भारत सरकार
Government of India
विद्युत मंत्रालय
Ministry of Power
उत्तर क्षेत्रीय विद्युत समिति
Northern Regional Power Committee

दिनांक: 28 अक्टूबर, 2025

सेवा में / To,

एनआरपीसी एवं टीसीसी के सभी सदस्य एवं विशेष आमंत्रित (संलग्न सूचीनुसार)
Members of NRPC & TCC & Special Invitees (As per List)

विषय: 56 वीं तकनीकी समन्वय समिति (टीसीसी) और 81 वीं उत्तरी क्षेत्रीय विद्युत समिति (एनआरपीसी) की अतिरिक्त कार्यसूची के संदर्भ में ।

Subject: Additional agenda for 56th Technical Co-ordination Committee (TCC) and 81st Northern Regional Power Committee (NRPC) & reg.

महोदय / महोदया,

The 56th meeting of Technical Co-ordination Committee (TCC) will be held on **30.10.2025 (10:30 AM) at Srinagar, UT of J&K.** The 81st meeting of Northern Regional Power Committee (NRPC) will be held on **31.10.2025 (10:30 AM) at same place.** The meetings are being hosted by JKPTCL and PDD, Ladakh.

Additional agenda for the above meetings is attached.

भवदीय,

28/10/2025

(ऋषिका शरण)
(Rishika Sharan)
सदस्य सचिव
Member Secretary

Copy to:

1. Sh. Shailendra Kumar, IAS, Chairperson, NRPC and Financial Commissioner (Additional Chief Secretary), to Government of J&K, Power Development

Department, UT of J&K (power.department@jk.gov.in)

2. Sh. Ravinder Kumar, IAS, Secretary PDD and NRE, UT Ladakh (secy.pddnre@gmail.com)
3. Sh. G.P. Singh Arora, IAS, Chairperson, TCC and Managing Director, JPDCL (md-jpdcl@jk.gov.in)

सत्यमेव जयते

उत्तर क्षेत्रीय विद्युत समिति

NORTHERN REGIONAL POWER COMMITTEE

Additional agenda of the

56th meeting of

Technical Co-ordination Committee &

81st meeting of

Northern Regional Power Committee

Date: 30th & 31st October 2025

Time: 10:30 AM

Venue: Srinagar, UT of Jammu & Kashmir

Contents

AA. Additional agenda for TCC meeting

AA.1 SOP for diversion of RPC approved spare Transformers/Reactors to constituents/state transmission utilities (Agenda by NRPC Secretariat)

AA.1.1 In line with the discussion held in 55th TCC and 80th NRPC meeting regarding diversion of RPC-approved spare transformers/ reactors, POWERGRID was asked to submit draft guidelines for diverting RPC-approved spare transformers and reactors to regional constituents. Guidelines should cover scope, cost implications, penalty provisions, responsibilities of borrowers, timeline for return, and other general aspects related to diversion.

AA.1.2 In compliance to the above, POWERGRID submitted draft SOP/Guidelines for diversion of RPC approved Spare Transformers to the constituents/state transmission utilities.

AA.1.3 Draft SOP submitted by POWERGRID was deliberated in the 234th and 235th OCC meeting of NRPC and 52nd Commercial Sub-Committee (CSC) meeting of NRPC. CSC forum requested POWERGRID to submit a revised draft SOP incorporating the following observations of CSC forum:

- SOP should include cases of diversion to ISTS regional substations developed by TSPs other than POWERGRID, Interconnecting Transformers S/s, and State Transmission Utilities within the region.
- The Yearly Transmission Charges (YTC), including any applicable penalties related to diverted regional spare recovered from the borrowing entity be credited to the regional ISTS charges pool. The SOP should explicitly outline the methodology for the adjustment of such YTC within the pool.

AA.1.4 The draft SOP was revised by the NRPC Secretariat to incorporate the aforementioned aspects and subsequently discussed during the 236th OCC meeting of NRPC. The Committee, in general, agreed to the draft SOP, with the observation that provisions related to Bank Guarantees should be included. Based on the deliberations held in the 236th OCC meeting, the revised draft SOP is enclosed as **Annexure-A.**

Decision required from Forum:

Forum may deliberate and decide on the SOP for diversion of RPC approved spare Transformers/Reactors to constituents/state transmission utilities.

AA.2 Implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region (Agenda by NRPC Secretariat)

AA.2.1. In the 55th TCC and 80th NRPC meeting, a proposal received from PGCIL for Implementation of Travelling Wave Fault Locator (TWFL) in hilly terrains, Critical Renewable, & NCR transmission lines in Northern Region was discussed. After detail deliberation, the NRPC forum decided to formulate a sub-group, comprising members from CEA, CTU, NRPC, NRLDC, Powergrid, Indigrid, ATIL, Sterlite, Sekura, RVPNL, PTCUL, HPPTCL and JKPCTL with the following Terms of Reference.

i. Formulate criteria to identify critical transmission lines that warrant the installation of TWFL, based on operational importance and reliability considerations.

ii. Evaluate the restoration benefits of TWFL—specifically in terms of fault location and faster restoration—by comparing scenarios with and without TWFL, using data provided by Powergrid for lines where TWFL is already implemented.

AA.2.2. Accordingly, based on nominations received from concerned utilities, the Sub-group was formed under Chairmanship of SE(O&P) NRPC. Sub-group held two meetings on 28.08.2025 and 17.10.2025 respectively (MoM of the meetings are attached at **Annexure-B**). Further, a physical visit at POWERGRID Meerut S/s was conducted by a team comprising of members from CEA, NRLDC, CTU and NRPC Secretariat on 19.09.2025 to understand the functioning of the TWFL system and to evaluate the benefits of its installation on transmission lines.

AA.2.3. After deliberation in the meetings, sub-group members agreed that;

a. Travelling Wave-Based Fault Locator (TWFL) has emerged as a highly advanced and precise fault location technology. This is useful for quickly identifying the fault location with accuracy (±500 m error), which directly contributes to reduced outage durations, improved system availability, and enhanced reliability of the transmission network.

b. TWFL implementation may be taken up in phased manner. Following criteria may be used to identify critical transmission lines for installation of TWFL in the first phase:

  i. 220kV, 400kV and 765 kV lines having length more than 200Km.

  ii. 220kV, 400kV and 765 kV lines used for evacuating nuclear and RE Power having length more than150 Km.

  iii. 220kV and above lines in hilly terrain.

  iv. Inter-regional 220kV and above lines having length more than150 Km.

c. Based on the above criteria committee reviewed the lines proposed by PGCIL in the 55th TCC and 80th NRPC meetings for TWFL implementation. Out of the 25 nos. lines, 20 nos. lines as mentioned at **Annexure-C** may be considered for TWFL implementation.

d. A policy may be formulated by CTU for implementation of TWFL in intra-state lines.

Decision required from Forum:

Forum may deliberate on the recommendation of the sub-group for implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region.

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NRPC Members for FY 2025-26				
S. No.	**NRPC Member**	**Category**	**Nominated/ Notified/Delegated Member**	**E-mail**
1	Member (GO&D), CEA	Member (Grid Operation & Distribution), Central Electricity Authority (CEA)	Member (GO&D), CEA	member.god@cea.nic.in
2	NLDC	National Load Despatch Centre	Director (System Operation)	rk.porwal@grid-india.in
3	NRLDC	Northern Regional Load Despatch Centre	Executive Director	mkagarwal@grid-india.in
4	CTUIL	Central Transmission Utility	Chief Operating Officer	drozekar@powergrid.in
5	PGCIL	Central Government owned Transmission Company	Director (Operations)	naveensrivastava@powergrid.in
6	NTPC	Central Generating Company	Director (Finance)	jaikumar@ntpc.co.in
7	BBMB		Chairman	cman@bbmb.nic.in
8	THDC		CGM (EM-Design)	rrsemwal@thdc.co.in
9	SJVN		CMD	sectt.cmd@sjvn.nic.in
10	NHPC		Director (Technical)	sadhikari@nhpc.nic.in
11	NPCIL		Director (Finance)	df@npcil.co.in
12	Delhi SLDC	State Load Despatch Centre	General Manager	gmsldc@delhisldc.org
13	Haryana SLDC		Chief Engineer (SO&C)	cesocomml@hvpn.org.in
14	Rajasthan SLDC		Chief Engineer (LD)	ce.ld@rvpn.co.in
15	Uttar Pradesh SLDC		Director	directorsldc@upsldc.org
16	Uttarakhand SLDC		Chief Engineer	anupam_singh@ptcul.org
17	Punjab SLDC		Chief Engineer	ce-sldc@punjabsldc.org
18	Himachal Pradesh SLDC		Managing Director	mdhpsldc@gmail.com
19	DTL	State Transmission Utility	CMD	cmd@dtl.gov.in
20	HVPNL		Managing Director	md@hvpn.org.in
21	RRVPNL		CMD	cmd.rvpn@rvpn.co.in
22	UPPTCL		Managing Director	md@upptcl.org
23	PTCUL		Managing Director	md@ptcul.org
24	PSTCL		CMD	cmd@pstcl.org
25	HPPTCL		Managing Director	md.tcl@hpmail.in
26	IPGCL	State Generating Company	Managing Director	md.ipgpp@nic.in
27	HPGCL		Managing Director	md@hpgcl.org.in
28	RRVUNL		CMD	cmd@rrvun.com
29	UPRVUNL		Director (Technical)	director.technical@uprvunl.org
30	UJVNL		Managing Director	mdujvnl@ujvnl.com
31	HPPCL		Managing Director	md@hppcl.in
32	PSPCL	State Generating Company & State owned Distribution Company	CMD	cmd-pspcl@pspcl.in
33	DHBVN	State owned Distribution Company (alphabetical rotational basis/nominated by state govt.)	Managing Director	md@dhbvn.org.in
34	Ajmer Vidyut Vitran Nigam Ltd.		Managing Director	MD.AVVNL@RAJASTHAN.GOV.IN
35	Purvanchal Vidyut Vitaran Nigam Ltd.		Managing Director	nomination awaited(md@puvvnl.in)
36	UPCL		Managing Director	md@upcl.org
37	HPSEB		Managing Director	md@hpseb.in
38	Prayagraj Power Generation Co. Ltd.	IPP having more than 1000 MW installed capacity	Head (Commercial & Regulatory)	sanjay.bhargava@tatapower.com
39	Aravali Power Company Pvt. Ltd		CEO	brahmajig@ntpc.co.in
40	Apraava Energy Private Limited		CEO	niraj.gupta@apraava.com
41	Talwandi Sabo Power Ltd.		Head Regulatory & Policy Advocacy	arun.kumar@vedanta.co.in
42	Nabha Power Limited		CEO	sk.narang@larsentoubro.com
43	MEIL Anpara Energy Ltd		COO & WTD, Executive Director	anandkumar.singh@meilanparapower.com arun.tholia@meilanparapower.com
44	Rosa Power Supply Company Ltd		Station Director	Hirday.tomar@relianceada.com
45	Lalitpur Power Generation Company Ltd		Managing Director	vksbankoti@bajajenergy.com
46	MEJA Urja Nigam Ltd.		CEO	hopmeja@ntpc.co.in
47	Adani Power Rajasthan Limited		Head, Thermal, O&M	Kanti.Biswas@adani.com
48	JSW Energy Ltd. (KWHEP)		Head Regulatory & Power Sales	jyotiprakash.panda@jsw.in
49	Transition Cleantech Services Private Limited	IPP having less than 1000 MW installed capacity (alphabetical rotational basis)		nomination awaited(pkanaujia@evrenenergy.com)
50	UT of J&K	From each of the Union Territories in the region, a representative nominated by the administration of the Union Territory concerned out of the entities engaged in generation/ transmission/ distribution of electricity in the Union Territory.	Chief Engineer, JKSPDCL/JKPDD	cejkpcl2@gmail.com/sojpdd@gmail.com
51	UT of Ladakh		Chief Engineer, LPDD	cepdladakh@gmail.com
52	UT of Chandigarh		Executive Engineer, EWEDC	seelo-chd@nic.in
53	NVVN	Nodal Agency appointed by the Government of India for coordinating cross-border power transactions	NVVN and PTC are two nodal agencies in Northern Region. Since PTC is already a member in this year for trader category, it is listed at serial no. 56.	ceonvvn@ntpc.co.in
54	TPDDL	Private Distribution Company in region (alphabetical rotational basis)	Head-Commercial	nomination awaited(ceo.office@tatapower-ddl.cpm)
55	Gurgaon Palwal Transmission Limited	Private transmission licensee (nominated by central govt.)	AVP-O&M	lokendra.ranawat@indigrid.com
56	PTC	Electricity Trader (nominated by central govt.)	CEO	cmd@ptcindia.com
57	ReNew Power Private Limited	RE Generating Company having more than 1000 MW installed capacity	CEO	sumant@renew.com
58	NTPC Green Energy Limited		CEO	rajivgupta@ntpc.co.in
59	Azure Power India Pvt. Limited		CEO	sunil.gupta@azurepower.com
60	Avaada Energy Private Limited		CEO	kishor.nair@avaada.com
61	Adani Green Energy Limited		COO	chaitanya.sahoo@adani.com

List of addressee (via mail)

TCC Members for FY 2025-26

S. No.	TCC Member	Category	Nominated/ Notified/Delegated Member	E-mail
1	Managing Director, JKPTCL	Chairperson, TCC	Managing Director, JKPTCL	mdjkptcl1@gmail.com
2	Member (GO&D), CEA	Member (Grid Operation & Distribution), Central Electricity Authority (CEA)		cegm-cea@gov.in
3	NLDC	National Load Despatch Centre		susha@grid-india.in
4	NRLDC	Northern Regional Load Despatch Centre	Executive Director	mkagarwal@grid-india.in
5	CTUIL	Central Transmission Utility	Chief Operating Officer	drozekar@powergrid.in
6	PGCIL	Central Government owned Transmission Company	ED, NR-I	aloksharma99@powergrid.in
7	NTPC	Central Generating Company	Regional ED, NR	rednr@ntpc.co.in
8	BBMB		Member (Power)	mp@bbmb.nic.in
9	THDC		GM (EMD)	neerajverma@thdc.co.in
10	SJVN		Director (Projects)	de.sectt@sjvn.nic.in
11	NHPC		ED (O&M)	hod-om-co@nhpc.nic.in
12	NPCIL		Outstanding Scientist & ED (commercial)	nrchoudhary@npcil.co.in
13	Delhi SLDC	State Load Despatch Centre		nomination awaited
14	Haryana SLDC		Chief Engineer/SO & Comml.	cesocomml@hvpn.org.in
15	Rajasthan SLDC		Superintending Engineer (SOLD) RVPN	SE.SOLD@RVPN.CO.IN
16	Uttar Pradesh SLDC		Chief Engineer (PSO)/Chief Engineer (C&S)	cepso@upsldc.org
17	Uttarakhand SLDC			nomination awaited
18	Punjab SLDC		Chief Engineer	ce-sldc@pstcl.org
19	Himachal Pradesh SLDC			nomination awaited
20	DTL	State Transmission Utility	Director (Operation)	dir.opr@dtl.gov.in
21	HVPNL		Director (Projects)	directorprojects@hvpn.org.in
22	RRVPNL		Chief Engineer (PP&D)	ce.ppm@rvpn.co.in
23	UPPTCL		Director (Planning & Commercial)	director_comm@upptcl.org
24	PTCUL		Chief Engineer	ce_oandmk@ptcul.org
25	PSTCL		Director / Technical	dir-tech@pstcl.org
26	HPPTCL		GM (C&D)	gmcd.tcl@hpmail.in
27	IPGCL	State Generating Company	Director(Tech.)	corporate.ppcl@gmail.com
28	HPGCL		Director/Technical	dirtech@hpgcl.org.in
29	RRVUNL		Dy. Chief Engineer	dyce.elect.katpp@rrvun.com
30	UPRVUNL		Director (Technical)	director.technical@uprvunl.org
31	UJVNL		General Manager	kkjaiswal99@gmail.com
32	HPPCL		Director (Electrical) General	dir_elect@hppcl.in gm_elect@hppcl.in
33	PSPCL	State Generating Company & State owned Distribution Company		nomination awaited
34	DHBVN	State owned Distribution Company (alphabetical rotational basis/nominated by state govt.)		directoroperations@dhbvn.org.in
35	Ajmer Vidyut Vitran Nigam Ltd.		Director (Tech.), AVVNL, Ajmer	DT.AVVNL@RAJASTHAN.GOV.IN
36	Purvanchal Vidyut Vitaran Nigam Ltd.			nomination awaited
37	UPCL		Director (P)	dpupcl29@gmail.com
38	HPSEB			nomination awaited
39	Prayagraj Power Generation Co. Ltd.	IPP having more than 1000 MW installed capacity	Head – Commercial & Regulatory	Sanjay.bhargava@tatapower.com
40	Aravali Power Company Pvt. Ltd		CEO	brahmajig@ntpc.co.in
41	Apraava Energy Private Limited			nomination awaited
42	Talwandi Sabo Power Ltd.		Dy. Head O&M	ravinder.thakur@vedanta.co.in
43	Nabha Power Limited			nomination awaited
44	MEIL Anpara Energy Ltd		COO & WTD, Executive Director	anandkumar.singh@meilanparapower.com arun.tholia@meilanparapower.com
45	Rosa Power Supply Company Ltd		VP-Technical Services	Niranjan.Jena@relianceada.com
46	Lalitpur Power Generation Company Ltd		GM Electrical	aupadhyay.ltp@lpgcl.com
47	MEJA Urja Nigam Ltd.		GM (O&M)	piyushkumar@ntpc.co.in
48	Adani Power Rajasthan Limited		AVP	Manoj.taunk@adani.com
49	JSW Energy Ltd. (KWHEP)		Head of Plant	kaushik.maulik@jsw.in
50	Transition Cleantech Services Private Limited	IPP having less than 1000 MW installed capacity (alphabetical rotational basis)		nomination awaited
51	UT of J&K	From each of the Union Territories in the region, a representative nominated by the administration of the Union Territory concerned out of the entities engaged in generation/ transmission/		nomination awaited
52	UT of Ladakh			nomination awaited
53	UT of Chandigarh			seelo-chd@nic.in
54	NVVN	Nodal Agency appointed by the Government of India for coordinating cross-border power transactions		VIKASKUMAR04@NTPC.CO.IN
55	TPDDL	Private Distribution Company in region (alphabetical rotational basis)		nomination awaited
56	Gurgaon Palwal Transmission Limited	Private transmission licensee (nominated by central govt.)		lokendra.ranawat@indigrid.com
57	PTC	Electricity Trader (nominated by central govt.)		bikramsingh@ptcindia.com
58	ReNew Power Private Limited	RE Generating Company having more than 1000 MW installed capacity		nomination awaited
59	NTPC Green Energy Limited			nomination awaited
60	Azure Power India Pvt. Limited			nomination awaited
61	Avaada Energy Private Limited			nomination awaited
62	Adani Green Energy Limited			nomination awaited

Special Invitees:

1. Smt. Rishika Saran, Member Secretary, NPC, Sewa Bhawan, R. K. Puram, New Delhi-66 [Email-rishika@nic.in]
2. Shri Deepak Kumar, Member Secretary, WRPC, Plot No- F-3, MIDC Area, Marol, Opp. SEEPZ, Central Road, Andheri (East), Mumbai-40093. [email: ms-wrpc@nic.in]
3. Shri Asit Singh, Member Secretary, SRPC, No.29, Race Course Cross Road, Bengaluru-560009. [Email: mssrpc-ka@nic.in]
4. Shri N.S. Mondal, Member Secretary, ERPC,14,Golf Club Road, ERPC Building, Tollygunje,Kolkata-700033.[Email: mserpc-power@nic.in]
5. Shri K B Jagtap, Member Secretary, NERPC, NERPC Complex, Dong Parmaw, Lapalang, Shillong-793006. [Email: ms-nerpc@gov.in]
6. Shri Brieflee Lyngkhoi, Chief Engineer, GM Division, CEA, Sewa Bhawan, R.K. Puram, New Delhi-66 [Email: cegm-cea@gov.in]

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Annexure-A

STANDARD OPERATING PROCEDURE
on
DIVERSION of REGIONAL SPARES (TRANSFORMERS AND REACTORS)

Draft Version 2.0

October 2025

NORTHERN REGIONAL POWER COMMITTEE

1. Background & Objective

POWERGRID procures and maintains regional spares- transformers and reactors- to ensure the continuity of power supply and grid stability in the event of a contingency, such as the sudden failure of an in-service transformer or reactor. The primary purpose of these spares is to meet contingencies/emergencies within ISTS substations of the region. Regional spares are primarily sanctioned for use in Inter-State Transmission System (ISTS) substations. However, diversion of such spares to a State Transmission Utility (STU) may be permitted only under exceptional circumstances, based on the criticality of the requirement and subject to expeditious replenishment by the Borrower.

