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Design of Improved Communication System for Indian Railways by using Power Line Carrier Communication (PLCC) System

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***Abstract*— This paper has realized the very essential gap in the Indian Railways (IR) communication system and focuses on its fulfilment i.e. direct transmission of passenger or goods locomotive or moving train-related data and sensory information, encompassing details like position, velocity, and vibration parameters, as well as environmental data such as weather conditions, and network-specific information like the number of interconnected trains. Analysing this data enables the implementation of effective policies to reduce maintenance costs, optimize maintenance schedules, and ensure the safe and proper operation of the network and transmit to the divisional control room & nearby station while enabling the complete control of the locomotive from the control room and propose the designing of a more centralized system of communication and control. Calculation of parameters such as frequency and harmonics by simulating the actual line parameters with related mathematical modelling and simulation required.**

Keywords: Indian Railways, locomotive communication over power line, power line carrier communication, safety.

I. INTRODUCTION

The dawn of electric traction in India, marked by its inception on 3rd February 1925, transformed the landscape of railway transportation. The Great Indian Peninsular Railway (GIPR) pioneered this innovative system, electrifying the 16-route-kilometer stretch between Bombay VT and Kurla Harbour, utilizing the 1500 V DC system. [1]
In 1955, a significant turning point occurred when the French National Railways, Société Nationale des Chemins de Fer (SNCF), demonstrated the superiority of the 25 KV single-phase, 50 cycles (Industrial Frequency) A.C. system over other electric traction technologies. Indian Railways embraced this revolutionary system, initiating electrification schemes in collaboration with SNCF in 1957 [2]. Presently, IR uses communication means such as quad cable and OFC (Optical Fiber Communication) based communication for the station to station communication, But for locomotive to station communication RF (Radio Frequency) based communication like VHF (Very High Frequency) set is used, which is having its limitations such as improper function during bad weather conditions, if the locomotive is not in a range of VHF set then the communication with the loco pilot is very difficult and in some cases, any unforeseen condition cannot be passed to loco pilot if the train has departed from a station until it reaches the next station. It can be taken as the use of traditional means of information communication system, which is very bulky, slow and requires continuous maintenance which may result in weak communication and delaying of information, etc. that is the whole backbone of railways transportation network.

II. PRINCIPAL OF THE PROPOSED SYSTEM

The term "LCoPL" (Locomotive Communication over Power Line) will be used and give a new insight into direct locomotive communication technology. This communication system will enable the transmission of internal parameters of a moving train or locomotive to the control room by using the overhead catenary or contact line by implementing a power line carrier communication system (PLCC). This can be utilized for safety logic designing, real-time moving trains or locomotive monitoring, and controlling and communicating with loco pilots directly from the divisional control room. A survey has been made on IR's present technology of communicating the information that is shown in the following figures,

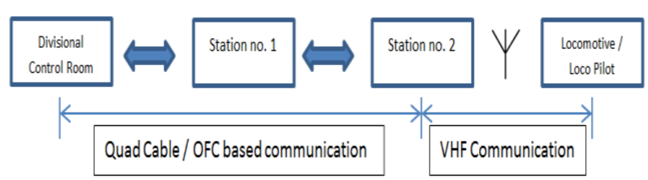

Fig.1. Block representation of traditional information communicating system with VHF commination during healthy connectivity.

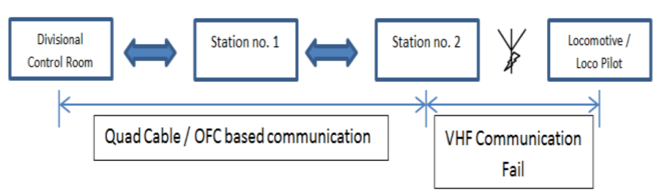

Fig.2. Block representation of traditional information communicating system with VHF commination failure due to bad connectivity.

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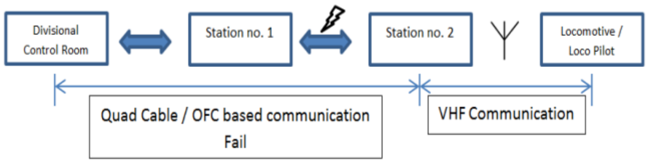

Fig.3. Block representation of traditional information communicating system with quad or OFC commination failure.

