

Performance of Total Vector Error of an Estimated Phasor within Local Area Networks

Ahmed Abdolkhalig, Rastko Zivanovic

Abstract—This paper evaluates the Total Vector Error of an estimated Phasor as define in IEEE C37.118 standard within different medium access in Local Area Networks (LAN). Three different LAN models (CSMA/CD, CSMA/AMP and Switched Ethernet) are evaluated. The Total Vector Error of the estimated Phasor has been evaluated for the effect of Nodes Number under the standardized network Band-width values defined in IEC 61850-9-2 communication standard (i.e. 0.1, 1 and 10 Gbps).

Keywords—Phasor, Local Area Network, Total Vector Error, IEEE C37.118, IEC 61850.

I. INTRODUCTION

PHASORS utilization in computation of power quantities dates back to 1916 when a mathematical technique developed by Proteus Steinmetz for analyzing AC networks is published [1]. Later in 1992, Jay Murphy from Macrodyne developed Proteus's technique into a new one for calculation the Phasors when synchronized to an absolute time reference and then he introduced the first Phasor Measurement Unit (PMU). Synchronization of the Phasors has been firstly defined in the IEEE 1344 and later codified and to be voted as IEEE C37.118 in 2005 and later to its update version in 2012 [2]. The parameters deviation of the input power signals has been restricted in this standard by defining a value (allowable error) over a range of operating conditions. This allowable error is named "Total Vector Error" or TVE and compares the vectorial difference of the estimated Phasor to the theoretical Phasor in percentages.

According to the IEEE C37.118 standard, PMU's should be reliable tools to estimate and provide Phasor measurement in steady-state and transient conditions (Burst changes). The steady-state conditions in power system assume no faults, line trippings or power swings. PMU's can be powerful tool for estimation in the steady-state but not in the transient conditions. The events sequence of the blackout that occurred on August 14, 2003 throughout wide areas of the USA and Canada started with incorrect telemetry data which caused state estimator to be inoperative.

The traditional Phasor estimators (PMUs) rely on the Discrete Fourier Transform (DFT) algorithm [3], [4] that can produce considerable values of magnitude and phase errors. These errors could lead to increase the Total Vector Error. On the contrary to the DFT, Kalman Filter (KF) has been

considered for many years as one of the most powerful algorithms for Phasors estimation at burst changes (Step changes) with less error [5]-[11]. KF is a mathematical technique, which has been extensively used to compute the optimal estimates of a dynamic system states. Today, the states of KF may updated by using the time-critical IEC 61850-9-2 Sampled Measured Values (SMVs) [12] streamed in the substation Process-Bus. The streamed values have sampling rates of 80 samples/cycle or 256 samples/cycle. These high sampling rates can be quite suitable for updating the states of KF and made it a robust tool for tracking the burst changes in input signals.

To realize the time-critical SMV, IEC 61850-9-2 communication standard has been defined three values for network Band-Width (BW). These values are standardized at 0.1, 1 and 10 Gbps transmission should be within Local Area Networks. Even though Latency is considered very small in LAN networks, the LAN type (i.e. CSMA/CD, CSMA/ AMP and Switched Ethernet) can play a big rule in evaluating the performance of the TVE. The performance can be affected by the Nodes Number and also by the network BW values assigned according to the IEC 61850-9-2 communication standard.

This paper is structured as follows: Section II is a review of the Local Area Networks and gives the main characteristic of each type and the algorithm used in packet transmission. Section III introduces the TVE as defined in IEEE C37.118 standard and also presents some description of the IEC 61850-9-2 Process-Bus and its SMV Frame structure. Section IV presents the evaluations of the performance under the effect of the Nodes Number. Section V is the conclusions.

II. PACKET TRANSMISSIONS IN LAN NETWORKS

The transmission of packets in Local Area Networks can be accomplished today in one of three different ways: (1) Using Carrier Sense Multiple Access with Collision Detection CSMA/CD (e.g. Ethernet). In this technique, the transmission depends on avoiding the traffic collision while the CSMA/CD network is busy. The sender node should wait until the network becomes free. If there is any collision detected, the sender node should back-off for awaiting period of time defined as $t_{\text{back-off}} = \text{minimum frame size} / (\text{data-rate} \cdot R)$ where $R = r$ and $(0, 2K - 1)$ and K is represents the number of collisions in one row. After the waiting period of time, the node should attempt to retransmit the last packet. (2) Carrier Sense Multiple Access with Arbitration on Message Priority CSMA/ AMP (e.g. CAN).

