Analysis of the Impact of Pervasive Wide-Area Communication Network Conditions on the Disturbance Recordings from PMUs

Adeyemi Charles Adewole, Raynitchka Tzoneva, and Alexander Apostolov

***Abstract*—Synchrophasor measurements from Phasor Measurement Units (PMUs) are beginning to find application in the post-mortem analysis of disturbances in the power system because of their ease of application in system-wide disturbance analysis. However, what remains to be investigated is the impact of pervasive communication network conditions on the synchrophasor measurements transmitted from the substation PMUs to the Phasor Data Concentrators (PDCs) at the control centre. This paper investigates and analyzes the impact of pervasive Wide Area Network (WAN) conditions on the IEEE C37.118.1-2011 synchrophasor measurements published from PMUs to the control centre PDCs during critical power system disturbances. Experimental results are presented using a co-simulation platform combining Software-In-The-Loop (SITL) emulation of a WAN and Hardware-In-The-Loop (HITL) real-time power system simulations using a 'proof-of-concept' facility comprising of the Real-Time Digital Simulator (RTDS), PMUs, PDCs, and communication network. Different communication network conditions consisting of network latency, jitter, packet losses, and network corruption are emulated and their impact on disturbance records is investigated. The maximum allowable pervasive network conditions are quantified. This study intends to serve as a guide in the design of future synchrophasor-based disturbance record platforms for online and post-mortem analyses.**

***Index Terms*—Disturbance analysis, latency, packet loss, phasor measurement unit, synchrophasor, wide area network.**

I. INTRODUCTION

THE complexity of power systems makes them prone to various equipment faults and system disturbances resulting from short circuit faults, transients, switching actions, auto reclose actions, load variations, and disturbances resulting from contingencies. These faults and disturbances are often accompanied by abnormal system parameters, and could propagate to neighboring regions, thereby affecting the stability of the system. Power system stability refers to the ability of the power system to maintain an acceptable level of equilibrium during normal operating condition, and to regain an acceptable level of equilibrium after being subjected to a disturbance [1]-[2]. When a severe disturbance occurs in a power system, the system could transition from the normal state to the alert or emergency states [1]-[2]. A protection/control action would be required to restore the system back to the normal operating state where all constraints are satisfied.

In view of the above, it is necessary to carry out disturbance analysis in order to identify the immediate and remote causes of any particular power system event, reconstruct the event, estimate the severity of the disturbance, and review the performance of protection/control devices. The effectiveness of any disturbance analysis will depend on the quality of the disturbance records available, and how relevant those records are to the particular event being investigated. Measurements from Digital Fault Recorders (DFRs), Sequence of Event Recorders (SERs), Remote Terminal Units (RTUs), Power Quality Recorders (PQRs), Fault Locators (FLs), and other Intelligent Electronic Devices (IEDs) have been applied for disturbance analysis in power systems in [3]-[7].

However, the measurements from most of these recorders are often inadequate for system-wide (wide area) disturbance analysis where records captured simultaneously are required in order to obtain a complete snapshot of a specific system event. Also, some of these devices are not time synchronized to an accurate time reference, and the measurements are not time-stamped at the point of acquisition. Furthermore, the collation and alignment of measurements from multiple devices configured with different triggers are difficult. In addition, some of these devices are compliant to different international standards.

Disturbance recording allows for the comprehensive analysis of system-wide disturbance. But this is simplified when records from across the power system are available. Disturbance analysis using the existing local records or records from the Supervisory, Control and Data Acquisition System (SCADA) platforms which are rarely synchronized to a common time reference is often tedious and time consuming. The 2003 North America blackout demonstrated the need for wide area long duration recording. During the blackout, many DFRs were triggered by local events for short durations only [4], and were inadequate.

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Time-synchronized measurements from Phasor Measurement Units (PMUs) have been shown in [8] to have an edge over the disturbance recordings polled by traditional SCADA platforms, especially in terms of measurement accuracy and reporting rate. Typically, SCADA systems have a reporting rate of 1 measurement every 2-10 seconds, while synchrophasor-based systems can have up to 240 measurements every 1 second (240 fps for 60 Hz system or 200 fps for 50 Hz system). Recently, PMUs have been applied for disturbance analysis [9]-[10] and generator trip event fault location [11]. The advantages of using PMUs for disturbance recording include their standardization and compliance to the IEEE C37.118 standard, time synchronization to a common time reference, and the ease of data collection and alignment by the control centre PDC.

