A Power Quality Indexes Measurement System Platform with Remote Alarm Notification

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***Abstract*— Nowadays, with global development in Internet of Things (IoTs), electricity, water, and gas information readings should be done in a convenient way. However, existing smart electric meters (SM) mainly focus on the information of financial transactions (the energy bill), whereas little effort has been done to promote the instrumentation dimension of the metering infrastructure. In this paper, we propose and develop a power quality indexes (PQIs) measurement system platform with remote alarm notification for electrical systems. Compared with the existing state-of-the-art, the proposed platform requires less development and maintenance cost, exhibiting higher flexibility. In this system we include the main power quality indexes, including root-mean-square (RMS) value, active power *P*, reactive power *Q*, apparent power *S*, power factor (PF), fundamental power factor (PF$_1$) and total harmonic distortion (THD). To acquire those power quality indexes, we use a anticonjugate decomposition cascaded delayed signal cancellation (ACD-CDSC) technique. At last, we provide the experimental results of PQIs in a single-phase system to verify the effectiveness of the measurement platform with remote alarm notification in comparison with the Fluke power quality analyzer.**

***Index Terms*—Remote alarm notification, anticonjugate decomposition cascaded delayed signal cancellation (ACD-CDSC), power, power factor (PF), total harmonic distortion (THD), power quality index (PQI).**

I. Introduction

The popularity of nonlinear loads such as switching power converters, transformer energizing and capacitor switching, has brought much negative effect to the power systems [1], [2]. Present smart electricity meters are primarily used by electricity providers only for availability monitoring and billing. However, with the increasing number of distributed energy resources (DERs), such as wind turbines, solar panels, and electric vehicles, strong and sometimes unpredictable variations in power quality are introduced, leading to an increased need for an efficient and effective monitoring and control [3].

Although Smart Meters (SM) are considered as a main enabler of novel energy services [4], their concern has been constrained to the interface between technology and markets, and little effort has been paid to improve the instrumentation dimension of the metering infrastructure [5].

Power Quality (PQ) is on the contrary an area related to technology improvement, not yet correlated to the energy market and services [5]. PQ monitoring requires dedicated instruments, assessment algorithms and standards [6] – [8].

SM is becoming more and more frequently-used in active distribution networks [9], [10]. Their functionalities [11] are still limited artificially, but efforts have been done [12], [13] for the integration of PQ information into an existing SCADA-framework [14]. However, in [12], [13], Wi-Fi technology is used as the remote communication technique and suffers from shared spectrum and uncontrollable interference [3].

To solve this problem, a measurement system platform with remote alarm notification (RAN) for electrical systems is proposed and developed in this paper. It consists of a signal preprocessing (SP) block, analog-to-digital conversion (ADC) block, algorithm execution (AE) block and a RAN block. The signal preprocess block consists of transducers and signal conditioning boards. ADC block contains an analog-to-digital converter, AE block is a field-programmable gate array (FPGA) or other digital controller, and RAN block is a data transfer unit (DTU). Inside the DTU, short message service (SMS) would be adopted as the remote communication technique, so as to eliminate the potential delays, ease of deployment and reduce the maintenance cost associated with the networks connectivity. [3]. More details would be discussed in section III.

The original signal from the electrical systems would first be preprocessed into a suitable range by the SP block for the ADC process, then converted this small analog signal into digital form by the ADC block and sent the converted digital signals to the AE block. The considered power quality indexes (PQIs) would be calculated by the AE block with anticonjugate decomposition (ACD) [15] technique, cascaded delayed signal cancellation (CDSC) technique [16], [17] and with the help of the definitions of PQIs by IEEE Std 1459 [6], and the results can be observed by a computer. Once the observed PQIs are over or less than the designed thresholds, a RAN message would be sent to the user's phone via SMS.

Power quality indexes, including root-mean-square (RMS) value, active power *P*, reactive power *Q*, apparent power *S*, power factor (PF), fundamental power factor (PF$_1$) and total harmonic distortion (THD) are considered in this paper.