As can be understood from Figure 2 and Figure 3, the limitation of the present technology of information communication i.e. any fault in VHF communication due to any faulty condition may result in a huge impact on loco pilot communication with the next station or vice-versa, that may result in delay information about any further caution condition to loco pilot and same can happen if any fault occurs in quad or OFC communication. As per the survey, this can be noted that the described situations are true and occur most frequently. The concept of "LCoPL" can be understand by the following figures,

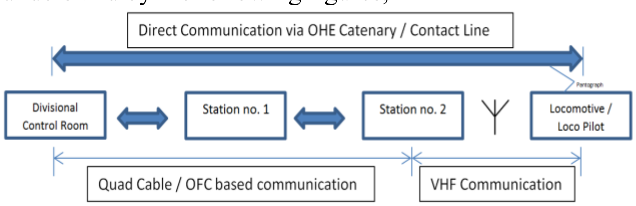

Fig.4. Block representation of LCoPL information communicating system that uses the pre-existing OHE catenary line for Communication along with traditional system.

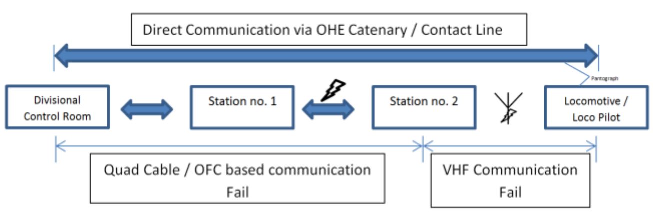

Fig.5. Block representation of LCoPL information communicating system with healthy communication along with faulty connectivity of traditional communication system.

As seen in figure 4, the direct communication of the divisional control room with the loco pilot is possible by using the pre-existing OHE catenary or contact lines that have the advantage of regular contact with the loco pilot and control room irrespective of the weather condition or any fault, if occur in quad or OFC communication, as seen in figure 5. The major advantage of this communication system is installation cost is not required as it uses the pre-existing OHE catenary or contact lines and can be easily implemented by using the power line carrier communication technology that has been used in power transmission and vice-versa.

III. Electric Traction System

Understanding of electric traction system, which consists of traction power distribution and overhead equipment.

A. Traction Power Supply

In this section, the traction electrification is described with the standard electrical connection as per described by research designs and standards organization (RDSO). Power is obtained from State Electricity Boards (SEBs) from their network at 220/132/110/66 kV (usually at 132kV), three phase supply system is used and then it is configured into 25KV, 50 Hz supplying two catenary lines.

The electrical traction system is divided into following,

1. TSS (Traction Sub Station)
2. SP (Sectioning Post / Sectioning and Paralleling)
3. SSP (Sub Sectioning and Paralleling Post)

Initially the generated power in power generating stations is transmitted over ultra-high voltages e.g. 400KV, and then it is step down to 220KV/132KV at substations and transmitted to traction substation (TSS) where the voltage level is step down to 25KV for electric traction purpose, the distance between two TSS is about 60 to 80 km as shown in fig. 6.

The sectioning post (SP) is provided between two adjacent substations in order to separate the feeding supply to avoid any phase to phase short circuit while negotiating the train pantograph, Sub sectioning and paralleling post (SSP) is provided in between TSS and SP to further sectionalize the overhead equipment, the configuration with high-voltage circuit breakers, traction transformers, lightning arresters, isolators, interrupters, booster transformers (BT), low tension transformers to provide local supply in nearby area or at station for light load. [3]

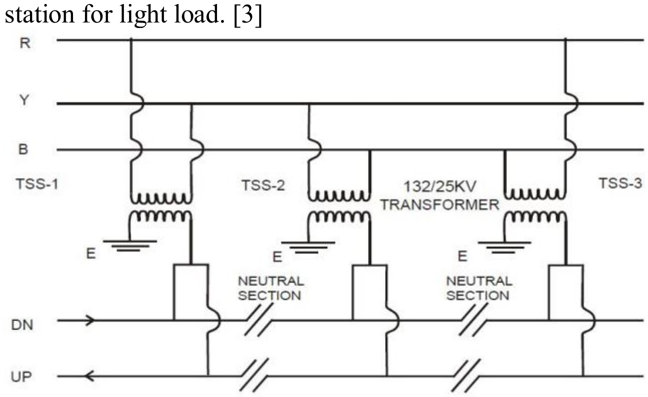

Fig.6. General supply arrangement.