In order to effectively communicate these time-critical high speed PMU measurements, modern communication infrastructures are needed. However, data can be lost during the communication of the synchrophasor measurements to the control centre as a result of the lack of adequate communication bandwidth, latency from cyber security applications, amongst other reasons. This paper initially presents disturbance events and the system responses observed. It then emulates a Wide Area Network (WAN) for studying the impact of pervasive communication network using a Linux-based Software-In-The-Loop (SITL) WAN emulator tool in a co-simulation platform integrated with a testbed for Hardware-In-The-Loop (HITL) simulations. Next, the allowable network latency, jitter, packet losses, noise/attenuation in the WAN are characterized and quantified. Lastly, the paper investigates the impact of pervasive communication network conditions on the disturbance measurements obtained from PMU measurements.

The rest of the paper is organized as follows: Section II presents an overview on disturbance analyses. Section III describes the communication network requirements for synchrophasor-based applications and the possible pervasive network conditions that can occur. A co-simulator 'proof-of-concept' platform developed for this paper is given in Section IV, while Section V presents the experimental results obtained. Section VI discusses the results, and the conclusion of the paper is given in Section VII.

II. DISTURBANCE ANALYSES

Disturbance records play an important role in the identification of the cause of a fault, its severity, and the performance evaluation of the associated protective or control devices implemented in the power system. Also, they record and provide the dynamic response of the system during power swings, system stability conditions, power quality conditions, and for post-mortem analysis of wide area disturbances.

A. Types of Disturbances

The various types of disturbances that can occur in power systems can be divided into four. They are [12]: i) steady-state disturbances; ii) transient disturbances; iii) short-term disturbances; and iv) long-term disturbances.

Steady-state disturbances occur during normal system operating condition. During these disturbances, the system operation is not at risk, but power quality issues comprising of harmonics and sub-harmonics ensue. Transient disturbances are brief faults with a short duration of 8-16 cycles [12]. Short-term disturbances include events with time delayed clearance and reclosing events. They are longer than transient disturbances and have a duration of 20-60 cycles. Long-term disturbances affect the stability of the system and are associated with rotor angle stability, frequency stability, and voltage stability respectively. It has a longer duration which can lasts for days.

B. Types of Disturbance Recordings

Three types of recordings are defined in [12]. They are: i) high speed disturbance recording; ii) low speed disturbance recording; and iii) steady-state (continuous) disturbance recording. High speed disturbance recording uses a high sampling frequency to capture the current and voltage samples of transient events. The typical length is about 2 seconds. Low speed disturbance recording is used for capturing the phasors or RMS analogue measurements during short-term and long-term disturbances respectively. Typical length can be between hundreds of seconds to 1 hour. Steady-state recording captures the average analogue measurements over several days.

The trigger used in initiating the recording of the disturbance can be based on magnitude (voltage, current, frequency, real power, reactive power, and apparent impedance), rate of change (voltage, current, frequency, real power, reactive power, and apparent impedance), and binary signals (e.g. breakers, protection trip, communication-assisted key, etc.).

C. Wide Area Disturbance Recording

Disturbance records include transient fault records, Sequence of Events (SOE) data, and dynamic disturbance records [12]. The IEEE C37.111-2013 Common Format for Transient Data Exchange (COMTRADE) standard specifies a common and easily interpretable format for the exchange of transient data in power systems. The COMTRADE file has a header (*.HDR) file, configuration (*.CFG) file, information (*.INF) file, and data (*.DAT) file [13].

Disturbance recording using conventional recording devices make use of local triggers to initiate the recording of the disturbance in the power system. However, the various recording devices in the system may not trigger for some events, or could trigger for different time frames without capturing any valuable data. Wide area disturbance recoding involves the simultaneous recording of faults or disturbances in the system using multiple devices widely dispersed in the power system. For fast and accurate disturbance analysis, these devices must be time synchronized with a common time reference such as the GPS. Also, these widely dispersed recording devices can be triggered using an event at a local end to initiate the recording at the rest of the recording devices via an IEC 61850 Generic Object Oriented Substation Event (GOOSE) message.

Alternatively, synchrophasor measurements from stand-alone PMUs or multi-functional IEDs with PMU functionality can be recorded locally at the PMU or streamed onto a communication network to a PDC. The measurements from the PMUs can be archived by a control centre historian or PDC, and retrieved using the COMTRADE or Comma Separated Values (CSV) formats. The continuous recording and communication of synchrophasor measurements from the substation to the control centre PDC is constrained by the available communication bandwidth and data storage facility. Thus, triggered recording/archiving of PMU measurements is preferable for disturbance analysis. For wide area disturbance recording, a cross-triggering technique whereby a local event at a PMU is used as a trigger to initiate recording at a PDC or at PMUs across the system can be applied. This trigger signal can be published to the PMUs via IEEE C37.118 synchrophasor commands or via IEC 61850 GOOSE messages.

III. SYNCHROPHASOR COMMUNICATION NETWORK REQUIREMENTS

The communication network deployed in a power system must support the various network-based applications and satisfy the minimum performance requirements. Usually, this comprises of a WAN spread across different geographical locations with several measurement acquisition field devices (e.g. substation PMUs, Intelligent Electronic Devices (IEDs)), substation Phasor Data Concentrators (PDCs), control centre devices (e.g. superPDCs, data archiver), and communication network devices connecting the control centre and the field actuating devices (e.g. bay controllers) together to form a WAN cloud. Typically, a communication backbone with a high bandwidth is required for such real-time applications.

