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Performance evaluation of G3-PLC over distribution transformers in Indian context

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The past few years have witnessed a tremendous development in Power-Line Communications (PLC) technology such as G3-PLC with existing power-lines for high speed data communication across High voltage (HV), Medium Voltage (MV) and Low Voltage (LV) transmission/distribution networks based Smart Grid (SG) applications. As power-lines were not originally intended for conveying high frequency signals, and any communication over these lines would be exposed to severe adversarial factors, such as interference, impulsive and phase noise. G3-PLC technology also elucidates the importance of employing robust modulation schemes across distribution-transformers and motivates research in this direction. Indeed, the aim of the paper is to investigate G3-PLC channel measurements through MV/LV distribution-transformers by implementing experimental tests to analyse the signal-to-noise ratio (SNR), Bit Error Rate (BER) and Packet Error Rate (PER) performance of DBPSK, DQPSK and ROBO (Robust) modulation schemes over multipath PLC channels in Indian context.

Keywords: *G3-PLC technology, panipat, power-line communications, smart grid, smart meters*

1.0 INTRODUCTION

The uses of power-lines for data communication over the last two decades has gained global interest. It is also well known that advanced control and operation systems for distribution grids and micro-grids (μGs) [1] are facilitated by the use of emerging measurement technologies such as smart metering [2] and phasor measurement units (PMUs) applications [3,4], which are providing more accurate and extensive measurement information to enable real-time data monitoring, state estimation and system analysis for Demand Side Management (DSM) applications [5]. It has already proved with experimental results that latest communication technologies are contributing for voltage regulation as well as DSM applications for SGs [6]. Nowadays most of the Advanced Distribution Automation (ADA) systems are based on IEC 61850 standard, which is reliable for long-time SG related analysis [7]. However the ADA relies heavily on a secure and robust bi-directional communication system. Recently, the worldwide use of power-line communications (PLC) for ADA systems has gained significant interest due to its low deployment costs [8]. The PLC reliability and varying distance of the LV systems/networks are mostly affected by the channel interference and the time varying load impedance. In Europe, with more than 40 million installed metering points, PLC is proved solution for smart metering industries [9]. Since 2010, various next-generation PLC standards like G3-PLC [10], PRIME [11], ITU G.9955/9956 standard [12] and IEEE 1901.2-2013 standard [13] has been introduced. G3-PLC standard, as shown in Figure 1[10], which has been standardized by the G3-PLC Alliance and accepted as the ITU-T

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(G.9903) standard. The G3-PLC standard employs Orthogonal Frequency Division Multiplexing (OFDM) technology for physical (PHY) layer. The Medium Access Control (MAC) layer, which is derived from IEEE 802.15.4 connects the Logical Link Control (LLC) and PHY layer. It is already adopted with low-power wireless-personal-area-network (6LoWPAN) specification to facilitate IPv6 interaction at the network layer. Due to hostile power-line environment, 6LoWPAN protocol is useful for efficient routing over varying network topologies. The IPv6 layer in G3-PLC technology can also contribute regarding internet-of-things (IoTs), smart home/buildings energy management schemes and various SG applications, as are shown in Figure 2. OFDM technology has excellent narrowband anti-noise capability and it compromise the robustness in presence of PLC channel issues (various types of noises and channel fading) and during higher data rate that speed may be achieved up to 100 Kbps [14].

