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Evolution of protective relays in 1- Φ , 25kV, 50Hz railway traction system

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Abstract

This paper presents the evolution of protective relays used for the protection of Power Transformer, Over Head Equipment (OHE) and Shunt Capacitor Bank in Indian Railways Electrical Distribution Systems. Initially during electrification Indian Railways adopted 1- Φ , 25KV, 50Hz AC system and electromagnetic relays (EM Relays) for feeder protection of OHE available at that time. But over the period of time with the drastic growth in traffic and sharp increase in demand for more electrical power to heavy goods trains haulage, the above said protective system doesn't catered the requirements like speed, sensitivity, reliability, post fault data analysis. Hence Indian Railways over the years have undergone a paradigm shift in protective relay schemes. The journey of evolution from EM relays and static relays to the latest state of art integrated Numerical relays which were approved by RDSO are dealt here.

Keywords: Over Head Equipment; Sensitivity; Reliability; Static relays; Numerical relays

1. Introduction

Indian Railways is the fourth largest railway network in the world transporting 8.39 billion passenger traffic and 1.212 billion Tonnes of goods traffic annually [1]. Haulage by electric locomotive is extremely economical compared to diesel locomotive apart from numerous other advantages [2]. The only drawback of electric traction compared to diesel traction is the high installation cost, but with the growing traffic scenario, it is extremely beneficial in the long run. Electric Traction accounts for 58.49 % of haulage and Indian Railways is aiming for 100% electrification of all its routes by 2023 [3]. Therefore, with this perspective, the importance of a reliable, efficient and failure free Traction Distribution system to the nation cannot be inflated. Traction Distribution (TRD) Department is responsible for procurement of electric power from grid of State Electricity Board or open access by employing ABT meters, step it down to 25 kV single phase AC and reliably supply it to the mobile electric locomotive running on the track.

TRD consists of the following sub departments, namely,

1.1. Power Supply Installation (PSI)

Electricity is obtained from the grid of State electricity boards at 220/132/110 kV 2 phase supply voltage and stepped down to 25 kV single phase at Railway Traction Substations (TSS). It is then supplied to the conductor lines running along the railway track (OHE). The feeding zone of a TSS is divided into various subsectors for isolation during maintenance and during segregation of faults. The TSS and the associated switching stations constitute the Power Supply Installation department and their purpose is to supply, control and regulate the electric power taken from the grid to OHE [4].

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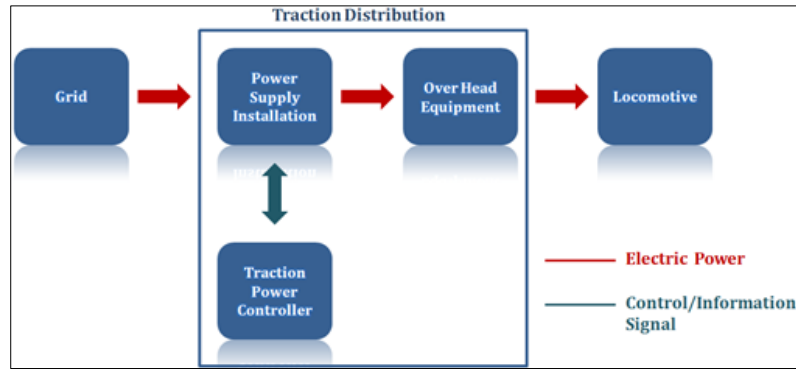


Figure 1 Role of Traction Distribution

1.2. Traction Power Controller/Remote Control (TPC)

Traction Power Controller is the single authority controlling the switching operations in the electrified section from a Remote Control Centre. He is directly responsible for maintaining the power supply of all electrified tracks while maintaining a close cooperation with Section Controller [5].