II. Theoretical Background

Three main theoretical concepts used in this paper will be introduced in this section: PQIs, CDSC [16], [17] technique and ACD [15] technique. The PQIs are the monitored targets of this paper, and in order to obtain the PQIs, the CDSC [16], [17] technique and ACD [15] technique will be used in the AE block (FPGA).

A. *Power Quality Indices*

PQIs are defined to quantify the condition of the power systems, which are the monitored target during the power system monitoring process. Different definitions for PQIs are defined by different organizations and most of them are very similar. In this paper, the PQIs defined by IEEE Std 1459 [6] are chosen and the mathematical models for them are listed in (1) – (11), while the symbols are collected and explained in Table. I.

TABLE I
Definitions for the Used Symbols

Symbol	Definition	Unit
t	Time	s
$v_{\alpha\beta}(t)$	Input $\alpha\beta$-frame signal	V
T/n	Delay time	s
T	Grid fundamental period	s
F_s	Sampling frequency	Hz
T_s	Sampling period	s
PQI_{FPGA}, PQI_{Fluke}	PQI measured by FPGA and *Fluke*	
n, m	Delay factor	-
h^*	Targeted harmonic order	-
h	Harmonic order	-
H	Highest considered harmonic order	-
φ	Initial phase angle	
φ_{Vh}, φ_{Ih}	Initial phase angle of voltage and current of h^{th} order component	rad
f	Power system frequency	Hz
ω	Angular frequency $2\pi f$	rad/s
γ	Phase angle	rad
γ_r	Rotation phase angle	rad
$v(t)$, $i(t)$	Instantaneous voltage and current	V and A
V_0, I_0	RMS value of the DC component of voltage and current	V and A
V_h, I_h	RMS value of the h^{th} order component of voltage and current (h=1, 2, …H)	V and A
V, I	RMS value of the voltage and current	V and A
θ_h	Phase angle between the current and the voltage of h^{th} order component (h=1, 2, …H)	rad
PF, PF_1	Power factor and fundamental power factor	-
P	Active power	W
Q	Reactive power	var
S	Apparent power	VA
THD_V, THD_I	THD of voltage and current	%

$$v(t) = V_0 + \sqrt{2}\sum_{h=1}^{H} V_h \sin(h\omega t - \varphi_{vh}) \quad (1)$$

$$i(t) = I_0 + \sqrt{2}\sum_{h=1}^{H} I_h \sin(h\omega t - \varphi_{ih}) \quad (2)$$

$$V = \sqrt{\sum_{h=0}^{H} V_h^2} \quad (3)$$

$$I = \sqrt{\sum_{h=0}^{H} I_h^2} \quad (4)$$

$$\mathrm{THD}_V = \sqrt{\frac{V_0^2 + \sum_{h=2}^{H} V_h^2}{V_1}} \cdot 100\% \quad (5)$$

$$\mathrm{THD}_I = \sqrt{\frac{I_0^2 + \sum_{h=2}^{H} I_h^2}{I_1}} \cdot 100\% \quad (6)$$

$$P = V_1 I_1 \cos\theta_1 \quad (7)$$

$$Q_1 = V_1 I_1 \sin\theta_1 \quad (8)$$

$$S = VI \quad (9)$$

$$\mathrm{PF}_1 = \cos\theta_1 \quad (10)$$

$$\mathrm{PF} = \frac{P}{S} \quad (11)$$

B. *Cascaded Delayed Signal Cancellation*

CDSC [16], [17] technique is a space vector based method to extract the information (including magnitude and phase angle) of the selected component in a $\alpha\beta$-frame space vector signal. It could be applied to both fundamental and harmonic components, so it could be used as a powerful tool in power quality monitoring.

