Development of a Micro- Phasor Measurement Unit for Distribution System Applications

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***Abstract*— In current scenario, Phasor Measurement Units (PMUs) are positioned mainly on transmission systems. The novelty of PMUs can also be best utilized in the case of distribution systems. This project extends the concept of Synchrophasor Technology, currently in use for transmission system, to provide synchronized measurements at distribution level by designing an instrument specifically for the purpose, called Micro-PMU. It investigates the properties of a Micro-PMU, taking distribution system constraints and the possible sources of measurement errors into account and then presents the hardware implementation of a prototype of Micro-PMU. Commercial importance and suitability for installation in actual distribution system of the product i.e. Micro-PMU has also been discussed.**

***Index Terms*: Phasor Measurement Units, Synchrophasor, Micro-PMU, Power Distribution, Smart Grid**

I. INTRODUCTION

Phasor Measurement Unit (PMU) that provides time synchronized phasor data is now a mature technology and is capable of realizing many applications related to power systems [1]. PMUs sample voltage/current signal and estimate the corresponding phasors. Along the process, they time stamp the phasors with time information from Global Positioning System (GPS) [2][3] receivers. The time tagged phasor data is communicated to further levels which include Phasor data Concentrators (PDCs) or Super PDCs via a suitable communication network. As per the need, multiple PMUs installed in an area hold the capability of dynamic state estimation of power system. The applications of PMU data is huge ranging from state estimation, Power system protection to post mortem analysis and Power System Planning.

When it comes to application of synchrophasor technology to power distribution system, a specialized PMU (called Micro-PMU) is required.[4] This is done keeping in view of the differences in measurement parameters in transmission and distribution network. The specifications of a measurement equipment for distribution system is quite different from that for transmission systems.

This paper first analyses the specialties that are needed to be catered for distribution system measurements. It also considers the possible sources of measurement errors[5] and their theoretical and practical limits. Based on above constraints, solutions are formulated to overcome them. Hardware implementation of a prototype of Micro-PMU is presented. Fig. 1 shows the hardware model of the prototype of Micro-PMU prepared as a part of research work of this paper. It has been designed to fit the measurement requirements at Power Distribution level. It does high speed processing, phasor estimation and accurate time stamping of input signals with the use of cutting-edge microcontrollers. [6] For signal acquisition, signal processing and phasor estimation, an ultra-high performance microcontroller, Tiva™ C Series TM4C123G (EK- TM4C123GXL) from Texas Instruments is used. For accurate time stamping, an ESP 8266 Wifi Development Module is used along with a central GPS server. The Micro-PMU presented is of Measurement type. With certain variations, it can be made of Protection type. The optimization involved in design of the product is significant, over similar models proposed by [6][7], from using low cost high power microcontrollers to cheaper and versatile wifi modules. Hence it holds huge commercial potential for large scale installation in actual distribution systems with a sound business case.

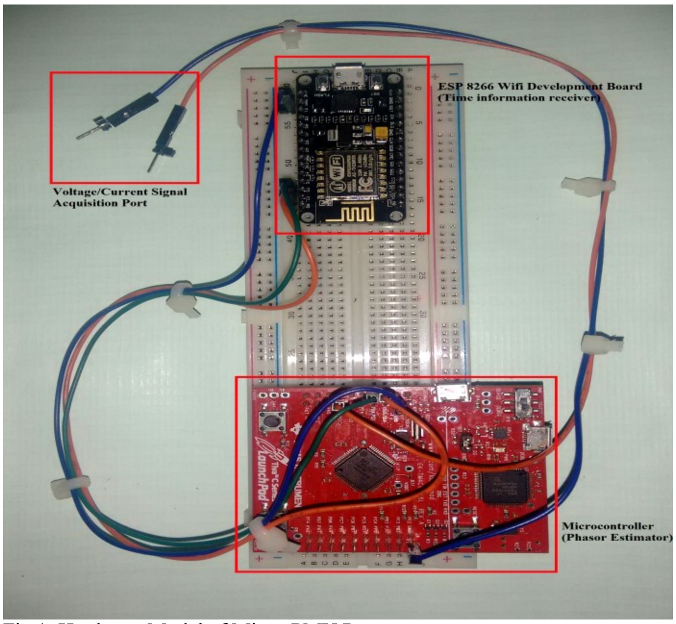

Fig 1. Hardware Model of Micro-PMU Prototype

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II. REQUIREMENT OF A SPECIALISED PMU FOR DISTRIBUTION SYSTEM

Till date, Synchrophasor Technology has only been successfully employed to observe transmission system. To apply it to distribution system, the difference between transmission and distribution system measurements must be analyzed first. Accordingly, suitable customization can be made and distribution system can be observed using synchrophasor technology.

