Peak Point Detection of Phase-to-Phase Effective Voltages for Smart Grids: A Comparative Study

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***Abstract*—Smart grid systems include many different power sources such as renewable and fossil energy basis. While collecting all type of energy on the grid, phase order, frequency, maximum voltage value and synchronization time of each power station should be known for a smooth operation of the smart grid. Therefore, the detection of peak values of grid voltages will help the smart grid operators to connect all power sources to the grid without having problems like voltage collapse, over voltage, over current and shutting down the power station. For this purpose, in an effective and efficient manner, we compare the original AMPD and the modified AMPD methods in terms of the peak point detection performance, analyze how the modified AMPD method is used for the phase-to-phase effective voltage values and show how FPGAs are able to accelerate the detection time as on-line.**

Keywords-Smart grid; Automatic multiscale-based peak detection; Phase-to-phase effective voltages, comparison

I. INTRODUCTION

According to the World Energy Outlook 2016 [1], the global energy-related carbon-dioxide emissions will reach 43.7 Gt in 2040, while it was 32.2 Gt in 2010. In the context of this phenomenon, smart grids play an important role to realize decarbonization in the energy sector [2, 3]. Since, smart grids have self-healing and self-monitoring capabilities, remote checks/tests, distributed generation, two-way communication, digital structure, etc. in comparison to the conventional electrical grids [4-6]. However, in terms of the voltage stability, the peak detection of grid voltages occurs as one of the fundamental requirements to meet the power quality standards in smart grids [7, 8].

In the literature, many different methods have been developed for the detection of peaks in different signals. *Wang et al.* proposed an R-peak detection method based on the adaptive Fourier decomposition for noisy electro-cardiography signals [9]. The proposed method achieved good positive predictivity performance. *Sumukha et. al.* used a sequential learning algorithm for detecting the peaks in photoplethysmogram signals [10]. The probability value was found as 0.8649. *Ghozzi et. al.* employed a lifting wavelet transform method to detect the peaks in ground penetrating radar signals [11]. The employed model estimated the thickness with the mean absolute percentage error of 14.27%. The global maximum power point was tracked in average 2.84 seconds. *Shi et. al.* improved a Gaussian fitting-based Levenberg-Marquardt algorithm in order to detect the peak wavelength for fiber Bragg grating sensors [12]. The improved method has the peak detection uncertainty of 0.87 pm with using STM32F4. *Schirmer et. al.* implemented the multilayer perceptron artificial neural network approach in the cyclic voltammetry peak detection using a FPGA [13]. The low power was consumed in online correction of drug dosage.

Kumar et. al. proposed the Weibull Pareto sine-cosine optimization algorithm for the maximum power point detection of a partially shaded photovoltaic panel [14]. The global maximum power point was tracked in average 0.73 seconds. *Singh et. al.* used a simple control algorithm for the peak detection of load currents of distribution static compensator using a DSP [15]. The detection performance was found satisfactory under unbalanced and balanced loads. *Kim et al.* employed an inductance maximum and minimum peak detection algorithm for the sensorless direct torque control of a switched reluctance motor [16]. The commutation point and instantaneous torque were computed without look-up tables. *Lee et. al.* utilized from the delta square operation in order to detect voltage sags and swells of a single-phase inverter system [17]. The delay in the average detection time was decreased within one sampling time. In addition to these studies, Bayesian algorithm [18], fuzzy-genetic approach [19], adaptive thresholding [20], gravitational search algorithm [21], golden band search algorithm [22], Hilbert transform [23], Kalman filtering [24], etc. were also used for the peak detection purposes in the literature.

In this paper, as the crucial contribution to the existing literature, both the original AMPD method in off-line form and the modified AMPD method in on-line form have been employed in order to compare their peak point detection performance for the phase-to-phase effective voltages. Many constructive assessments have been made to help smart grid operators in the decision support process.