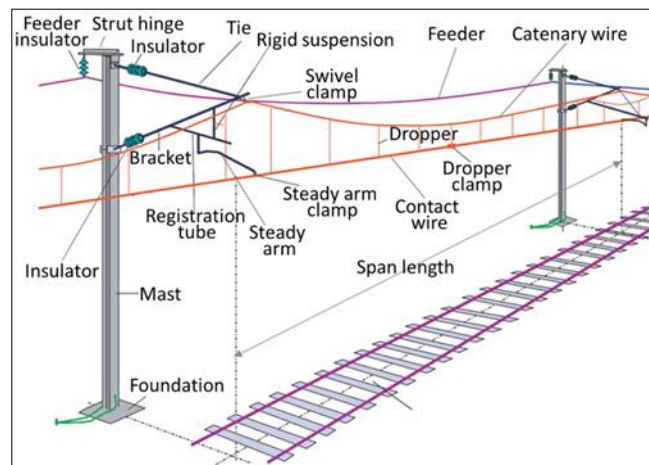


Figure 2 Schematic of swivelling cantilever arrangement

1.3. Over Head Equipment (OHE)

Overhead Equipment constitutes the conductors suspended over the locomotive and the associated fixed installations. Its purpose is to reliably supply the electric power to the pantograph of locomotive, in other words, ensuring proper contact of pantograph and conductor wire all along the track. It is achieved by means of a swivelling cantilever arrangement with two conductors, catenary and contact wire suspended from fixed supports. A simple polygonal type of OHE is adopted by the Indian Railways. In order to have a flat profile, the contact wire (107 mm² size hard drawn grooved copper) is suspended from a catenary wire (65 mm² size stranded cadmium copper) above by means of droppers and a tension of 1000 kg is given to each conductor which is always regulated by special equipment in all seasons. It is staggered at supports to avoid grooving on pantograph surface. Pre-sag is introduced to balance the stiffness variations and wave propagation which can lead to intermittent loss of contact with the pantograph. Fig. 2 shows a comprehensive sketch of a swivelling cantilever support structure for conductors [6].

2. Protective schemes in traction sub-station

The Indian Railways was decided to electrify its tracks with 25KV, 1 \emptyset , 50Hz AC supply in the year 1957 by adopting the technology of French National Railways (SNCF) because of the merits like simple and economical compared to other systems of electrifications across the world [7]. The first project was completed and commissioned in the month of December 1959 from a place called Rajkharswan to Dongaposi belongs to South Eastern Railways of Indian Railways [8]. The protection schemes adopted in Control & Relay panel for the protection of Power Transformer, OHE/Feeder Protection and Shunt capacitor banks is of basic models of electromagnetic relays available in the years 1950's.

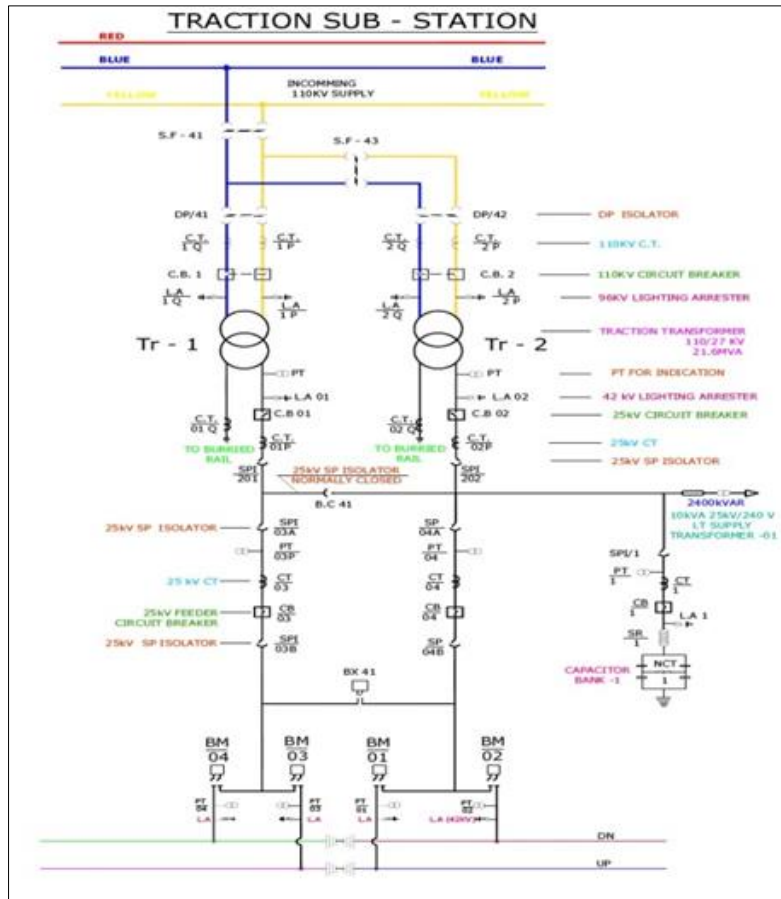


Figure 3 Schematic of Traction Sub-station

Each Traction sub-station as shown in Fig.3, is equipped with two Power transformers each of rating 21.6/30.24 MVA (ONAN/ONAF) and two OHE feeders to feed 25kV supply through circuit breakers either side of the TSS to Neutral section [9]. The other important equipment is Shunt Capacitor bank of rating 25kV, 2400 KVAR is provided in all Traction Sub-Station for power factor and voltage improvement along with other necessary switch gear. Normally feeding zone for double line section is 40 to 60 Km depending up on number of block stations in that feeding zone.