The differences between transmission and distribution system measurements are as following. 1) Phase angle resolution for distribution system is as low as 20 milidegrees whereas in case of transmission system, it is around a few degrees.[7] 2) Voltage magnitude resolution is much lower in case of distribution systems. 3) Distribution measurements are affected by various errors and white noises to a greater extent than transmission systems.[7] 4) With increasing distributed sources of generation, distribution system needs more number of measurement units than transmission system, hence the business case for actual installation of distribution system measurement unit needs to be made strong. It is due to the above reasons, that there is a need of specialized PMUs for distribution system measurement adhering to synchrophasor technology. That specialized measurement unit for distribution system is named as Micro-PMU. The parameters of an ideal Micro-PMU are decided by the voltage/current magnitude and phase angle resolutions that it is aimed to measure.

III. MICRO-PMU PROTOTYPE PARAMETER SPECIFICATIONS

Based on the requirements of a Micro-PMU, a prototype of the same was prepared. The parameters of the same is tabulated in table 1.

Parameter	Parameter Value
ADC Bitwidth	12
ADC Sampling Rate	2.5 kHz
System Clock Frequency	80 MHz
Reporting Rate	50 Hz

Table 1. Micro-PMU prototype parameter specifications

Additionally, there can also be installation of a predictive compensator block with the synchronized time receiver of the Micro-PMU to compensate the system clock drift from GPS time. It will sense the drift of system clock from GPS clock in one time interval (1s for GPS) and accordingly predict the amount of compensation needed at each clock ticks as per fig.2.

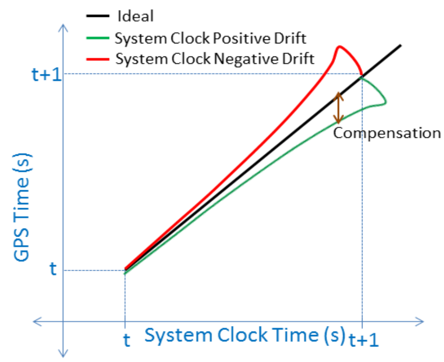

Fig.2 Functioning of Predictive Compensator

IV. HARDWARE AND SOFTWARE REQUIREMENT FOR MICRO-PMU PROTOTYPE

The following hardwares were required for realization of prototype of a standard Micro-PMU.

1) Tiva™ C Series TM4C123G Launch Pad (EK-TM4C123GXL) from Texas Instruments (Fig.3). It is used for Voltage/Current Signal Acquision, Signal Processing, Phasor Estimation and Time tagging. [8]

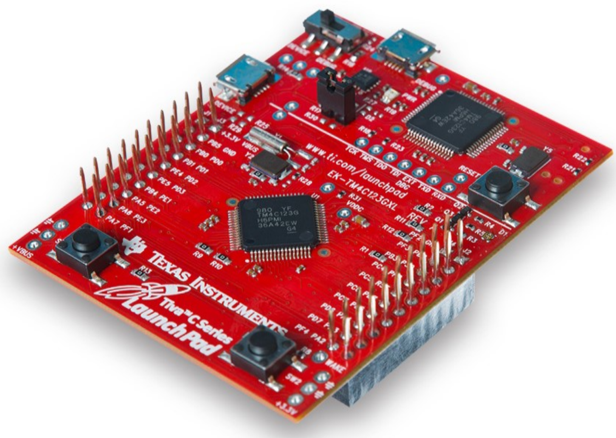

Fig. 3 Tiva™ C Series TM4C123G Launch Pad

Specifications of above microcontroller is given in Appendix. It was programmed using IAR Embedded Workbench from IAR Systems.

2) ESP 8266 Node Mcu Wifi Development Board (Fig.4). It is used to retrieve time information from internet and communicate the same to the microcontroller via some suitable mode of communication.

Fig. 4 ESP 8266 Node Mcu Wifi Development Board

Above wifi module was programmed using Arduino IDE from Arduino.