This Standard Operating Procedure (SOP) sets out the framework, eligibility, processes, roles, responsibilities, and conditions under which regional spares- transformers and reactors- maintained by POWERGRID may be diverted to STUs or other eligible utilities. The SOP seeks to balance the need to extend emergency support to constituents with the responsibility of ensuring adequate spare availability for the ISTS network.

2. Scope & Applicability

This SOP applies exclusively to transformers and reactors approved by the respective Regional Power Committee (RPC) as *Regional Spares* for use in Inter-State Transmission System (ISTS) substations within the region. These spares are procured, owned, and maintained by POWERGRID to ensure operational continuity of the ISTS network during contingencies. Diversion of Regional Spares may be considered for the following eligible beneficiaries within the same Region:

- **ISTS Substations** including those developed by Transmission Service Providers (TSPs) other than POWERGRID.
- **State Transmission Utility (STU) Substations**: Diversion may be considered only in case of failure of existing in-use equipment and where diversion is essential for grid security and reliability.

Diversion for commissioning of new assets may not be permitted under this SOP. Inter-regional diversion of equipment to any constituent may not be permitted. All diversions may be executed strictly on a replenishment basis and may not amount to sale or transfer of ownership of the equipment.

3. Roles and Responsibilities

3.1. Lender (POWERGRID): POWERGRID may ensure that the regional spares- **Transformers and Reactors**- are maintained in operationally ready condition and available for deployment during contingencies. POWERGRID may:

- Maintain a central inventory of all Regional Spares with technical particulars and locations.
- Implement the diversion only after RPC forum approval and in accordance with this SOP.

- Record every approved diversion in the central register, including date of diversion, borrower, and approved return timeline.
- Monitor adherence to approved diversion timelines and report deviations to the RPC Secretariat.

3.2. Borrower (TSP/STU): The Borrower may be responsible for safe custody and operation of the diverted Regional Spare during its possession. The Borrower may:

- Submit a formal diversion request to the RPC Secretariat with required technical and contingency details.
- Jointly verify the equipment condition at POWERGRID substation prior to MoU signing.
- Bear all expenses associated with transportation (both ways), transit insurance, erection, testing, commissioning, and related statutory charges, as applicable, and any incidental expenditure or loss to POWERGRID.
- Ensure site readiness and compatibility of the spare equipment before diversion.
- Furnish a valid Bank Guarantee equal to the prevailing cost of the equipment, effective till 45 days after return or replenishment is completed.
- Maintain and operate the equipment in accordance with applicable technical standards and POWERGRID's guidelines.
- Return or replenish the equipment in healthy condition within the approved timeframe and bear any repair or replacement cost arising from damage or failure.
- After returning of equipment, all pre-commissioning tests may be jointly performed at POWERGRID station to ascertain healthiness. In case of any deviation, POWERGRID may take up the repair of equipment and cost of the repair may be borne by the Borrower.

3.3. RPC Secretariat: The concerned RPC Secretariat may facilitate deliberation of the diversion proposal in the RPC forum and place the Borrower's request before the members for decision. It may record all decisions, including timelines for return or replenishment. RPC Secretariat may communicate the decision of the forum to borrower and Powergrid within one week of decision in RPC meeting.

4. Procedure for Diversion

4.1. Submission of Request: The Borrower may submit a written request to the concerned RPC Secretariat, specifying:

- The nature of contingency or failure necessitating diversion, including details of affected substation and equipment.
- Technical parameters of the failed equipment and the matching requirement from the Regional Spare pool.
- A detailed action plan and proposed timeline for return or replenishment of the diverted equipment.

4.2. Evaluation and Approval: The RPC forum may evaluate the request on merit, considering:

- The severity and genuineness of the contingency.
- Availability of the Regional Spare and its necessity for ISTS grid reliability.
- Impact on overall system stability and adequacy of remaining spares.

The decision of the RPC forum may be final and binding on all concerned entities. Upon approval, the forum may record the diversion details and the agreed period of utilization in its proceedings.

4.3. Execution of Memorandum of Understanding (MoU)

- Following the approval of diversion by the respective RPC forum, the Borrower and POWERGRID may execute a Memorandum of Understanding (MoU) within forty-five (45) days from the date of RPC approval. For the purpose of this SOP, date of RPC approval shall mean the date of RPC meeting.
- The MoU may specify all terms and conditions of diversion, including equipment details, responsibilities of both parties, financial implications, Bank Guarantee (BG) requirements, maintenance and reporting obligations, timelines for return/replenishment, and applicable penalties for default.

4.4. Condition Assessment and Testing

- Before diversion, a joint inspection of the equipment may be carried out by POWERGRID and the Borrower at the designated POWERGRID substation. The physical condition and test results may be documented and signed jointly.
- Upon return, the equipment may undergo joint pre-commissioning testing at the POWERGRID station to ascertain its healthiness. Any deviation, defect, or damage observed during inspection may be rectified at the Borrower’s cost. Where repair or refurbishment is necessary, the Borrower may carry it out through the OEM or other approved agency as per POWERGRID specifications.

5. General Conditions of Diversion

5.1. Timeframe for Diversion and Return

- The Borrower should take the physical handover of the equipment from the designated POWERGRID substation or storage location within forty-five (45) days from the date of execution of the MoU.
- Failure to take the physical handover of the equipment within the ninety-days (90) days from RPC approval may be construed as revocation the diversion approval. In exceptional circumstances, a single extension of up to thirty (30) days may be granted by POWERGRID with intimation to the RPC Secretariat.
- The maximum diversion period may not exceed twenty-four (24) months from the Zero Date of Diversion.

- The Borrower may ensure return or replenishment of the diverted equipment within this period as per the action plan approved by the RPC forum and the provisions of the MoU.
- Any request for extension of the diversion period beyond twenty-four (24) months may require prior approval of the concerned RPC forum, supported by written justification.
- On completion of the diversion period, the Borrower should return the equipment in healthy condition to POWERGRID to POWERGRID's technical specifications.
- The "Zero Date of Diversion" shall be the date recorded in the joint handover certificate signed by representatives of POWERGRID and the Borrower at the time of physical transfer from the designated POWERGRID substation or storage location.
- The "Date of Return" shall be the date recorded in the joint handover certificate signed by representatives of POWERGRID and the Borrower, after successful healthiness checking, at the time of physical transfer at the designated POWERGRID substation or storage location.

5.2. Early Recall

- RPC Forum may recall any diverted equipment at any time before the expiry of the approved period if required in the interest of grid security or system reliability.
- The Borrower should return the equipment immediately upon receipt of such recall notice, and the RPC Secretariat may be intimated accordingly.

5.3. Financial Provisions: Diversion of Regional Spares may be carried out on a cost-neutral basis, ensuring that POWERGRID neither incurs financial loss nor earns additional revenue on account of such diversion. The diversion should not result in any change in the Yearly Transmission Charges recoverable by POWEGRID as per the approved tariff against the diverted asset All financial adjustments, if any, may be settled within the regional pooling mechanism as approved by the RPC forum.

- **ISTS Substations:** Diversion to any ISTS substation, whether owned by POWERGRID or another TSP, forming part of the ISTS network in the region should be without financial liability to any TSP or DIC. Such diversion should not affect the Regional tariff or cost-sharing framework.
- **STU Substations:** For diversions to STU-owned substations, the equivalent Yearly Transmission Charge (YTC) of the diverted asset on pro-rate basis, along with any applicable penalty, may be credited to the Regional Component for the diverted period. The same amount may be billed to the concerned State(s) through a suitable mechanism decided by the NPC.

The Borrower shall bear all direct and incidental costs, including transportation, loading/unloading, insurance, erection, testing, and commissioning charges. The Borrower may be fully liable for any loss, damage, theft, or deterioration of the equipment during the diversion period. Insurance coverage may be obtained in the joint name of POWERGRID and the Borrower, with POWERGRID designated as the primary beneficiary.

5.4. Bank Guarantee (BG) requirements:

- Borrower may furnish a valid Bank Guarantee equal to the prevailing cost of the equipment, effective till 45 days after return or replenishment is completed.
- The BG may be invoked by POWERGRID to recover any financial loss or liability arising from events such as failure to return or replenish the equipment within the agreed timeframe, or failure to repair, refurbish, or replace the equipment in the event of damage, failure, or loss during transit, erection, or operation.

5.5. Penalty and Default:

- If the Borrower fails to return or replenish the diverted equipment within the agreed timeframe, which may not exceed 24 months, a penalty of 15% of the approved Yearly Transmission Charge (YTC) of the diverted asset may be levied on a pro-rata basis for the delayed duration.
- The penalty amount may be credited to the Regional Component of ISTS charges for the corresponding period. In case of continued default or non-replenishment, POWERGRID may report the matter to the RPC forum for further decision, which may include encashment of the Bank Guarantee and/or regulatory intervention.

5.6. Record-Keeping and Monitoring: POWERGRID may maintain a centralized and up-to-date register of all diversions, containing the following information:

- Borrower entity name and category (TSP/STU).
- Equipment details (type, rating, make, serial number).
- Date of diversion and expected return date.
- Physical and test condition at dispatch and upon return.
- Financial treatment and applicable YTC adjustments.
- Status of replenishment or replacement.

6. **Review and Amendment:** This SOP may be reviewed from time to time to incorporate operational experience, regulatory updates, or changes in system requirements. Any amendment may be proposed by POWERGRID or any RPC member in the RPC forum or its sub-forum and may become effective only after approval by the RPC forum.

Annexure-B

CEA-GO-17-11(11)/1/2023-NRPC 	I/55530/2025

सत्यमेव जयते

भारत सरकार
Government of India
विद्युत मंत्रालय
Ministry of Power
उत्तर क्षेत्रीय विद्युत समिति
Northern Regional Power Committee

विषय: Minutes of the Second meeting of the Sub-Group for implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region held on 17th October 2025 -reg.

Kindly find attached minutes of the Second meeting of the Sub-Group for implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region held on 17th October 2025.

This issues with the approval of SE(O), NRPC.

Encl: As above

27.10.2025

(ओमकिशोर)
कार्यपालक अभियंता (प्रचालन)

List of addressees:

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9. Ms. Rashmi, Assistant Director-II, PSE&TD Division, CEA (rashmi.cea@gov.in)
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12. General Manager, HPPTCL, (gmcd.tcl@hpmail.in)
13. Superintending Engineer, JKPTCL, (ravikantkalsotra01@gmail.com)

<u>Minutes of the Second meeting of the Sub-Group for implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region held on 17th October 2025</u>

Superintending Engineer (Operation), NRPC welcomed all the participants to the meeting. List of Participants is attached at **Annexure-I**.

1. SE(O), NRPC apprised the forum that in the 1st meeting of the sub-group held 28.08.2025 it was decided that a physical visit at POWERGRID Meerut S/s may be conducted to see the functioning of TWFL (MoM of the first meeting is attached at **Annexure-II**). Accordingly, a team comprising of members from CEA, NRLDC, CTU and NRPC Secretariat visited the 765/400 kV Meerut Substation on 19.09.2025 to understand the functioning of the TWFL system and to evaluate the benefits of its installation on transmission lines. A brief report of the visit is attached at **Annexure-III**.

2. During the visit the team was apprised about the details of the fault location recorded by TWFL at Meerut Substation for some of the faults in last two months are tabulated below:

Sr. No.	Line Name	Date	Time	M-1	M-2	TWFL		Patrolling Distance
				(km)	(km)	Local End (km)	Remote End (km)	(km)
1	Koteshwar-2	12.09.25	10:50:22	117.1	116.9	128.31	47.32	128.4
2	Koteshwar-2	18.09.25	04:57:07	92.8	89.69	74.37	104.32	74.9
3	Koteshwar-1	07.09.25	03:58:56	117.2	118.8	125.38	53.31	125
4	Moga	31.07.25	01:13:21	222.2	222.7	245.64	91.5	245.6
5	Moga	16.07.25	09:29:07	0.3	0.3	0	337.14	0.3

3. SE(O), NRPC stated that from the above data it can be observed that fault location provided by TWFL is much more accurate as compared to the fault location provide by M-1 and M-2 relays.

4. PGCIL representative stated that in the 1st meeting PGCIL was asked to share operation philosophy of TWFL and the literature related to it so that the same could be studied by members of the sub-group. Accordingly, PGCIL had shared TWFL manuals and a conference paper on TWFL. Documents shared by PGCIL is attached at **Annexure-IV**.

5. PGCIL representative delivered a presentation highlighting the limitations of conventional fault location methods, along with the working principle and architecture of TWFL. (Presentation of PGCIL is attached at **Annexure-V**)

6. Regarding the manufacturers of TWFL devices, the PGCIL representative informed that GE and Qualitrol manufactured of TWFL devices are available in the Indian market. Additionally, TWFL devices manufactured by SEL and Kehui are also available globally.

7. The RVPN representative inquired whether these devices are equipped with inbuilt GPS or rely on the substation's GPS. The PGCIL representative clarified that the devices are provided with inbuilt GPS; however, the substation GPS can also be utilized if required.

8. Based on the data provided by PGCIL during the first meeting and the subsequent site visit, the sub-group members agreed that TWFL is useful for accurate fault detection and, consequently, enables faster restoration of transmission lines.

9. SE(O), NRPC enquired from PGCIL about the criteria adopted for selecting the transmission lines for TWFL implementation as proposed by PGCIL in the 55th TCC and 80th NRPC meetings.

10. PGCIL representative replied that 765 kV lines in RE pockets, critical lines in the NCR region, lines in hilly areas, lines connected to generating stations, lines with frequent faults, and long transmission lines were considered for TWFL implementation.

11. SE(O), NRPC asked view of members regarding criteria to identify critical transmission lines that warrant the installation of TWFL.

12. CTU representative stated that TWFL implementation may be taken up in phased manner. In first phase lines having long length and lines of hilly terrain may be considered. Based on the experience of first phase, other lines may be considered subsequently.

13. PGCIL representative stated that in case of long lines error in fault distance shown by DR is high and therefore more time is required for restoration. Therefore he stated that lines having long length and lines of hilly terrain may be considered. Further, lines of RE Pocket may also be considered.

14. SE(O), NRPC enquired about the threshold length that can be considered.

15. It was discussed that all 765kV lines may be considered in the first phase.

16. NRLDC representative stated that some 765 KV lines are having length less than 100Km. So these lines may not require TWFL.

17. RVPN representative stated that patrolling of transmission lines up to a distance of 200 km requires around 5 hours. Therefore, to minimize outage duration, lines longer than 200 km may be considered for TWFL implementation. In hilly terrain all lines may be considered irrespective of the length.

18. SE(O), NRPC enquired about the number of 765 kV and 400 kV transmission lines having a length of more than 200 km.

19. The NRLDC representative informed that in the Northern Region, around 40 transmission lines at 765 kV and 72 lines at 400 kV voltage level have lengths more than 200 km.

20. SE(O), NRPC stated that in the first phase 765 kV and 400 kV lines having length more than 200km may be considered.

21. It was discussed that in case of lines used for evacuating nuclear and RE Power, threshold length of 150 Km may be considered. Further, in hilly terrain all 220kV and above lines may be considered.

22. CEA representative enquired about requirement of TWFL in HVDC lines.

23. PGCIL representative replied that in HVDC, TWFL principle is already used for LFL by all the OEM. Therefore, no additional TWFLs are required to be installed for HVDC lines.

24. SE(O), NRPC enquired about the cost of TWFL devices.

25. PGCIL representative replied that the cost of supply, installation, testing and commissioning of TWFL, as per the latest Purchase Order (PO), is approximately ₹25 lakh per end for a two-line module, ₹50 lakh per end for a four-line module, and ₹100 lakh per end for an eight-line module.

26. SE(O), NRPC stated that a policy may be formulated by CTU for implementation of TWFL in intra-state lines.

27. **After detailed deliberation, Committee members agreed that;**

A. Travelling Wave-Based Fault Locator (TWFL) has emerged as a highly advanced and precise fault location technology. This is useful for quickly identifying the fault location with accuracy (±500 m error), which directly contributes to reduced outage durations, improved system availability, and enhanced reliability of the transmission network.

B. TWFL implementation may be taken up in phased manner. Following criteria may be used to identify critical transmission lines for installation of TWFL in the first phase:

i. 220kV, 400kV and 765 kV lines having length more than 200Km.
ii. 220kV, 400kV and 765 kV lines used for evacuating nuclear and RE Power having length more than150 Km.
iii. 220kV and above lines in hilly terrain.
iv. Inter-regional 220kV and above lines having length more than150 Km.

C. Based on the above criteria committee reviewed the lines proposed by PGCIL in the 55th TCC and 80th NRPC meetings for TWFL implementation. Out of the 25 nos. lines, 20 nos. lines as mentioned at Annexure-VI may be considered for TWFL implementation.

D. A policy may be formulated by CTU for implementation of TWFL in intra-state lines

Meeting ended with vote of thanks to the Chair.

*****

Annexure-I

Name	Designation	Organisation
Dharmendra Meena NRPC	Superintending Engineer	NRPC
Omkishor	Executive Enginner	NRPC
Deepak Kumar	Dy. Manager	NRLDC
Pankaj Kumar Jha	Chief Manager	PGCIL
Rashmi	Assistant Director	CEA
SHOBHNA SINGH KURMI	Assistant Director	CEA
Vijay Pal RVPN	Executive Enginner	RVPN
Sandeep Kumawat	Deputy General Manager	CTU

Annexure-II

सत्यमेव जयते

भारत सरकार
Government of India
विद्युत मंत्रालय
Ministry of Power
उत्तर क्षेत्रीय विद्युत समिति
Northern Regional Power Committee

विषय: Minutes of the first meeting of the Sub-Group for implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region held on 28th August 2025 -reg.

Kindly find attached minutes of the first meeting of the Sub-Group for implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region held on 28th August 2025.

This issues with the approval of SE(O), NRPC.

Encl: As above

Signed by Omkishor
Date: 03-09-2025 17:11:14

(ओमकिशोर)
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List of addressees:
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3. Sh. D. K. Jain, SE (Protection Engg.) RRVPNL (se.prot.engg@rvpn.co.in)
4. Sh. Lokendra Singh Ranawat, Head Regulatory, IndiGrid (lokendra.ranawat@indigrid.com)
5. Sh. Rajender Kumar Thakur, Vice President, Sekura Energy Pvt. Ltd. (Rajender.thakur@energy-sel.com)
6. Sh. Nitesh Ranjan, Manager, Assistant Vice President, Resonia (nitesh.ranjan@resonia.com)
7. Sh. Abhishek Kukreja, Lead O&M, ATIL, (abhishek.kukreja@adani.com)
8. Ms. Shobhna Singh Kurmi, Assistant Director (PSPA-I Division), CEA (shobhnasingh@cea.nic.in)
9. Ms. Rashmi, Assistant Director-II, PSE&TD Division, CEA (rashmi.cea@gov.in)
10. Sh. Deepak kumar , Dy.Manager, NRLDC (deepak.kr@grid-india.in)
11. Chief Engineer, PTCUL, (hitendra0107@gmail.com)
12. General Manager, HPPTCL, (gmcd.tcl@hpmail.in)
13. Superintending Engineer, JKPTCL, (ravikantkalsotra01@gmail.com)

Minutes of the first meeting of the Sub-Group for implementation of Travelling Wave Fault Locator (TWFL) on critical transmission lines in the Northern Region held on 28th August 2025

Superintending Engineer (Operation), NRPC welcomed all the participants. List of Participants is attached at **Annexure-I**.