This section discusses the message structure of synchrophasor measurements, typical communication infrastructure, and some pervasive communication network conditions that could occur in practical systems.

A. Synchrophasor Message Structure and Format

Four types of messages are defined in the IEEE C37.118 standard for synchrophasor measurements. These include data, configuration, header, and command messages [14]. The data, configuration, and header messages are transmitted from a PMU/PDC (data source) to the PDC (data concentrator). While the command messages are sent from the PDC (data concentrator) and received by the PMU/PDC (data source). The communication between the C37.118 client and a C37.118 server can be summarized as given in Fig. 1.

The data frame contains the synchrophasor measurements computed by the data source (PMU/PDC). It includes an identification header, message length, message source ID, status information, and the data. The data payload includes the phasors, frequency, ROCOF, analogue, and digital data types. The knowledge of the payload in the data frame is important in the sizing of the communication bandwidth and the data storage facility required for data archiving. The configuration frame is a machine-readable dataset containing information relating to a synchrophasor data stream. The *Config1* (CFG-1), *Config2* (CFG-2), and *Config3* (CFG-3) configuration frames are defined in the IEEE C37.118.1-2011 standard.

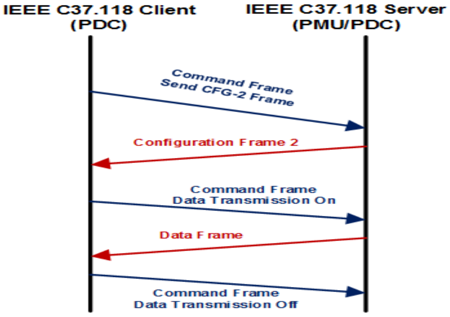


Fig. 1. Synchrophasor client-server connection and message formats

The header frame is a human-readable frame in ASCII format sent from the data source to the data concentrator. It is user configured and contains the information relating to the PMU, type of algorithm, data sources, type of signal processing, and scaling. The command frame is sent from the PDC to the data source to start/stop the transmission of data, or to request for configuration data prior to data transmission.

B. Communication Protocols

The communication in power systems requires real-time measurements achievable via Wide Area Measurement Systems (WAMS). The intra-substation PMU-to-PDCs synchrophasor data communication can be done using the Transmission Control Protocol (TCP), while the data communication between the substation PDC-to-the SuperPDC in the control centre can be via the User Datagram Protocol (UDP). The rationale behind this is that the TCP is a connection-oriented protocol, and would introduce some unacceptable latency when used for wide area control schemes. The UDP protocol is suitable for the substation-to-control centre communication because it is a connectionless protocol with no handshaking/flow control constraints. Thus, the latency experienced is minimal. Also, less bandwidth is required for the UDP communication since there is a reduction in the communication overhead required.

Another possibility for synchrophasor data transfer is the use of the communication mechanism defined in the IEC 61850-90-5 Technical Report (TR) on synchrophasor communication. This involves the transmission of synchrophasor measurements using the IEC 61850 data modelling, configuration, and infrastructure. Typically, the UDP protocol with multicast addressing is used. This can be implemented using the Routed GOOSE (R-GOOSE) or Routed Sampled Values (R-SV) [15]. The communication medium can be optical fibre, power line carrier, leased line, satellite, microwave link, radio link, or IP-based network.

C. Pervasive Communication Network Conditions

Adverse communication network conditions can occur as a result of the communication route length between the substation clients and the control centre servers, the presence of repeaters, electromagnetic interference, constraints in the available bandwidth per channel, and the type of communication infrastructure deployed.

These conditions can result in the following pervasive conditions:

1) *Latency*

Latency or delay is the time taken by a network packet to travel from one host to another. Jitter is associated with latency, and it is the variation recorded in each consecutive delay. It is usually caused by insufficient bandwidth or path congestion. Five types of delays are present in wide area measurement systems. These are: i) measurement delay (t_{meas}); ii) measurement uplink delay (t_{up}); iii) computation delay (t_{comp}); iv) control action downlink delay (t_{down}); and v) control action delay (t_{con}). The total delay in a communication network is given by [16]:

$$T_{delay} = t_{meas} + t_{up} + t_{comp} + t_{down} + t_{con} \tag{1}$$

The measurement delay is introduced during the measurement acquisition stage by the Current Transformers (CTs) and the Voltage Transformers (VTs) respectively. The uplink delay is caused by the serialization of data packets, data framing, signal propagation delay, and the queuing delays from the substation PMUs to the PDC.