V. FUNCTIONS OF TM4C123G MICROCONTROLLER

The TM4C123G microcontroller is used for signal acquisition, signal processing, phasor estimation and time tagging. The functional block diagram of the above microcontroller in Micro-PMU prototype is given in fig. 5.

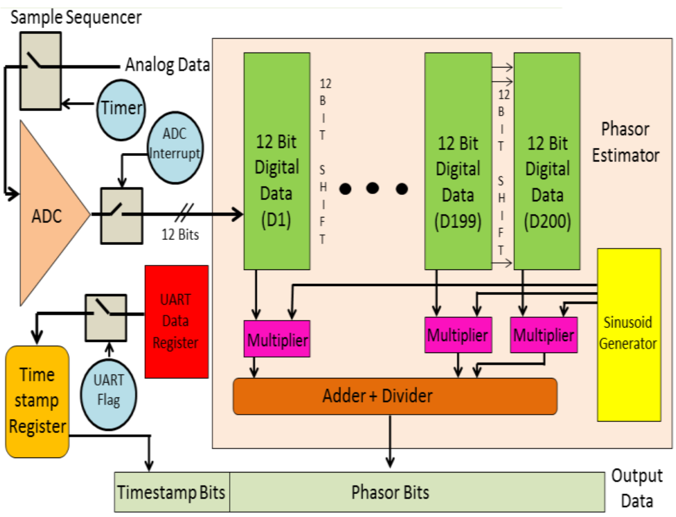

Fig. 5 Functional block diagram of microcontroller in Micro-PMU prototype

The series of events in the microcontroller are mentioned in flowchart given in fig. 6.

The TM4C123G Microcontroller receives analog voltage and current signals through dedicated ports. TM4C123G comes inbuilt with 2 ADCs of Successive Approximation Register (SAR) type. The ADCs are of 12 bits each. The sampling of the ADC can be set at some particular sampling frequency. The microcontroller has 4 sample sequencers which have the capacity to sample up to 8 Analog channels at a time. In present research, one channel is used for testing purpose. Hence Sample Sequencer 0 which samples one analog input channel is used. The sample sequencer is configured to sample at 2.5 kHz using time count from inbuilt timer in the microcontroller. The ADC digitizes the signal and sends an interrupt upon successful conversion. The status of Flag of time information register is continuously monitored. The flag becomes '0' when it receives a signal from ESP 8266 wifi module. Upon signal reception as sensed by the time information register flag, the reference time is updated based on the time data in the time data storage register. The status of ADC sample conversion interrupt is also continuously monitored. If there is an interrupt, the DFT computation loop is run. Initially the newly acquired value needs to be stored and the oldest sample in DFT window must be discarded. Then the DFT calculation is done and the real and imaginary part of the phasor is stored. For varying Power System frequencies, the variation in frequency can be estimated using powerful frequency estimation tools and accordingly, the DFT method can be applied. This phasor data is time stamped with the current time (Time reference + number of clock cycles passed after reference time signal was acquired). Then the time stamped data is sent to monitoring system for further communication to Phasor Data Concentrators (PDCs).

VI. FUNCTIONS OF ESP 8266 WIFI DEVELOPMENT BOARD

The ESP 8266 wifi development board is used for time signal acquisition from internet and subsequent communication of the same to the microcontroller. The functional block diagram of the ESP 8266 wifi development board is given in fig. 7.

The series of events in the ESP 8266 wifi module are mentioned in flowchart given in fig. 8.

