

## Phasor Measurements within Local Area Networks

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### **Abstract:**

*This paper evaluates the performance of Phasor measurements under medium access and packet transmission in Local Area Networks. Four models of networks are evaluated: CSMA/CD (e.g. Ethernet), CSMA/AMP (e.g. CAN), Round Robin (e.g. Token Bus) and Switched Ethernet. The error of Phasor measurements is evaluated for the effects of network Band-width and Latency. The criterion for evaluating is the Total Vector Error as define in IEEE C37.118 standard and the allowable maximum value of Latency is the value defined in IEC 61850 communication standard.*

**Keywords-component;** *Phasor; Local Area Network; Total Vector Error; IEEE C37.118; in IEC 61850*

### **I. INTRODUCTION**

The concept of utilizing Phasors in computation of power quantities backs to 1916 when Proteus Steinmetz published a paper on a mathematical technique for analyzing AC networks [1]. In 1992, Jay Murphy of Macrodyne developed Proteus's technique into the calculation of synchronized Phasors to an absolute time reference and introduces his Phasor Measurement Unit (PMU).

The time-synchronized Phasor has been firstly defined and codified in the IEEE 1344 and later to be voted as IEEE C37.118 in 2005 and later to its update version in 2012 [2]. In this Standard, the parameters deviation of the input power signals has been restricted by 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.

PMU's can be reliable tools to provide Phasor measurement according to the IEEE C37.118 standard in steady-state conditions. These steady-state conditions in power system assume no faults, line trippings or power swings. The sequence of events of blackout that occurred throughout parts of the USA and Canada on August 14, 2003 started with incorrect telemetry data cause to be inoperative state estimator.

The classical Phasor estimators rely on the Discrete Fourier Transform (DFT) algorithm [3, 4], which produces considerable magnitude and phase errors that increases in turn the TVE. Conversely to DFT, Kalman Filter (KF) has been recognized as one of the most powerful algorithms for Phasors estimation at burst changes with less error [5-11]. It's a mathematical technique, which is extensively used to compute the optimal estimates of a dynamic system states. Updating states of KF may done by using the time-critical IEC 61850-9-2 Sampled Measured Values (SMVs) streamed in the substation Process- Bus [12]. The streamed values have sampling rates of 4 kHz or 12.8 kHz at the 50 Hz nominal frequency of power systems. These high sampling rates can be quite suitable for application of tracking the robust changes in input signals. To satisfy the time-critical SMVs, the transmission should be within

Local Area Networks (LAN). Even though Latency is considered very small in LAN networks, Band-Width (BW) assigned in each network (i.e. CSMA/CD, CSMA/ AMP, Round Robin and Switched Ethernet) can affect both TVE and Latency and then should be evaluated for our application.

The structure of the paper is as follows. Section II Review of Local Area Networks and describe the main characteristic of each algorithm used in packet transmission. Section III defines the Total Vector Error and presents the IEC 61850-9-2 Process-Bus with description of the SMV Frame structure. Section IV includes the simulations and the tests results. In this section, effects of Band-width assigned to each LAN network on TVE and Latency introduced is evaluated. Section V is the conclusions.

## II. REVIEW OF LOCAL AREA NETWORKS AND PACKET TRANSMISSION

Today, transmission of packets in Local Area Networks can be done in different ways: (1) Using Carrier Sense Multiple Access with Collision Detection (CSMA/CD). This technique of transmission depends on the traffic collision avoidance. When the network is busy, the sender node will wait until the network become free. If there is any collision, the sender node will back off for a time defined by  $t_{\text{backoff}} = \text{minimum frame size} / \text{data rate} \times R$  where  $R = \text{rand}(0, 2K - 1)$  and  $K$  is represent the number of collisions in one row. After the waiting time period, the node will reattempt to transmit the packet. (2) Carrier Sense Multiple Access with Arbitration on Message Priority (CSMA/AMP). When the network is busy, the sender node should wait until the network become free. When the collision occurs here, the message that has highest priority should be continued to be transmitted. If any two messages having same priority and request a transmission at the same time, the priority can be decided by network in an arbitrary way to make which one is transmitted first. (3) Using Round Robin (Token Bus) where the transmission turn of each of the sender nodes in the network runs from lowest to highest node number so one frame each can be transmitted. The network is idle for a period of time  $t_{\text{idle}}$  ( $t_{\text{idle}} = \text{minimum frame size} / \text{date rate}$ ) between turns. (4) Using a Switched Ethernet where each sender node in the network has its full duplex connection to the network central switch. In this manner, there are no any collisions on the network segments which provide best collision avoidance compared to an ordinary Ethernet. The network central switch stores any received message in a buffer and then forwards it to the right destination receiving node.

