) To sample
4) Data processing

An analog signal is first processed by insulating, amplifying and filtering, then sampled and converted to digital signal. There are some analog components in isolation and filter circuits. Because electrical parameters of analog components have dispersing, the gain-phase characteristic of a model is a little different from that of other model with same circuits. When input signals are processed via the circuits, their gains and phases will product offsets. Although the offsets are small, they are enough larger to affect the accuracy of the finally results. In order to meet higher precisions, gain and phase offsets must be compensated.

3 MANUAL ADJUSTMENT

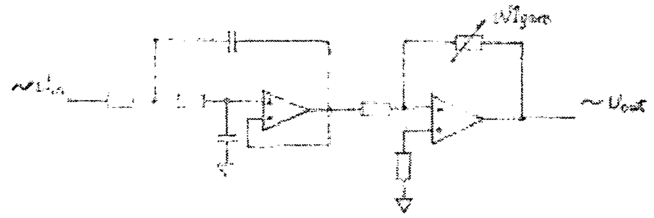
Manual adjustment consists of two parts.

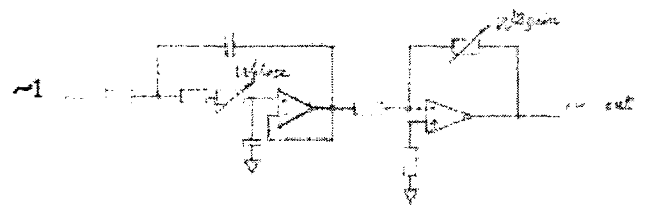
1) Offset and full-scale errors need to be trimmed out

completely in A/D converter

2) The gain and the phase adjustment

For every input signal, its gain needs to be adjusted by a potentiometer W_{gain} in the filter and amplification circuit. For every pair of input signals, a phase adjustment need to be done by adjusting a potentiometer W_{phase}, thus preserving the relative phase information of the signals on the two analog inputs. There are 6 analog input signals for a 3-phases power line, so the gains are adjusted by $6W_{gain}$ and the phases are adjusted by $3W_{phase}$. The compensations are all implemented by adjusting 9 potentiometers.





First the currents and voltages gain adjustments are separately done by applying a standard AC signal below 100V or 5A and adjusting separately potentiometer $W1_{gain}$ and $W2_{gain}$ until the last reading data is equal with the input signal virtual value. Next their phase adjustments is done by applying a standard AC signal below 100V and 5A and adjusting potentiometer W_{phase} until the last reading data is equal with the input power virtual value. Doing this work is onerous and needs circumspection a. If the 9 potentiometers must be adjusted for one line, 90 potentiometers must be adjusted for 10 lines. The workload is very heavy.

Moreover, the precision is directly related with the worker to handle, the value of potentiometers is easily influenced by environment and the models are difficult for reciprocal interchange.

4 AUTOMATIC COMPENSATION

4.1 Extract the gain eigenvalues

On gain –bandwidth, there are:

$$x_o = K_1 x_i \qquad \ldots\ldots\ldots\ldots \quad (1)$$

Here, x_i is input, x_o is output and K_1 *is the gain constant without gain offset.*

In the same way, there are

$$x_o' = K_2 x_i \qquad \ldots\ldots\ldots\ldots \quad (2)$$

Here, x_o' is output and K_2 *is the gain constant with gain offset.*

The formula (1) divided by the formula (2), that is

$$x_o / x_o' = (K_1 / K_2) \qquad \ldots\ldots\ldots\ldots \quad (3)$$

Let the gain eigenvalues $K=K_2/K_1$, *that is*

$$K = x_o/x_o' \qquad \ldots\ldots\ldots\ldots \quad (4)$$

We can get x_i from standard signal generator and get x_o by the formula (1). We can get x_o' by measuring the circuit output. Thus, we can get the gain eigenvalues K finally formula (4).

4.2 Extract the phase eigenvalues

We need only extract eigenvalues of phase difference between the voltage and the relevant current, because the phase difference causes error on power.

According to electric engineering principle, the mean power of non-sinusoidal cyclic current circuit equals to the summary of the mean power of the harmonics, that is:

$$\dot{S} = \sum_{n=1}^{15} \dot{S}(n) = \sum_{n=1}^{15} [P(n) + jQ(n)] \qquad \ldots\ldots\ldots\ldots \quad (5)$$

Here, P(n) is the mean active power of the n^{th} harmonics. Q(n) is the mean reactive power of the n^{th} harmonics

The mean active power and reactive mean power of the n^{th} harmonics without phase offset is respectively

$$\begin{cases} P(n) = S(n)\cos\varphi(n) \\ Q(n) = S(n)\sin\varphi(n) \end{cases} \qquad \cdots\cdots\cdots\cdots \quad (6)$$

Let the phase-difference offset of the n^{th} harmonics is □ $\varphi(n)$, The mean active power and reactive mean power of the n^{th} harmonics with phase offset is

$$\begin{cases} P'(n) = S(n)\cos[\varphi(n) + \Delta\phi(n)] \\ = S(n)[\cos\varphi(n)\cos\Delta\phi(n) - \sin\varphi(n)\sin\Delta\phi(n)] \\ Q'(n) = S(n)\sin[\varphi(n) + \Delta\phi(n)] \\ = S(n)[\sin\varphi(n)\cos\Delta\phi(n) + \cos\varphi(n)\sin\Delta\phi(n)] \end{cases} \qquad \cdots\cdots\cdots\cdots \quad (7)$$