Accordingly three types of protective schemes adopted in a Traction Sub-Station.

2.1.1. Power Transformer protection

Generally power transformer is considered as the heart of the sub-station for an uninterrupted power supply to the OHE .In order to protect this critical asset from being failure prone several protection schemes are to be implemented such as Instantaneous overloads, Restricted Earth Faults on both HV and LV sides, Transformer Internal Faults detection and isolation are required.

2.1.2. Feeder (OHE) protection

Basically Feeder line is connected to the contact wire which is generally suspended by means of Over Head Equipment where a pantograph of a locomotive draws current for traction purpose at rated voltage. This feeder line (contact wire) is subjected to wide varieties of faults like low impedance to ground, high impedance to ground ,panto flashover, wrong phase coupling etc., such that prolonged duration of occurrence of fault may lead to parting of feeder line (contact wire) which ultimately leads to huge number of train detentions and financial losses.

2.1.3. Capacitor bank protection

Most of the locomotives in Indian Railways are driven by induction motors which are generally inductive in nature. In order to improve the power factor and voltage profile, a capacitor bank of rated reactive power is connected in series with reactor (inductor) and whole equipment is connected in shunt manner with the 27.5kV busbar and ground. As this

capacitor bank is highly sensitive to over current faults, under and over voltage faults, unbalancing bridge faults which has to be protected by any means.

3. Relay characteristics

The main function of protective relays is to cause the prompt isolation from service of any element of the power system when it starts to operate in an abnormal manner or interfere with the normal operation of the rest of the system.

A protective relay system can perform this function satisfactorily, if it has the following qualities [10]:

- Selectivity

It is the ability of the relay to identify correctly that part of the system which is faulty and immediately isolate the faulty part by opening the circuit breakers closest to the fault with minimum or no damage to the system by not disturbing the rest of the system.

- Speed

The ultimate goal of protective relaying is to disconnect a faulty system element as quickly as possible because any electrical apparatus may be damaged if they are made to carry the fault currents for a long time and high-speed relay system decreases the possibility of development of one type of fault into the other more severe type.

- Sensitivity

It is the ability of the relay system to pick up the lowest possible changes in the system such that a low value of actuating quantity is enough to operate a relay.

- Reliability

It is the ability of the relay system to operate under pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

- Simplicity

The relaying system should be simple so that it can be easily maintained. Reliability is closely related to simplicity. The simpler the protection scheme, the greater will be its reliability.

- Economy

The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection.

As a rule, the protective gear should not cost more than 5% of the total cost.

4. Evolution of relays in traction sub station

In early years of electrification with 25kV, the OHE protection scheme is achieved by Electromagnetic relays [11].

4.1. Electromagnetic Relays

Electromagnetic relays as shown in Fig.4, operate on the principle of electromagnetic attraction or repulsion. The magnetic field generated then used for opening and closing the switch and for performing the mechanical operation.



Figure 4 Control and Relay panel with Electromagnetic Relays

4.1.1. MHO Relay

A MHO Relay is also known as admittance relay is a high-speed relay which is used for distance protection in OHE. A mho relay is a voltage controlled directional relay with circular characteristic because the operating torque is obtained by the volt-amperes element and the controlling element is developed due to the voltage element.

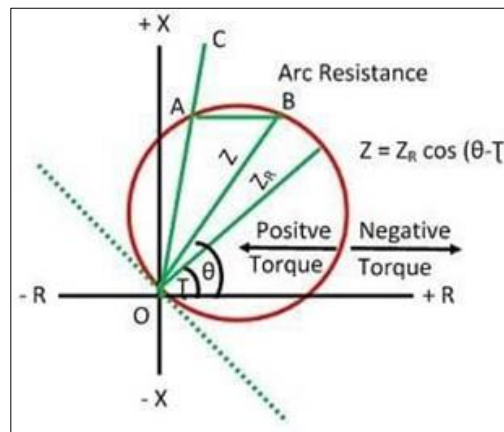


Figure 5 Operating characteristics of MHO relay

The characteristics as shown in Fig.5, of a mho impedance element, when plotted on R-X plot, results in a circle whose circumference passes through the origin, as illustrated in Fig.5 above. Due to the power swings and over loads (load due to bunching of trains) affects the performance of this MHO relay as a large area is covered by the circle on each side on R-X plane, due to functional characteristic limitations in electromagnetic distance relays like trippings due to overloads is unavoidable.