## III. PHASOR TOTAL VECTOR ERROR DEFINITION

As the IEEE C37.118 standard published in 2005 and its updated version in 2012, one of the innovations in both versions is that the measurement must be accurate to within one percent TVE. The standard defines the TVE as follows:

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

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

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

The IEEE C37.118 standard was defined the TVE for Phasors, but not confined the technique to be used for calculating these Phasors. The produced Phasor by traditional estimator can be displaced by the Phasor by IEC61850 [13] high streaming time-critical packets. In general, the IEC 61850 standard consists of two kinds of communication Buses, Process-Bus and the Station-Bus which both are Ethernet technology supported. The conceptual architecture of IEC 61850 Process-Bus is shown in Fig 1.

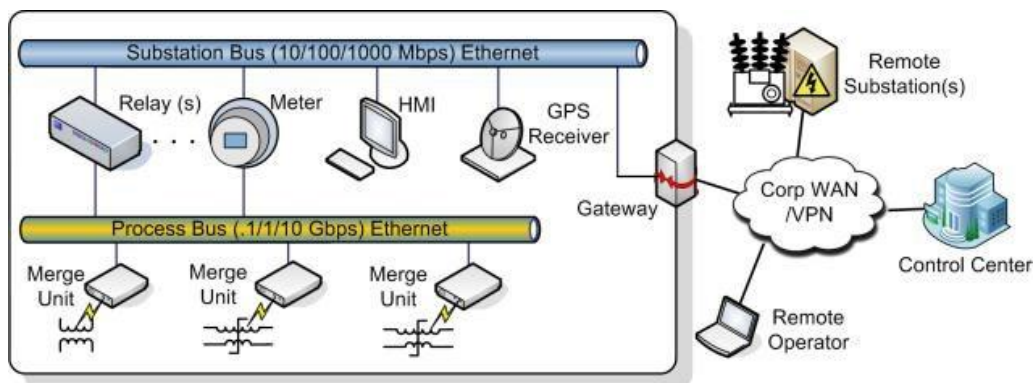


Figure 1. IEC 61850 Process-Bus Based SAS

Merging Unit (MU) shown in Fig. 1 performs sampling and should be synchronized to a global clock with the required accuracy to guarantee that all samples are taken at the same time. The MU is converting 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.

The structure of the SMV packet is defined into four layers as seen in Fig 2. From the Fig. 2, it can be noticed that the SMV Frame structure has one Application Protocol Data Unit (APDU). The APDU is consisting of one or more (Up to eight) Application Service Data Units (ASDUs). The ASDU is the data unit in which the measured values and other related information can be saved. The measured values of voltage or current signals are saved in the field "DataSet". The standard also defines the detailed packet format for the "DataSet" as can be seen also in the Figure. 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.

It's previously mentioned that, KF is recognized as one of the most powerful algorithms for Phasors estimation. There is a model which has been suggested by [14] for calculating Phasor from input signals by using KF. This model can be used recursively by updating the states of KF using the IEC 61850 Sampled Measured Values streamed in the substation Process- Bus. The KF is able to solve nonlinear system in the following discrete form:

$$\mathbf{x}_{k+1} = \mathbf{f}(\mathbf{x}_k) + \mathbf{q}_k, \quad (3)$$

$$\mathbf{U}_{k+1} = \mathbf{h}(\mathbf{x}_{k+1}) + \mathbf{r}_{k+1}, \quad (4)$$

where  $\mathbf{x}$  is the discrete state vector,  $\mathbf{U}$  is the discrete measurements vector.