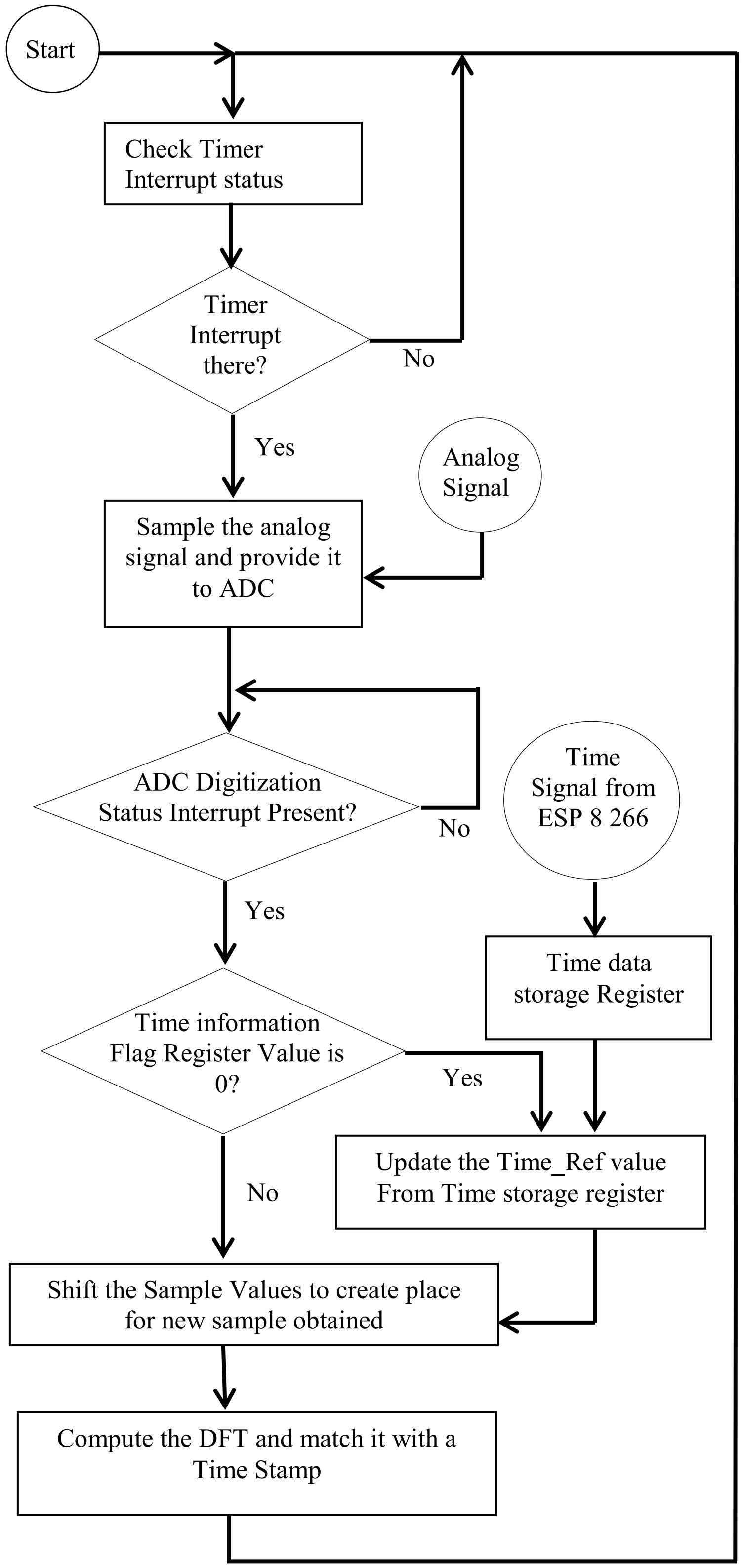

Fig. 6 Flowchart depicting operations inside the Microcontroller in Micro-PMU prototype