1. SE(O) NRPC apprised the forum that in the 55th TCC and 80th NRPC meeting, a proposal received from PGCIL for Implementation of Travelling Wave Fault Locator (TWFL) in hilly terrains, Critical Renewable, & NCR transmission lines in Northern Region was discussed. After detail deliberation, the NRPC forum decided to formulate a sub-group, comprising members from CEA, CTU, NRPC, NRLDC, Powergrid, Indigrid, ATIL, Sterlite, Sekura, RVPNL, PTCUL, HPPTCL and JKPCTL with the following Terms of Reference.

   i. Formulate criteria to identify critical transmission lines that warrant the installation of TWFL, based on operational importance and reliability considerations.
   ii. Evaluate the restoration benefits of TWFL—specifically in terms of fault location and faster restoration—by comparing scenarios with and without TWFL, using data provided by Powergrid for lines where TWFL is already implemented.

   Accordingly, based on nominations received from concerned utilities, the sub-group was formed under chairmanship of SE(O&P) NRPC. Composition of the sub-group is mentioned in Annexure-II.

2. EE(O), NRPC stated that agenda was brought by Powergrid NR-1 in 55th TCC & 80th NRPC meeting, wherein Powergrid proposed for implementation of TWFL in 06 nos. 765 kV Lines, 08 nos. 400 kV lines & 02 nos. 220 kV lines based on criticality and various parameters like line terrain, power flow capacity, generator connectivity, tripping frequencies etc.,under Additional Capitalization for tariff block 2024-29.

3. Representative from Powergrid presented the comparison of the distance shown by distance relays during fault, distance observed on TWFL and the actual fault location detected by the patrolling team on the lines on which TWFL has already been installed. (Attached at Annexure-II)

4. Representative from Powergrid mentioned that in case of line of long length or in case of transmission line in hilly terrains TWFL is very beneficial as the fault location as per TWFL is matching with that of the location of fault detected during patrolling giving an accuracy within limit of one tower span or 0.5 km distance.

5. Representative from Powergrid submitted that since the terrain of the transmission lines is hilly, distance of fault location obtained from TWFL will ease the efforts during patrolling and early fault rectification will help during mismatch of fault location in Main -1 and Main-2 relays at S/S.

6. POWERGRID representative explained the reasoning behind difference in values obtained from Distance relays and TWFL. He said that the distance relays are impedance based relays and hence depends on parameters like R0, X0, R1, X1, mutual compensation in case of double circuit line. Also, distance relays are affected by in feed /out-feed to fault (depending on the number of lines in

service). However, TWFL is independent of these parameters and only depends upon the current and voltage waves generated due to fault, which transmits from the fault location towards both the ends of the line. The time it takes to reach the end of the line and reflects, multiplied with the speed of light give the distance of fault location from both the ends.

7. SE(O) NRPC asked about the time which it usually takes to detect and rectify fault in absence of TWFL. To this, POWERGRID representative replied that fault detection and rectification usually gets delayed in case of fault during evening hours on lines located in difficult terrains and usually the patrolling starts from early morning of next day hence causing delay. However, with TWFL time is saved in fault identification.

8. SE(O), NRPC asked POWERGRID to submit data regarding the time saved in respect of faults occurred on lines where the TWFL was installed. He also asked POWERGRID to provide the details of cost of installation of TWFL.

9. EE(P), NRPC asked POWERGRID whether the existing relays were replaced after installation of TWFL. To this, POWERGRID representative replied that existing relays will remain as such and TWFL shall be used only for identifying fault location.

10. NRLDC representative suggested that a physical visit at POWERGRID Meerut S/S may be conducted to see the functioning of TWFL. He also asked that operation philosophy of TWFL and the literature related to this may be shared by POWERGRID with all the members so that the same could be studied before visit.

11. SE(O), NRPC requested Powergrid to share the required data, operation philosophy & the literature of TWFL and arrange the visit before 2nd meeting of the committee.

Meeting ended with vote of thanks to the Chair.

*****

Annexure-I

Name	Designation	Organisation
Dharmendra Meena NRPC	Superintending Engineer	NRPC
Omkishor	Executive Enginner	NRPC
Reeturaj Pandey	Executive Enginner	NRPC
Rajat Dixit	Asst. Executive Enginner	NRPC
D K JAIN	Superintending Engineer	RVPN
Sunil Aharwal/NRLDC	General Manager	NRLDC
Gaurav Singh	Chief Manager	NRLDC
Deepak Kumar	Dy. Manager	NRLDC
Akash Tomar	Dy. Manager	NRLDC
Pankaj Kumar Jha	Chief Manager	PGCIL
Rashmi	Assistant Director	CEA
SHOBHNA SINGH KURMI	Assistant Director	CEA
D K JAIN	Superintending Engineer	RVPN
Vijay Pal RVPN	Executive Enginner	RVPN
Sandeep Kumawat	Deputy General Manager	CTU

Case Number	REGION	NAME OF ELEMENT	TRIPPING DATE (sample 01-12-2022)	TIME HRS (sample 00:00)	REASON (Type of fault)	Total Line length	Relay Details	Relay Details	Location as per TWFL (H)		Location as per Patrolling (J)		Error(in km) B	% error (B)	Make of TWFL
						in km	M-1 Distance	MAIN-2	From Station A	From Station B	From Station A	From Station B	(H-J)		
1	NER	400 KV New Mariani-Misa-2(404L)	24.07.2024	11:57		221.7	126.7	128.7	138.57	82.24	139	82	-0.24	-0.3	GE
2	NERTS	400kV Misa-Silchar #1	29-05-2024	02:34		178.36	127	108.1	130.92	47.44	131.384	46.97	-0.47	-1.0	GE
3	NERTS	400kV Misa-Silchar #2	01-05-2024	20:00		178.36	--	102.9	133.16	45.2	133.954	44.4	-0.8	-1.8	GE
4	NERTS	400kV Misa-Silchar #1	26-06-2024	15:11		178.36	151.1	102.2	113.04	65.32	111.32	67.034	1.714	2.6	GE
5	NERTS	400kV Silchar-Misa #2	23-07-2024	13:08		178.36	28.91	29.9	--	26.1	151.834	26.52	0.42	1.6	GE
6	ER-1	765KV GAYA-VARANASI-2	21-05-2024	05:07	TRIPPED DUE TO R-N FAULT.	273.18	109.4	108.2	116.09	157.09	115.71	157.47	0.38	0.2	GE
7	ER-1	765KV NEW RANCHI-DHARAMJAIGARH-	11-05-2024	18:12	TRIPPED DUE TO R-N FAULT.	302	2.9	NA	1.24	299.76	1.3	300.7	0.94	0.3	GE
8	ER-1	400KV RANCHI - SIPAT 2	07-05-2024	18:23	TRIPPED DUE TO Y-N FAULT	404.5	23.16	NA	23.9	380.6	24.5	380	-0.6	-0.2	GE
10	SR-I	765kV NIZAMABAD-WARDHA-1	21.10.2024	13:45	R-N fault	291.1	118	120	125.7	165.4	126	165	-0.4	-0.2	Qualitrol
11	SR-I	765KV KURNOOL- NPS-2	18.08.2024	15:30	B-N fault	302.2	200	201	199.11	103.09	198.9	103.3	0.21	0.2	GE
12	SR-I	JEYPORE- GAJUWAKA-2	27.08.2024	13:37	Y-N fault	225	13	10	2.43	222.07	2.5	222.5	0.43	0.2	GE
13	SR-I	RAICHUR- KURNOOL-2	18.09.2024	03:37	Y-N fault	118.4	21.51	21.5	97.26	21.14	97.484	20.916	-0.224	-1.1	GE
14	SR-I	RAICHUR-KURNOOL-2	29.09.2024	19:11	R-N fault	118.4	45.16	45.2	70.3	48.1	71.48	46.92	-1.18	-2.5	GE
15	ODISHA	5KV SUNADARGARH-DHARMAJAYGARI	20-08-2024	04:48	R-N fault	151.5	22.1	22.9	23.4	128.1	24	127.5	-0.6	-0.5	GE
16	ODISHA	765KV ANGUL-SUNDARGARH-II	05-09-2024	12:04	B-N fault	272	220.2	212.8	208.6	63.4	210	65	1.6	2.5	GE
17	ODISHA	400KV JEYPORE-GAZUWAKA-I	06-09-2024	17:45	B-N fault	225	43.43	41.1	55.24	170.1	53.67	171.33	1.23	0.7	GE
22	NR3	765KV VARANASI-BALIA	27-08-2024	16:44:00	B-N fault	167.676	125.10	125.3	141.9	24.72	142.57	25.106	0.386	1.5	GE
24	NR3	765KV AGRA-FATEHPUR-II	14-11-2024	04:38:00	B-N fault	334.308	89.00	88.7	84.72	249.92	84.95	249.358	-0.562	-0.2	GE
25	NR3	765KV AGRA-FATEHPUR-II	14-11-2024	04:42:00	B-N fault	334.308	89.50	89	85.15	249.53	84.95	249.358	-0.172	-0.1	GE
26	NR3	765KV AGRA-FATEHPUR-II	14-11-2024	04:53:00	B-N fault	334.308	77.70	77.4	82.46	252.21	84.95	249.358	-2.852	-1.1	GE
27	NR3	765KV AGRA-FATEHPUR-I	20-11-2024	05:49:00	Y-N fault	333.582	293.30	294.5	302.96	31.2	302.282	31.3	0.1	0.3	GE
29	ER-1	400KV BIHARSHARIF-BALIA-1	28-09-2024	16:08	Y-N fault	241.79	119.30	120.9	122.98	118.81	123.49	118.3	-0.51	-0.4	GE
31	NR-1	765kV PHAGI(RRVPNL)-GWALIOR-1	02-07-2025 02:22	03-07-2025 02:07	R-N fault. Gwalior_gis_ais:5.73kA/119.30km /78.53deg. IN:6.10kA & VF:344.83 kV.Line tripped on persistent	306.21	181.2	119.3	185.65	120.49	189.24	120.92	0.43	0.4	GE
32	NR-1	765kV BHIWANI-MOGA	02-05-2025 03:40	02-05-2025 09:18	B-N fault. Moga765_ais_gis:3.14kA/194.418 km/88.331deg. Tripped on fault in reclaim time.	273	33.31	239.69	Distance not fetched	238.86	33.7	239.3	0.44	0.2	GE
33	NR-1	765kV KOTESHWAR-MEERUT-2	15-03-2025 03:05	15-03-2025 03:05	Y-N fault. Koteshwar765:3.58kA/37.52km/82.73deg. Double-End distance(Koteshwar765):40.03km.	175.63	37.84	134.1	38.49	137.14	38.498	137.14	0	0.0	GE
34	NR-1	765kV KOTESHWAR-MEERUT-1	21-02-2025 04:38	21-02-2025 04:38	B-N fault. Koteshwar765:3.26kA/74.44km/86.31deg. Double-End distance(Koteshwar765):73.88km.	179.27	74.44	100.47	73.86	104.83	77.42	101.85	-2.98	-2.9	GE
35	NR-1	765kV CHITTORGARH-AJMER-1	13-01-2025 05:23	15-01-2025 07:20	R-N fault. Chittorgarh:6.15kA/38.03km/87.62deg. Autoreclose attempt taken but line tripped on Persistent	211.79	36.86	161.1	37.35	174.04	37.758	172.934	-1.106	-0.6	GE
36	NR-1	765kV KOTESHWAR-MEERUT-1	01-01-2025 20:54	02-01-2025 16:07	Y-N fault. Koteshwar765:4.39kA/44.5km/84.9deg. Tripped on Reclaim.	179.27	44.5	132.712	48.61	130.53	49.165	130.008	-0.522	-0.4	GE

REPORT ON VISIT OF COMMITTEE MEMBERS AT POWERGRID, MEERUT SUBSTATION FOR TWFL

A committee consisting of members from NRPC, CEA, CTU, Grid India and POWERGRID visited the 765/400 kV Meerut Substation on 19.09.2025 to understand the functioning of the TWFL system and to evaluate the benefits of its installation on transmission lines. During the visit, the committee visited the kiosks where TWFL systems were installed and held detailed discussions on their functionalities, wiring arrangements, communication architecture, and fault location details. A comparative analysis was carried out between fault location data recorded by TWFL and those obtained from the distance relays for the same fault events. A brief technical presentation on these aspects was delivered by the representatives of Meerut Substation.

The committee noted that TWFLs have been installed on several 765 kV transmission lines emanating from Meerut Substation, namely Meerut–Koteshwar Line-1 and Line-2, Meerut–Bhiwani Line, and Meerut–Moga Line.

At the Meerut Substation, all the installed TWFLs are of GE (Reason) make and operate on a decentralized architecture. In this configuration, each transmission line is equipped with a dedicated acquisition unit responsible for capturing high-frequency voltage and current signals. These acquisition units communicate with a central processing unit that can interface with up to four such line-based units. The decentralized system offers flexibility, redundancy, and scalability for multi-line substations.

Electrical connection/wiring diagram of GE make TWFL installed is shown in Figure 1 below.

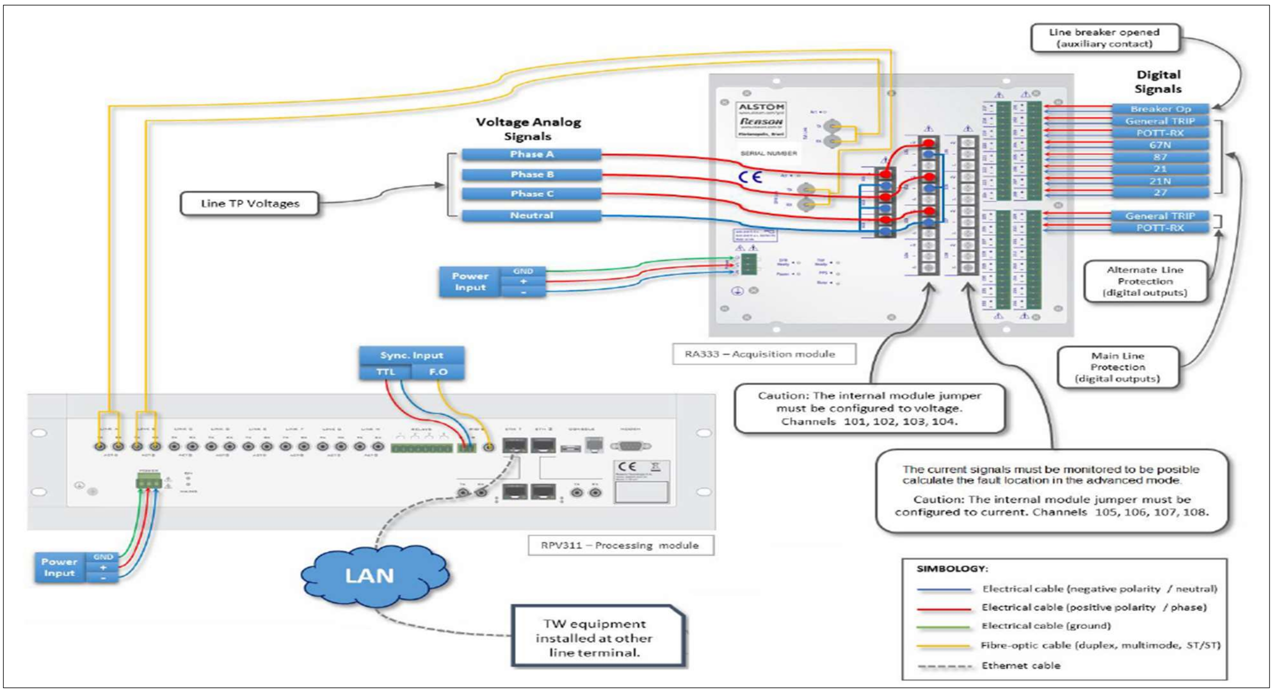


Figure 1: Electrical Connection of GE make TWFL

The decentralized architecture of the GE make TWFL installed at Meerut Substation is shown in Figure 2 below

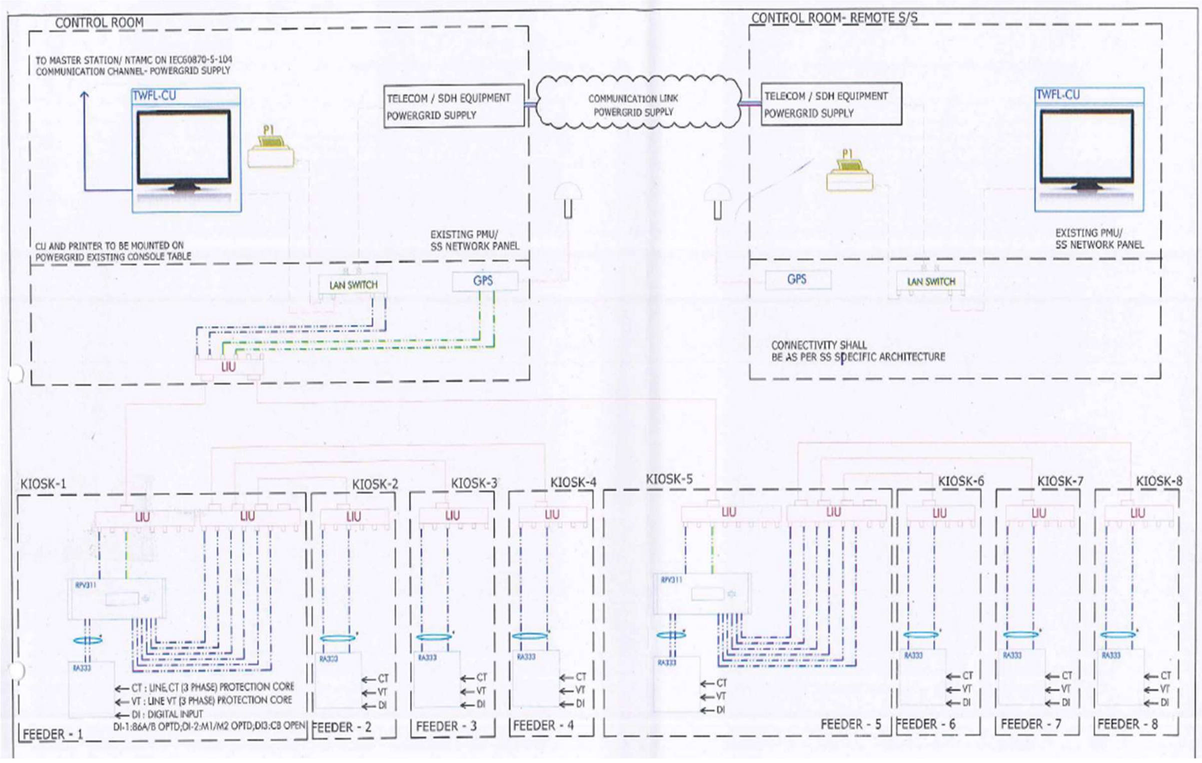


Figure 2: Decentralized Architecture of GE make TWFL

The field experience at Meerut Substation demonstrates that TWFL-based systems can identify and localize faults far more accurately than conventional impedance-based approaches. Their independence from system parameters, high resolution in fault distance estimation, and integration with digital substation communication networks make them an essential tool for modern transmission system operation and asset management. The successful implementation and operation of TWFLs at 765 kV Meerut have provided valuable insights and practical validation for wider adoption of this technology across the Indian transmission grid.