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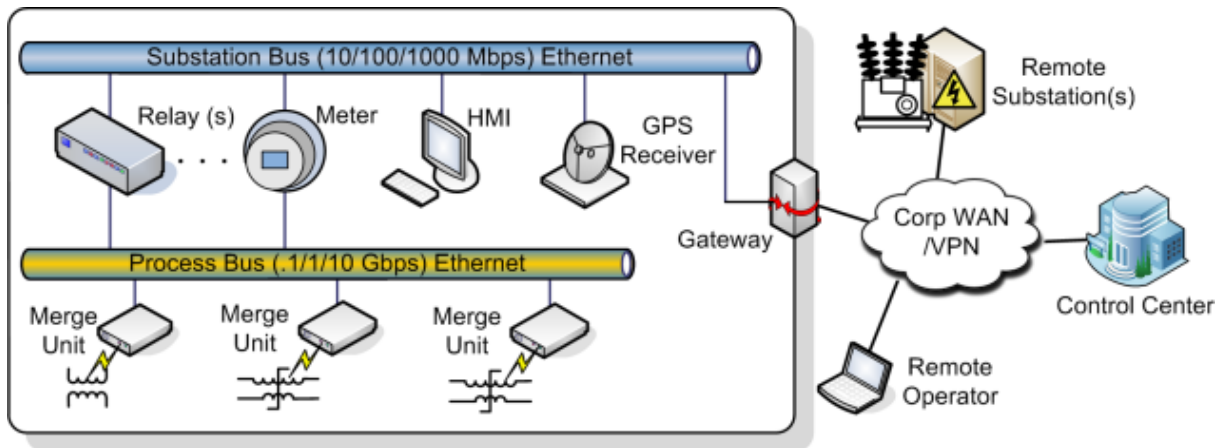


Fig. 1 The conceptual architecture of IEC 61850 process-bus and substation-bus

When the CSMA/AMP network is busy, the sender node should wait until the network becomes free. If there is any collision detected, the message that has the highest priority should be transmitted. If there is any two messages that having the same priority and requesting the transmission at the same time, then, the priority can be decided by the network in an arbitrary manner to make which one should be transmitted first. (3) Using a Switched Ethernet, where each sender node in the network connects the network central switch by using a full-duplex connection. By this way, there are no collisions on the network segments and the best collision avoidance compared to an ordinary Ethernet can be provided. Here, the network central switch should stores any received message in its buffer and the forwards it to the right receiving node.

III. PHASOR TOTAL VECTOR ERROR DEFINITION

Since the IEEE C37.118 standard published in 2005 and its updated version in 2012, one of the innovations in both versions is defining the measurements allowable error. The allowable error of the measurements must be accurate to within one percent TVE. The TVE has been defined in this standard as follows:

$$TVE = \frac{|\vec{V}_{Measured} - \vec{V}_{Ideal}|}{|\vec{V}_{Ideal}|} \quad (1)$$

where $\vec{V}_{Measured}$ is the measured Phasor and \vec{V}_{Ideal} is the ideal Phasor. The measured Phasor can be a voltage or a current Phasor. The error of the estimated Phasor can be written as follows:

$$\vec{V}_{Error} = \vec{V}_{Measured} - \vec{V}_{Ideal} \quad (2)$$

The IEEE C37.118 standard has defined the measurements allowable error (TVE) for Phasors, but has not restrained the technique to be used for estimating these Phasors. The produced Phasor by the traditional estimator can be displaced by the Phasor produced by implementing the IEC61850-9-2

communication standard and updating the KF with the high streaming time-critical packets of IEC61850. In general, the IEC 61850 standard consists of two kinds of communication Buses, Process-Bus and Substation-Bus which both are Ethernet technology supported. Process-Bus should realize Band-Width of (i.e. 0.1, 1 and 10 Gbps) while the Station-Bus should realize Band-Width of 10, 100 and 1000 Mbps. The conceptual architecture of IEC 61850 Process-Bus is shown in Fig. 1.

