Versatile High-Sample Frequency Power Quality Measurement Device

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***Abstract*—Rapidly advancing technology has seen the adoption of non-linear loads which may be considered improving efficiency and decreasing cost. Unfortunately this advance of technology often exceeds the measures to control the unforeseen effects of systems or unwanted interference between multiple manufacturer's devices. In this paper a relatively modern building, with a common experience of conducted electromagnetic interference including power quality problems such as harmonic distortion of the supply, is discussed. A system is developed to monitor the power quality of the mains in various locations and aid in identifying the extent of the electromagnetic interference. With high sampling frequency and synchronising of measurement data between various locations accurate within millisecond scale in the power distributed user network, the extent of conducted emission events especially sub millisecond range, is analysed.**

***Index Terms*—Power quality, Total harmonic distortion, Raspberry Pi, Multi-point measurement, Electromagnetic interference**

I. INTRODUCTION

The adoption of power supplies utilising switching power electronics converter (SPECs) has drastically increased over two decades [1], [2]. This adoption has advantageous elements such as higher efficiency, weight and size reduction as well cost savings [3]. The disadvantageous elements linked to this trend include radiated and conducted interference between devices, general reduction of power quality due to electromagnetic interference, which can lead to device malfunction, overheating of systems and in certain cases failure of the electrical supply often leading to enormous financial implications [2], [4]. The adoption of SPECs is unlikely to change, therefore techniques must be developed to counteract or control the negative effects. Also, standards should be changed appropriately with the advance of technology to force compliance from manufactures [5]. A common problem with electromagnetic interference (EMI) diagnosis is identifying the source of the interference [6], [7]. This originates from a two folded problem.

EMI is traditionally observed using expensive receivers, that have a very high dynamic range but that were originally very slow. Next to this, they were only capable of observing a single point in the system under investigation. With the development of Fast Fourier Transform (FFT) based test receivers, the speed with which an EMI analysis was performed increased drastically, however the costs did as well. FFT receivers are based on high speed Analog-to-Digital Converter (ADC) followed by Short Time Fast Fourier Transform (STFFT), research has shown this to be applicable in many cases for low frequency analysis as well using relatively cheap oscilloscopes [8]–[10]. Several benefits of using a time domain approach can be found in [11]. Amongst other, the changes in background noise do not pose an issue, several Device Under Test (DUT) functional modes can be tested, and the effective measurement time can be reduced. In case of using oscilloscopes together with Digital Signal Processing (DSP) to evaluate EMI, another opportunity arises. Due to the synchronised acquisition of signals over multiple channels, one is able to decompose the interference into the different modes [12] (normal mode, differential mode and common mode) [10], [13], and to extend frequency ranges with higher dynamical range [14], [15]. Several other opportunities have been presented in [10], like the effect of *di/dt* on the magnetic field and varying impedance. These solutions and opportunities are often limited to a single system or DUT, while most power quality (PQ) issues arise in large systems with many different devices interconnected. In this paper a system is developed to assist with the investigation of PQ of large and complex installations, especially in weak or islanded smart grids cases [16]. PQ analyzers, similar to EMI test receivers, are often expensive and inflexible in their programming as they are developed according to standards and their main function is logging data over long periods of time. Which inherently poses a data transmission and storage problem, when distributed observations are required/wanted.
This paper proposes to use credit card sized, single board computers in combination with Picoscopes (USB connected oscilloscope) as a power monitoring node (PMN); namely a Raspbery Pi 4 (RP4) platform, with the capability of being placed in multiple locations due to a small size footprint and flexibility with communication link and power supply requirements. On each PMN a database is hosted which stores data processed during monitoring of the grid supply phases

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with a flexible sampling frequency. The proposed system is deployed in a real world problem in which a modern building experienced significant PQ problems. The strategies used to address the PQ problems in this specific case will be discussed as well as measurements of the difference in PQ before and after implementation of corrective measures. The RP4 receives streaming data from a Picoscope which monitors voltages from phases L1, L2, L3 and neutral to protective earth (PE). The streamed data is processed to obtain the rms voltage and total harmonic distortion (THD). The wave-forms are monitored for any significant events. In case an event occurs the data window of the event is stored locally on the device for later inspection and a timestamp is stored to note the occurrence of the event.

II. CAPABILITY OF THE PMN

The RP4 device used in the PMN contains a powerful Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5 GHz with 4 GB RAM. Importantly the RP4 may be connected via ethernet (ETH) or IEEE 802.11ac wireless making this device truly versatile. The CPU performance allows on the fly processing of high sample rates. In this case sample rates of up to 10 MS/s were achieved with multi-threading utilised for processing while continuously streaming data from the Picoscope. This enables very high resolution sampling as well as synchronisation between devices in different locations for analysis of events between different measurement points. The high sample rate allows detection and monitoring of high frequency transients or voltage deviations.

III. PQ CASE STUDY

In [5] a situation is described in which a modern building experienced major PQ issues directly after commissioning. Initially a capacity of 4.0 MVA was installed and determined to be sufficient according to the consults. Once the building was equipped and light emitting diode (LED) luminaires installed significant distortion of the supply occurred. LED lights especially appear to contribute significantly to THD [17], [18]. In Fig. 1, the supply voltage wave-forms are shown at the point of interface (POI) with the grid.