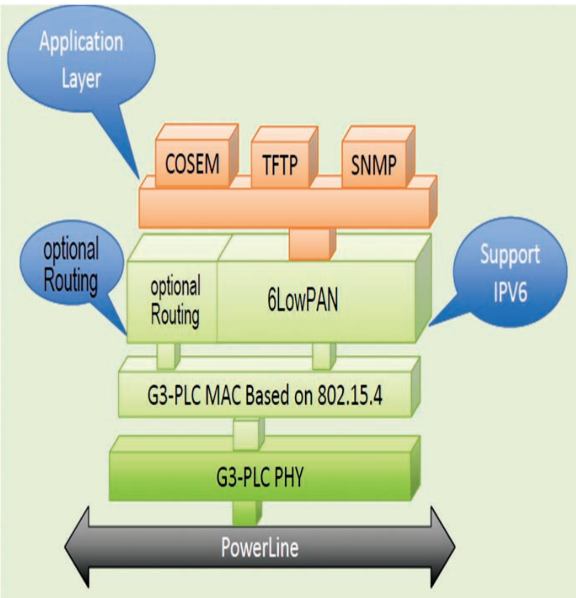

FIG. 1 G3-PLC TERMINAL PROTOCOL STACK

G3-PLC is an OFDM modulation based technology, which guarantees fast data transfer over existing power-lines within 150-500 kHz frequencies (CENELEC A band (within 35-91 kHz) or CENELEC B band (within 98-122 kHz) in Europe, on ARIB band (within 155-403 kHz) in Japan, FCC band (within 155-487 kHz) in USA and the rest of the globe is secure and stable technology for various SG applications [15]. Modern OFDM technology based PLC modems (within 9-95 kHz CENELEC-A frequency band) can be directly connected to LV power-lines [16]. G3-PLC technology with data rate up to 60 Kbps on application layer, is quickly gaining ground with latest Germany's smart metering standards and various SG applications [17]. G3-PLC technology also provides a reliable and secure connection between PLC devices, including crossing data from MV to LV distribution-transformers.

FIG. 2 A TYPICAL G3-PLC BASED SMART GRID INFRASTRUCTURE

To the best of authors' knowledge, no G3-PLC technology based testing to perform BER and PER analysis of two types of transmission (i.e. packet transfer and data file transfer) across two distribution-transformers in Indian context has been conducted yet. The remainder of this paper is structured as follows: G3-PLC technology based proposd measurement system is described in Section 2. Test results are discussed in Section 3. And finally, the paper is concluded in Section 4.

2.0 PROPOSED ALGORITHM

In our previous work using G3-PLC modems [18] in NIT Kurukshetra (Deemed University) campus, we examined PLC channel reliability and survivability during building area networks (BANs) applications. G3-PLC modem consists of MAX2991 integrated analog front-end (AFE) transceiver, which interfaces with MAX2992. The G3-PLC modem operates as per CENELEC A band (within 10-95 kHz) and FCC band (within 150-490 kHz) with 72 carriers and supports ROBO, DBPSK, DQPSK and D8PSK modulation schemes. It has an operating temperature range of -40°C to +85°C and power consumption is 3.6W. In order to perform following tests (i.e. BER and PER analysis) with G3-PLC modems in Panipat (Haryana), India, a transparent protocol using GUI software were implemented. A GUI software running on notebooks having (i.e. intel® Core™2 Duo CPU P8700 @2.53GHz with 4 GB RAM) configuration with Microsoft.net framework 2.0 on Windows XP environment, were used to configure the G3-PLC modems as RX-receiver and TX-transmitter to select suitable frequency band, selective gain, subcarrier modulation type and data packet size. During experimental investigation one G3-PLC Modem termed as Coordinator Communication Module (CCM), while second termed as Terminal communication module (TCM) and monitored the data rate estimation, number of transmitted/ received and data packets loss between distribution-transformers. We implemented a transparent protocol between CCM and consumer device/application type1, as shown in Figure 3, where the TCM directly connects with consumer device/application type 2 through Universal Asynchronous Receiver/ Transmitter (UART) interface, and G3-PLC modems can handle the network formation (i.e. connect, data transmission etc).

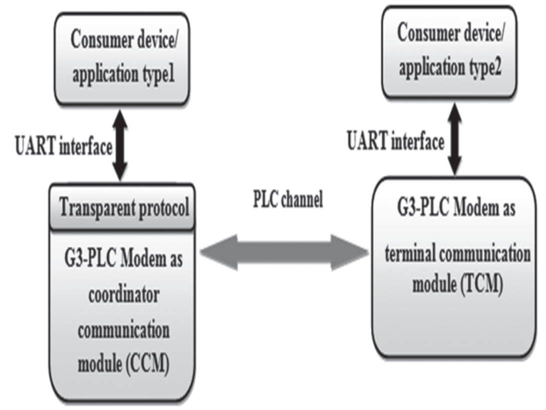

FIG. 3. BLOCK DIAGRAM OF G3-PLC MODULE SOFTWARE ARCHITECTURE

If we implement the application program in consumer device/application type 1, then Advanced Protocol Interface (API) supports transparent protocol, which can communicate with consumer device/application type 1 through PLC channel. During operation within the network, if more than one TCM nodes are required, then transparent protocol provides a peer-to-peer (P2P) connectivity with other nodes. Flowchart of the proposed algorithm, as shown in Figure 4: The proposed algorithm is as follows:

Step 1: Start.