In general, CDSC [16], [17] operator consists of a number of delay signal cancellation (DSC) operators, which are cascaded in series. The DSC operator can be presented as follows:

$$DSC_n\left[\vec{v}_{\alpha\beta}(t)\right] = \frac{1}{2}\left[\vec{v}_{\alpha\beta}(t) + \boldsymbol{R}(\gamma_r)\vec{v}_{\alpha\beta}\left(t - \frac{T}{n}\right)\right] \quad (12)$$

$$\boldsymbol{R}(\gamma_r) = \begin{bmatrix} \cos\gamma_r & \sin\gamma_r \\ -\sin\gamma_r & \cos\gamma_r \end{bmatrix} \quad (13)$$

$$\gamma_r = -\frac{2\pi h^*}{n}. \quad (14)$$

In which all the symbols used in above equations are collected and explained in Table. I.

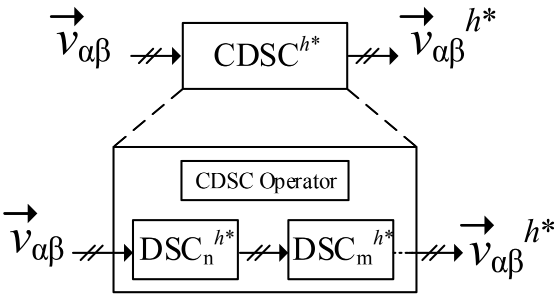

Fig. 1. Diagram of a general CDSC operator and the included DSC operators.

The DSC operator is renowned for its regular and customized magnitude response with periodic unity-gain and zero-gain points. The density and location of the periodic unity-gain and zero-gain points are determined by delayed factor, n, and the selected harmonic order, h^*. The CDSC [16], [17] operator with h^*, CDSC$^{h^*}$, is depicted in Fig. 1, consisting of several specific DSC operators with the same h^*, but different delay factor (n and m denoted in Fig. 1). By choosing the suitable parameters in CDSC block, it is capable of filtering out the desired information of specific component.

$$\begin{cases} V_{h^*} = 2\sqrt{v_{h^*\alpha}^2 + v_{h^*\beta}^2} \\ \theta_{V_{h^*}} = \tan^{-1}\left(\frac{v_{h^*\beta}}{v_{h^*\alpha}}\right) \end{cases} \tag{15}$$

C. Anti-conjugate Decomposition

Space vector-based methods are renowned for its power and high efficiency in the signal processing, such as CDSC [16], [17] technique. However, they are mainly conducted within a two-dimensional space, $\alpha\beta$-space, and the single phase signal cannot be adapted directly. To overcome this issue, a process named quadrature signal generation (QSG) is required during the transformation from single-phase signal into $\alpha\beta$-frame vector, which is by either phase shifting or delaying the original input signal or manipulating the output estimates (closed-loop QSG). Unfortunately, the merits are followed by the unnecessary computing burden or time delay.

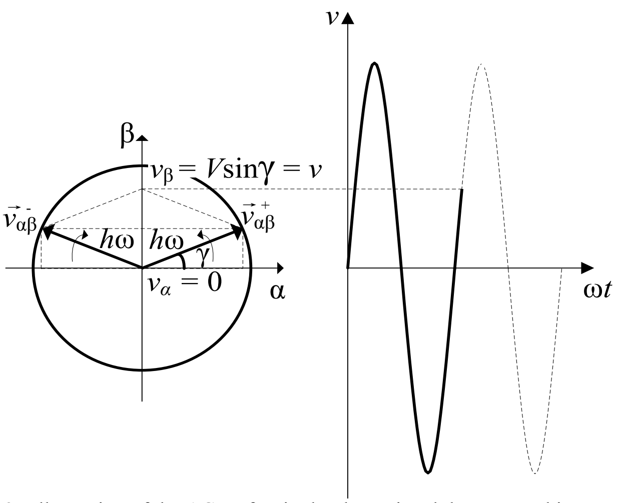

Fig. 2. Illustration of the ACD of a single-phase signal decomposed into a pair of oppositely rotating space vectors.