4.1.2. Instantaneous Over Current Relay

When a line to ground fault occurs on the feeder (OHE) line, the current flowing in the line increases abruptly and this high current actuate the over current relay instantly resulting in opening of feeder circuit breaker.

4.1.3. Wrong Phase Coupling (WPC) Relay

The simplified diagram in Fig. 3 illustrates the different phasing combinations along the trajectory of a railway system. There are several disconnect switches in the installation for operational purposes, allowing the operators to feed the loads from different locations. It may happen that operators and/or interlocks fail.

Fig.7 shows the situation and the phasors of the voltages and currents that the protection device would be measuring. The current is lagging the line angle by the difference between the two source-voltages ($V_{AB} - V_{CA}$), but the protective relay is using the local source voltage (V_{AB}). The relay current is lagging the relay voltage by angle α (shown in the phasor diagram), which will be in the range of 130 to 180 degrees, depending on the feeder impedance angle.

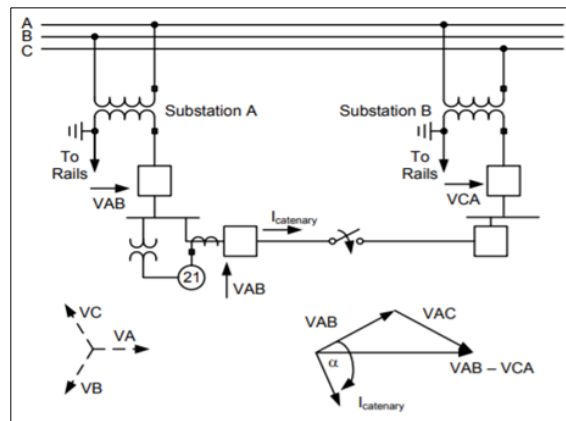


Figure 6 Wrong Phase Coupling

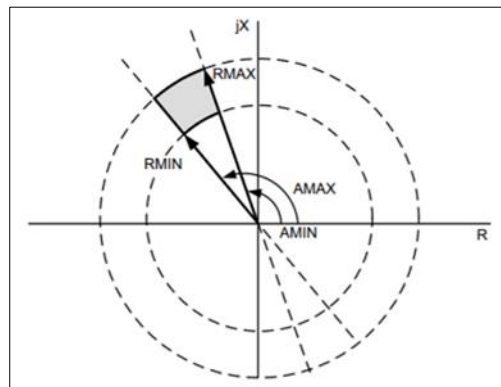


Figure 7 Operating characteristics of WPC relay

Limitations of electromagnetic relays

- Integration of several protection functions in one relay is not possible.
- Implementation of complicated logic functions is difficult and requires lot of control panel wiring.
- More VA burden on CT & PT. Bulky in size and gets affected due to vibration & shock.
- Deterioration of relays characteristics with time requiring periodic maintenance & calibration.
- Non availability of self-check feature or redundancy of components.
- Non availability of features like communication & data storage.
- Operation affected due to distorted wave forms & harmonics.
- Fine steps of setting are not possible.

4.2. Static Relays

Later electromagnetic relays were replaced with Static relays due to the fact that absence of moving parts which have improved the factor of Reliability to a great extent.

In static relays as shown in Fig.8, the analogue measurement techniques are used and comparison of measured parameters is performed by electronic/magnetic/optical or other components without mechanical motion. Its functioning comprise of the analog voltage/current rectification, filtration to provide a conditioned input to the relay and relay measuring circuit by using discrete solid state electronic components like comparators, transistors etc. The low level output is amplified to drive the output circuit providing the trip contacts to operate [12].

The protective schemes offered by the static relays are similar to that of Electro-magnetic relays and due to the absence of moving parts, the static relays offers certain advantages like faster operation, reduced burden on CT and PT, greater sensitivity, smaller overshoot, higher reset ratio, shorter reset time, with the absence of moving parts and contacts, more compact etc.