Step 2: Configure G3-PLC modem A, G3-PLC modem B and their host UARTs.

Step 3: Receive the sample data signal from via host UARTs.

Step 4: Initialize G3-PLC modems to take necessary sample data signal and display.

Step 5: Check and wait for the sample data signal.

Step 6: Send the sample data signal via host UARTs.

Step 7: Continue till all G3-PLC modems received their sample data signal.

Step 8: Stop.

During tests 1000 packets (size: 256 bytes each packet) from one G3-PLC modem to other G3-PLC modem, and the GUI software were informed about the data transfer rate (DTR) and the packets error rate (PER). Even afterwards the PER were not detected correctly, estimated through given formula:

PER%= Number of packets loss / Total number of packets sent * 100 ...(1)

For the sake of reliability, the test was repeated 10 times (after every five seconds interval) and the average PER of these tests were displayed.

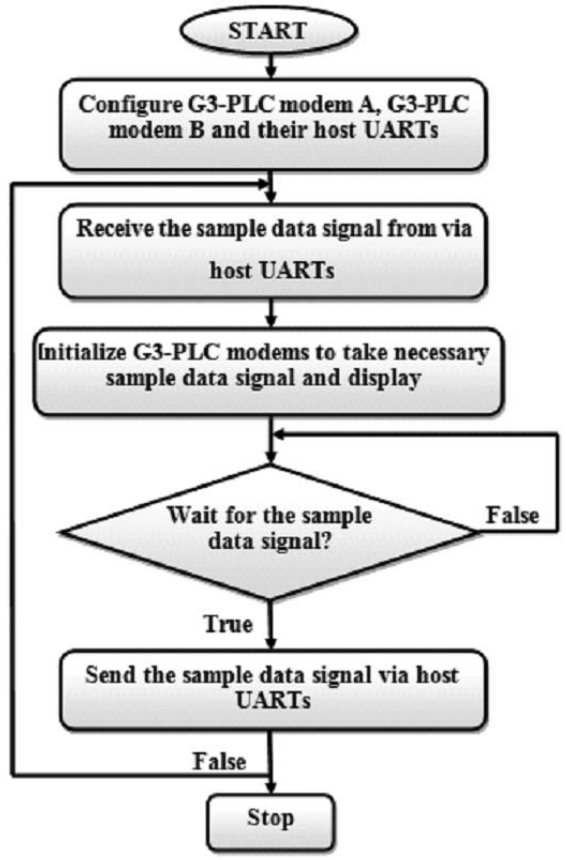

FIG. 4 FLOWCHART OF PROPOSED ALGORITHM

3.0 FIELD TRIAL RESULTS AND ANALYSIS

Table 1. specifies the worldwide comparison of distribution transformers, which were used for various narrow band power-line communication (NBPLC) applications. In this paper, we used G3-PLC modems to work uniquely in harsh conditions, where a negative signal-to-noise ratio (SNR) is also expected. G3-PLC technology is robust, and operating at low voltage (and low current) is not an issue. In power distribution substation the voltage limit is set from 215-240 V, which can be normally seen during LV network μGsin India. In G3-PLC standard, DBPSK and DQPSK modulation schemes are most popular [10]. DBPSK modulation is an incoherent form of phase shift keying without restoring the coherent reference signal at the receiver, which reduces the complexity at receiver side. As per the operating principle, the input binary data should be in DBPSK mode and the corresponding output does not change until input bit is 0, otherwise the output will turn over. Otherwise there is a simple mapping relationship: bit 1 is output 1 and bit 0 is output -1, which is termed as BPSK modulation. During our experimental verification with G3-PLC modems for two types of transmission (i.e. packet transfer and data file transfer) for communication testing purpose were performed from both directions, as shown in Figure 5. A transfer comparison of PLC signal using DBPSK, DQPSK and ROBO (Robust) modulation schemes connecting across secondary sides of two 11 kV–433/266.67 V distribution-transformers (LV-MV-LV type), and nearly 55 meters distance were covered. Typical Indian distribution-transformer specifications are given in Table 2. Packet transmission from both directions were performed. During a transfer block size (TBS) of 256 bytes using DBPSK, DQPSK and ROBO (Robust) modulations, as shown in Table 3 and Figure 6, the channel performance were measured on notebooks through USB cables. During experimental verification ROBUST mode was essential to establish reliable communication among distribution-transformers. In Table 4 and Figure 7, we compared the five data files (i.e. with different sizes in KB), which were successfully transferred using DBPSK and DQPSK modulation schmes. During experimental verification the best results for 25 KB and 50 KB file transmission were achieved. It is found during high speed that the data files transmission decreased or packet lost and re-transmissions of data files were performed. As presented in this paper, the data transfer speed was slow, but the G3-PLC technology through MV power-lines, has proved the successful communication through two distribution-transformers, and it observed that in coming years this technology will be useful and deployable for Indian smart metering networks/ applications.