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II. Detection of Daily Maximum and Minimum Peak Points for Phase-to-Phase Effective Voltages

In this paper, the phase-to-phase effective voltage values of a medium-voltage transformer located in the Organized Industrial Zone have been used for the period from September 1 to September 31, 2015. The corresponding dataset contains 4320 data points recorded at 10-min intervals for each L3-L2, L2-L1 and L1-L3 phase-to-phase effective voltages.

The automatic multiscale-based peak detection (AMPD) method has been employed for the detection of daily maximum and minimum peak points for phase-to-phase effective voltages in this study. The original AMPD method is a novel technique that uses basically matrix equations to calculate the peak points and determines the local maxima points in different time periods, named as the scales. Herein, the term scale represents the number of compared data at a time. In addition, the original AMPD method is separated into four different steps as local maxima scalogram (LMS) calculation, row-wise summation of LMS, LMS rescaling and peak detection [25]. In our study, we modified the original AMPD method by only running the stages of LMS calculation and peak detection in order to make the online processing possible on an FPGA. The other stages have been performed in advance as a calibration phase. The detailed explanations about the original AMPD method and the modified AMPD method can be found in [25] and [26], respectively. The following subsections make the performance comparison of both models in terms of detecting daily maximum and minimum peak points.

A. Simulation Results for the Original AMPD Method

The daily maximum and minimum peak points detected by the original AMPD method are illustrated in Figures 1(a) to 1(c) for L3-L2 (V_{L3-L2}), L2-L1(V_{L2-L1}) and L1-L3 (V_{L1-L3}) line voltage values, respectively.

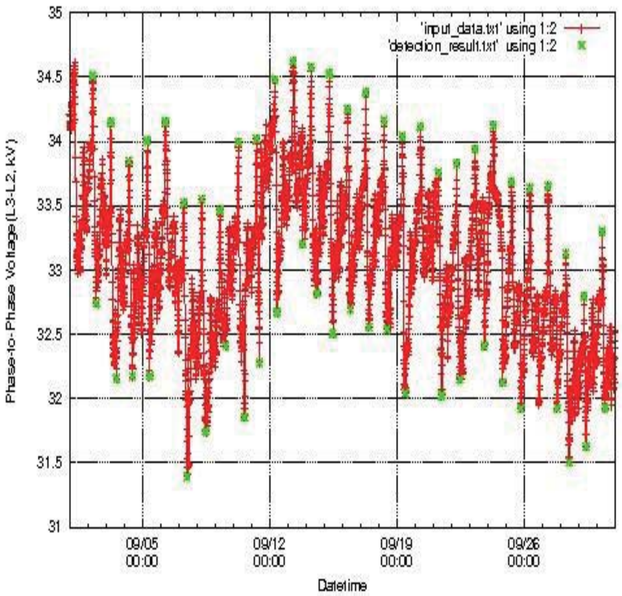

Fig. 1(a). Daily maximum and minimum peak points detected by the original AMPD method for L3-L2 line voltage values

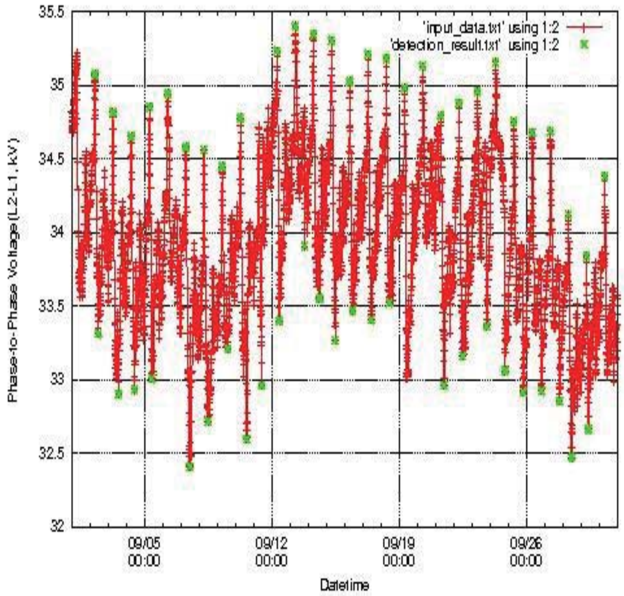

Fig. 1(b). Daily maximum and minimum peak points detected by the original AMPD method for L2-L1 line voltage values