For this reason, a new concept of ACD is proposed in [15] in recent years, which brings a transformation of single-phase to $\alpha\beta$-space efficiently and without time-delay. In ACD [15] process, the input single-phase would be fed to the β-component directly while a constant zero to the α-component simply. The newly constructed $\alpha\beta$-space vector $\vec{v}_{\alpha\beta}$ is regarded as the sum of 2 $\alpha\beta$-space vectors with the same angular speed, a positive-sequence one, $\vec{v}_{\alpha\beta}^{+}$, and a negative-sequence one, $\vec{v}_{\alpha\beta}^{-}$. They are symmetrical with the imaginary-axis (β-axis) and with the same amplitude, which is the half of the amplitude of input single-phase signal. The positive-sequence one would be regarded as being in phase with the input single-phase signal. As shown in the Fig. 2, the single-phase input signal, v and the new constructed $\alpha\beta$-space vector, $\vec{v}_{\alpha\beta}$ would be assumed as:

$$v = V\sin\gamma = V\sin(\omega t + \varphi). \tag{16}$$

$$\vec{v}_{\alpha\beta} = \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \vec{v}_{\alpha\beta}^{+} + \vec{v}_{\alpha\beta}^{-} = \begin{bmatrix} v_\alpha^{+} \\ v_\beta^{+} \end{bmatrix} + \begin{bmatrix} v_\alpha^{-} \\ v_\beta^{-} \end{bmatrix} = \begin{bmatrix} 0 \\ v \end{bmatrix} \tag{17}$$

where the used symbols in (16) and (17) would be assembled and explained in Table. I.

As explained in (17) and Fig. 2, $v_\alpha^{-} = -v_\alpha^{+}$ and $v_\beta^{+} = v_\beta^{-} = \frac{v_\beta}{2}$. It is obvious that the v_α would always equal to 0 and v_β would equal to v. Signals with different frequency would have similar effect, so the harmonics within the input single-phase signal can also be paired with corresponding decompositions and transformed into $\alpha\beta$-space vectors.

III. Implementation

In this paper, the operations of the algorithm are processed by an *Altera DE2-115* FPGA, the ADC sampling frequency f_s is 25kHz. Two test cases of the system are designed for the demonstration of this system. The input harmonics are generated by a current i through a circuit consists of a diode rectifier, a resistor R, an inductor L, two capacitors $C1$ and $C2$, and a power source voltage v. The structure and parameters of the tested circuit are shown in Fig. 3. The case A is defined as the C1 is connected to the system, while case B is defined as the C2 is connected to the system.

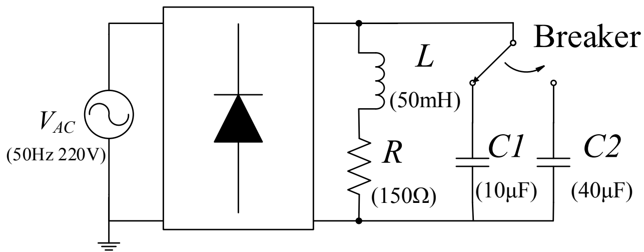

Fig. 3. The structure of the tested system.

As the FPGA can only deal with the digital signals and the signals from the tested system as shown in Fig. 3 are in analog form, the ADC provided by a digital signal processor (DSP) *TMS320F2812* is made used of in this paper, to convert the small analog signals into digital signals. The large electrical signals from the tested system have to be transformed into small analog signal with appropriate input voltage range (0-3.3V) for the safety operation of the DSP, thus current and voltage signal conditioning boards are required to convert large electrical signals into small analog signals before being sent to the ADC of the DSP. The current and voltage conditioning board is made used by the *HS02-50/0.05A-P* current transducer and *LV25-400* voltage transducer. The hardware structure of the system is