TABLE 1

WORLDWIDE COMPARISON OF VARIOUS DISTRIBUTION-TRANSFORMERS FOR NARROW-BAND POWER-LINE COMMUNICATION BASED APPLICATIONS

DISTRIBUTION TRANSFORMER SPECIFICATIONS	MODULATION TYPE / FREQUENCY RANGE	MODE OF OPERATION		COUNTRY
		REAL TIME	SIMULATION	
400 KVA / 10kV-380 V	(-) 9-95 KHZ	✓	✓	NETHERLANDS [19]
(-) /20 kV/200 V	G3-PLC 35.9-90.6 KHZ	✓	✓	FRANCE [15]
10-100 KVA / (-)	G3-PLC UPTO 95 KHZ	-	✓	AUSTRALIA [20]
100 KVA / (-)	FREQUENCY SHIFT KEYING (FSK) 50-150 KHZ	✓	✓	ITALY [21]

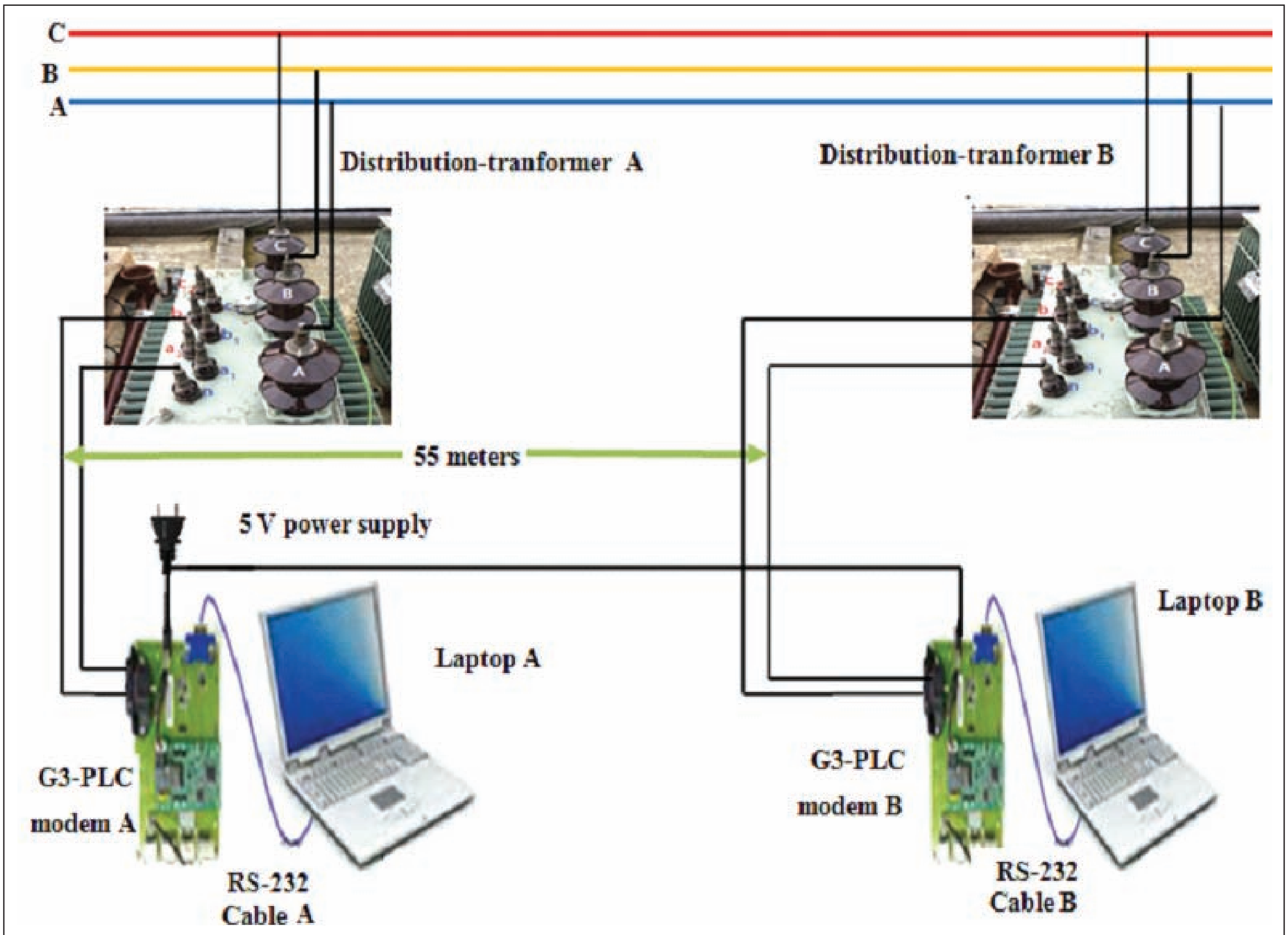

FIG. 5 EXPERIMENTAL SET-UP FOR G3-PLC PERFORMANCE ANALYSIS ACROSS SECONDARY WINDINGS OF TWO 11 KV DISTRIBUTION-TRANSFORMERS AT PANIPAT (HARYANA)

TABLE 2	
11 kV DISTRIBUTION-TRANSFORMER SPECIFICATIONS	