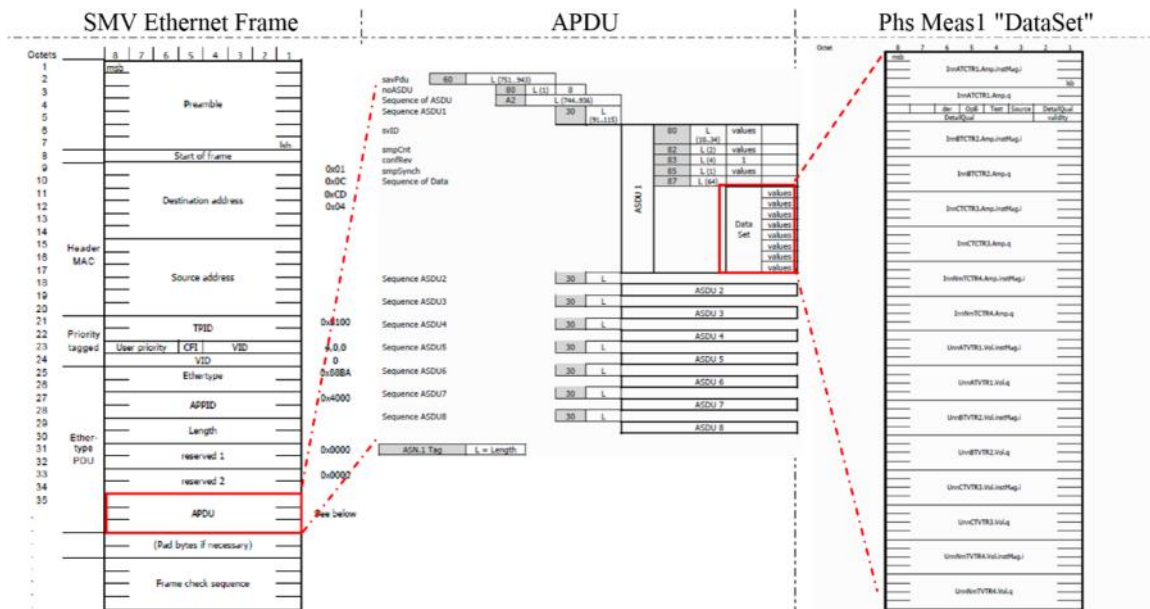


Figure 2. Layers Structure of IEC61850 SMV Packet

#### IV. SIMULATION ENVIRONMENT AND EVALUATION

To evaluate the performance of TVE under using different medium access and packet transmission in Local Area Networks, the TrueTime software [15] has been used for the simulation of different LAN networks with a packet structure as defined in IEC 61850 Process-Bus. TrueTime 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 [16], [17]. It facilities 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.

It is mentioned previously that TVE error should be less than the maximum value allowable in IEEE C37.118 ( 1%). TVE is depended on a number of factors, (i) the traffic load or more precisely how many nodes are effective and generating SMV, and (ii) BW occupied. The size of the SMV Frame when it carries eight samples (Maximum Samples/Frame according to the standardized Frame structure in IEC61850-9-2) is about 1000 bytes which means one MU will consume at 4 kHz sampling frequency approximately 30 Mbit/sec.

##### A. Effect of BW on TVE at different LAN Networks

The BW assigned at different LAN network can affect the accuracy of estimated Phasor (i.e. TVE). This BW depends on a number of operational factors like the Number of Nodes and the size of the Packet (Frame). According to the IEC 61850 SMV structure, the frame size occupies 1000 Bytes when there is one ASDU. Only one transmission Node with one ASDU has been used in the evaluation. The effects of BW on TVE at different LAN network can be seen in Fig 3.

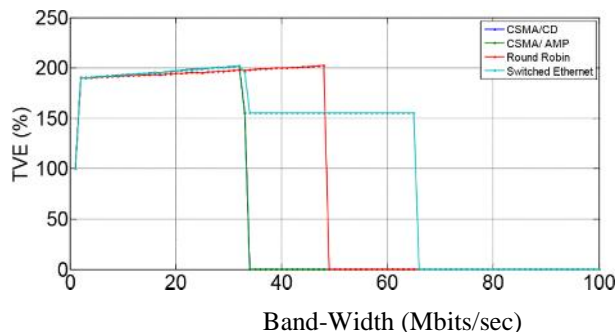


Figure 3. TVE performance at different LAN networks

It's noted from the figure that to satisfy TVE value less than the maximum value allowable in IEEE C37.118 ( 1%), each LAN network needs different BW and the Switched Ethernet needs a higher BW (65 Mbits/sec) . It's also noted that, both CSMA/CD and CSMA/AMP networks have the lesser and the same value of BW (35 Mbits/sec) to satisfy the allowable TVE value.

**B. Effect of BW on Latency at different LAN Networks**

It's assumed in real-time networks (i.e. LANs) that the Latency is very small and can be neglected. Actually, the value of the latency is varying from network to other and this value should be considered (even, if it's value is very small) in many applications. According to the IEC 61850 implementation guideline [18], the maximum recorded Latency should be less than 3 msec. This value can be satisfied with any real-time network, but at different assigned BW. Figure 4 shows the BW needed for each network. It's clear that the Switched Ethernet needs less BW then others to satisfy the allowable value of Latency. Also, BW is changing linearly until it satisfies allowable value of Latency in the case of Round Robin network.