Figure 8 Control and Relay panel with Static Relays

4.2.1. Limitations of static relays

- Poor thermal stability i.e. operation and relay characteristics get affected with temperature.
- Frequent calibration is required due to ageing and drift effect.
- Fine steps of setting range are not possible due to limitation of voltage /current dividers, potentiometers etc.
- Multiple characteristics and integrated protection functions are not possible in a single unit.
- No digital data is available. Fault wave form recording, time stamping and digital communication are not possible.
- Sensitive to electrostatic discharge.

4.3. Numerical Relays

A Numerical relay uses a microprocessor or a microcontroller to analyze power system parameters like voltages, currents, frequencies or other process quantities for the purpose of detection of faults in an electric power system [13].

4.3.1. Need for Switching over to Numerical Relays

- Faster digital logic and absence of electro-mechanical moving parts makes relay more selective and sensitive to faults.
- Discrimination between load current and fault current avoids unwarranted tripping while catering to permitted over load conditions.
- Storage and retrieval of pre-fault and post-fault currents and voltages for analysis of faults and possible reasons thereof.
- Continuous online display of variable real time voltage and current parameters capable of being monitored through computer either locally or through remote control system.

- Wide range of relay settings to protect costly equipment like power transformer and OHE during parallel operation to cater to dynamically fluctuating load encroachments.
- Restraint to harmonics inherent with Electric Locomotive to avoid false tripping.
- Capable to clear high resistive faults by discriminating sudden raise due to high starting load currents and low fault currents.

4.3.2. Protection schemes employed with Numerical relays

The complete protection schemes catered by the Numerical Relays as shown in Figure 9 and 10, are broadly categorized into seven integrated relay modules as below

- HV and LV protection module.
- Differential protection module.
- Feeder Protection module.
- Capacitor bank protection module.
- Delta –I type high resistive fault relay module.
- Pantograph flashover protection relay module.
- DC under /over voltage protection relay module.

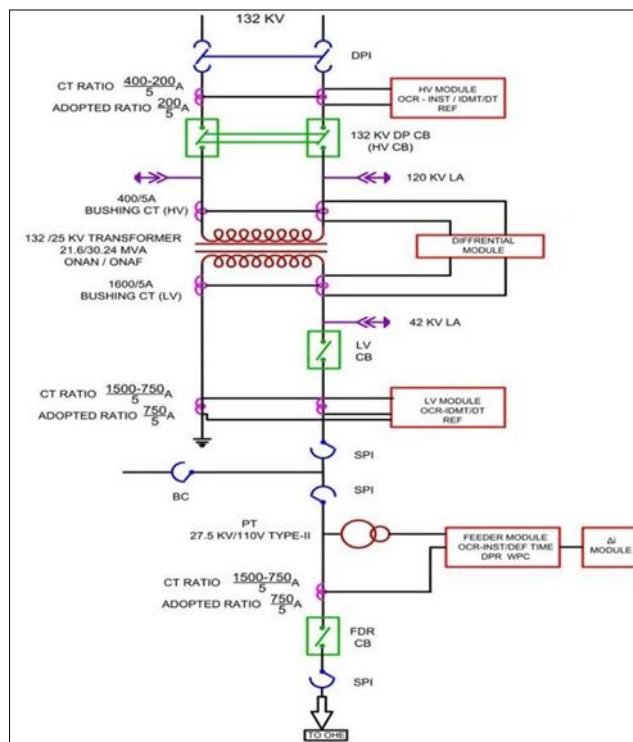


Figure 9 Numerical Relays protection scheme modules

HV and LV protection relay module

The HV and LV protection relay modules offer the following varieties of protections like

- Over Current relay
 - Instantaneous over current relay.
 - Inverse Definite Minimum Time Lag relay.
 - Definite Time (for transformer overloading protection).
 - ❖ Stage-1
 - ❖ Stage-2
 - ❖ Stage-3.

- ❖ Post Overload Protection
- Restricted Earth Fault relay.
- Oil temperature alarm (in HV module only).
- Buchholz alarm (in HV module only).
- Winding temperature alarm (in LV module only).
- Low Oil level alarm (in LV module only).

Differential protection relay module

The Differential protection relay is used to identify the internal faults in the power transformer of the traction sub-station and the relay module offers the following protections

- Biased differential protection
- Second harmonic blocking feature
- Fifth harmonic restraint feature
- Buchholz relay protection
- Pressure Relief Device protection
- Oil temperature trip protection
- Winding temperature trip protection

Feeder protection relay module

Generally a feeder line in traction sub-station is considered as the contact wire which allows the pantograph of a locomotive to collect current for traction purpose at a rated voltage; hence it has to be protected by the following protective schemes.