MANUFACTURER NAME/ YEAR MAKE	CENTURY INFRAPOWER (PVT.) LTD./ 2016
RATED VOLTAGE, HV	11KV
RATED VOLTAGE, LV	433-266.67 V*
FREQUENCY	50 HZ +/-5%*
NUMBER OF PHASES	3
CONNECTION HV	DELTA
CONNECTION LV	STAR (NEUTRAL BROUGHT OUT)
VECTOR GROUP	DYN-11
WINDING MATERIAL	ALUMINIUM
COOLING TYPE	ONAN

TABLE 3				
PACKETS TRANSMISSIONS ACROSS SECONDARY WINDINGS OF TWO 11 kV DISTRIBUTION-TRANSFORMERS				
MODULATION TYPE	DISTRIBUTION-TRANSFORMER A TO DISTRIBUTION-TRANSFORMER B			
	SNR 1 (DB)	BER 1	PER 1 (%)	DATA TRANSFER RATE (KBPS)
DBPSK	7	0	0	11.21
DQPSK	7	0	0	17.43
ROBO	7	0	0	5.38
	DISTRIBUTION-TRANSFORMER B TO DISTRIBUTION-TRANSFORMER A			
	SNR 2 (DB)	BER 2	PER 2 (%)	DATA TRANSFER RATE (KBPS)
DBPSK	9	0	0	11.21
DQPSK	8	0	0	17.43
ROBO	8	0	0	5.38