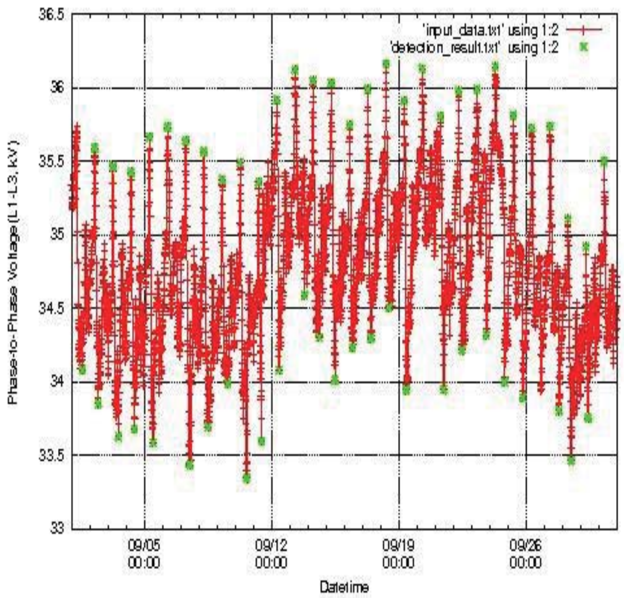

Fig. 1(c). Daily maximum and minimum peak points detected by the original AMPD method for L1-L3 line voltage values

In case of comparing these figures in detail, the original AMPD method detects the daily maximum peak points with the sensitivities of 96.67% for V_{L3-L2}, 93.33% for V_{L2-L1} and 96.67% for V_{L1-L3}. In addition, most of the daily maximum peak points are observed at the time of 06:30, 06:40, 06:50, 07:00 and 07:10. On the other hand, it detects the daily minimum peak points with the sensitivities of 86.67% for V_{L3-L2}, 83.33% for V_{L2-L1} and 86.67% for V_{L1-L3}. Besides, most of the daily minimum peak points are identified at the time of 10:50, 11:00, 11:10, 14:20 and 19:20. It should be noted that the original AMPD method introduced in this section has been designed in C Programming Language and it has been run as the off-line.

B. Simulation Results for the Modified AMPD Method

We have designed the modified AMPD method in the Verilog Hardware Description Language with the Cadence NC-Verilog Simulator and implemented with the Xilinx Kintex-7 XC7K325T FPGA board [27]. In addition, the Vivado 2016.3 simulator has been used as a mapping tool and the DC919A-F with 100 MHz maximum system frequency has been utilized as an analog-to-digital converter (ADC). The bit size has also been selected as 12, which is compatible with the ADC. Figure 2 shows how to implement the proposed system on the FPGA board. Firstly, FPGA sends the initial signal to ADC that converts the analog signal to digital signal and then, 12-bit input data and 100 MHz system clock signal are sent to FPGA. Finally, our modified AMPD method starts the detection of daily maximum and minimum peak points only computing the LMS and the standard deviation. It should be noticed that the modified AMPD method presented in this section has been run as the on-line.