- Three Zone Distance protection.
- Inst. Over Current protection.
- Two Stage Definite Time over current protection.
- Wrong Phase coupling protection.
- P T Fuse Failure protection.
- Switch on to Fault.
- Built in multi shot Auto reclosure feature.
- Auto-reclosure Bypass on high current earth fault.
- Local Breaker Backup

Capacitor bank protection module

Capacitor bank is provided in the traction sub-station to improve the power factor and voltage profile the bus bar. This capacitor has is very sensitive to voltage and current fluctuations and hence capacitor bank protection module offers the following protection schemes.

- Over Voltage Protection.
- Under Voltage Protection.
- IDMTL over Current Protection.
- Current Unbalance Protection.

Delta –I type high resistive fault selective relay module

The short circuits due to earth faults occurring on OHE are usually cleared by the feeder CBs, which is activated through a distance Relay. But under certain typical conditions, like.

- High resistance earth faults (like tree falling on OHE, arcing, snake climbing, monkey tail, bird nesting etc.,)
- Far end faults the impedance can fall outside the zone of the relay.

In such cases Delta-I relay acts and module offers the following protection schemes.

- High Resistive Fault Protection.
- Second Harmonic Restraint feature.
- Third Harmonic Restraint feature.

Pantograph flashover protection module

When a pantograph of a locomotive happens to pass through an Insulated Overlap (IOL) with one side of which is live and the other end is dead, results in a heavy flashover on OHE. The relay is designed to identify such situation and originate trip command to the feeder circuit breakers connected to the live part at the instant of start of undesirable pantograph bridging.

- Panto Flashover Protection.
- Independent Line PT Indications.
- Inbuilt Trip Circuit Supervision.

DC under /over voltage protection relay module

This Relay module is provided in the Control & Relay Panel to monitor DC voltage fed to all circuit breakers, relays and other auxiliary equipment which runs on DC voltages in traction sub-station.

- Under voltage DC protection.
- Over voltage DC protection.



Figure 10 Control and Relay panel with Numerical Relays

5. Conclusion

Modern numerical protection devices offer innumerable features as compared to static and electromechanical protection system which are stated in Table-1 as below.

Communication capability makes the numerical protection system more intelligent and provides valuable information to the user. Hence for complex, reliable, multi-functional requirements numerical relays shall be used.

The milestones achieved in the field of traction protection system on Indian Railways in last 3 decades are given Table-2 as below.

Table 1 Merits of Numerical Relays over Electromagnetic and Static Relays

Features	EM Relay	Static Relay	Numerical Relay
VA Burden	High	Medium	Low
Operation Speed	Low	Medium	Fast
Setting Range	No	Medium	Most Precise
Size	Large	Compact	More compact
Protection Functions	Single function	Single function	Integrated function
Accuracy	Medium	High	Very High
Waveform Recorder	No	No	Yes
Communication Interface	No	No	RS 232/RS 485
Communication protocol for SCADA	No	No	IEC 60870-5-103
Computer Interface	No	No	Yes
Fault Waveform Analysis	No	No	Yes
Real Time monitoring of parameters	No	No	Yes
Password Protected Settings	No	No	Yes
Time stamped events	No	No	Yes

Table 2 Milestones achieved in the field of traction protection system on Indian Railways

Year	Milestones
1982	Auto reclosure with overriding scheme introduced
1984	Static relays were introduced superseding the electromechanical relays
1990	Development of parallelogram characteristics microprocessor based distance protection relays
1991	High speed single shot auto reclosure scheme introduced
1998	Development of high resistive fault selective relay (Delta-I) and Panto flashover protection relays
2000	Development of microprocessor based compact Control & Relay panel for trial
2000	Development of protection scheme for Mumbai suburban area to isolate the minimum possible faulty sub sector automatically.
2005	Development of protection scheme for MRVC project in Mumbai sub urban area having all numerical relays, minimum subsector isolation and parallel operation
2008	Development of numerical relays for all protection functions with reduced panel size
2009	Integration of numerical relay with SCADA RTU as per IEC 60870-5-103 protocol in Mumbai area.
2012	TI/SPC/PSI/PROTCT/6070 (9/08) with A&C slip No.1 incorporating Numerical type protection relays.
2015	TI/SPC/PSI/PROTCT/6071, Introduction for Master Trip Relay with type AEMS-32

Compliance with ethical standards

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Disclosure of conflict of interest

There was no clash between the authors, as they worked harmoniously without any visible altercation or conflict.

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