The Merging Unit (MU) shown in Fig. 1 is responsible to performs sampling and produce the high streaming time-critical packets. All MUs should be synchronized to a master clock with the required accuracy to guarantee that all samples are taken at the same time. The MU converts the analogue voltage and current waveforms into the IEC 61850-9-2 Sampled Measured Values and then cast them on the substation Local Area Network (Process-Bus) as time-critical packets. IEC 61850 standard has defined the structure of the SMV packet as seen in Fig.. It can be seen from Fig. that the SMV Frame structure has one Application Protocol Data Unit (APDU). This APDU contains up to eight Application Service Data Units (ASDUs). The ASDU is a buffering unit in which the measured values and all other related information can be saved. The measured values signals can be saved in the field "DataSet". Each "DataSet" field can carry eight measured values which represent three-phase voltage and current measured signals with neutral. The total size of the SMV is about 1000 bytes when one ASDU is assigned. Every addition of one ASDU can add 124 Bytes to the total size of the SMV Frame which means 1868 Bytes when eight "DataSet" are assigned.

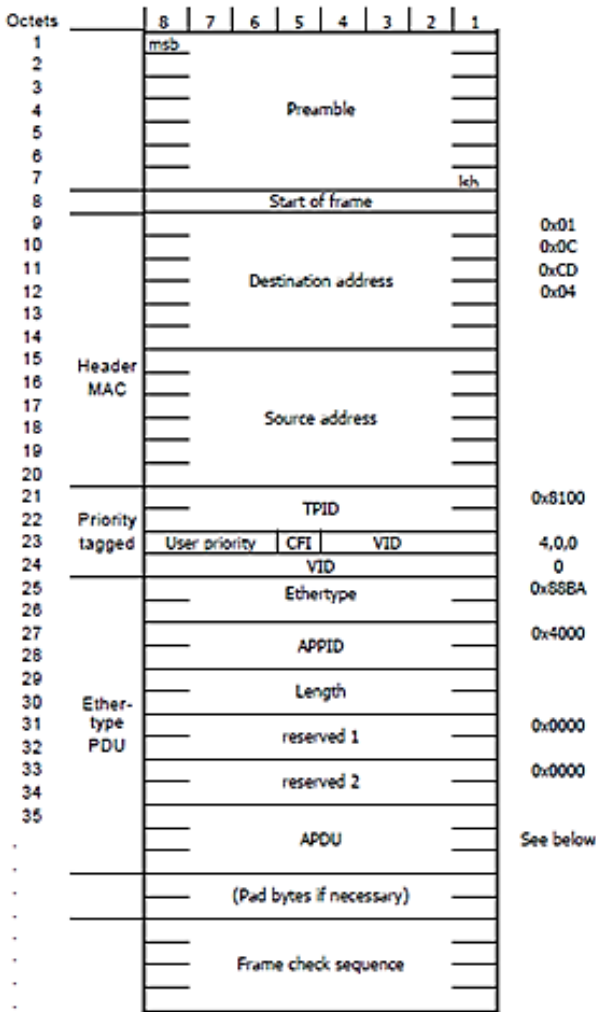


Fig. 2 Layers Structure of IEC61850 SMV Frame

As it is previously mentioned, KF is recognized as a powerful algorithm for estimating Phasor. There is a model which has been suggested by [13] for calculating the Phasor from the input signals by using KF. The states of this model can be updated recursively using the high streaming time-critical packets of IEC61850-2 Process-Bus. The KF should be able to solve a nonlinear power system that can be represented in a discrete form as in (3) and (4).

$$x_{k+1} = f(x_k) + q_k, \tag{3}$$

$$U_{k+1} = h(x_{k+1}) + r_{k+1}, \tag{4}$$

where x is the discrete state vector, U is the discrete measurements vector.

IV. SIMULATION AND PERFORMANCE EVALUATION

In this section, the simulation and performance evaluation of the TVE under different medium access packet transmission in Local Area Networks are presented. TrueTime

software [14] has been used for the simulation of different LAN networks with a packet structure as defined in IEC 61850 Process-Bus. True Time is a Matlab/Simulink-based simulator for simulating real-time networks, developed at Lund University, Sweden. It's extended to emulate the IEC 61850-9-2 SMV by ABB Corporate Research Group in 2008 [15], [16]. It facilitates co-simulation in real-time of task execution and network transmission dynamics by providing a Simulink block library and a collection of MATLAB MEX functions.