B. Over Head Equipment System and Its Functioining

The function of overhead equipment is to feed the energy to the traction unit that it needs. There are two systems of current collection, namely, third rail and from overhead wire. The current collection from overhead system is more adoptable due to the ease of insulation and also reduces the danger to any personnel. Current collection is done with the help of pantograph. Pantograph remain installed on the roof top of electric traction with its assemblies e.g. circuit barker, spark arrester etc. [4].

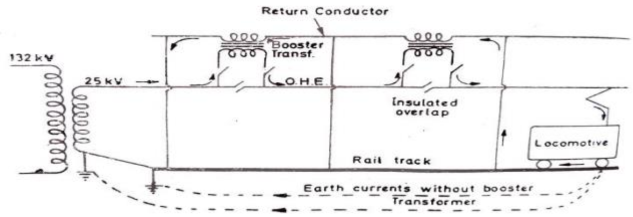

Fig.7. Booster transformer arrangement, return conductor and leakage earth current representation.

In fig.7 the supply system of single-phase 25KV with booster transformer is shown. In the AC traction system, the return current flows from the locomotive to the track, but leaks to the ground over a short distance returning to the substation through its earth. Consequently, this leakage interferes with the communication lines. In order to limit the leakage current booster transformer is used, which consists of 1:1 ratio transformer, whose, primary winding remain connected in series with contact wire, and booster transformer is connected with the return feeder [5].

IV. Power Line Carrier Communication

A. *PLCC Functioining*

Power line communication (PLC) harnesses the inherent potential of the electrical distribution network to enable data transmission, utilizing the existing infrastructure of the power distribution network or power grid. Data signals are transmitted through electrical lines, allowing the simultaneous transfer of electrical power and data for signaling and remote-control purposes [7, 8] as mentioned in [6]. With a growing emphasis on the safety and maintenance of railway systems and an increasing demand for robust communication technologies, the need for high data rates, low latency, and continuous coverage has become paramount. The primary objective is to establish high-speed internet connections for efficient service management [9]. Power line carrier communication is already employed by power transmission companies for power line communication and signaling of relays, ensuring the effective functioning of the power system and facilitating fault identification. The system comprises specific components, each serving a distinct function, contributing to its seamless operation.

- Wave trap – It is used in power line communication in power transmission companies which act as a high pass filter; It separates the carrier frequency and power frequency, shown in fig. 8.
- Capacitive voltage transformer (CVT) or Coupling transformer – It is used for coupling the high tension line to PLC Equipment and vice versa, shown in fig. 9.
- Line matching unit (LMU) – It is used for impedance matching of line for proper signal attenuation and to reduce communication interference by matching the power line impedance, used with CVT, shown in fig. 10.

Fig.8. Wave Trap used for PLC communication act as high pass filter.

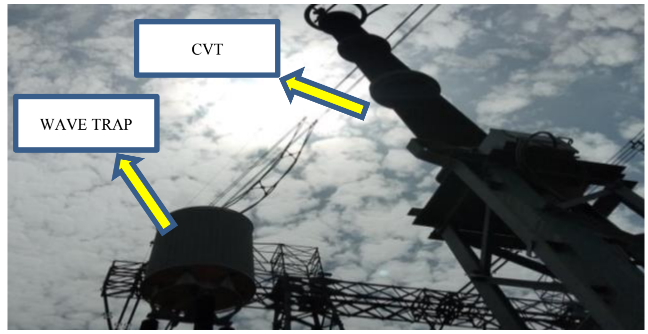

Fig.9. Wave Trap (left) and CVT (right).