The computation delay results from the time required in the concentration of PMU measurements at the control centre, the execution of the control applications, and the issuance of the control signals to the actuating devices. The time between when the control signals were issued to when they were received by the field actuating devices is referred to as the control downlink delay. The delay due to the time taken for the field actuating devices to receive the control signals and implement the required remedial actions is referred to as the controller action delay.

2) *Packet Loss*

Data packet losses may degrade the performance of power systems wide area applications. It may occur as a result of congestion, routing instability, and signal loss in the communication network. For instance, in PMU applications where the required bandwidth is not appropriately sized, congestion may occur as a result of the inability of the communication network to support the large amount of PMU measurements being published.

3) *Network Corruption*

Network corruption can be introduced in the data packets as a result of data transmission errors, noise in the communication channel, and signal attenuation. This degrades the throughput of the communication network and causes packet losses and congestion. In practical systems, this can be as a result of the electrical noise in the substation, noisy communication channel, interference, signal attenuation, and network congestion.

IV. TESTBED ARCHITECTURE

A co-simulation platform using Software-In-The-Loop (SITL) WAN emulation and Hardware-In-The-Loop (HITL) power system simulation was developed. The various aspects of the co-simulation platform are presented below.

A. *Power System Modelling*

The 10-bus multi-machine equivalent network [1] shown in Fig. 2 was modelled using the RSCAD software which is the simulation tool used in conjunction with the RTDS® simulator. It is made up of three generators supplying a total of 6,655 MW of load at load level-1, with generators G1 and G2 injecting a total of 5,717 MW across five 200 km 500 kV transmission lines. Generator G3 supplies the rest of the load demand. A transformer ULTC is incorporated between buses-10 and -11. Further information on the study network and parameters used can be found in [1].

B. *Proof-of-Concept Testbed*

The lab-scale HITL testbed developed (Figs. 3-4) in this paper comprises of the Real-Time Digital Simulator® (RTDS) (1) incorporating the GTNET-PMU protocol(3), analogue amplifiers (2), GPS satellite clock (4), communication network switches (5), PDC (6), SEL-3378 Synchrophasor Vector Processor (SVP) (6), and PMUs (7).

The RTDS is used in the simulation of the study network modelled in the RSCAD software and the simulations are carried out in real-time with a time-step of 50 microseconds. The measurements from the GTNET-PMU (P-class PMU) and the external PMUs are published as three phase and positive sequence phasors, in real and polar formats with a reporting rate of 60 fps. IRIG-B time synchronization supplied from a GPS satellite clock is connected to the PMUs. For triggered recording at a substation PMU or at the control centre PDC, the recording trigger used is the binary status of the transmission line breaker between buses-6 and -7. Continuous recording at the PDC is also possible. The amount of continuous data that can be recorded will depend mainly on the number of PMU measurements (phasors, analogues, and binary data), the reporting rate, and the size of the storage facility available.

The event recording is triggered using the logic given below:

$$ER = NOT\left(52ACL1\ \ OR\ \ 52BCL1\ \ OR\ \ 52CCL1\right) \tag{2}$$

where *52ACL1*, *52BCL1*, and *52CCL1* are the closed states of the single phase poles (poles A, B, C) of circuit breaker 1.

C. *Communication Network Modelling*

The architecture of the Linux-based WAN emulator tool (WANem) used in this paper is given in Fig. 5 [17]. These are the Linux kernel, the shell, and the web interface respectively.

A SITL emulation was carried out using the WAN emulator for the emulation of the wide area communication network between the substation-to-control centre levels. The WAN emulator was configured as a transparent proxy server acting as a gateway for the bi-directional traffic between the IEEE C37.118 Clients and the IEEE C37.118 Servers.

Thus, the synchrophasor measurements from the substation PMUs are routed via the emulated virtual WAN (indicated by the arrow head dashed lines in Fig. 4) to the control centre PDC. A network analyzer was used in testing the various segments of the implemented communication network.