The details of the fault location recorded by TWFL at Meerut Substation for some of the faults in last two months are tabulated below:

Sr. No.	Line Name	Date	Time	M-1	M-2	TWFL		Patrolling Distance
				(km)	(km)	Local End (km)	Remote End (km)	(km)
1	Koteshwar-2	12.09.25	10:50:22	117.1	116.9	128.31	47.32	128.4
2	Koteshwar-2	18.09.25	04:57:07	92.8	89.69	74.37	104.32	74.9
3	Koteshwar-1	07.09.25	03:58:56	117.2	118.8	125.38	53.31	125
4	Moga	31.07.25	01:13:21	222.2	222.7	245.64	91.5	245.6
5	Moga	16.07.25	09:29:07	0.3	0.3	0	337.14	0.3

GE
Grid Automation

TW COMMISSIONING MANUAL
Travelling wave fault location in transmission lines

Revision 2 – alberto.becker@ge.com
Revision 1 – alberto.becker@ge.com

Summary

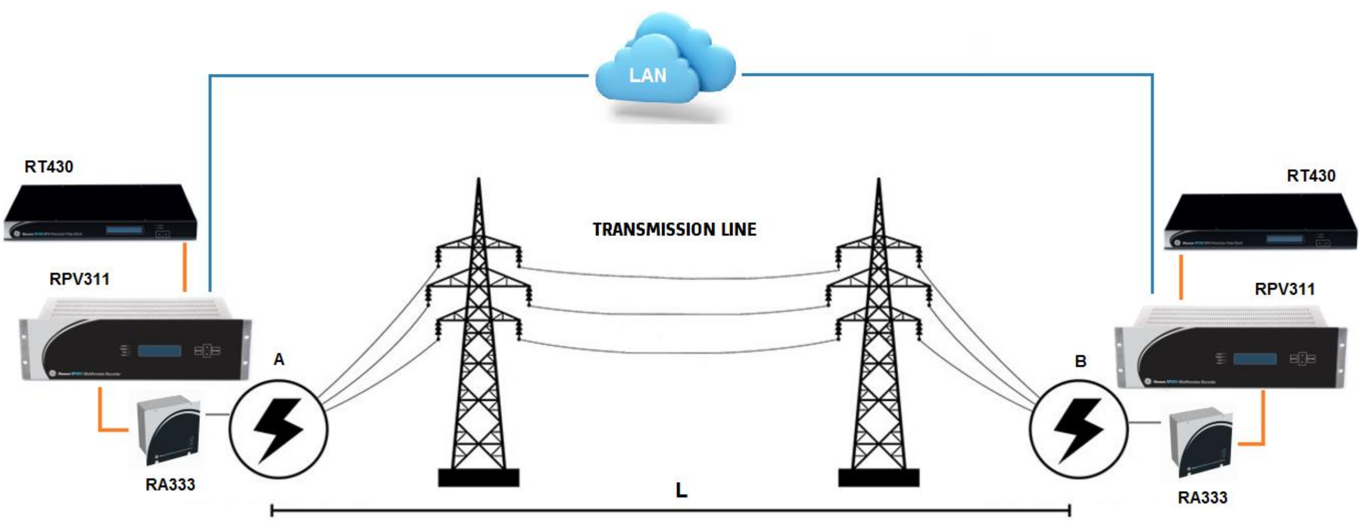
Objective

This document aims to guide the professionals involved in the commissioning TW Reason systems for the correct setup procedure and tests necessary to locate faults in overhead or mixed transmission lines (with an overhead section and one underground). The correct functioning of the monitoring system is subject to the use of configuration and commissioning techniques described herein.

Application

Fault location in mixed transmission lines through TW Reason system comprising the use of the following equipments:

- Processing module of the digital fault recorder, Reason RPV311
- Remote acquisition module for traveling wave, Reason RA333
- GPS Grandmaster clock, Reason RT430 (or other compatible sync source)
- RPV Manager Software, Reason version 07A00



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1. INITIAL CONSIDERATIONS

Before starting the commissioning of the TW system, it should be borne in mind that the fault for traveling waves of Reason tracking system works in conjunction with an DFR, so it is essential that the DFR is properly commissioned and this includes the parameter setting circuits monitored and the realization of acquisition test of all digital and analog signals monitored by DFR. These signals form the basis for triggering the limits associated with the system. The DFR commissioning should be performed using the document referred to as "Test Report - Commissioning" and must precede the commissioning of the TW system. To be able to perform commissioning, the customer will need to provide some details of the construction characteristics of the transmission lines needed to determine the system configuration parameters, as will be described herein. The procedures will be described only refer to the commissioning of the TW system, both in exclusively overhead lines as in mixed lines.

2. INSTALLATION

2.1. Checking the internal jumpers of the RA333 module

When using more than one module RA333 in the same processing unit, RPV311, you must configure the QTW board RA333 module, a combination of jumpers to define a unique ID for each module. As RPV311 can work with up to four RA333 modules connected in their links, these modules should be identified each IDs different from each other. It is not necessary that the modules are connected in any sequence in RPV311 links. The important thing is that each has a different ID from the others. The figure below shows all ID combinations possible to be configured in the RA333. Note that the ID-0 is the only combination that does not require jumper in any position of JP2, JP3 and JP4.

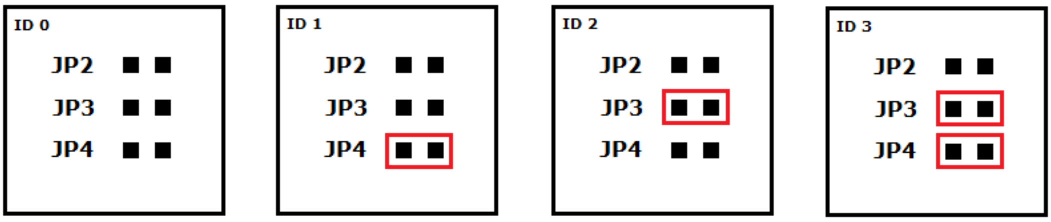


Figure 1 – Combinations of the ID jumpers on the board QTE

The QTW board is one that makes the communication link TW RA333 module with links from RPV311. To extract the QTW card is to open the back cover of the RA333 module, preferably before installing the panel. Only after checking and setting the ID's, you should do the installation on the panel. In the picture below presents the location of the JP2 pins, JP3 and JP4, where the jumpers must be connected.

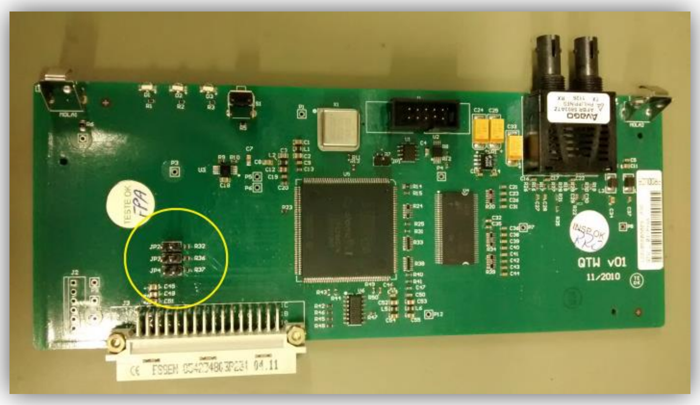


Figure 2 –Link TW QTE board (extracted from the RA333)

2.2. Electrical connections

Once installed on the panel makes the electrical connection of current signals, voltage and digital from the monitored line.The module RA333 makes recording of traveling waves through high frequency voltage acquisition channels, in the MHz range, channels 301, 302 and 303. Therefore, it is necessary to make a parallel connection between the low frequency channels (50 / 60Hz), numbers 101, 102 and 103, for the DFR with high frequency channels (MHz), numbers 301, 302 and 303, for the TW. Briefly, it needs to be monitored three voltage/current of the line and digital signals 52 (operated) GENERAL TRIP, POTT-RX, 67N, 87, 21, 21N and 27N, regarding main protection line. If possible it is indicated that the equivalent signals of the secondary protection, are also wired to the equipment and monitored. To be able to locate the faults nimbly through the localization software, it is recommended that the two devices are connected to a network for remote access. Below is the schematic example of the installation.

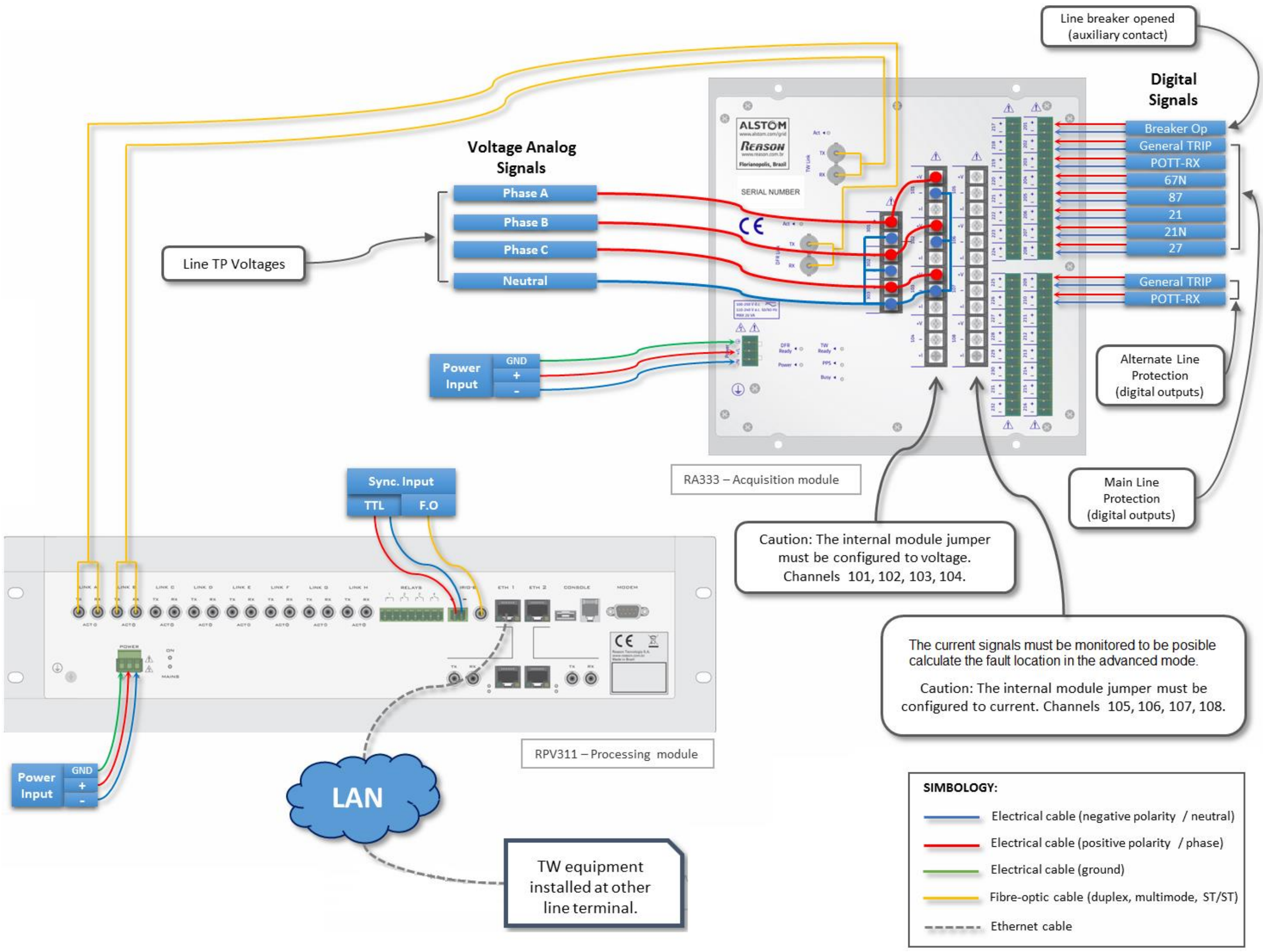


Figure 3 – Electrical schematic wiring

2.3. Installation and acquisition validation tests

After completion of physical installation must be done tests that prove the correct functioning of the DFR on both ends of the line, as indicated in the "Test Report – Commissioning" used in the DFR commissioning. After validating the operation of the DFR the TW acquisition system should be specifically tested to ensure that the RA333 module is installed properly and acquiring the signals properly.

For this, It is suggested the following:

a) Open the RA333 modules and verify that the jumper that sets the ID number of each module is consistent with the number of modules installed in each RPV, and the position of the voltage / current analog channels jumpers. Physically check the installation of TW module to ensure that there is wiring in parallel with the TW channels with the voltage channels of the monitored transmission line.

b) First the current/voltage channels (50 / 60Hz) must be tested, applying three-phase signal through test case on equipment channels from the source panel of these signals and check by monitoring web interface the correct acquisition of these signals.

c) After validating the acquisition of analog signals should be tested all digital points used in the system trigger, closing the digital contacts from terminal blocks of the signal source panels.

d) Before testing the TW acquisition system the TW terminal must be set up and activate the recording register. Create and activate an undervoltage threshold of 0.9 PU. Apply nominal value in line voltage inputs to be monitored. Ensure that the equipment is synchronized with IRIG-B000 signal and PPS LED is blinking in the RA333 module. In DFR web interface the synchronism status should be "Locked" and, in addition, all the RA modules connected in DFR links must be active.

e) After ensuring that the system is properly synchronized and with all links active, the TW system should be tested. To test the acquisition, provoke the appearance of a small traveling wave through the electrical opening of at least one of the voltage channels (eg, by opening the test block) and check the trigger of the RA333 module through the Busy LED lighting. When LED turns off (after 2 minutes) access the equipment and check the existence of traveling wave record. Open the registry and visualize the traveling wave generated by the opening of voltage circuit during the test.

3. TW CONFIGURATIONS

The TW system configuration consists in creating specific limits so that equipment located in both line terminals simultaneously trigger when a fault occurs because during the fault, travelling waves are generated spontaneously. Any type of electrical interruption, even the opening of a line circuit breaker can generate traveling waves, so it is important that the equipment is set to trigger only when needed. Therefore, for each equipment operation condition, are created specific limits to be activated according to the equipment operation mode.

3.1. Thresholds trigger configurations for the travelling wave system

The configuration of the trigger limits of the equipment must be made in web interface configuration of equipment installed at each end. They should be set up analog and digital limits and subsequently activated in the "traveling wave recorder" option.

The trigger limits used in equipment while operating in operation mode are different from those configured during the step of calibration field testing, because the trigger condition is different in both cases. All limits are created together and are available in the configuration, but only the limits related to equipment operating mode at the time must be activated. The limits are set by equipment configuration web interface, in the option "Thresholds".

Therefore, we use the following threshold settings for each situation:

a) Thresholds for trigger in test mode

- Phase overcurrent (greater than 10% of the load current)
    - Example: If the line current with load is 800A must be set the threshold value in 80A. For practical reasons, it was suggested the setting of an overcurrent limit greater than 10% of the line current before opening the line. Therefore to determine the trigger limit should be monitored what the current of the line in operation condition is and then calculate the current limit equivalent to 10% of the line load value.

b) Thresholds for trigger in the operation mode

Digital thresholds:

• 52 (open circuit breaker, ABC phase) - with normal logic

Example: Create a limit for each open breaker contact with normal logic so that the recording is triggered when the circuit breaker contacts are closed. The objective is to trigger the recording at the time when the line is de-energized.

• TRIP GENERAL POTT-RX

• 67N, 87, 27, 21, 21N

• If possible also TRIP contacts and 52 (circuit breaker) equivalent alternating protection.

Analog thresholds:

• Phase undervoltage (less than 0.9PU)

• Phase overvoltage (greater than 1.1PU)

• Neutral overvoltage (greater than 0.2PU)

• Overcurrent (greater than 10% of the phases nominal value)

Example: If the line current with load is 800A must be set the threshold value in 80A.

• Negative sequence overcurrent (greater than 10% of the nominal value of phases)

Example: If the line current with load is 800A must be set the threshold value in 80A.

3.2. TW Configuration in the equipment web interface

Accessing to equipment configuration web interface, through the option "traveling wave recorder" you can add and create TW terminals in each equipment. This option is set the terminal name of the equipment in question and a list of all limits that have been created is displayed. Only the limits related to TW should be activated in this option. These are the limits that when violated will trigger the traveling wave recording. Must be attentive to activate and deactivate the limits required for each device operating condition. This will depend on the operating condition to which you want the equipment to work.

3.3. Necessary parameters for TW Fault Locator Software

The RPV Manager software tools, will pool the CONTRADE files records of traveling waves, at the two ends of the line, on the same computer and based on the time stamp of the front wave of each record, it will calculate the fault location. For this it is necessary to have network connection with the two devices.

The fault location with accuracy requires to be determined some necessary variables to correct parameterization of location software. These variables are parameters that can be used directly in the RPV Manager software configuration, in the case of L1 and L2 as well as calculated based on the characteristics of the conductors in the case of K1 and K2, where:

- L1 - overhead section length
- L2 - the underground section length
- K1 - reduction factor in overhead section
- K2 - reduction factor in underground section

Following this document the methods to be used for determining those factors will be presented.

3.3.1. Parameter determination of an overhead line

a) Determination of L parameter – overhead line

The L value is the overhead project length, however it is known that this differs from the actual length of the line conductors, it does not consider the line catenaries and not the internal substation cables (TP until TW acquisition modules). When it has two or more events it is possible to minimize the errors associated with the L calculation by using the linear regression method. This method will be described following this document.

b) Determination of K parameter – overhead line

The value of K is the total factor of wave velocity reduction in line in relation to the speed of light, in general this value varies from 0.985 to 0.995. A value in this range can be adjusted experimentally until mathematical methods can be used for its determination. When there is a single event in the line is already possible to determine a first estimated value using the equation below. The calculation of K with only an event should not be considered definitive, since the values of the variables Ta, Tb, L and X generally have intrinsic measurement errors.

$$k = \frac{2x - L}{c\,(\tau_a - \tau_b)}$$

Where:

• X - Real location of the fault

• L - Line Length

• C - Speed of light

• Ta, Tb - Wave front Time in Terminals A and B

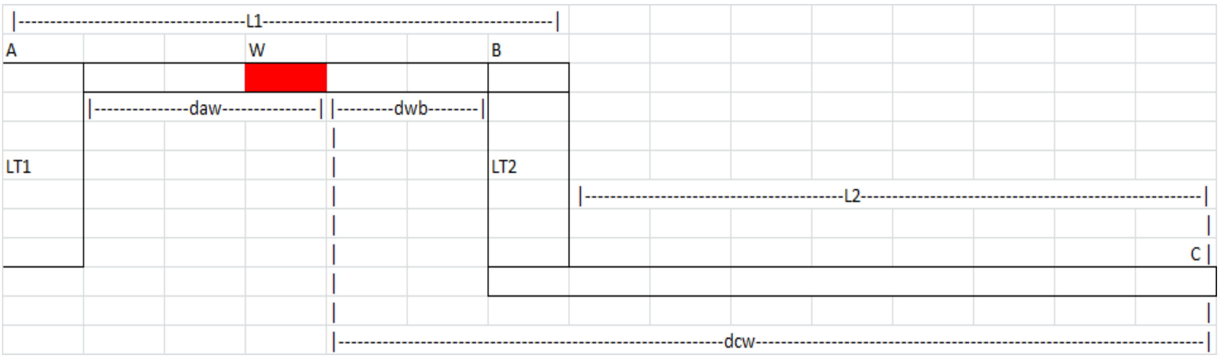
When there are two or more events it is possible to minimize the errors associated with K calculated by using the linear regression method. This method will be described following this document.

3.3.2. Parameter determination of a mixed line

a) Mathematical modeling to locate faults in mixed lines

To calculate the location of faults in mixed lines, we must first determine if the failure occurred in the overhead or underground section of the line. Depending on the segment where ocurred the fault you must use a specific set of equations. To know which section was the fault, first calculate the Daw value for the overhead line section. If the result is lower than or equal to the overhead line section (L1) means that the fault occurred in the overhead section. In this case the fault location is Daw value already calculated. When the calculated value of Daw is greater than the length of the overhead section means that the fault is located in the underground section, L2, therefore it must use the set of equations of the underground section to find the fault.