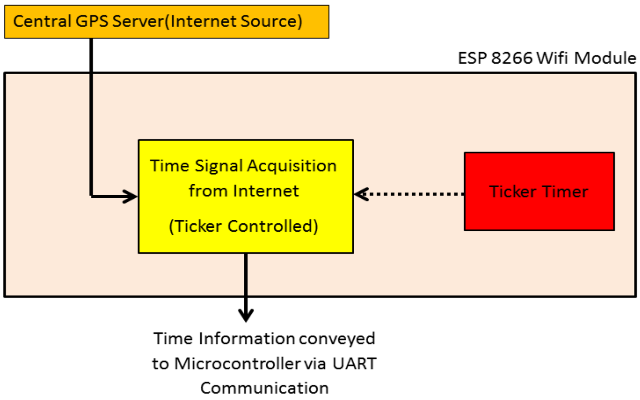

Fig. 7 Functional Block Diagram of ESP 8266 Wifi development board

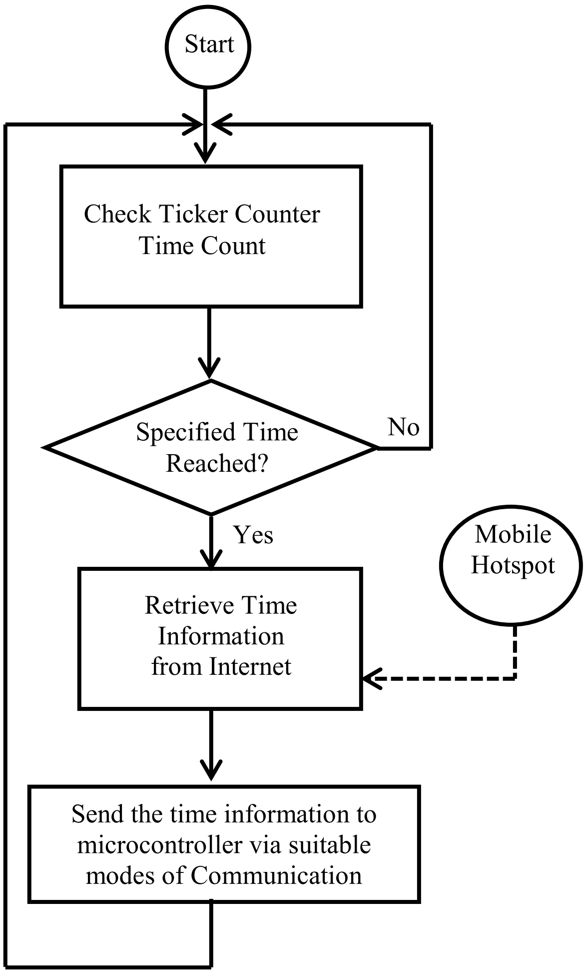

Fig.8 Flowchart depicting operations inside ESP 8266 Wifi module

The ESP 8266 Wifi module is programmed using Arduino software. Arduino has a function named Ticker which repeats a particular function again and again after a specified amount of time. The same function is used to demand time information from internet. For actual distribution system applications, time information can be retrieved from a central GPS server located in a sub-station. The time signal so acquired is sent to the microcontroller using some suitable modes of communication and the whole process is repeated again and again at specified intervals specified by the ticker function. The delays can be compensated using Network Time Protocol (NTP).

VII. DATA TRANSMISSION CAPABILITIES

A Micro-PMU is incomplete without provisions for data transmission to PDCs. In the prototype prepared, the data transmission capability to the Micro-PMU is provided. The time stamped phasor data so computed by the microcontroller is achieved at the monitoring system (Laptop or a PC). This data can be communicated to further levels through LAN/Ethernet or some other mode of communication adhering to standard C37.118 protocol for PMUs.

VIII. RESULTS

The reporting rate for the Micro-PMU can be set as per the need of the power system. The prototype so prepared was run in two modes. 1) Cycle-to-cycle reporting mode and 2) Digital recorder mode. The cycle-to-cycle reporting mode is the one whose reporting rate is 50 Hz i.e. One phasor reported per cycle. The digital recorder mode is the one where phasors are reported as they are computed i.e. one phasor per analog sample acquired. Analog sampled data in a Digital Fourier Transform (DFT) window is shown in fig. 9. Typical results obtained for digital recorder mode of Micro-PMU is shown in fig. 10. The applied voltage is 3.3V p-p sinusoidal. For higher distribution level voltages/currents, a voltage/current transformer of appropriate rating can be used to step down the level and feed it to the Micro-PMU. The first graph of fig. 10 shows the magnitudes of phasors so obtained. The second graph of fig. 10 shows the phase angles of the phasors. As the phasors are reported along with each analog sample, the phase angles can be seen to vary from 0 to 2∏ radians.