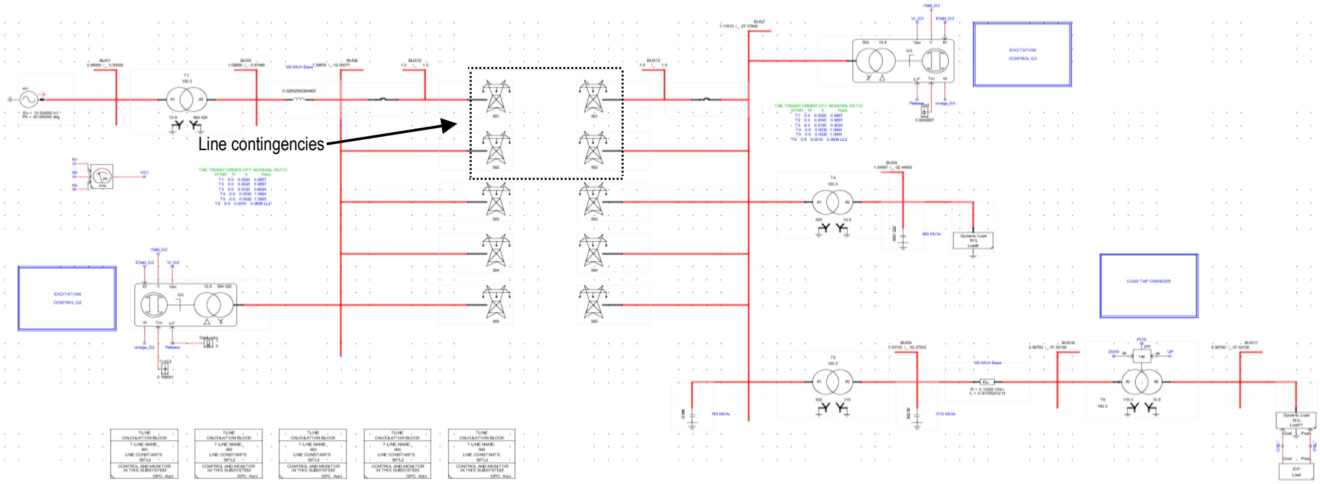


Fig. 2. RSCAD model of the multi-machine equivalent test system.

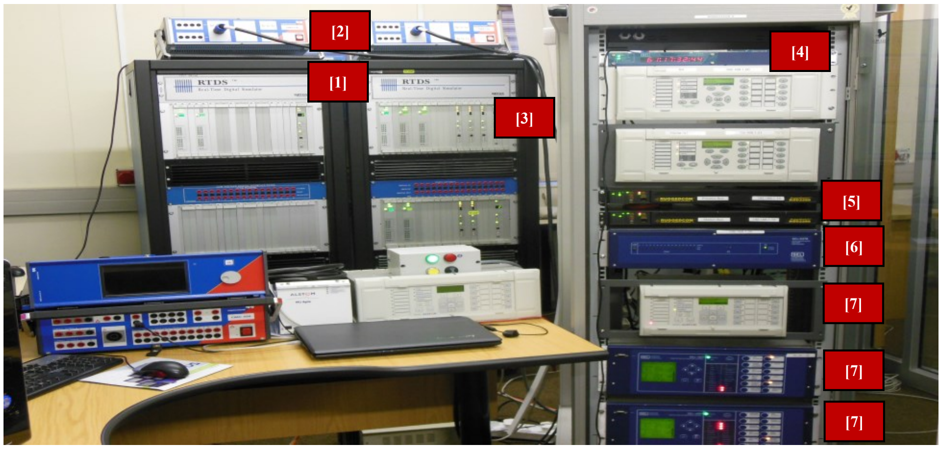


Fig. 3. Proof-of-concept tesbed.

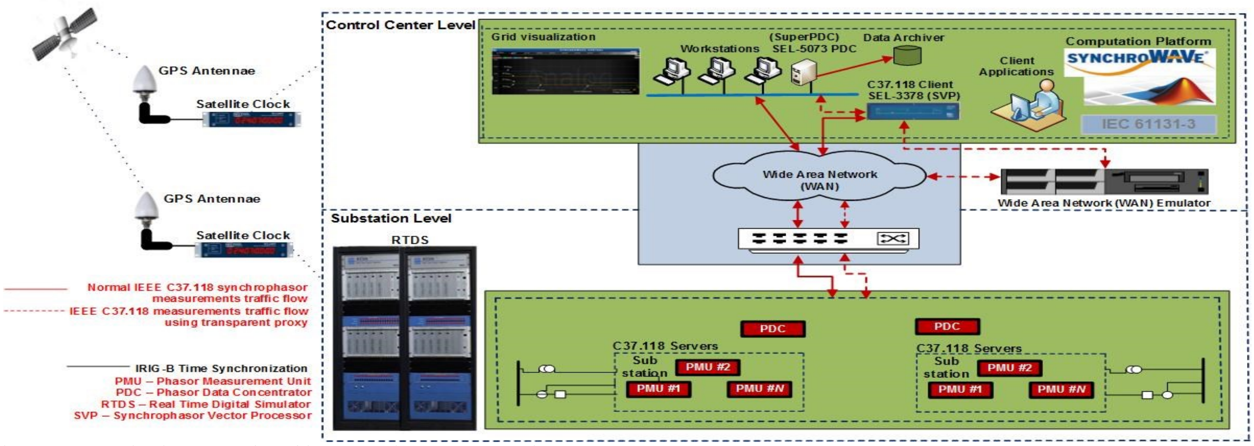


Fig. 4. Communication network architecture using a WAN emulator.