Fault in the overhead line section (AB):



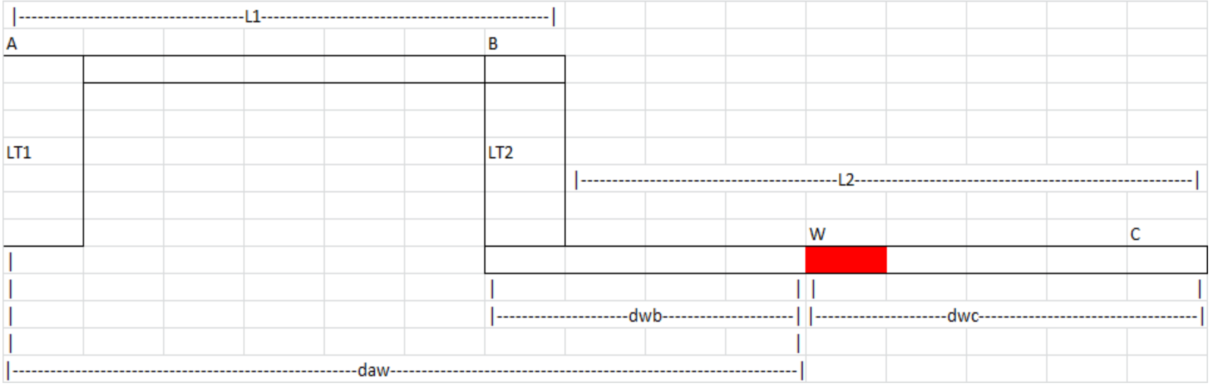
Where:

$$\boxed{D_{wb} = L_1 - D_{aw}}$$

$$\boxed{D_{aw} = \frac{L_2 + \alpha L_1 + \alpha K_1 C \Delta T}{2\alpha}}$$

$$\boxed{D_{wc} = L_2 + L_1 - D_{aw}}$$

Fault in the overhead line section (AB):



Where:

$$\boxed{D_{wb} = L_2 - D_{wc}}$$

$$\boxed{D_{aw} = L_2 + L_1 - D_{wc}}$$

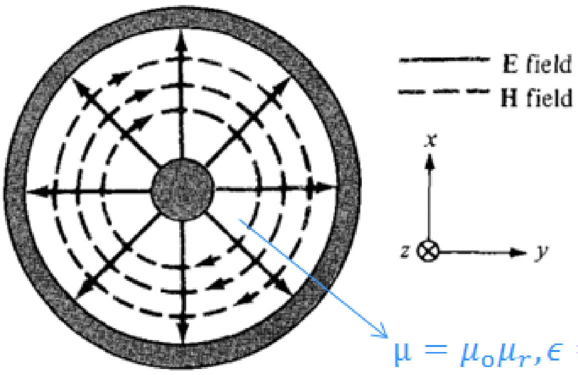
$$\boxed{D_{wc} = \frac{L_2 + \alpha L_1 - \alpha K_1 C \Delta T}{2}}$$

- W: The fault point
- Daw = Distance from terminal A to fault
- Dwb = Distance from terminal B to fault
- Dcw = Distance from terminal C to fault
- C = Light Speed (~ 300.000 km/s)
- L1 = Length of overhead line
- L2 = Length of underground line
- K1 = Velocity Coefficient for overhead Line
- K2 = Velocity coefficient for underground line
- Ta = Time to TW arrive on ending point A
- Tb = Time to TW arrive on ending point B
- Tc = Time to TW arrive on ending point C

Now it is known what are the variables involved in the fault location equations for each faulting condition to determine the parameters of the line.

b) Determination of K parameter – mixed lines

The parameter K is a variable that determines the speed reduction factor of the wave conductor according to the characteristics of each line section. It is considered that the vacuum propagation velocity of electromagnetic waves equals the speed of light. However, the velocity of propagation of a traveling wave in the coaxial cable depends on the permeability and permittivity constants that determine the dielectric insulation characteristics of each type of cable.



$$\mu = \mu_o \mu_r, \epsilon = \epsilon_o \epsilon_r$$

$$V_{wave} = \frac{1}{\sqrt{\mu_o \epsilon_o}} = \frac{C}{\sqrt{\mu_r \epsilon_r}}$$

<u>Where:</u>

- μ_o – Magnetic permeability constant vacuum $4\pi \text{ x } 10^{-7}$ H/m
- μ_r – Relative permeability of each material
- ϵ_o – Dielectric permittivity of vacuum $\cong 8.854 \text{ x } 10^{-12}$ F/m
- ϵ_r – Permittivity relative of each material

In a mixed line there are different K-factors for each line section, for the isolation of these conductors has different characteristics. Thus we have:

- K1 - reduction factor in overhead section
- K2 - reduction factor in underground section

Thus, the K value representing the mixed line is calculated by the ratio of K2 and K1:

$$K = \frac{K2}{K1}$$

Therefore to determine the K parameter is first necessary to calculate the values of K1 and K2, as will be described below.

- **K1 factor calculation – overhead section**

In the case of K1 factor relating to overhead line, without insulating material, it is considered that the dielectric material insulating the cable is only the air. In this case the constant of permeability and permittivity is very close to 1.

$$\mu_{r_{air}} \cong 1 \qquad \epsilon_{r_{air}} \cong 1$$

$$\boxed{V_{wave_{overhead}} = \frac{C}{\sqrt{\mu_{r_{air}}\epsilon_{r_{air}}}} \cong C}$$

In overhead lines, the speed of wave is very close the speed of light, between 98% and 99.5%, it means that the factor K1 is in the range from 0.985 until 0.995. For calculating with precision is a very complex task, because it depends on unknown constants of permeability and permittivity of the dielectric of overhead line cable. As in this case the dielectric is air, these constants may vary with humidity, atmospheric pressure and distance between the the conductors of the transmission line in question. Therefore, during the commissioning of a line, we fix the K1 value at 0.99 and it therefore infers an initial error in the location of faults.

- **K2 factor calculation – underground section**

For the underground line section it is necessary to calculate the K2 factor. This factor can be calculated easily because the underground line cable has a great difference regarding to the cables used in overhead lines, that is the dielectric insulation material. In these cables the insulation is not only the air but a previously known material and designed for the application wich the cable is used, therefore known by the manufacturer and reported in the datasheet cable. Knowing the material used in cable insulation can be obtained its constant permeability and permittivity, so you could determine the value of the wave velocity reduction factor for each type of cable. A common material used in the insulation of these cables is XLPE, but you must find what material is in fact used in the isolation of the underground cable in question. In the example below, it is calculated the value of K2 to an insulated cable with XLPE and with their constant permeability and permittivity, where the result is K2 = 0.66.

$$\mu_{r_{xlpe}} \cong 1 \qquad \epsilon_{r_{xlpe}} \cong 2.3$$

$$\boxed{V_{wave_{underground}} = \frac{C}{\sqrt{\mu_{r_{xlpe}}\epsilon_{r_{xlpe}}}} \cong 0.66C}$$

c) Determination of L parameter – mixed line

The length of the line section is known by the owner to be part of the transmission line project, however knowing the length of the line does not mean knowing the length of its cables. The length of the cables can vary depending on the catenary of the overhead line and also the internal substation cables that carry the signal from the TP to the input panel on which is installed the RA333 acquisition module. This difference is found in the overhead line section and is a source of error in the fault locations. In the underground line section, it is known the exact cable length because the length of the underground line is exactly the length of the cable itself, so in this case we do not have a source of error for the system. So L is the sum of L1 and L2 as shown below:

$$L = L_1 + L_2$$

Where:

- L – Line real length
- L1 – Overhead section length
- L2 – Underground section length

The value of L1 is the line project length; however it is known that this differs from the real length of the line cables because it does not consider the catenaries and substation internal cables. But the L2 value is not need to be calculated because the length of the cable project in the underground section will be exactly the length of the underground section of the line. When there are two or more events it is possible to minimize the errors associated with L1 through the calculation using the linear regression method. This method will be described following this document.

4. CALIBRATION PROCESS

The TW system calibration process involves applying the mathematical method of linear regression to find the optimum value of each setting parameter of the location system considering a series of events occurring in the line transmission. Thus, it is reduced the location errors associated with imprecision in the theoretical determination of the parameters.

The obtaining of samples required for calibration can be done at the commissioning stage or even after the line is in operation.

4.1. Linear regression method

When there are two or more events with known line fault location you can use the linear regression method to get the results of K1 and L closer to reality.

Using the linear equation is possible to determine the linear projection of y depending on the sets of x and y samples from each event occurred on the line. As more samples are considered more accurate will be the y linear projection. Below is an example of linear projection chart.

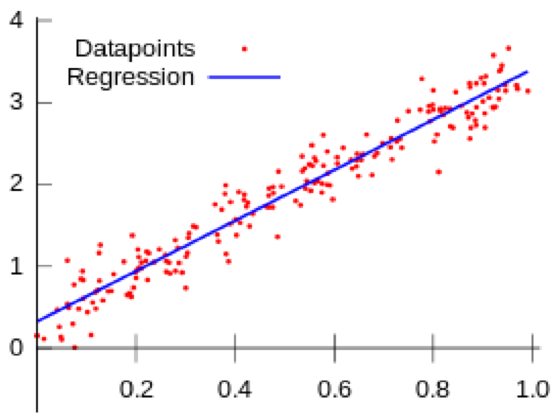


Figure 4 – Example of linear regression graph

For calculating A and B use the following equations:

$$A = \frac{\overline{\sum x} \,.\, \overline{\sum y} - \overline{\sum x.y}}{\overline{\sum x} \,.\, \overline{\sum x} - \overline{\sum x.x}}$$

$$B = \overline{\sum y} - A.\overline{\sum x}$$

Based on the calculated values of A and B it is possible to calculate the linear projection of y using the linear equation:

$$y = A.x + B$$

4.2. Linear regression equations for overhead lines

- ***Determination of L1 – overhead line***

When there are two or more events, it is possible to calculate the linear projection of L1, using the following equation:

$$L1 = 2B$$

- ***Determination of K1 – overhead line***

When there are two or more events, it is possible to calculate the linear projection of k1, using the following equation:

$$k = \frac{2A}{c}$$

4.3. Linear regression equations for mixed lines

- ***Determination of L1 – mixed line***

When there are two or more events, it is possible to calculate the linear projection of L1, using the following equation:

$$\boxed{L_1 = \frac{2.B.K_2 - K_1.L_2}{K_2}}$$

The value of L2 need not be calculated because the project cable length of the underground section will be exactly the length of the underground line.

- ### *Determination of K1 – mixed line*

If possible to do the circuit breaker switching tests at the line in the commissioning stage, also will be possible to calculate the initial K1 value using the equation below for when there is only a single event:

$$\boxed{K_1 = \frac{2.K_2\,.Daw - K_2.L_1}{L_2 + K_2.C.\Delta T}}$$

Where:

- K2 – Wave propagation factor in underground cable
- Daw – Distance from the fault (Terminal A ref.)
- L1 – Overhead line length L2
- L2 – Underground line length
- ΔT – Time difference between the wavefront recorded at the line terminals A and B

When there are more than one event is possible to use linear regression to calculate K1 using the following equation:

$$\boxed{K_1 = \frac{2.A}{C}}$$

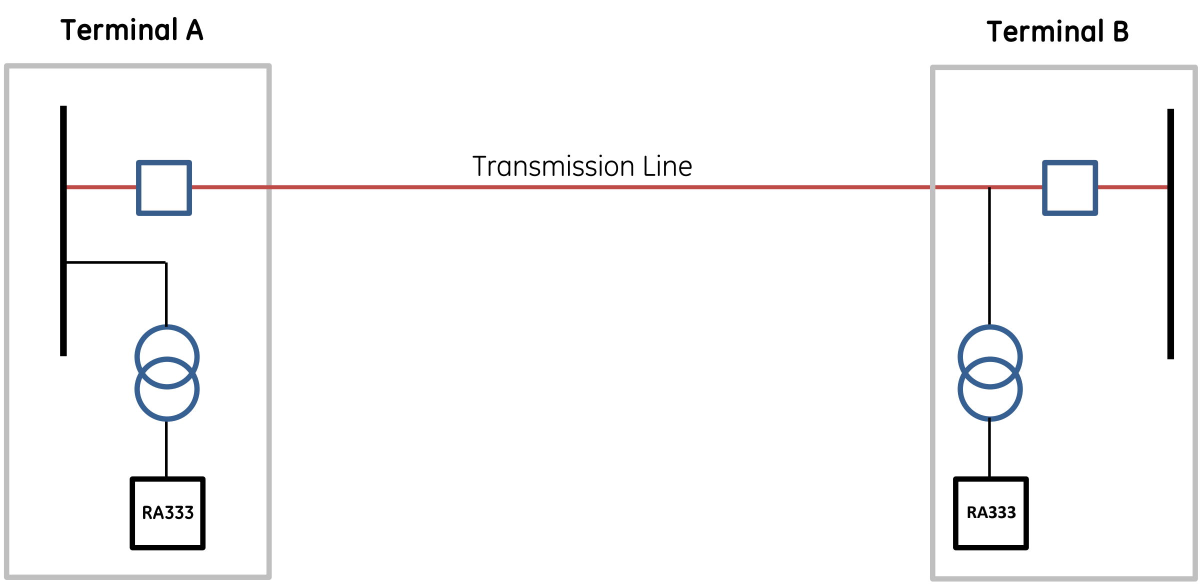
4.4. Obtaining linear regression samples

4.4.1 Through real faults – line in operation

When the line transmission is already in operation it is possible to calibrate the system using samples related to the real faults that occurred in the line. In this case for each real fault occurred it is necessary to know the location calculated by software and the real location confirmed by field team. Based on the two records it is possible to calculate the error location for each event and then calculate the linear projection of the K and L. It is recommended that the linear regression will be calculated from the third event and should continue until there is stabilization of K1 and L an acceptable error range.

4.4.2 Through circuit-breaker switching – line in test

During commissioning it is also possible to obtain the events necessary to be able to make the linear projection of K1 and L, for that will be possible it is necessary cause the appearance of traveling waves in known points on the transmission line. Usually just switching the circuit-breaker is enough to generate these waves, so it is suggested to do at least three switches in line-breakers during commissioning period for obtain at least three events required for calculating a first linear projection. However, this type of test depends on the operating line availability at the time of commissioning, it is necessary that the line is loaded; otherwise there will be no traveling waves.



Before performing any type of TW test in the transmission line is necessary to configure the equipment trigger thresholds for operation in "test mode". This configuration is described in item 3.1.a of this document.

To obtain the samples, we suggest the following sequence of circuit-breaker switching tests from the line terminal A:

Step 1: Opening the line breakers

Wait two minutes before continuing...

Step 2: Closing the line breakers

Wait two minutes before continuing...

Step 3: Opening the line breakers

Wait two minutes before continuing...

Step 4: Closing the line breakers

Wait two minutes before continuing...

Step 5: Opening the line breakers

Wait two minutes before continuing...

Step 6: Closing the line breakers

By performing this sequence of tests you have three events that will allow to calibrate the system by first linear projections of K1 and L. This will significantly improve the precision of fault location. You can also improve the result as new events are recorded by the equipment and new samples are added to the linear regression. This activity can be continued after the line is in operation.

After the tests were completed the equipment thresholds configuration should be re-established for the line transmission operation "operation mode", as described in item 3.1.b of this document.

5. FAULT LOCATION WITH THE RPV MANAGER SOFTWARE

5.1. Configuration

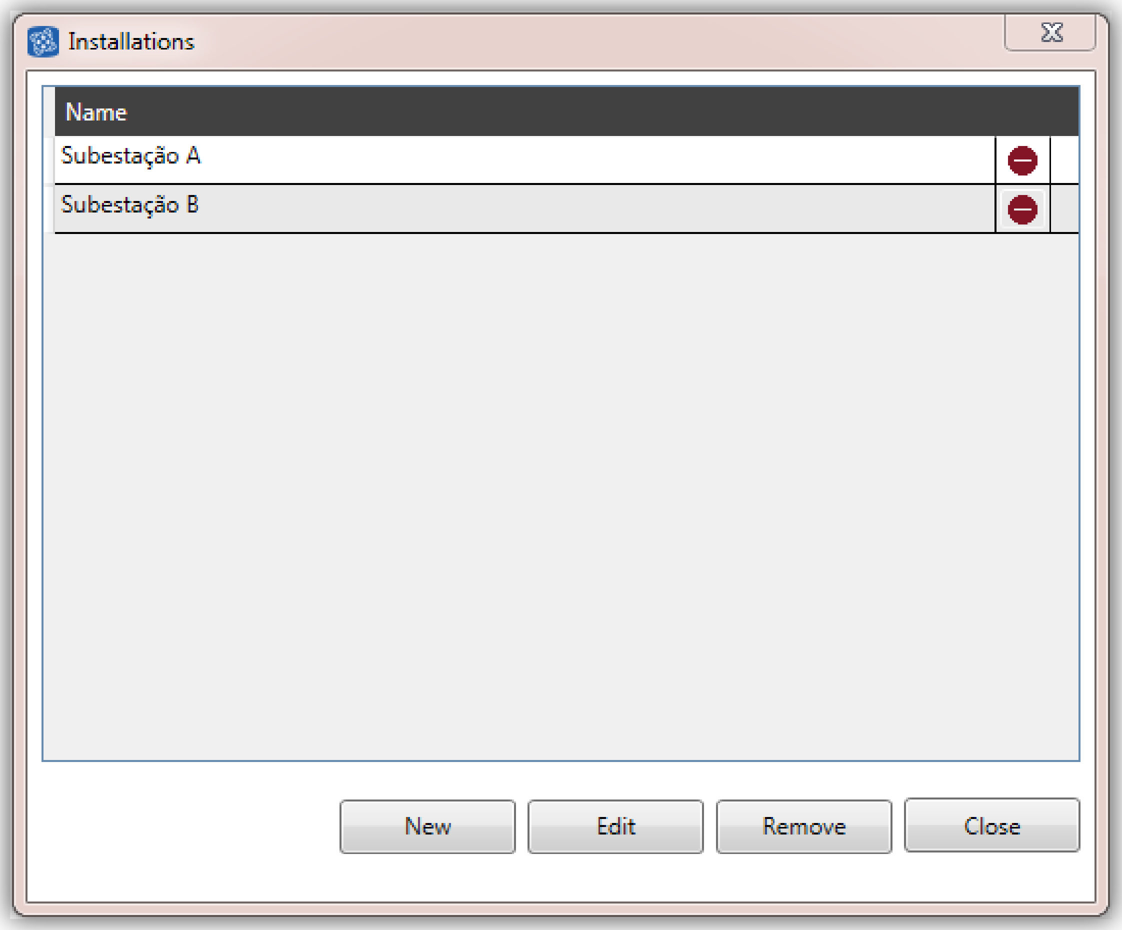
The RPV Manager is software developed specifically to work with the line of Reason's DFR, RPV311 model. The software integrates scanning tools and records management, log message display, goose configuration and fault location by traveling waves. The software is able to manage information collected from multiple devices distributed throughout the customer network. Communication is all done by TCP / IP protocol, so the computer where you installed the software needs to have connectivity to the monitored equipment. The connection to the equipment allows the software to scan all records of equipment, focusing on the local computer client. The software also uses the traveling wave records downloaded from the equipment for locating faults by the traveling wave method.

As the software manages information of various equipment installed in various places, it has a configuration method that makes the registration of lines in a structured way, you must first configure the data from substations, after the equipment and finally the monitored transmission lines.

In the screenshot below is observed the three steps of the process of setting up transmission line in the software, which will be described below.