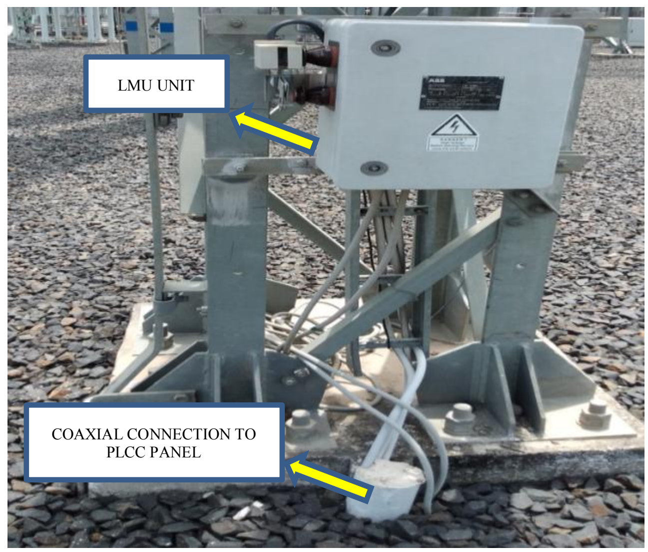

Fig.10. Line impedance matching unit (LMU).

V. DEVELOPMENT OF PLCC BASED LOCOMOTIVE COMMUNICATION

In countries such as Italy, the UK, and the USA, railway operators are prioritizing Broadband Traction Power Line Communication (BTPLC). This approach utilizes the electric traction line as a channel for broadband communication [10, 11]. BTPLC facilitates the transmission of train-related data and sensory information, encompassing details like position, velocity, and vibration parameters, as well as environmental data such as weather conditions, and network-specific information like the number of interconnected trains. Analyzing this data enables the implementation of effective policies to reduce maintenance costs, optimize maintenance schedules, and ensure the safe and proper operation of the network [12, 13]. Contrastingly, Indian Railways haven't adopted power line communication for locomotive communication purposes, highlighting a significant gap in the utilization of this technology [14]. PLC technologies is classified based on the following electrical system characteristics,

- Nominal voltage – Based on operating voltage value in the power grid on which PLC is installed. As per European norms *EN 50160* [15], power grid is classified as low voltage (LV) if nominal voltage is less than 1KV, medium voltage (MV) if nominal voltage is within the range of 1-35KV, and high voltage (HV) if it is above 35KV.
- Current regime – It is based on the utilization of either direct current (DC) or alternating current (AC) regime. PLCC seems facilitated on DC regime as it does not require phase and reactive power control [16].
- Frequency range – It is classified based on transmitting signal frequencies [17], Depending on transmission of data speed and distance. The frequency range in which PLC system can operate is from 125 Hz to 100 MHz [18, 19].
- Transmission distance – For short range PLC system the transmission distance is up to 80 km; for medium range the distance is about 80-250 km and for long range the distance is above 250 km [20].

TABLE I. PLC SYSTEM FREQUENCY RANGES.

Band	PLC system frequency ranges.
	Frequency range
Ultra-narrowband	Frequency range (125-3000) Hz, UN-PLC used in long distance transmission its data rate is in order of kbps [21].
Narrowband	Frequency range (3-500) KHz, NPLC used in mudium/long distance transmission, it has data rate from 1 kbps up to 1 Mbps [21].
Broadband	Frequency range (1.8-100) MHz [22], NB-PLC is used for short distance transmission, it has data rate of above 200 Mbps [23].

The primary advantage of the PLCC system over other systems lies in its utilization of pre-existing infrastructure, specifically the electric traction power lines. This approach can lead to substantial cost savings, as it eliminates the need for installing additional cables or optical fibers. It also significantly reduces labor-related accidents and the time consumed during installation, thereby enhancing the overall efficiency of the system. Additionally, compared to radio or wireless transmission, PLCC offers improved connectivity and real-time monitoring of train parameters. This live connectivity to locomotives enables efficient data transmission and ensures seamless communication within the railway network.

VI. LCoPL PARAMETERS CALCULATION

Parameters for LCoPL communication system such as signal attenuation, line impedance and frequency response can be calculated as follows,

A. Signal Attenuation

Signal attenuation is one of the primary challenges for PLC system; it refers as the reduction in power level between the signal generated by the transmitting device and the signal received by the receiving device. It is primary caused by energy absorption in the transmitting medium, reflection of signal which results in impedance mismatching, dispersion along the line into other devices, and branching of the guiding structure into different paths [24], the loss in transmission, denoted as L_t, can be expressed in dB as shown in equation (1),

$$L_t = 10\log_{10}\left(\frac{P_0}{P_i}\right) \tag{1}$$

Where, P_o represents the signal power received, P_i represents the signal power transmitted by the transmitting device.