The lowest communication bandwidth of about 50 Mbps was obtained between the RTDS® and the rest of the testbed as shown in Table I. A data payload of 2 positive sequence phasors, 4 analogues, and 1 binary word will have a data frame of 60 bytes. If TCP protocol is used with a 60 fps reporting rate, a 50 Mbps network will efficiently support 853 PMUs.

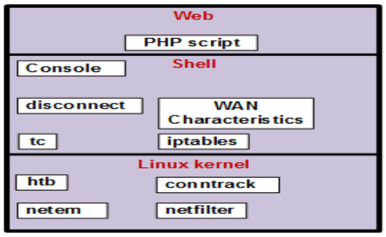
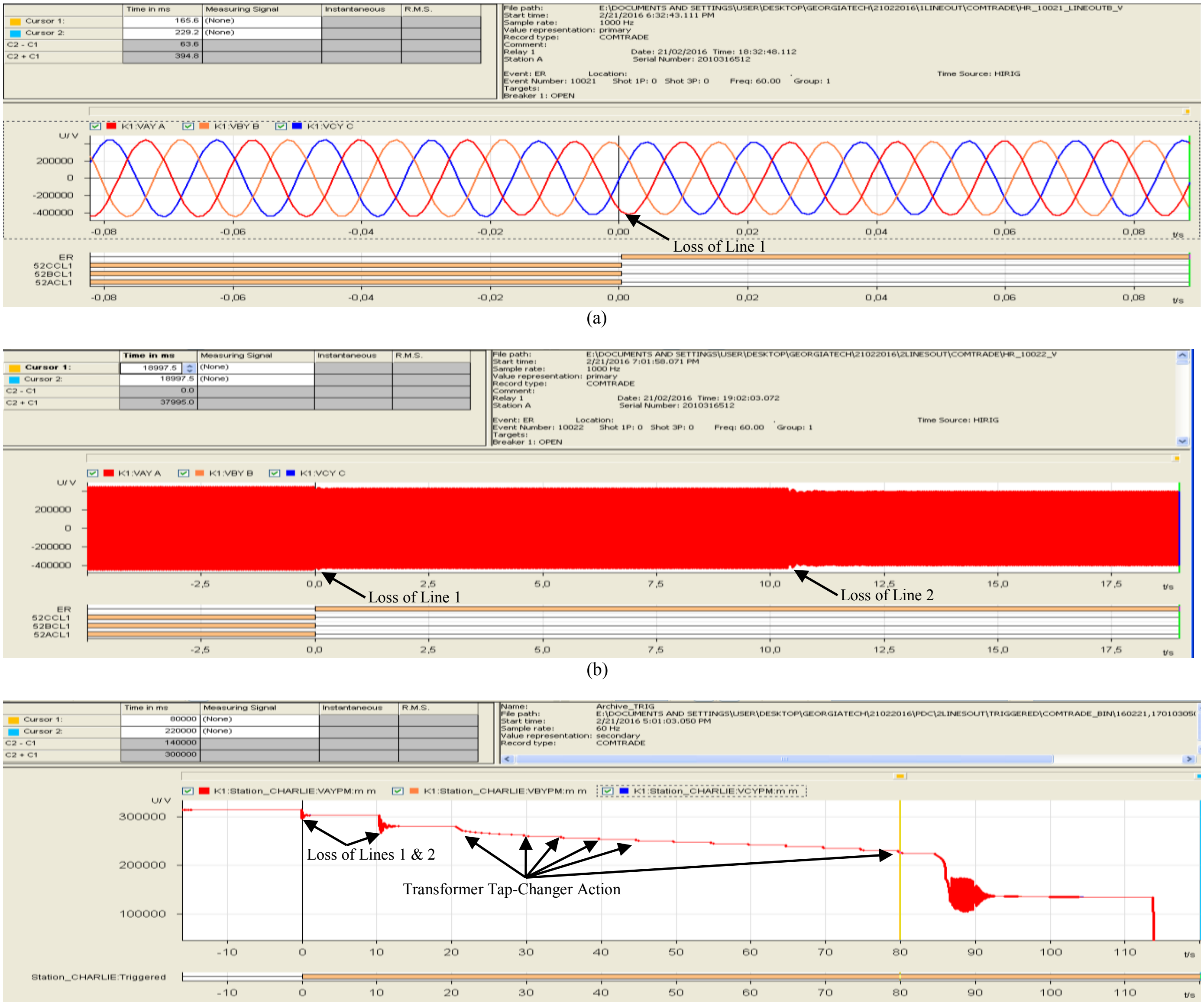


Fig. 5. Architecture of the wide area network emulator used [17]



	Time in ms	Measuring Signal	Instantaneous	R.M.S.
🟨 Cursor 1:	165.6	(None)		
🟦 Cursor 2:	229.2	(None)		
C2 - C1	63.6			
C2 + C1	394.8			