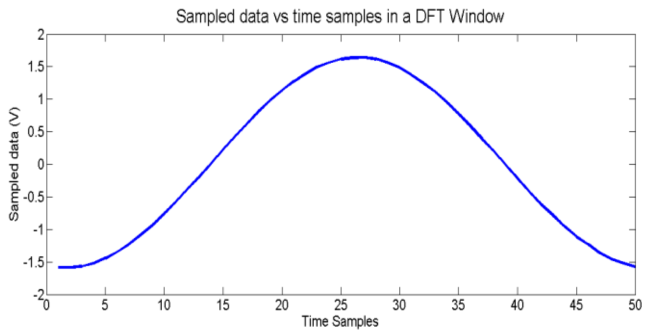

Fig. 9 Sampled voltage data in a DFT window

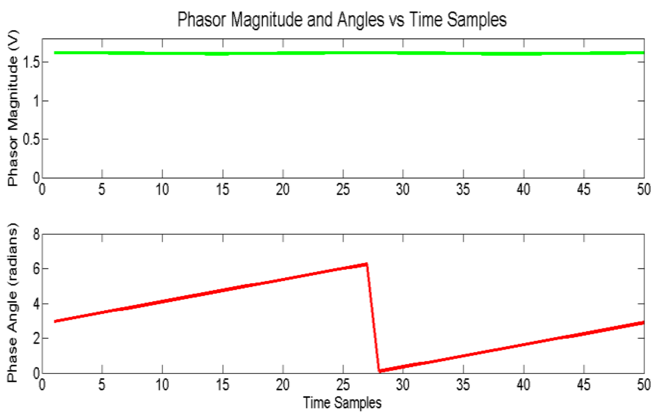

Fig. 10 Typical results obtained in digital recorder mode of operation of Micro-PMU prototype

IX. MICRO-PMU INTEGRATION INTO THE GRID

The Micro-PMU can be integrated into the grid in a manner as suggested by fig. 11. Several Micro-PMUs are allotted a central GPS server to retrieve time information. All those Micro-PMUs under the accuracy limitations of time signal, use their ESP 8266 wifi module to receive time information from a central GPS server located at a distribution sub-station. The central GPS server gets UTC time from GPS and has wifi capability to disseminate time information to several Micro-PMUs.

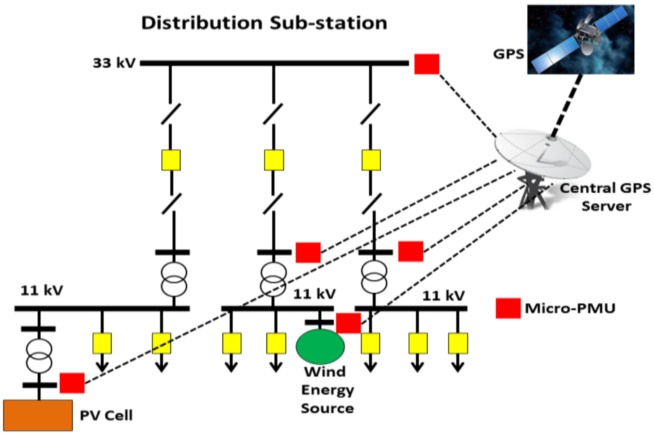

Fig. 11 Integration of Micro-PMUs into the grid

X. APPLICATIONS OF MICRO-PMU DATA

The phasor data so obtained from the Micro-PMU has a variety of applications. Some of them include State estimation of power system, Fault detection and tracing, Power system oscillation detection, Protective relaying, Harmonics Detection, Microgrid coordination etc.[9] Micro-PMU data can also be used for post-mortem analysis and power system planning. The product, Micro-PMU, has great importance as is clear from the plethora of application that it caters to.

XI. COMMERCIAL POTENTIAL OF THE PRODUCT

The product holds huge commercial potential as it has been designed taking into account the economic constraint of large scale installation in distribution system. The optimization involved is significant, from using low cost high power microcontrollers to cheaper and versatile wifi modules. The product can be commercialized as the measurement tool adhering to synchrophasor technology for distribution systems under the same banner as Phasor Measurement Unit is for transmission systems.

XII. CONCLUSION

The range of sampling rates that can be employed and few other parameters of Micro-PMU are dependent on processor efficiency and required accuracy of results. The steps required to obtain phasor data from voltage/current samples using Micro-PMU was planned so as to have minimum possible errors or delays. Parallel processing capability of microcontroller was exploited to update its reference time with time sent by wifi module. Concept of interrupts in microcontrollers was used to control sampling of input data, ADC conversion and communication with wifi module. The accuracy of the Micro-PMU can be further improved by more optimization of codes that run the microcontrollers and wifi modules. The installation of Micro-PMUs in actual distribution systems must be according to optimal placement so as to have better state observation and at the same time a sound business case.

APPENDIX

Technical Specifications of Tiva™ C Series TM4C123G Launch Pad

A. 32-bit ARM® Cortex™-M4F architecture
B. Clock Frequency: 80 MHz
C. 12 Bit ADC
D. Motion control PWM

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