Let K_1=cos□ $\varphi(n)$, K_2=sin□ $\varphi(n)$, *then*

$$\begin{cases} P'(n) = K_1(n)P(n) - K_2(n)Q(n) \\ Q'(n) = K_1(n)Q(n) + K_2(n)P(n) \end{cases} \qquad \cdots\cdots\cdots\cdots \quad (8)$$

The phase eigenvalues of the n^{th} harmonics is

$$\begin{cases} K_1(n) = \dfrac{P(n)P'(n) + Q(n)Q'(n)}{P^2(n) + Q^2(n)} \\ K_2(n) = \dfrac{P(n)Q'(n) - Q(n)P'(n)}{P^2(n) + Q^2(n)} \end{cases} \qquad \cdots\cdots\cdots\cdots \quad (9)$$

We can get *P(n) and Q(n)* from standard signal generator and get *P'(n) and Q'(n)*' by calculation. Thus, we can get the eigenvalues of phase difference K_1(n) and K_2(n) finally by the formula (9).

4.3 Automatic gain compensation process

In a general way, every sample should be compensated. Thus, N samples in a cycle need to be calculated N times to compensate their gain offset. In order to meet real time operation of the transducerless RTU, we should reduce the times of calculation as possible as. It will be proved that the result is same to compensate the virtual value of the measured signal as to compensate the samples of sampled signal. Thus calculation times will be reduced from N times to one time.

The effective length sequence being processed x(k) is one cycle of a cyclic sequence. If N samples without compensation are sampled in a cycle of a analog input signal, there are:

x'(0), x'(1), x'(2), ..., x'(N-1)

Then Fourier Transform is.

$$X'(n) = \sum_{k=0}^{N-1} x'(k)e^{-j2\pi nk/N} = X'_r(n) + jX'_i(n) \qquad n=0,\ 1,\ \ldots,\ (N-1)/2 \qquad \cdots\cdots\cdots\cdots \quad (10)$$

If every sample is compensated, there are

$$X(n) = \sum_{k=0}^{N-1} Kx'(k)e^{-j2\pi nk/N} = K\sum_{k=0}^{N-1} x'(k)e^{-j2\pi nk/N} = K[X'_r(n) + jX'_i(n)] = KX'(n) \qquad \cdots\cdots\cdots\cdots \quad (11)$$

Virtual value of n^{th} harmonic with gain compensation is

$$X_V(n) = \sqrt{[KX'_r(n)]^2 + [KX'_i(n)]^2} = K\sqrt{[X'_r(n)]^2 + [X'_i(n)]^2} = KX'_V(n) \qquad \cdots\cdots\cdots\cdots \quad (12)$$

Here, X'_V is the virtual value without gain compensation. Since the virtual value of non-sinusoidal cyclic signal equals the square root of the summation of the square root of each harmonic, the virtual values of the measured signal are:

$$X_{SUM} = \sqrt{\sum_{n=1}^{(N-1)/2} [X_V(n)]^2} = \sqrt{\sum_{n=1}^{(N-1)/2} [KX'_V(n)]^2} = KX'_{SUM} \qquad \cdots\cdots\cdots\cdots \quad (13)$$

Here, X'_{SUM} is the virtual value of the measured signal without gain compensation. It is obvious that calculation efficiency is greatly improved.

4.4 Automatic phase compensation process

After the voltage and the current gains are compensated, we should compensate phase offset.

From the formula (8), we can export the formula:

$$\begin{cases} P = \sum_n \dfrac{K_1(n)P'(n) + K_2(n)Q'(n)}{K_1^2(n) + K_2^2(n)} \\ Q = \sum_n \dfrac{K_1(n)Q'(n) - K_2(n)P'(n)}{K_1^2(n) + K_2^2(n)} \end{cases} \quad \cdots\cdots\cdots\cdots \quad (14)$$

here, n=0,1,2, ..., (N-1)/2, n is harmonic number.

$P'(n)$ *and* $Q'(n)$' is respectively the mean active power and reactive mean power of the n^{th} harmonics with phase offset and can be get by calculation. K_1(n) and K_2(n) are the phase eigenvalues of the n^{th} harmonics and can be get by the formula (9). Thus, we can get the mean power of non-sinusoidal cyclic current circuit finally by formula (14).

5 CONCLUSION

Manual adjustment is a way of hardware. It needs nice adjustment by worker for the precision. Automatic compensation is a way of software. It is based on a microcomputer data processing. Using a set of standard AC analog signal as the input to the system, the gain and phase eigenvalues are identified by formulas (4) and (9). When RTU collects real-time analog signals from power system, the measure values are corrected by formulas (13) and (14). Thus the gain and phase offsets have been compensated automatically in the final results and complexity of algorithm is greatly simplified, the times of calculation is greatly reduced. The method has strong practicability.

Automatic gain and phase compensation using microprocessor data processing technology have many advantages over manual method, especially high efficiency and superior stability. It makes the process of adjustment easy, convenient and efficient.

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