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Sample rate: 1000 Hz
Value representation: primary
Record type: COMTRADE
Comment:
Relay 1 Date: 21/02/2016 Time: 18:32:48.112
Station A Serial Number: 2010316512

Event: ER Location: Time Source: HIRIG
Event Number: 10021 Shot 1P: 0 Shot 3P: 0 Freq: 60.00 Group: 1
Targets:
Breaker 1: OPEN

(a)

	Time in ms	Measuring Signal	Instantaneous	R.M.S.
🟨 **Cursor 1:**	18997.5	(None)		
🟦 Cursor 2:	18997.5	(None)		
C2 - C1	0.0			
C2 + C1	37995.0			

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Sample rate: 1000 Hz
Value representation: primary
Record type: COMTRADE
Comment:
Relay 1 Date: 21/02/2016 Time: 19:02:03.072
Station A Serial Number: 2010316512

Event: ER Location: Time Source: HIRIG
Event Number: 10022 Shot 1P: 0 Shot 3P: 0 Freq: 60.00 Group: 1
Targets:
Breaker 1: OPEN

(b)

	Time in ms	Measuring Signal	Instantaneous	R.M.S.
🟨 Cursor 1:	80000	(None)		
🟦 Cursor 2:	220000	(None)		
C2 - C1	140000			
C2 + C1	300000			

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Start time: 2/21/2016 5:01:03.050 PM
Sample rate: 60 Hz
Value representation: secondary
Record type: COMTRADE

(c)

Fig. 6. Disturbance records from (a) IED for *N*-1 Line contingency; (b) from IED for *N*-2 Line contingency; and (c) from PMU for *N*-2 Line contingency.

TABLE I
ANALYSIS OF A SEGMENT OF THE IMPLEMENTED WAN

S/N	Network parameter	Result
1	Latency	0.1683ms
2	Loss of packet	0.0000 %
3	Jitter	0.1781
4	Available bandwidth	51.3418 Mbps

The performance metrics of interest in this paper include network delays (latency) jitter, packet losses, and network corruption caused by noise or attenuation. Experimental results are presented in the next section.

V. CASE STUDIES AND EXPERIMENTAL RESULTS

The experiments conducted covered the impact of network delay, packet losses, network corruption, and their combinations on synchrophasor measurements from PMUs. Table II gives the parameters used for the pervasive conditions. The results obtained are given in the proceeding subsections.

TABLE II
EMULATED WAN CONDITIONS

S/N	Network condition	Parameters
1	Latency	(100:50:1000) ms
2	Jitter	10% of latency
3	Packet loss	0.1% - 10.0 %
4	Noise	0.1% - 10.0 %

A. Case Study-1

Case Study-1 presents *N*-1 and *N*-2 line contingencies on the 10-bus multi-machine test system given in Fig. 2. Figs. 6a-6b show the plots of the disturbance event recording obtained from an IED at Bus-8 for the *N*-1 and *N*-2 line contingencies respectively. The maximum fault record length possible with the IED used is 24.0 s at a sampling frequency of 1 kHz [18]. Fig. 6c shows the result for a triggered PDC recording of 120.0 s for synchrophasor messages from a PMU at bus-8. The triggered PDC recording can have a maximum of 90 minutes of pre-trigger duration, and a maximum of 90 minutes of post-trigger duration respectively. If continuous PDC recording is desired rather than the triggered recording, the duration can be for days, depending on the size of the PDC archiving storage facility.

B. *Case Study-2*

Case Study-2 investigates the impact of pervasive communication network on synchrophasor measurements. The scenario described in Case Study 1 involving a *N*-1 line contingency is used. In Case Study-2, network delay using the parameters given in Table II is emulated with a Linux-based WAN emulator. Fig. 7a shows the plots of the synchrophasor voltage at Bus-8 obtained without any network latency, and for the emulated network latency of 250 ms to 750 ms with a jitter of 10% of the network latency.

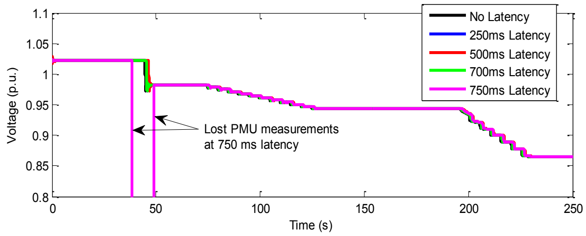

Fig. 7a. Network latency of 0-750 ms for Case Study-2.

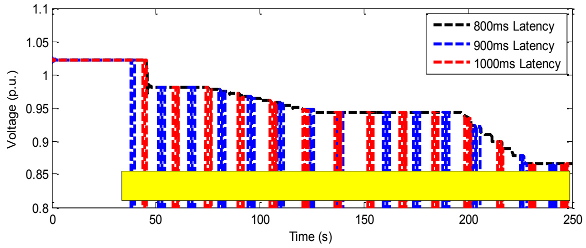

Fig. 7b. Network latency of 800-1000 ms for Case Study-2.