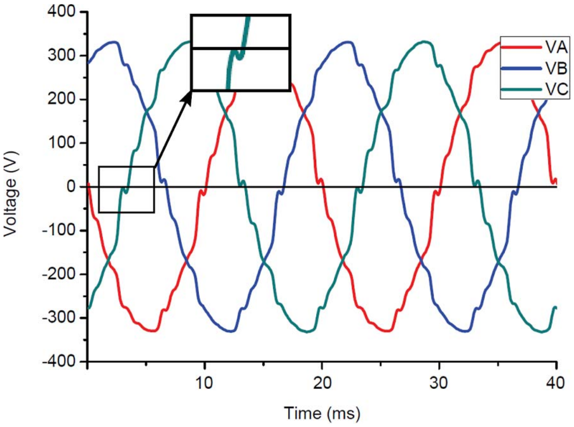

Fig. 1: Highly distorted supply voltage [5]

Especially worrying is the double-zero crossing, which causes faults in certain devices. After investigation it was determined that the most cost effective corrective action would be to add more capacity to the power supply to the building. Another two transformers of 1600 kVA each were installed and the total capacity was increased to 7.2 MVA. This to supply a real power consumption, which at the time is less than 3 MW. This can be considered a large, and arguably unnecessary, expense to the developer. Especially since technicians raised concerns that this was a possibility during the building design phase. More details of the negative effects of this distorted supply voltage are discussed in [5].

IV. PQ MEASUREMENT RESULTS

The measurements discussed in the case study are performed once more after the corrective measures are implemented. Measurement point A is located at the POI with the building and the grid in the main control room (MCR) on the low voltage (LV) side of the transformer from medium voltage (MV). The second point is measured in a lab a significant distance from the MCR and is referred to as point B. The measurement equipment or PMN is setup in a simple manner as depicted in Fig. 3.

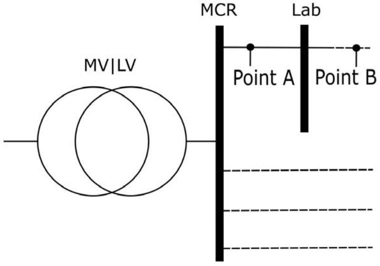

Fig. 2: Single line diagram of measurement locations

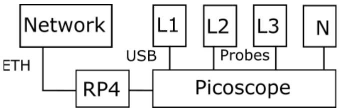

Fig. 3: Measurement setup diagram

The phase voltages and neutral are measured with respect to PE with a 4 channel Picoscope. Voltage probes are used to connect the phase bus bars and industrial connector to the Picoscope at point A and point B respectively. The Picoscope is connected to the RP4 via USB. The RP4 connects to the local network via ordinary Ethernet cable. The RP4 is accessible via SSH over the network (or internet) and controls the Picoscope via USB commands. The latest measurement results shown in Fig. 4 and Fig. 5 illustrate the voltage supply at the POI and measured at a point in a laboratory. The situation has clearly improved, but is far from ideal. Note the absence of double-zero crossings and voltage wave-form deformation which is diminished. Visual inspection of the measurement results plotted in Fig. 4 compared to the measurements plotted in Fig. 5 show slightly lower THD present in the latter. The harmonic distortion measured is tabulated in Table. I. From the calculated THD it is confirmed that the distortion levels are higher measured at point A. The measurements from [5] are added for purpose of comparison. The improved PQ of phase C can be attributed to many factors. Most likely this is due to the changes implemented with the corrective measures taken initially with the addition of extra supply capacity.

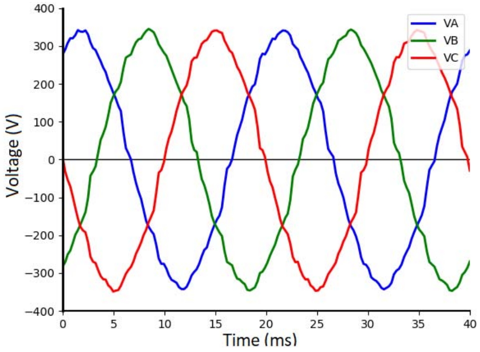

Fig. 4: MCR (Point A)

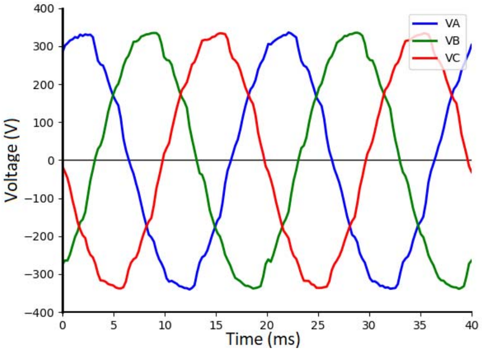

Fig. 5: Lab (Point B)

TABLE I: THD measurement results

VTHD (% Fundamental Freq.)						
	Point A			Point B		
Period	VA	VB	VC	VA	VB	VC
Previous [5]	5.4	5.4	5.7	-	-	6.7
Current	4.5	4.4	4.4	3.4	3.3	3.3

CONCLUSION

Previously, power quality analysers which are inflexible in their programming and expensive were commonly used in conducted electromagnetic interference investigations. The ease of use associated with this monitoring device has truly proved to be valuable. With quick installation times, seamless connectivity and high performance packed into a small and low cost package the possibilities are vast. The measurement data were easily accessed utilising SSH via local network for observation or post-processing. The measurement data-set discussed in the case study is easily duplicated and showed the improved power quality achieved by the additional installed 1600 kVA capacity to the building power system of 4.0 MVA. Increasing the supply capacity amongst other measures reduced harmonic distortion by a significant margin in phase voltages from average of 5.5 % to 4.4 % of fundamental harmonic at the POI with the grid. Line to neutral voltages in user zones (Point B) reduced by a margin on voltage phase C from 6.7 % to 3.3 % of fundamental harmonic. High sample rates of up to 10 MS/s were performed for detection of high frequency transients and noise. The findings of this paper conclude that such mentioned measurement devices can be used for convenient building or smart-grid power quality measurements.

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