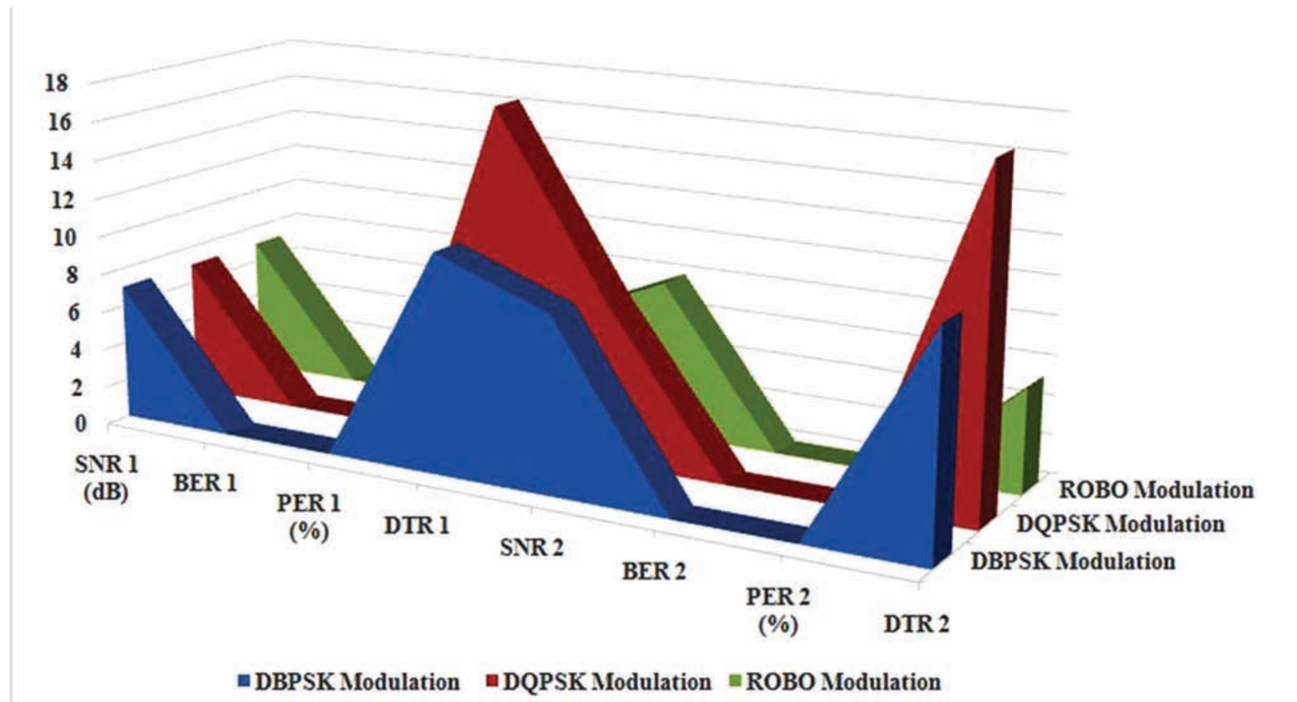

FIG. 6 PACKETS TRANSMISSIONS ACROSS SECONDARY WINDINGS OF TWO 11 KV TRANSFORMERS

TABLE 4

DATA FILE TRANSMISSIONS ACROSS SECONDARY WINDINGS OF TWO 11 kV TRANSFORMERS

Data file size (KB)	Distribution-transformer A to distribution-transformer B			Distribution-transformer B to distribution-transformer A		
	SNR 1 (dB)	PER 1 (%)	Data transfer rate 1 (Kbps)	SNR (dB)	PER (%)	Data transfer rate 2 (Kbps)
25	8	0	6.6	8	0	6.6
50	8	0	6.8	8	0	6.8
75	8	0.7	6.5	8	0.6	6.5
100	8	1.1	6.5	8	1.2	6.5
125	8	1.2	6.4	8	1.5	6.3

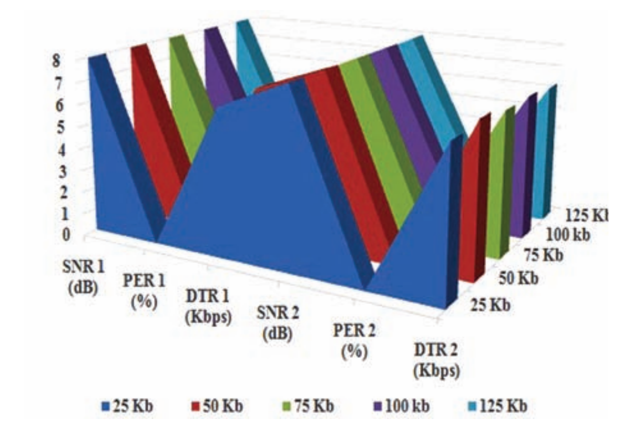

FIG. 7 DATA FILE TRANSMISSIONS ACROSS SECONDARY WINDINGS OF TWO 11 KV TRANSFORMERS

4.0 CONCLUSION

This paper has aimed to measure G3-PLC performance analysis practically over distribution-transformers in Panipat (Haryana), India. In our test implementation the PLC channel measurements were performed to achieve BER performance, and G3-PLC using different modulation schemes (i.e. DBPSK, DQPSK and ROBO (Robust) modulation schemes) looks truly promising due to availability of Reed-Solomon (RS) codes to communicate very high volumes of data over distribution-transformers.With recent field measurement results the following main discussion points are:

- First, to the best of authors' knowledge, no G3-PLC technology based testing to perform BER and PER analysis of two types of transmission (i.e. packet transfer and data file transfer) across two distribution-transformers in Indian context has been conducted yet.
- Second, the measurements in this study were realized only for specific industry power lines in India, the proposed algorithm in its present form is not generic to all other industrial power lines. Therefore, further studies should be carried out to prove the accuracy of algorithm for other industry power-lines.
- And the last discussion is about the measurements with G3-PLC technology is highly reliable, economical, expandable and efficient, which could effectively help to implement the future Indian AMI systems with a preferable rate and reliability, even in the noisy environments.

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