From Fig.7b, it can be seen that the network latency ≥ 800 ms had adverse effects on the synchrophasor measurements. This is demonstrated by the loss in the synchrophasor measurements as indicated by the vertical lines (highlighted).

C. *Case Study-3*

Fig. 8 shows the impact of emulated packet losses using the scenario in Case Study-1 for *N*-1 line outage. From the results obtained, it was observed that packet losses up to 2.5% were acceptable without any consequence on the synchrophasor measurements published to the control centre using the emulated virtual WAN. Above a packet loss of 2.5%, the loss in the data packets had a greater impact as indicated by the increase in the number of measurements dropped.

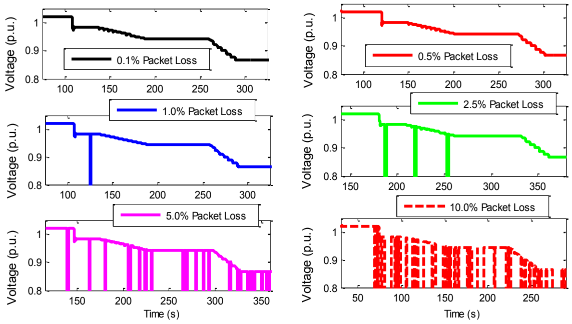

Fig. 8. Phasor measurements of bus-8 for Case Study-3.

D. *Case Study-4*

Case Study-4 presents an investigation on the impact of the corruption introduced by noise and signal attenuation. From Fig. 9, it can be seen that corruption up to 1.0% is acceptable and did not have an adverse effect on the synchrophasor measurements.

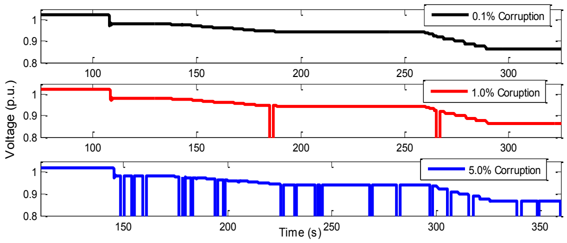

Fig. 9. Phasor measurements of bus-8 for Case Study-4.

VI. DISCUSSION

The record length of the event obtained from the IED configured for disturbance recording had a maximum recording length of 24.0 s. This will fail to capture the transformer tap changer action which is activated 30 s after the regulated bus voltage drops below the reference value. The PMU recording functionality of the IED used has a recording length of 120 s per triggered record. If a recording length greater than 120.0 s is required, the triggered recording functionality of most PDCs can be used. Usually, power swings and other power system stability phenomena would require record lengths of hundreds of seconds. Thus, wide area measurements from PMUs will serve.

When triggered PDC recording is used, the integrity of the synchrophasor measurements streamed to the control centre in real-time is dependent on the communication medium used. For the testbed implemented, the maximum pervasive network conditions permissible are quantified. From the results obtained for the latency investigations in Case Study-2, it was observed that a delay greater than 800 ms would severely degrade the network throughput. However, a latency of 800 ms is a worst case network scenario since the typical latency obtainable in most utility communication network is about 200 ms [19]. Thus, a latency of 800 ms would only occur in very rare cases. Similarly, packet losses less than 1% were shown to be acceptable. With increased packet loses, the communication network degraded to an unacceptable level as shown in Fig. 8 for Case Study-3. The impact of corruption due to noise and signal degradation was demonstrated in Case Study-4. This showed a reduction in the throughput of the network.

From the extensive experimentation carried out, it can be inferred that a maximum network latency of 500 ms could be tolerated simultaneously with packet losses of 0.1% and network noise of 1%. Beyond this, these adverse network conditions could affect the control signals designed for mitigating power system stability and other post-mortem applications for which triggered/continuous PMU recording would be used for.

VII. CONCLUSION

PMUs are increasingly being applied in disturbance analysis, situational awareness, and wide area monitoring and control.

Since these measurements are transmitted over an Ethernet communication network, there is the need to investigate the impact of pervasive communication network conditions on the measurements collected, aligned, and archived by the control centre PDC. In this paper, a platform for wide area disturbance recording using synchrophasor measurements was developed. The impact of key performance metrics (latency, jitter, packet losses, and network noise) on the measurements transmitted through an emulated wide area network was investigated.

The analysis of the experimental results showed a tolerance to latency up to 800 ms. Similarly, the system also tolerated packet losses up to 5% and network corruption of 1%. However, a combination of latency, packet losses, and network corruption occurring simultaneously was observed to be very severe. The results of this paper can be used as a guide in the design of wide area disturbance recording, network planning, and evaluation of the WAN between the substation and the control centre. As part of future work, the impact of cyber security on communication network latency is being considered.

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