B. Input Impedence

The input impedance is obtained by expression (2),

$$Z_i(f) = Z_0\,\frac{1+s_{11}(f)}{1-s_{11}(f)} \tag{2}$$

$Z_i(f)$ – Input impedance seen by the transmitter, Z_0 – line impedance and s_{11} – is one of the four scattering parameters s_{ij} (i, j = 1, 2) generally used to verify the impedance matching quantity [25].

C. Frequency response

- Average channel gain

$$G_C = 10\log_{10}\left(\frac{1}{N}\sum_{i=0}^{N-1} |H_i|^2\right) \tag{3}$$

Equation (3) is for channel gain, averaged, where H_i denotes the i-th sample of the channel frequency response [26].

- Root mean square delay spread (RMS-DS),

$$\sigma_\tau = \sqrt{\mu_0' - \mu_0^2} = T_S\sigma_0 \tag{4}$$

Equation (4) measure the time dispersion, due to the reflections at the joint of different branches with impedance mismatching [27], where $T_S = 1/fs$ i.e. sampling period, σ_0 is RMS-DS normalized for unit sampling time, μ_0 is the average delay, μ_0' is its second order central moment, its value is less than 0.5 [28].

- Channel capacity

$$C = \max_{P_t(f)} \int_{f_1}^{f_2} \log_2\left(1 + \frac{|H(f)|^2 P_t(f)}{P_n(f)}\right) df \tag{5}$$

In equation (5) the maximum amount of information in bytes that can be reliably transmitted along the channel in a given period of time (in seconds). Its frequency interval (f_1, f_2) denoted in bps, where $P_t(f)$ and $P_n(f)$ are the power spectral density (PSD) of the transmitted signal and of the noise (background noise is assumed as Gaussian noise) [29].

- Coherence bandwidth

$$R(\Delta f)=\int_{B_1}^{B_2} H(f)H^{*}(f+\Delta f)df \qquad (6)$$

In equation (6), the coherence bandwidth represents a statistical measure that provides the range of frequencies over which $R(\Delta f)$ is constant [30, 31].

VII. Modelling and Calculation

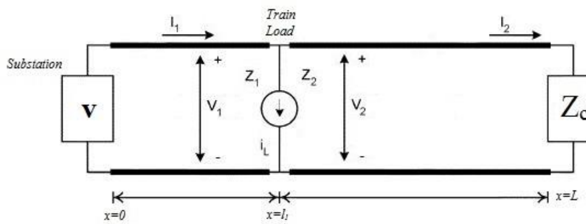

Fig.11. Modeling of railway feeder with harmonic filter impedance Zc

For calculation the distributed parameters such as R, G, L and C, the steady-state time harmonic voltage and current expression are given by equation (7),

$$\left.\begin{aligned} V(x)&=V^{+}e^{-\gamma\cdot x}+V^{-}e^{+\gamma\cdot x}\\ I(x)&=\frac{1}{Z_o}\left(V^{+}e^{-\gamma\cdot x}-V^{-}e^{+\gamma\cdot x}\right)\end{aligned}\right\} \qquad (7)$$

Where position x, is measured from substation, and Zo and γ are the characteristic impedance and propagation constant given by equation (8),

$$\left.\begin{aligned} Z_o(\omega)&=\sqrt{\frac{R+j\omega L}{G+j\omega C}}\\ \gamma(\omega)&=\alpha+j\beta=\sqrt{(R+j\omega L)(G+j\omega C)}.\end{aligned}\right\} \qquad (8)$$