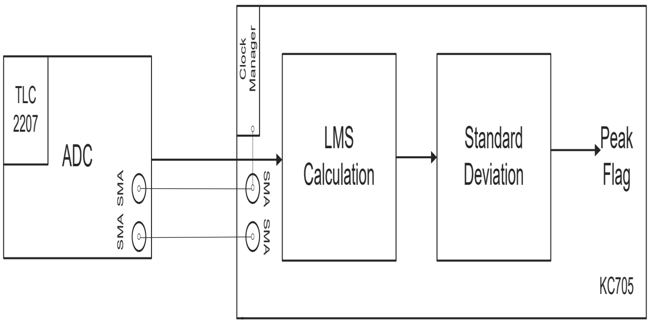

Fig. 2. The proposed system implemented on the FPGA board

The daily maximum and minimum peak points detected by the modified AMPD method are depicted in Figures 3(a) to 3(c) for L3-L2 (V_{L3-L2}), L2-L1(V_{L2-L1}) and L1-L3 (V_{L1-L3}) line voltage values, respectively.

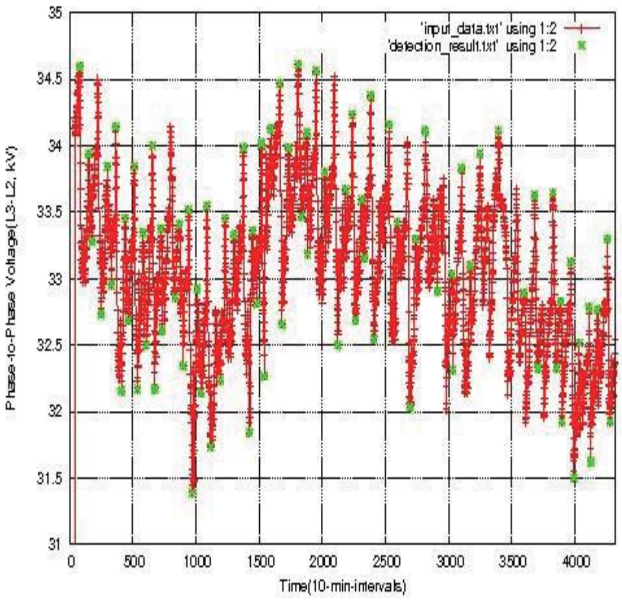

Fig. 3(a). Daily maximum and minimum peak points detected by the modified AMPD method for L3-L2 line voltage values

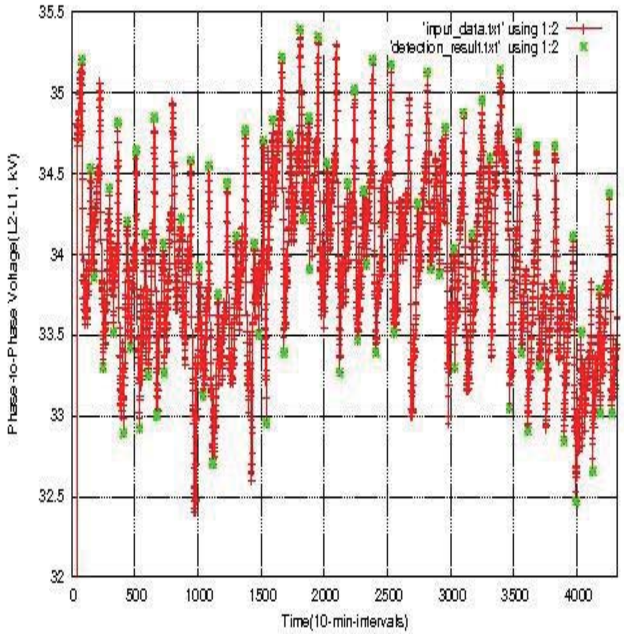

Fig. 3(b). Daily maximum and minimum peak points detected by the modified AMPD method for L2-L1 line voltage values