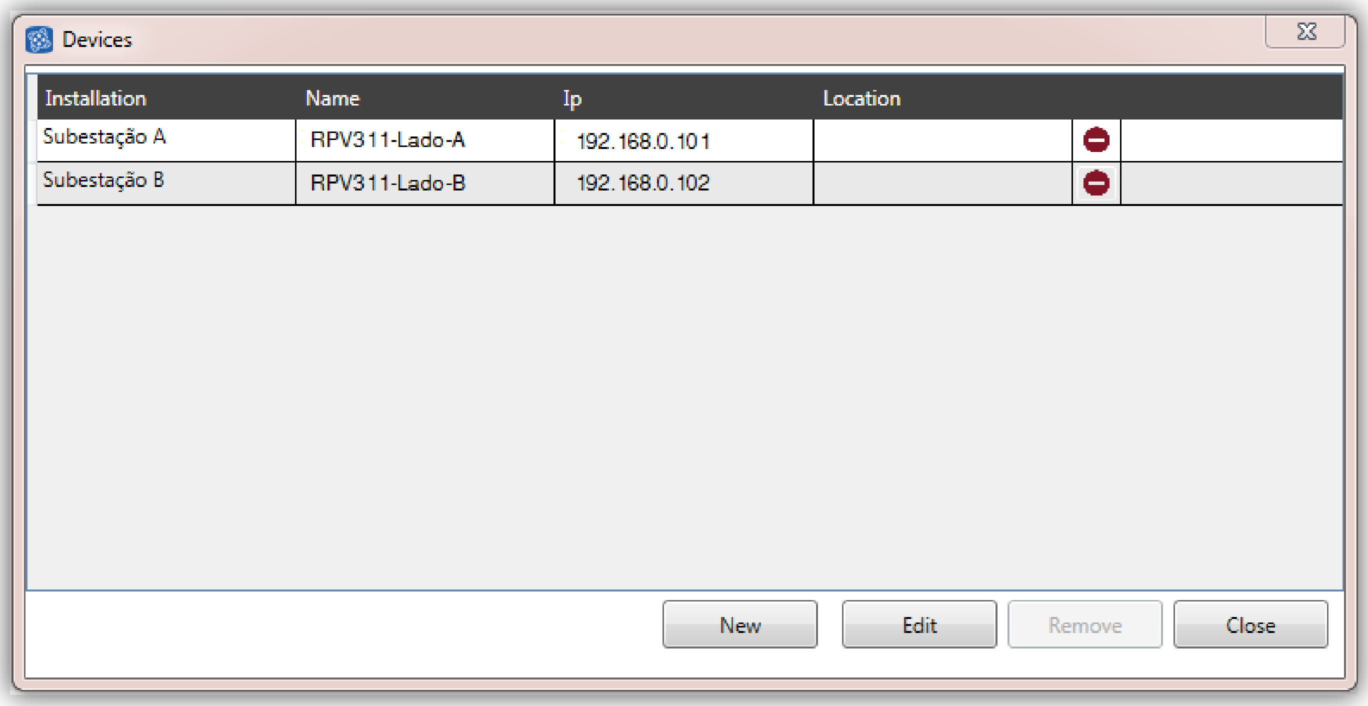
- ### *1º step – Installations*

It should be registered, the name of the substations on each side of the line.



- ### *2º step – Devices*

For each substation created in the previous step should be created and associated an equipment. It is possible that a substation there are multiple equipment installed, as several lines can be derived from it. For each equipment is necessary to inform the IP address because the software establishes communication with the equipment at the time of setting to get information related to identification of the equipment, such as name and location.



- ***3º step – Transmission Line***

Once created the substations and configurations of equipment installed in it, we have to associate the equipment according to the lines that they monitor. Reason TW system requires a set of equipment installed at each end. Thus when creating a transmission line is necessary to inform the substations that are on each side of the line and which equipment monitors this line. After that you must enter the number of sections, 1 for airline and 2 for mixed line.

Then must be informed of the line parameters, as follows:

- **Length (Km)** – Enter the line length in the overhead section (A = L1) and in the underground section (B = L2).
- **K** – Emnter the line K factor in the overhead section (A = K1) and in the underground section (B = K2).
- **Treshold** – Used as a reference to determine at what point of the traveling wave will be taking time. By default it should be at 0.5 and is used in the basic location method.
- **Terminal A** - Enter the name that was given to the line terminal A . This name should be identical to that set in the "Travelling Wave Recorder" in the device configuration web interface.

- **Current Circuit A** – Enter the name that was given to the line current circuit. This name should be identical to the name configured in the "Current Circuits" on the configuration web interface equipment.

- **Terminal B** - Enter the name that was given to the line terminal B. This name should be identical to that set in the "Travelling Wave Recorder" in the equipment configuration web interface.

- **Current Circuit B** – Enter the name that was given to the line current circuit. This name should be identical to the name configured in the "Current Circuits" on the configuration web interface equipment.

- **Line Name** – Enter the name that will be given to the line. This is the name that will be displayed to identify the line in the Fault Locator Tool in the RPV Manager interface.

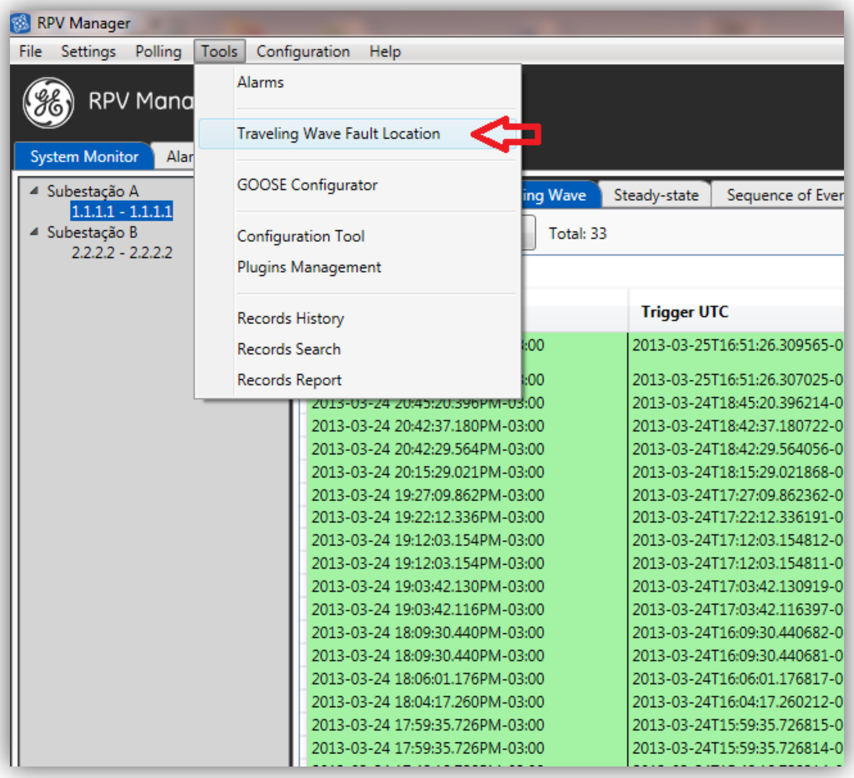
5.2. Fault location tool

The software uses the traveling wave records automatically downloaded from the equipment to make the location of faults by the traveling wave method. There are two fault location methods, advanced and basic, that depend on the type of records available for apply the location method.

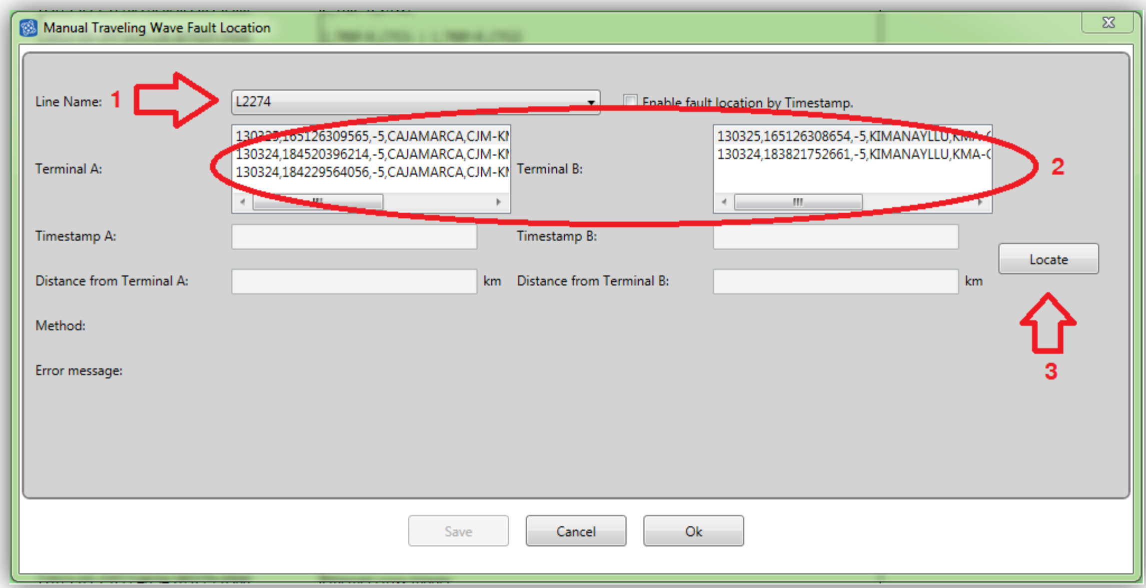
Basic Mode: Locates faults using only the traveling wave records. In this method, the time stamp on each considered traveling wave is the point where the signal level exceeds the threshold setting, usually set at 0.5 PU. This method is not very reliable when it has been traveling wave records from faults of high impedance faults, since these records have a very high noise level, which can cause the software to determine misrepresented the front wave time stamp.

Advanced Mode: In this mode is used, a signal processing algorithm that filters out high frequency signals which are not part of the traveling wave and allows the software to make a determination of the time stamp of reliably wavefront in any type fault. However it is needed the fault waveform records, with the line current signals at both terminals. Moreover, in the line setting process it is necessary to inform the current path name for each terminal.

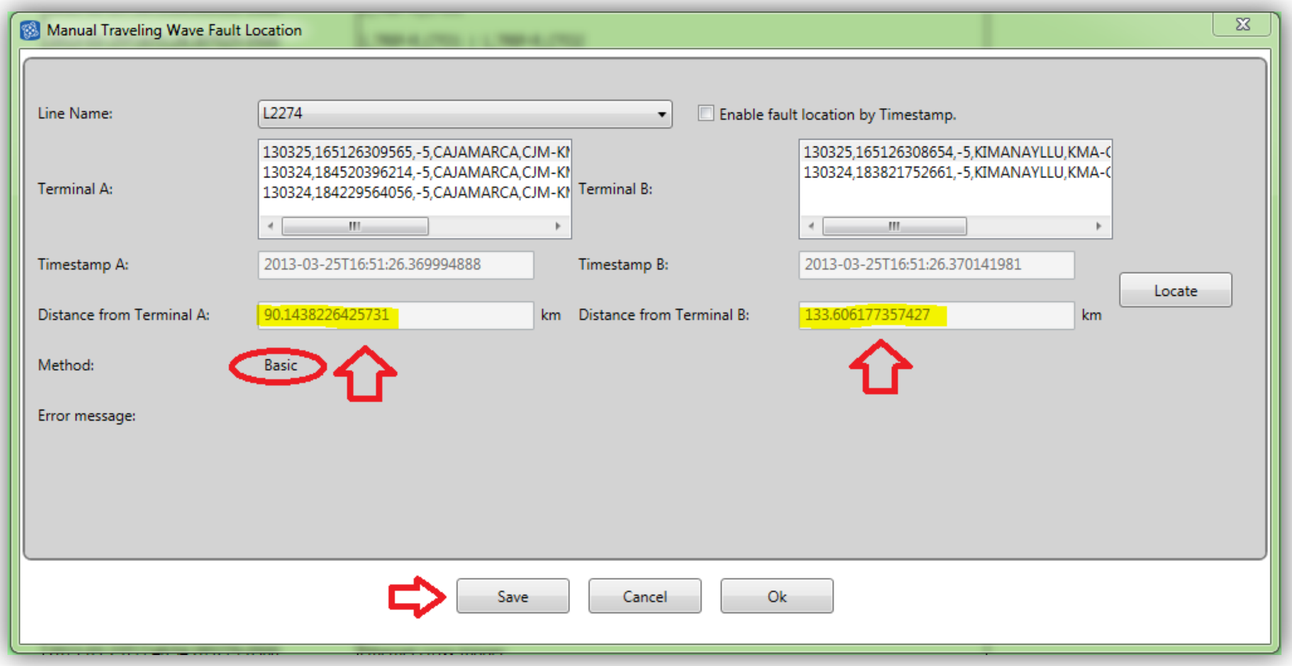
The fault location is done using the locator tool called “Travelling Wave Fault Locator”, found in the menu below:



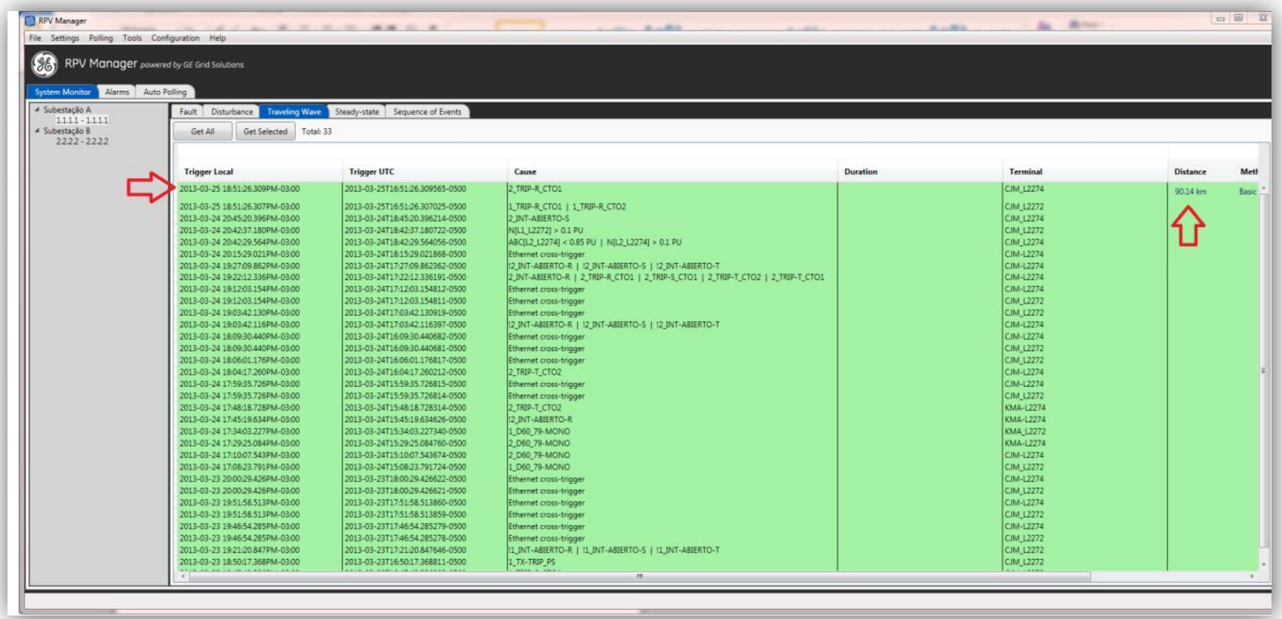
The localization tool will open the window below. You should select the line and then should be selected the tw fault records, in terminals A and B. After selecting the records the "Locate" button must be pressed.



After clicking the "Locate" the fault is located and is informed the distance in kilometers from the line terminals A and B.



After located the fault, you can save the result so that it is visible in the software interface, for that you must click the "Save" button.



GE
Grid Solutions

How to remove and import COMTRADE records in the Reason DR Manager software

VERSION CONTROL

Version	Author(s)	Department	Reason for change	Date
01	Ana Lúcia de Oliveira Tavares	R&D	Initial	05/19/2020
02	Leandro de Marchi Pintos / Ana Lúcia de Oliveira Tavares	GA&S / R&D	Review	05/21/2020

Content

1. INTRODUCTION

This application note presents how to remove and import Traveling Wave records in the Reason DR Manager 9.1.4 to fix messages in the logs as for example "*All fault locations related to Comtrade ID 4080should belong to the same Power Transmission Line*".

This error message appears to the records whose faults were located with the software version 09A00. In this old version, the software located faults with the wrong pair of TW records when more one line was configured per RPV311. This occurred because the software did not use the terminal identification to relate records. The version 9.1.4 fixed this issue ("*DR Manager locates faults in unrelated lines when a device monitors more than one line*").

Thus, when removing the records and importing them again in version 9.1.4, it will be possible to locate the fault again and thereby avoid this type messages in log files.

The fault location results are stored in Database. The "Remove" option will remove records from Database and from hard disk. Therefore, **it is necessary to make backup of ZIC files related to COMTRADEs saved in C:\RPV\records\XXX,YYY\tw to allow importing them after.**

The "Import" option is only necessary if the old records no longer exist in RPV311 and the user would like to keep the records in database. If the records are still in the RPV311, they will be downloaded in the next polling sequence.

2. REMOVAL OF RECORDS

The instructions to remove TW records are described below:

1. Open Reason DR Manager;
2. Make backup of data from “File -> Backup Data”. This is recommended for precautions;
3. Change polling to “Manual” on “Polling” Tab and disable the option “Start Auto Polling on Initiation” in Configuration -> Polling. **The software will ask to be restarted, then click Yes**;
4. Make backup of records (.zic files). This is essential if it was necessary import this records later;
5. In Tools -> Records Search, select a correspondent device and setting filters.

The following are the instructions for case “LSN-3081_TWFL-DR Manager – Bina” from backup “DRManager-Backup-20200508T181718.pg” sent to us on May 9th, 2020.

2.1. Removing records of DFR1_BINA

The following messages were extracted from the log file:

2020-05-19 10:42:14.1015 ERROR All fault locations related to Comtrade ID 7021should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 ERROR All fault locations related to Comtrade ID 7022should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 ERROR All fault locations related to Comtrade ID 7024should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 WARN All fault locations related to Comtrade ID 6798 should have the same Fault Location Algorithm
2020-05-19 10:42:14.1133 ERROR All fault locations related to Comtrade ID 4090should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 ERROR All fault locations related to Comtrade ID 4079should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 ERROR All fault locations related to Comtrade ID 4082should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 ERROR All fault locations related to Comtrade ID 4080should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 ERROR All fault locations related to Comtrade ID 4059should belong to the same Power Transmission Line
2020-05-19 10:42:14.1133 WARN All fault locations related to Comtrade ID 4017should have the same Fault Location Algorithm

The R&D team identified the record names on database through the Comtrade ID in the log messages. For example, the “ID 4017” refers to:

“190716,130146846949,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA1”

The following records must be removed:

1. 190716,130146846949,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA1
2. 190724,003810506951,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA1
3. 190724,131945646950,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA1
4. 190724,131945646950,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SEONI
5. 190724,131945646952,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA2
6. 190724,155112126947,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA1
7. 191212,211755597497,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA1
8. 191228,005304050858,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA2
9. 191228,005304050858,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SEONI
10. 191228,005304050859,+5h30,BINA_765KV,DFR1_BINA,POWERGRID,000000080000,tw,BINA_SATNA1

To do so, go to “Records Search” option in the “Tools” menu and:

1. Select “DFR1_BINA” device, set “Start Date and “End Date”, and select “Traveling Wave recorder” on Type field (as shown in Figure 1);
2. Select the correspondent records;
3. Click “Delete” button.

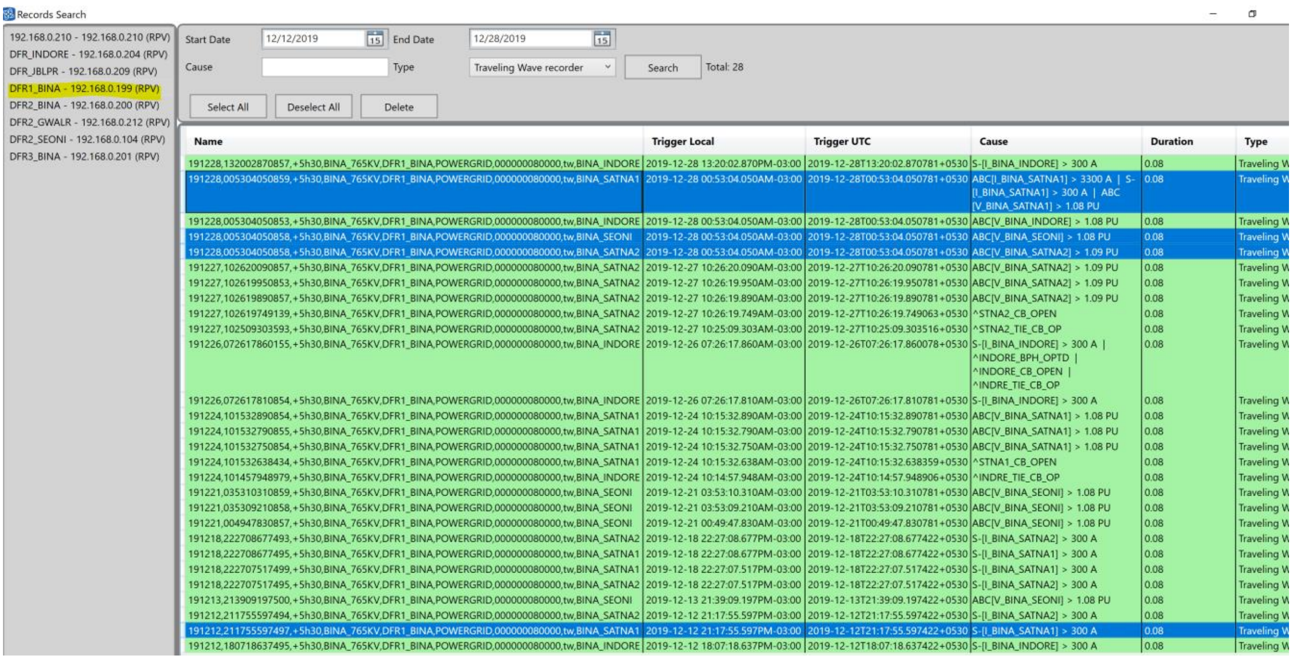


Figure 1 - Records Search window.