As it is mentioned previously, the allowable maximum error (TVE) should be equals or less than the maximum value allowable defined in IEEE C37.118 ($\leq 1\%$). Here, we study the TVE performance under two factors: (i) The Nodes Number and (ii) BW assigned according to the standardized values as in IEC61850-9-2 (i.e. 0.1, 1 and 10 Gbps). The size of the SMV Frame is set to carry eight samples (The maximum Samples/Frame according to the standardized Frame structure in IEC61850-9-2) or 1868 bytes. The accuracy of the estimated Phasor (i.e. TVE) is affected by the different types of LAN network. Each type of LAN network can handle (keep the TVE within the allowable value) at a specific Number of Nodes.

For testing a LAN network, the BW is set to one of the standardized values and the Nodes Number was changeable from 1 to 25 Nodes. Fig. 2, 4 and 5 below show the result of this testing. In Fig. 2, when the BW is set to 10 Gbps, the LAN type CSMA/CD can handle until 10 Nodes with a value of TVE is within the allowable error.

When the BW is set to 1 Gbps, the CSMA/CD can handle only one node while the CSMA/AMP can handle until seventeen Nodes with TVE value within allowable error (Fig. 3). Also, it can be seen from Fig. 4, when BW is set to 0.1 Gbps all types of LAN networks are failed to handle any number of Nodes. It's obvious from Fig. 2 and Fig. 3 that, Switched Ethernet LAN type cloud be preferable among the others types if a BW of 10 or 1 Gbps can be realized.

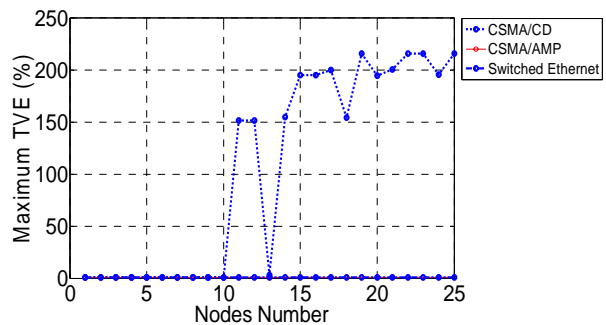


Fig. 2 Maximum TVE (%) at BW= 10 Gbps

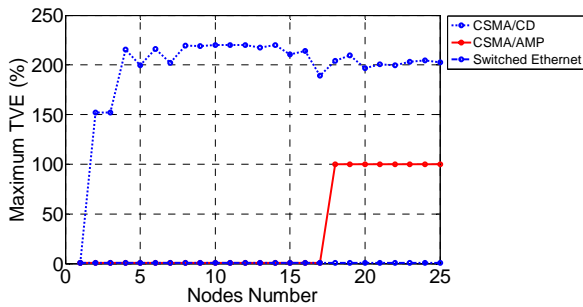


Fig. 3 Maximum TVE (%) at BW= 1 Gbps

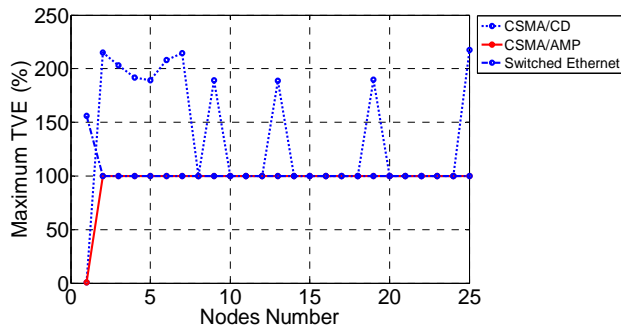


Fig. 4 Maximum TVE (%) at BW= 0.1 Gbps

It can be noted from the last three figures that to satisfy TVE value less than the maximum value allowable in IEEE C37.118 ($\leq 1\%$), each LAN network needs a different standardized BW value to handle a specific Nodes Number. This specific Nodes Number has been found equals to 10 Nodes for CSMA/CD, 17 Nodes for CSMA/AMP and zero Nodes for all types when the BW is equals 10, 1 and 0.1 Gbps, respectively.

V. CONCLUSIONS

Performance of TVE of an estimated Phasor under different medium access packet transmission in Local Area Networks has been evaluated. Results showed that allowable values of TVE can be satisfied for CSMA/CD when Nodes Number is less than ten Nodes with at BW= 10Gbps. When the BW is 1 Gbps, the allowable values of TVE can be satisfied at only at one node. Results also showed that the Switched Ethernet type can be preferable if BW of 10 or 1 Gbps can be realized. For a BW of 0.1 Gbps, all types of LAN network are failed to satisfy the requirement of TVE.

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