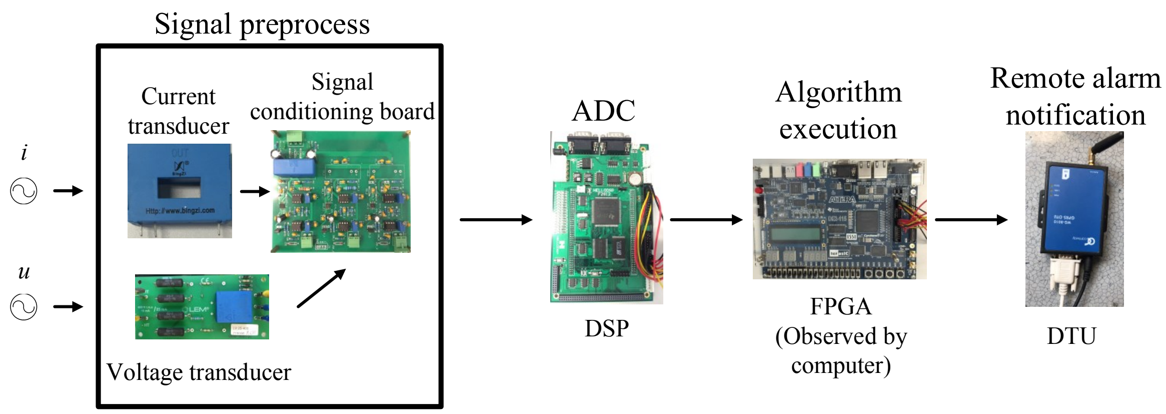

Fig. 4. The hardware structure of the system.

shown in Fig. 4. When the FPGA-detected PQIs are larger or less than the designed thresholds (eg. $THD_I > 50\%$), the DTU module will be triggered via RS232 to send an alarm message to the user's mobile phone. The used DTU module is the model WG-8010 by *comway* company. A sim card of *Companhia de Telecomunicações de Macau* is used in the DTU for telecommunication service.

For comparison with the proposed system platform, the measured PQIs by using *Fluke* power quality analyzer is used. For the proposed platform, the PQIs can be observed via *Signal Tap II Logic Analyzer* provided by *Quartus II* software in the computer. To verify the practicability of the platform, the measurements of the V_{RMS}(V), I_{RMS} (A), S (Va), P (W), Q (Var), PF (percentage), PF_1 (percentage) and THD_I (percentage) of the 2 tested cases by using the *Fluke* power quality analyzer are presented and compared in Table. II. The error is defined as follow (the used symbols are explained in Table. I):

$$\% \text{ Error } = \left| \frac{PQI_{FPGA} - PQI_{Fluke}}{PQI_{Fluke}} \right| \cdot 100\% \qquad (15)$$

TABLE II
COMPARISON OF THE EXPERIMENTAL RESULTS OF 2 CASES MEASURED BY THE PROPOSED PLATFORM AND FLUKE POWER QUALITY ANALYZER

PQIs	Case A			Case B		
	PROPOSED	FLUKE	ERROR	PROPOSED	FLUKE	ERROR
V_{RMS} (V)	228	229	0.4%	228	229	0.4%
I_{RMS} (I)	1.62	1.61	0.6%	2.34	2.35	0.4%
P (W)	333	342	2.6%	387	383	1.0%
S (Va)	365	371	1.6%	534	533	0.2%
Q (Var)	149	144	3.4%	368	371	0.8%
THD (%)	18	18	0%	55	53	3.8%
PF_1 (%)	91	92	1.1%	74	71	4.2%
PF (%)	92	93	1.1%	86	84	3.6%

While in case B, the DTU would be triggered when the detected THD is over 50%. An alarm message has been received by the mobile phone, as shown as Fig. 5.

Fig. 5. Alarm message sent by the DTU.

IV. CONCLUSION

In this paper, a power quality indexes measurement system platform with remote alarm notification for electrical systems is proposed. It consists of a SP block, ADC block, AE block and a RAN block. Once the detected PQIs are over or less than the designed thresholds, a RAN message would be sent to the user's phone via SMS. Power quality indexes, including RMS value, active power P, reactive power Q, apparent power S, power factor (PF), fundamental power factor (PF_1) and THD_I is considered and included in this system. With this system, the administrators can be notified through SMS service in real time, and the efficiency and flexibility can be improved.

V. ACKNOWLEDGMENT

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