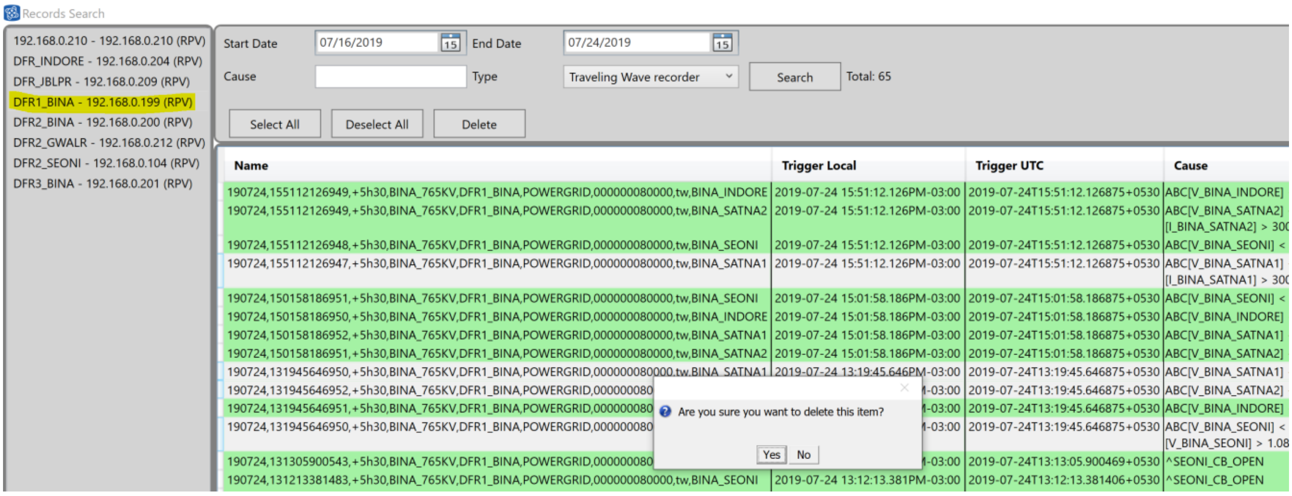


Figure 2 - Remove Records confirmation screen.

2.2. Removing records of DFR2_BINA

The following messages were extracted from the log file:

2020-05-19 10:50:30.1825 ERROR All fault locations related to Comtrade ID 6573should belong to the same Power Transmission Line

2020-05-19 10:50:30.1825 ERROR All fault locations related to Comtrade ID 6572should belong to the same Power Transmission Line

2020-05-19 10:50:30.1825 WARN All fault locations related to Comtrade ID 4290 should have the same Fault Location Algorithm

The following records must be removed through the Records Search option:

1. "190716,130146855859,+5h30,BINA_765KV,DFR2_BINA,POWERGRID,000000080000,tw,BINA_GWALR1"
2. "191128,175454075932,+5h30,BINA_765KV,DFR2_BINA,POWERGRID,000000080000,tw,BINA_GWALR1"
3. "191128,175454075937,+5h30,BINA_765KV,DFR2_BINA,POWERGRID,000000080000,tw,BINA_GWALR2"

2.3. Removing records of SATNA

The following messages were extracted from the log file:

2020-05-19 10:55:27.9258 ERROR All fault locations related to Comtrade ID 3946should belong to the same Power Transmission Line

2020-05-19 10:55:27.9258 ERROR All fault locations related to Comtrade ID 3947should belong to the same Power Transmission Line

2020-05-19 10:55:27.9258 ERROR All fault locations related to Comtrade ID 3944should belong to the same Power Transmission Line

2020-05-19 10:55:27.9296 ERROR All fault locations related to Comtrade ID 3945should belong to the same Power Transmission Line

The following records must be removed through the Records Search option:

1. "190716,130146843823,+5h30,SATNA_765KV,DFR1_SATNA,POWERGRID,000000080000,tw,SATNA_BINA2"
2. "190716,130146843822,+5h30,SATNA_765KV,DFR1_SATNA,POWERGRID,000000080000,tw,SATNA_SASAN2"
3. "190716,130146843825,+5h30,SATNA_765KV,DFR1_SATNA,POWERGRID,000000080000,tw,SATNA_BINA1"
4. "190716,130146843824,+5h30,SATNA_765KV,DFR1_SATNA,POWERGRID,000000080000,tw,SATNA_SASAN1"

3. IMPORTING RECORDS

The instructions to import COMTRADE records are described below:

1. Access "Import COMTRADE Records" from File menu:

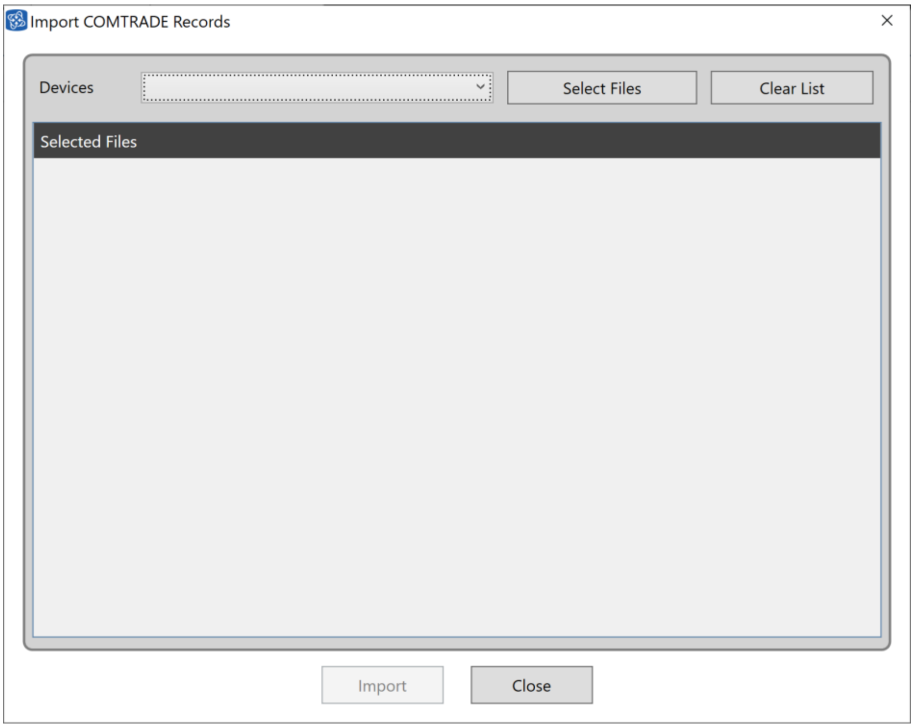


Figure 3 - Import COMTRADE Records

2. Select the Device;
3. Select TW files from hard disk:
    - The files will be saved in "C:\RPV\records\XXX,YYY\tw"
4. Click Import button.

4. REFRESH ALL DEVICES

After import all TW records, select “Refresh All Devices” from File menu to locate faults.

Finally, change polling to “Auto” on “Polling” menu and enable again the option “Start Auto Polling on Initiation” on Polling Configuration. **The software needs to be restarted.**

GE T&D India Limited

(Formerly Alstom T&D India Limited)

Grid Automation-Pallavaram Chennai

Typical Architecture for Kiosk S.S

PROJECT: POWERGRID- Travelling Wave Fault Locator (TWFL) Project.

CUSTOMER : POWER GRID CORPORATION OF INDIA LTD

PGCIL NOA REF: CC-CS/740-CC/ MISC-3335/3/G8

SALES ORDER NO.:3269046299

ENGG. REF. NO.: KXQ5

ENGINEER : SY

पावरग्रिड
श्रेणियां
I. फेब्रिकेशन/निर्माण/हेतु अनुमोदित/जारी।
II. फेब्रिकेशन/निर्माण/हेतु अनुमोदित/जारी। बशर्ते दी गई टिप्पणियों एवं आशोधनों को सम्मिलित किया जाए। कृपया आशोधिक दस्तावेज़ अनुमोदनार्थ प्रस्तुत करें।
III. टिप्पणियाँ सम्मिलित कर पुनः अनुमोदनार्थ प्रस्तुत करें।
IV. सूचनार्थ एवं रिकार्ड हेतु।
V. अनुमोदित नहीं।
(हस्ताक्षर)
Sr. Engr.
(पदनाम)
13/04/18
(तिथि)
पावरग्रिड कॉरपोरेशन ऑफ इंडिया लि.
ऐसेट मैनेजमेंट, गुड़गाँव, हरियाणा

अरिन्दम सेनशर्मा
ARINDAM SENSARMA
अपर महाप्रबन्धक (एसेट प्रबन्धन)
Addl. General Manager (Asset Management)
पावरग्रिड, के.का. / POWERGRID, CC

LIST OF DOCUMENTS SUBMITTED

S.NO.	DESCRIPTION	DRAWING NO.	ISSUE
1	Typical Architecture for Kiosk S.S	CPD KXQ5SA1	C-07.04.2018

पावरग्रिड
श्रेणियां
I. फेब्रिकेशन/निर्माण/हेतु अनुमोदित/जारी।
II. फेब्रिकेशन/निर्माण/हेतु अनुमोदित/जारी। बशर्ते दी गई टिप्पणियों एवं आशोधनों को सम्मिलित किया जाए। कृपया आशोधिक दस्तावेज अनुमोदनार्थ प्रस्तुत करें।
III. टिप्पणियाँ सम्मिलित कर पुनः अनुमोदनार्थ प्रस्तुत करें।
IV. सूचनार्थ एवं रिकार्ड हेतु।
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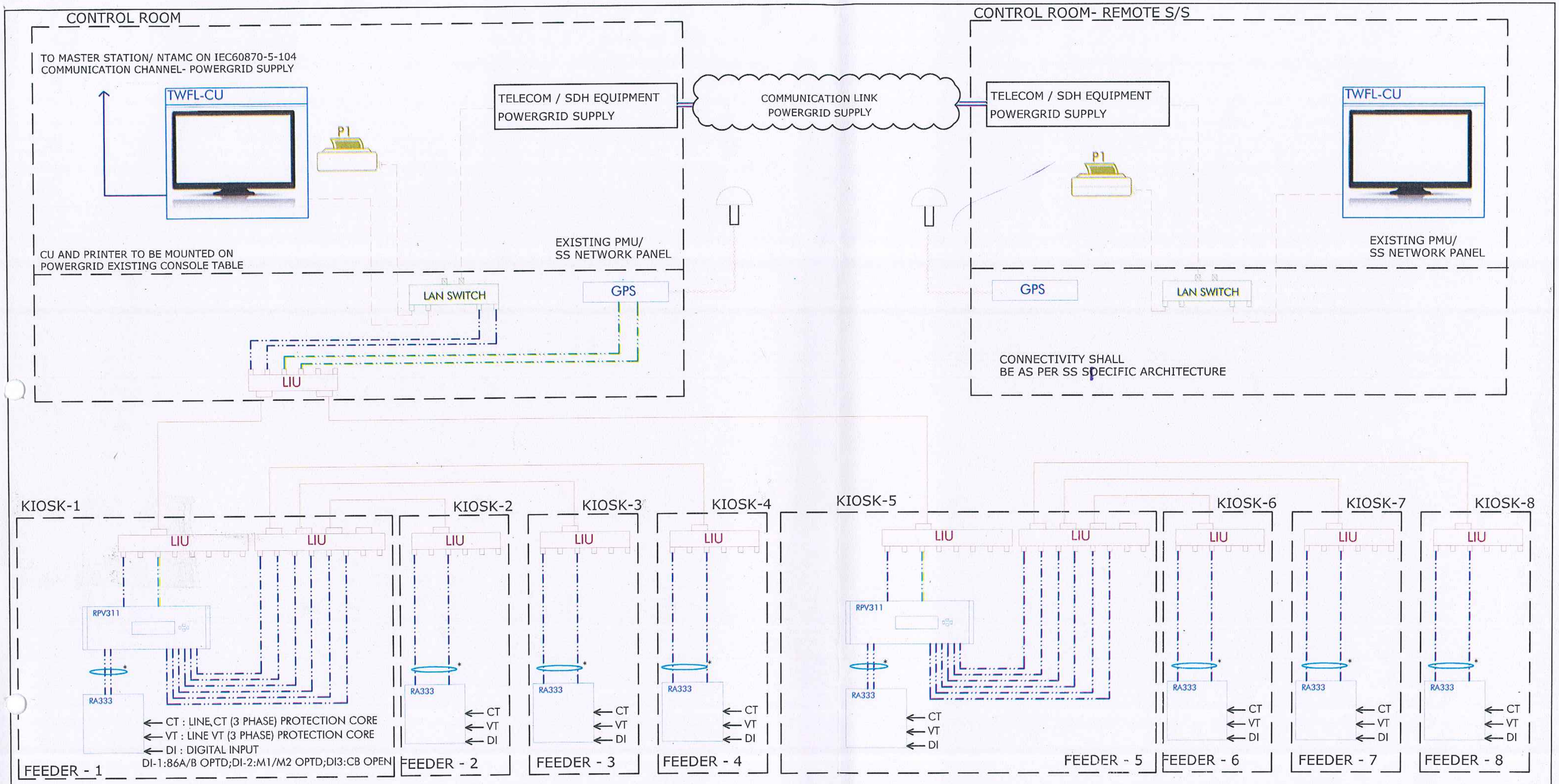
Addl. General Manager (Asset Management)
पावरग्रिड, के.का. / POWERGRID, CC



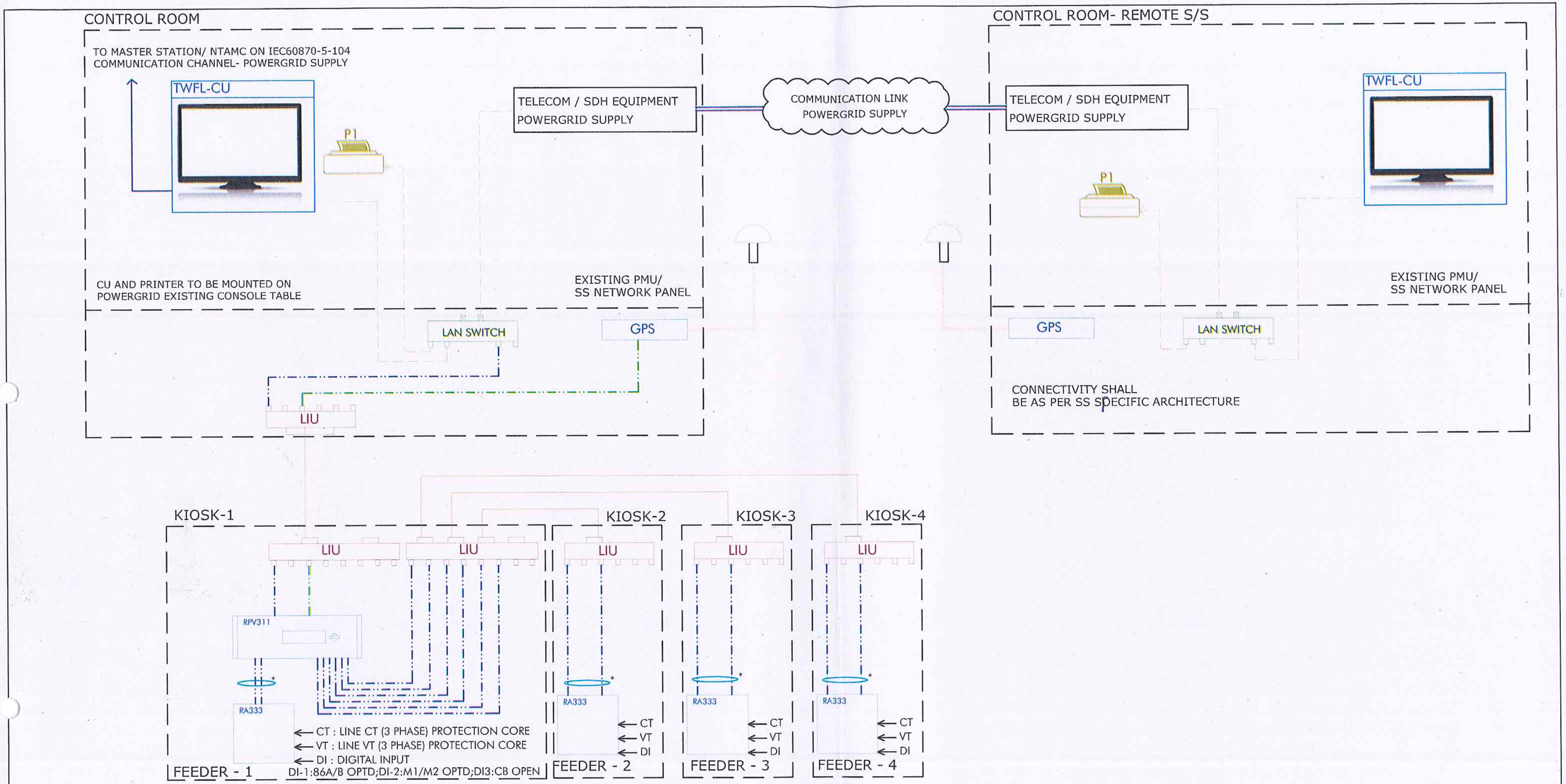
NOTE : RPV311,RA333 WILL BE MOUNTED IN EXISTING PMUPANEL AS PER SPACE AVAILABILITY.

NOTE * : RA333(BAY UNIT) OCCUPIES TWO PHYSICAL LINKS OF RPV311(ACQUISITION UNIT)
ONE FOR DATA TRANSMISSION OF ANALOG CHANNELS (DFR)
OTHER FOR DATA TRANSMISSION OF TW CHANNELS (TW)

LEGEND:-

FIBER OPTIC CABLE (ARMOURED)	:100 MBPS, MULTI MODE
ETHERNET PATCH CHORD - COPPER(CAT6)	:100 MBPS, MULTI MODE
ETHERNET PATCH CHORD - FIBER OPTIC(ST-ST)	:100 MBPS, MULTI MODE
COAXIAL CABLE (GPS LINK)	
ETHERNET PATCH CHORD FOR GPS - FIBER OPTIC(ST-ST)	:100 MBPS, MULTI MODE

FOR GE REF:	ENGG.REF.NO.: KXQ5	CUSTOMER: POWERGRID CORP. OF INDIA LTD	GE T&D India Ltd. (Formerly Alstom T&D India Ltd) Grid Automation-Pallavaram, India	PREPARED BY: SY / REVISION: C
SCHEME TYPE:		PROJECT: TWFL PACKAGE	SCHEMATIC DRAWING / FILE:	CHECKED BY: GSS / DATE: 07.04.2018
		P.O.NO.: -	TITLE: TYPICAL ARCHITECTURE FOR KIOSK S/S	APPROVED BY: SSS / SCALE: --
SALES ORDER: 3269046299		Dated -	QTY OF FDRS: 8 FDRS ALLOCATED IN 8 KIOSKS	DRG. NO.: CPD KXQ5SA1 SHT 01 OF 02



NOTE : RPV311,RA333 WILL BE MOUNTED IN EXISTING PMU PANEL AS PER SPACE AVAILABILITY.