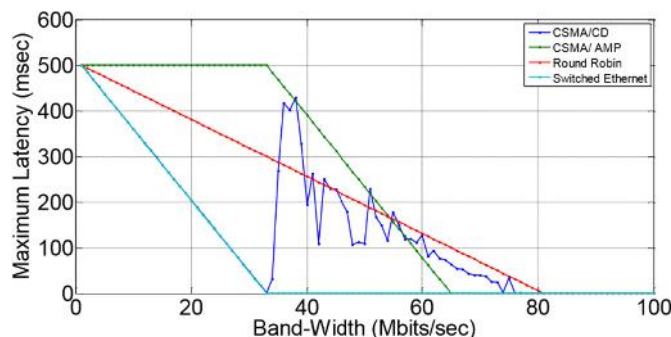


Figure 4. Maximum Latency introduced at different LAN networks

**V. CONCLUSIONS**

Performance of Phasor measurements evaluated using Total Vector Error under medium access and packet transmission in Local Area Networks has been evaluated. Results showed that allowable values of TVE and Latency can be satisfied with all LAN networks but at different values of BW. In the TVE evaluation, it's found that both CSMA/CD and CSMA/AMP networks have the same value of BW (but lesser than others) at which the TVE has a value less than allowable in IEEE C37.118 standard. Also, for Latency, it has been found that the Switched Ethernet needs less BW than other to satisfy the value of latency less than that specified in IEC 61850.

## REFERENCES

- [1] C. P. Steinmetz, *Theory and calculation of alternating current phenomena* vol. 4: McGraw-Hill Book Company, inc., 1916.
- [2] IEEE, "IEEE Std C37.118™- Standard for Synchrophasor for Power Systems," ed, 2005.
- [3] A. Phadke, J. Thorp, and M. Adamiak, "A new measurement technique for tracking voltage phasors, local system frequency, and rate of change of frequency," *Power Apparatus and Systems, IEEE Transactions on*, pp. 1025-1038, 1983.
- [4] A. Phadke, "Synchronized phasor measurements in power systems," *Computer Applications in Power, IEEE*, vol. 6, pp. 10-15, 1993.
- [5] H. Ma and A. A. Girgis, "Identification and tracking of harmonic sources in a power system using a Kalman filter," *Power Delivery, IEEE Transactions on*, vol. 11, pp. 1659-1665, 1996.
- [6] V. M. Saiz and J. B. Guadalupe, "Application of Kalman filtering for continuous real-time tracking of power system harmonics," in *Generation, Transmission and Distribution, IEE Proceedings-*, 1997, pp. 13-20.
- [7] P. Dash, A. Pradhan, and G. Panda, "Frequency estimation of distorted power system signals using extended complex Kalman filter," *Power Delivery, IEEE Transactions on*, vol. 14, pp. 761-766, 1999.
- [8] S. Bittanti and S. M. Savaresi, "On the parametrization and design of an extended Kalman filter frequency tracker," *Automatic Control, IEEE Transactions on*, vol. 45, pp. 1718-1724, 2000.
- [9] P. Dash, R. Jena, G. Panda, and A. Routray, "An extended complex Kalman filter for frequency measurement of distorted signals," *Instrumentation and Measurement, IEEE Transactions on*, vol. 49, pp. 746-753, 2000.
- [10] P. Dash, A. Pradhan, G. Panda, and R. Jena, "Harmonics estimation in stressed electric power networks," in *Power Electronics and Drive Systems, 2001. Proceedings., 2001 4th IEEE International Conference on*, 2001, pp. 782-788.
- [11] R. Aghazadeh, H. Lesani, M. Sanaye-Pasand, and B. Ganji, "New technique for frequency and amplitude estimation of power system signals," *IEE Proceedings-Generation, Transmission and Distribution*, vol. 152, pp. 435-440, 2005.
- [12] IEC, "Communication networks and systems in substations: Specific Communication System Mapping (SCSM) – Sampled Values over ISO/IEC 8802-3," vol. IEC 61850-9-2, ed, 2003.
- [13] "IEC 61850 Standard for Communication Network and Systems in Substations," ed, 2003.
- [14] A. A. Girgis, W. B. Chang, and E. B. Makram, "A digital recursive measurement scheme for online tracking of power system harmonics," *Power Delivery, IEEE Transactions on*, vol. 6, pp. 1153-1160, 1991.
- [15] M. Ohlin, D. Henriksson, and A. Cervin, "TrueTime 1.5 Reference Manual," *Department of Automatic Control, Lund University, Sweden*, 2007.
- [16] M. Passerini, "Design of an ECMA368 simulator for evaluating network performance for electrical substation applications based on IEC618510," Master's Thesis Project, KTH Electrical Engineering, KTH Royal Institute of Technology, Stockholm, Sweden September 2008, XR-EERT 2008: 021.
- [17] A. Fiorenza and J. Kjellsson, "Performance Evaluation of an ECMA368 network in an electrical substation application based on IEC61850," ABB Corporate Research, Sweden, 2008.

- [18] "IEC 61850-9-2 LE: Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850 9-2," ed: UCA International Users Group.