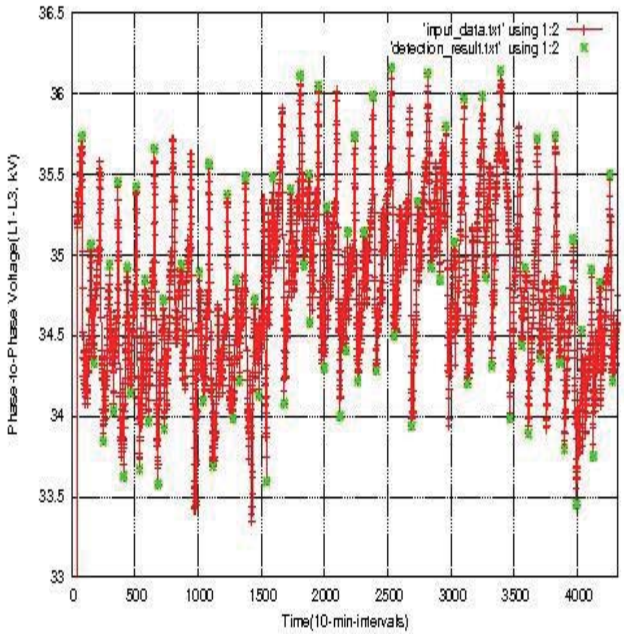

Fig. 3(c). Daily maximum and minimum peak points detected by the modified AMPD method for L1-L3 line voltage values

In case of comparing these figures elaborately, the modified AMPD method detects the daily maximum peak points with the sensitivities of 63.83% for V_{L3-L2}, 62.50% for V_{L2-L1} and 69.77% for V_{L1-L3}. In addition, most of the daily maximum peak points are observed at the time of 06:30, 06:40, 06:50, 17:00 and 19:10. Despite that, it detects the daily minimum peak points with the sensitivities of 88.24% for V_{L3-L2}, 88.24% for V_{L2-L1} and 76.92% for V_{L1-L3}. Furthermore, most of the daily minimum peak points are identified at the time of 10:50, 11:00, 11:10, 18:10 and

22:40. Apart from these evaluations, the resource usage summary of Kintex-7 XC7K325T FPGA board is also given in Table I. In terms of the performance, the latency of peak detection has been recorded as 40 clock cycles for the scale 65. So, this corresponds to the detection latency of 400 ns for the modified AMPD method.

TABLE I. RESOURCE USAGE SUMMARY OF THE FPGA BOARD

Resource Type	Existing Resource	Employed Resource	Utilization Ratio (%)
Number of Slice Look-Up Tables (LUTs)	203800	3016	1.48
Number of Slice Look-Up Tables as Distributed RAM (LUTRAMs)	64000	96	0.15
Number of Flip-Flops (FFs)	407600	4289	1.05
Number of Block RAMs (BRAMs)	445	52	11.69
Number of DSP Blocks	840	31	3.69

III. CONCLUSION AND DISCUSSION

In this paper, both the original AMPD method and the modified AMPD method have been used to detect the daily maximum and minimum peak points of phase-to-phase effective voltage values of a medium-voltage transformer located in the Organized Industrial Zone. The original AMPD method has the average sensitivity of 95.56% in the stage of detecting the daily maximum peak points, while it is found as 85.56% in the stage of detecting the daily minimum peak points. On the other hand, the modified AMPD method possesses the average sensitivity of 65.37% for the phase of detecting the daily maximum peak points, while it is obtained as 84.46% for the phase of detecting the daily minimum peak points.

It is obvious that the original AMPD method shows better sensitivity than the modified AMPD method in terms of the maximum peak point detection. The reason for this is that the original AMPD method also contains the steps of row-wise summation of LMS and LMS rescaling along with LMS calculation and peak detection. Despite that, both methods exhibit almost the same sensitivity in terms of the minimum peak point detection although the modified AMPD method only contains the steps of LMS calculation and peak detection. In addition to this, the modified AMPD method has the capability of on-line processing on a FPGA while the original AMPD method is run as off-line. Furthermore, the modified AMPD method only utilizes the 3.6% of all FPGA resources and it leads to the short detection latencies. As a result of overall evaluations, the proposed system is going to serve as an efficient and effective decision support mechanism for smart grid operators in the on-line detection of daily maximum and minimum peak points for the phase-to-phase effective voltages.

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