Harmonic current, i_L located somewhere along the transmission line to represent a locomotive load. The voltage and current profile along the feeder are given by two sets of equations, one for left- and right-hand line section as shown in fig. 11. In equation (9), the four constant V_1^{+}, V_1^{-}, V_2^{+}, and V_2^{-} can be expressed in terms of Z_s, Z_c and i_L using the boundary conditions, expressed in equation (10), Line length is taken as 30 km railway section, and distributed Pi model parameters such as R=1.69 Ω, L=1.38mH and C=0.11µF, compensating filter impedance Zc=5Ω, These line parameter values are typical values for the National Railways of Zimbabwe having 25KV, 50 Hz traction supply [32, 33].

$$\left.\begin{aligned} V_1(x)&=V_1^{+}e^{-\gamma\cdot x}+V_1^{-}e^{+\gamma\cdot x}\\ I_1(x)&=\frac{1}{Z_o}\left(V_1^{+}e^{-\gamma\cdot x}-V_1^{-}e^{+\gamma\cdot x}\right)\\ V_2(x)&=V_2^{+}e^{-\gamma\cdot x}+V_2^{-}e^{+\gamma\cdot x}\\ I_2(x)&=\frac{1}{Z_o}\left(V_2^{+}e^{-\gamma\cdot x}-V_2^{-}e^{+\gamma\cdot x}\right)\end{aligned}\right\}\ell_1\le x\le L. \qquad (9)$$

$$\begin{aligned} -I_1(0)\cdot Z_S&=V_1(0)\\ I_1(\ell_1)&=i_{Lh}+I_2(\ell_1)\\ V_1(\ell_1)&=V_2(\ell_1)\\ V_2(L)&=Z_C\cdot I_2(L).\end{aligned} \qquad (10)$$

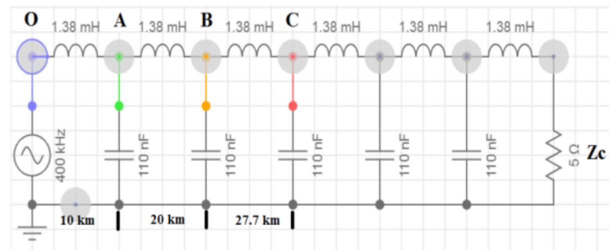

Fig.12. Pi modeling of the distributed parameters of railway feeder.

Result of the Simulations

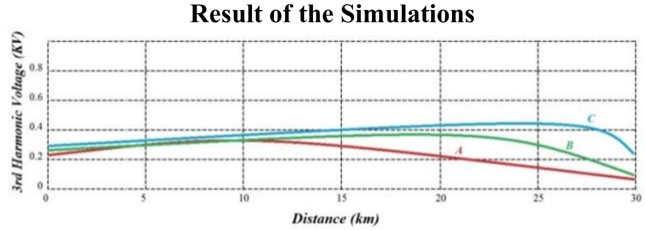

Fig.13. Harmonic voltage profiles for a 30-km feeder section due to a single harmonic current source of 20 A at point A - 10 km, B - 20 km and C- 27.7 km from the substation.

Figure 13, Indicates the 3rd harmonic voltage on OHE line, at point A, 0.3KV, at point B it is 0.37KV and at point C, 0.42KV these are the approximated data (including environmental factor), these simulated vales can be utilized for designing of locomotive CVT and line matching unit or LMU.

	Freq	Mag	Phase
●	400 kHz	0 dB	-229 z°
●	400 kHz	-59.6 dB	-15.7 k°
●	400 kHz	-119 dB	-360 °
●	400 kHz	-179 dB	-540 °

Fig.14. transmission of 400 KHz frequency (Narrowband) over the distributed pi network of railway feeder.

Figure 14, Shows the frequency simulation with magnitude in dB and phase angles, from point these values can be utilize in the designing of wave trap or high pass filter for communication with PLCC equipment.

VIII. Conclusion

This research work concludes, that, The LCoPL communication system can become a better means of communication as compared to traditional communication systems and the result of simulations of actual distributed railway parameters can help in designing PLCC equipment such as wave traps, CVT and LMU. The main advantage of this system is the direct transmission of passenger or goods locomotive or moving train-related data and sensory information, encompassing details like position, velocity, and vibration parameters, as well as environmental data such as weather conditions, and network-specific information like the number of interconnected trains. Analysing this data enables the implementation of policies to reduce maintenance costs, optimize maintenance schedules, and ensure the safety.

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