NOTE * : RA333(BAY UNIT) OCCUPIES TWO PHYSICAL LINKS OF RPV311(ACQUISITION UNIT)
ONE FOR DATA TRANSMISSION OF ANALOG CHANNELS (DFR)
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श्रेणियां
I. फेब्रिकेशन/निर्माण/हेतु अनुमोदित/जारी।
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III. टिप्पणियाँ सम्मिलित कर पुनः अनुमोदनार्थ प्रस्तुत करें।
IV. सूचनार्थ एवं रिकार्ड हेतु।
V. अनुमोदित नहीं।

पावरग्रिड
(हस्ताक्षर)
Sr. Engr.
(पदनाम)
13/04/18
(तिथि)

पावरग्रिड कॉरपोरेशन ऑफ इंडिया लि.
ऐसेट मैनेजमेंट, गुड़गाँव, हरियाणा

LEGEND:-

FIBER OPTIC CABLE (ARMOURED)	:100 MBPS, MULTI MODE
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ETHERNET PATCH CHORD - FIBER OPTIC(ST-ST)	:100 MBPS, MULTI MODE
COAXIAL CABLE (GPS LINK)	
ETHERNET PATCH CHORD FOR GPS - FIBER OPTIC(ST-ST)	:100 MBPS, MULTI MODE

FOR GE REF:	ENGG.REF.NO.: KXQ5	CUSTOMER: POWERGRID CORP. OF INDIA LTD	GE T&D India Ltd.	SCHEMATIC DRAWING
SCHEME TYPE: .		PROJECT: TWFL PACKAGE	(Formerly Alstom T&D India Ltd.)	FILE: .
.		P.O.NO.: .	Grid Automation-Pallavaram, India	TYPE: TYPICAL ARCHITECTURE FOR KIOSK S/S
SALES ORDER: 3269046299		Dated .		QTY OF FDRS: 4 FDRS ALLOCATED IN 4 KIOSKS

PREPARED BY: SY	REVISION: C
CHECKED BY: GSS	DATE: 07.04.2018
APPROVED BY: SSS	SCALE: --
DRG. NO.: CPD KXQ5SA1	SHT 02 OF 02

अरिन्दम सेनशर्मा
ARINDAM SENSARMA
अपर महाप्रबंधक (परि. प्रबंधन)
Addl. General Manager (Asset Management)
पावरग्रिड, गु. /POWERGRID, GGN

Experience in application of Traveling Wave Fault Detection

Leandro de Marchi Pintos – GE Grid Solutions, Brazil
Carlos Pimentel – GE Grid Solutions, Brazil
Gilmar Krefta – K Consulting, Brazil

1 Introduction

The need to detect and locate faults in transmission lines quickly and accurately has grown significantly in power systems globally, especially in recent decades. Changes in the market model have caused transmission companies to change the way they manage and operate their assets since they are paid not by the transmitted power but by the availability of the line they operate [1]. Thus, protection and fault location systems based on new techniques that are faster and more accurate than the traditional ones, essentially based on phasors, have attracted the interest of several utilities to overcome accuracy limitations of traditional phasor-based approaches. Furthermore, the increasingly significant penetration of renewable generation in the system, whose responses to transients are different from conventional generation systems, have demanded protection systems with faster actuation times than conventional protection relays in order to prevent systemic collapses in large scale [2].

In this context, the use of traveling waves in fault detection both for fault location and protection functions has been studied for application in power transmission systems on a larger scale [3]. The use of fault location systems based on traveling waves, instead of phasors, has been studied for decades, and the first publications date from the 1930s [4]. Since then, several articles and theses have been published, where different types of traveling wave fault locators were classified according to their method of application, and protection systems using this technique were presented.

With the evolution of equipment for protection and control, mainly in the 80s, the first equipment that used the concepts of traveling waves for selectivity and protection began to appear on the market in static relays where the actuation times became less than 5 ms, reaching 2 ms, something by that time impossible using conventional techniques. Furthermore, in the same decade the first traveling wave fault locators appeared, where accuracies in fault locations of hundreds of meters were achieved without significant influence of the length of the transmission lines or electrical parameters, such as reactive compensation [3].

From this study could be seen that is even more remarkable the interest of power system engineers in the application of systems that guarantee more accurate fault location, compared to conventional techniques [1], as well as in protection systems with faster operating times than conventional systems, normally aiming to minimize transient stability problems in the protected electrical system [5].

2 Traveling Wave in Power Systems

The traveling wave phenomena (*TW – Traveling Waves*) on power transmission lines arise from a number of causes, of which the most common are faults, switching operations and lightnings, and the propagation speed of current and voltage waves in overhead power lines is in general close to the speed of light [6]. These traveling waves are typically composed of a wavefront usually with a short rising time and a long falling time [1].

The use of traveling wave detection techniques, mainly for fault location, has been cited in the literature since 1931 [4] and became popular in the following decade after Bewley proposed a graphic method to determine the reflection time instants of the traveling waves, known as Bewley-Lattice diagram [7]. That method allowed a relatively simple analysis of the traveling wave behavior in time and space mainly for fault location where the time is represented vertically and distance horizontally. Figure 1 shows a typical Bewley diagram for a transmission line with the reflections and refractions caused by the traveling waves when a fault is present on a power system.

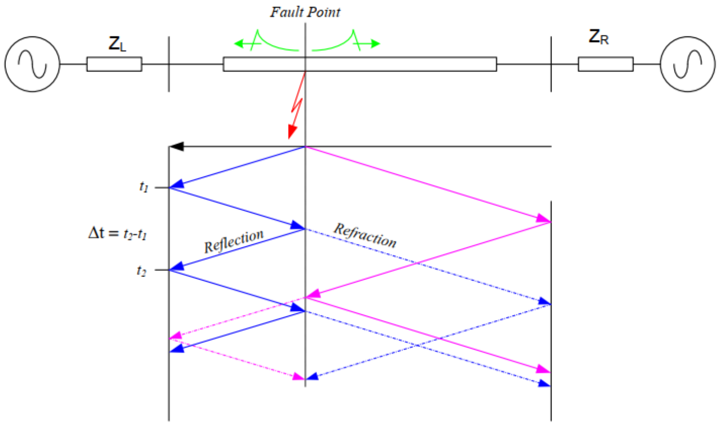

Figure 1 – Bewley-Lattice diagram [6].

Later, in 1951, Lewis classified the traveling wave detection equipment based on its mode of operation as A, B, C and D [8]. Currently, in addition to the methods defined by Lewis, the E method is also used [6].

The fault detection and location methods basically differ in two points: the first is if they have measurement in only one of the substations of the monitored line or in both substations, and the second is if they are passive detectors that are based on the generated traveling waves by the event or have pulse generators for signal injection. Thus, type A is a passive single ended terminal detector, type B is an active single ended detector, type C is an active double ended, and type D is a passive double ended detector [4]. Finally, there is the E method which consists of a single ended detector that is based on the signals generated when a line is re-energized and is used essentially for permanent fault detection [6].

Although studies date back to the 30s, 40s and 50s, applications in protections systems based on traveling waves started only in the late 1970s [9], and since the 2000s there have been several studies to develop and improve the traveling wave detection criteria for protection functions such as distance, directional, differential and for HVDC lines [10]. It is noted in this context that, even though the technique had already been available in protection relays since the late 1970s, there are a very low adoption of this technology in transmission lines in the electrical system that uses traveling wave for protection purposes, and mostly conventional protection relays are applied for this purpose. Traveling wave applications in power systems are mostly related to fault location.

Practical applications of traveling wave fault location, on the other hand, gained strength mainly after the development of synchronized clock technology via GPS (*Global Positioning System*) became available for civil use, as it allowed the TW system to have a unique time base used by the equipment that is generally installed at both ends of the transmission line, that is, far from each other. For double ended fault location methods it is necessary to use the GPS system so that the Traveling Wave records at both ends of the line are synchronized [11].

A more recent study presented in [4] compared different types of traveling wave fault locations applicable in power systems, including GPS based location. Recent studies over the last decade comparing single and double ended impedance fault location methods with traveling wave methods show that errors for a nearly 200 km line can be on the order of kilometers for impedance-based methods and hundreds of meters for methods based on traveling waves [12].

To guide engineers and technicians in the selection of how to perform fault location, the IEEE published the *C37.114 IEEE Guide for Determining Fault Location on AC Transmission and Distribution Lines* [6] where several ways to perform the fault location are compared, in which are also listed the advantages and ways of implementation in transmission lines. Finally, the ways to perform the fault location by measuring current or voltage are compared, where it is concluded that, although the initial analysis indicated that the current should be preferred, in practice both ways are applied in fault location and showing good results.

Field experience shows that the accuracy in both methods is similar, making the decision up to manufacturers on how the traveling wave signal is measured in their equipment. To illustrate this relationship, as well as to illustrate the typical behavior of TW signals captured in voltage or current is like, Figures 2 and 3 show an example of a traveling wave signal used for fault location, where Figure 2 shows the signal measured by the secondary voltage of a 500 kV CVT and Figure 3 shows the secondary current measured by the line CT for the same fault.

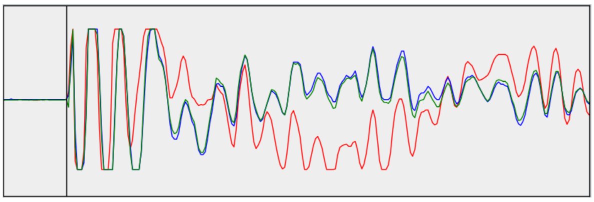

Figure 2 – TW Voltage signal measured during a fault in a 500kV system.

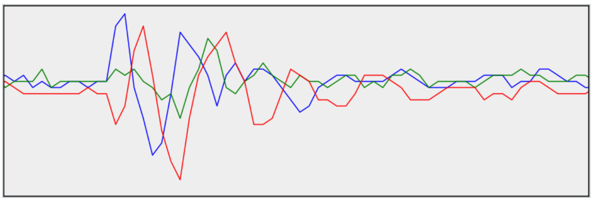

Figure 3 – TW Current signal measured during a fault in a 500kV system.

3 Considerations in the use of Traveling Wave for Power Systems application

Given the intrinsic characteristics of fault location by traveling waves, the assertiveness of its application is established when it provides better fault location accuracy in relation to conventional impedance methods. For short alternating current lines (up to 80 km), for long lines (greater than 240 km), as well as for applications in mixed lines and HVDC lines, the results obtained over time show that its applicability is positive in terms of accurate fault location.

Added to this benefit is the fact that the observed accuracy has little or no relationship with the length of the line, power flow, series compensation or usage of reactors in the busbar or the transmission line. It is noted, on the other hand, that the complexity of determining the fault location when there are elements of compensation, medium or high impedance faults, as well as faults related to lightnings, is greater compared to low impedance faults or faults in uncompensated lines.

In order to locate a fault with the traveling wave method, it is necessary that the system accurately captures the desired signals. Single ended locators must be able to distinguish the wavefronts and reflections from the signals of interest, as well as Double ended locators must distinguish wavefronts when a fault occurs. Traveling wave signals have different characteristics depending on the type and impedance of the fault and are captured differently in HVAC and HVDC systems.

The behavior of traveling wave signals, in general, summarizes the result of the location system: a fault location system is perceived as accurate when, in front of different fault scenarios, it remains accurate in the location within the expected range by the technology, of a few hundred meters, even in situations where the wavefront is low or barely perceptible against the captured noise. High impedance faults, faults with slow wavefront rise, faults caused by lightning or transmission lines in circuits with radial characteristics are examples of situations in which locators can suffer a negative influence on fault location.

However, it is noted that even the fault location accuracy, once the wavefront is accurately determined, is not significantly impacted by factors such as fault impedance or line compensation, the difficulty in determining the wavefront is greater in these situations when compared with the location of low impedance faults. Thus, the accuracy in fault location, whether performed manually or by automatic algorithms, is generally negatively impacted mainly by the impedance of the fault if the operator has not been properly trained or the algorithm used by the fault locator software does not have the necessary robustness for field applications.

To illustrate these differences, the following figures show several TW records captured by traveling wave fault locator recorders for lines with voltages above 220 kV and whose signals are measured by secondary voltage of inductive voltage transformers (IVT) and capacitive voltage transformers (CVT).

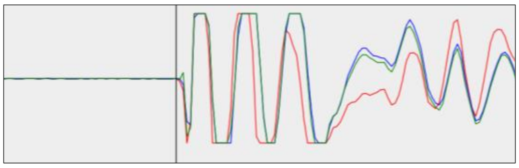

Figure 4 – Example of TW signal measured by a CVT for low impedance fault.

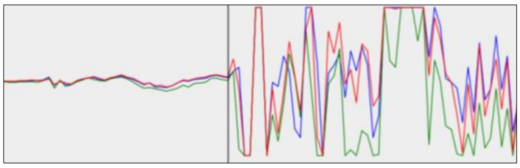

Figure 5 – Example of TW signal measured by a CVT for low impedance fault in a compensated line.

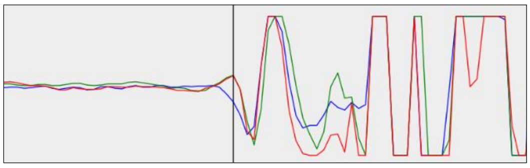

Figure 6 – Example of TW signal measured by a IVT for low impedance fault.

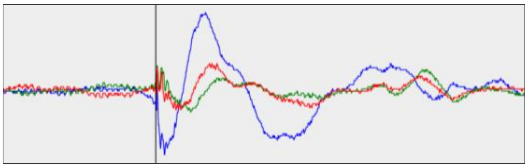

Figure 7 – Example of TW signal measured by a CVT for medium impedance fault.

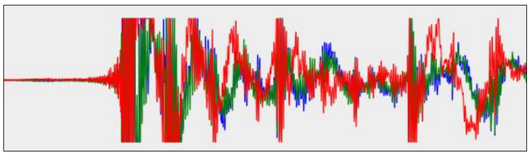

Figure 8 – Example of TW signal measured by a CVT for a lightning strike in a line with reactors.

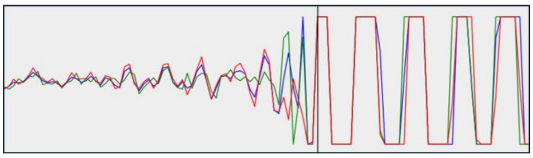

Figure 9 – Wavefront detail of Figure 8.

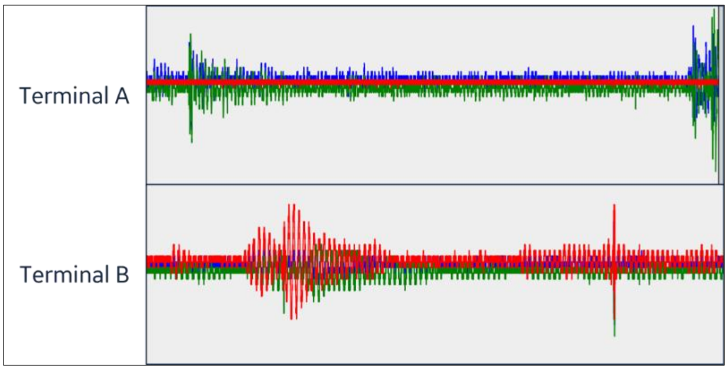

Figure 10 – Traveling wave signals in both terminals of a radial transmission line during a fault, measured by an IVT.

For faults with high or very high impedance, as in cases involving faults with trees, the level of the signal to be captured from the wavefront, in general, is superimposed by noise related to the fault, but the noise is not interesting to the fault locator. In these situations, the locator must be able to distinguish the signals of interest from the measured noises. Figure 11 shows a typical example of a high impedance fault with the details of the correct point to be used by the fault locator and the time reference range of the record in the different time scales used.

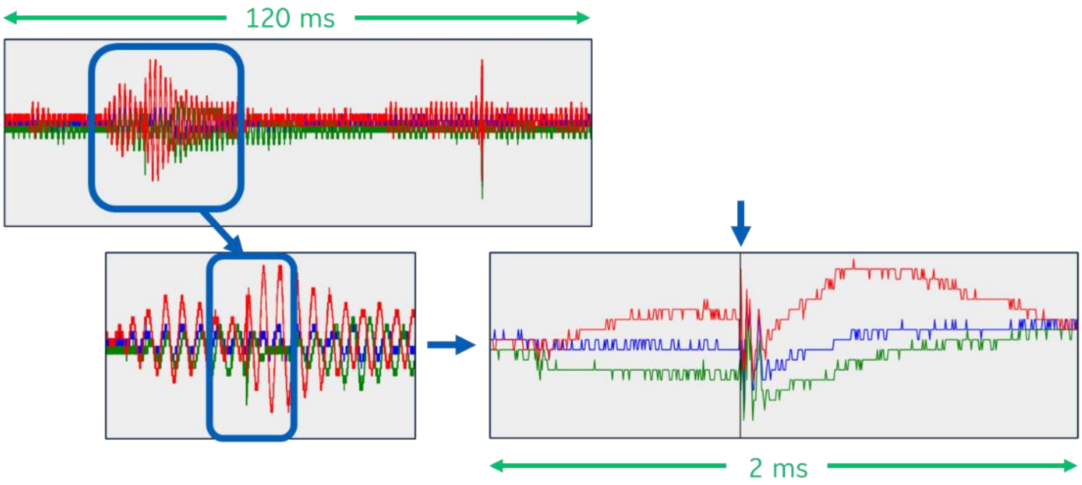

Figure 11 – Example of the determination of wavefront for a high impedance fault.

Mainly in cases of high impedance faults, the traveling wave record shows that, although the wavefront behavior is visually perceptible, the same cannot be said to the automatic fault location algorithms since the magnitude, the duration and the behavior of the traveling waves is not easily modeled in these situations. While it is possible to evaluate only the traveling wave record in these cases, in general these situations require additional tools from the operator or algorithm in order to determine a time zone smaller than the record as a whole, a tool that works as a guide to perform a more in-depth filtering in a smaller time interval.

One possibility in this case is the use of the records triggered by a Fault Recorder synchronized in the same time base as the fault locator, where the oscillography record is used as an additional tool to evaluate the time instant when the fault occurs, then the traveling wave record is used with the same time base. Figure 12 shows, as example, the use of this technique to define the time range – three-phase voltage signals at the top, three-phase current signals at the middle and traveling wave signals at the bottom.

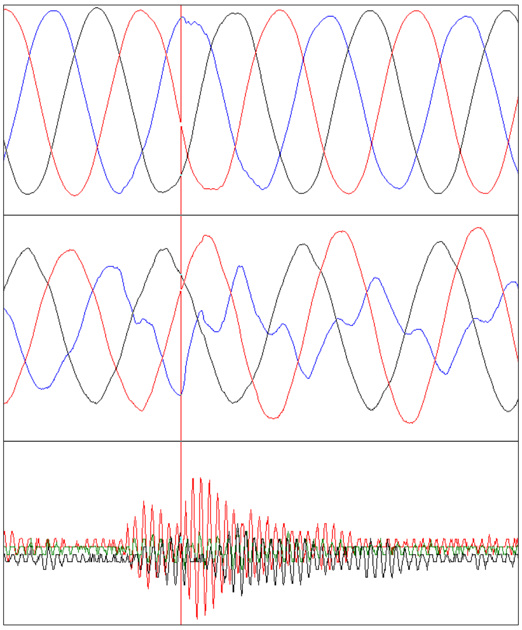

Figure 12 – Fault and Traveling Wave records combination to wavefront peak determination.

4 Traveling Wave Fault Location examples with confirmed location

Currently, there are several applications of global scope using traveling waves and the vast majority are related to fault location. Despite having a clear improvement in the accuracy of fault location with the traveling wave technique, it is generally perceived that its use globally is more widespread or is more consolidated in electrical systems and countries that have a significant number of long transmission lines, mainly due to the fact that the relative error on short lines can, in general, result in absolute errors with values acceptable to local utilities.

Numerous applications have been established around the world with the traveling wave fault location tool and some are brought here for this article in order to show its applicability for different voltage levels and types of faults.

Table 1 shows some results from locations in different regions with low and high impedance faults, different operating voltage levels and line lengths, as well as compensated lines up to 765 kV. Additionally, the estimated fault locations by the traveling wave fault locator, the actual fault location determined by line inspection and the calculated error in relation to the line length are shown too.

Table 1 – Examples of results of Traveling Wave Fault locations compared to real fault location according to maintenance personnel team.

System Voltage	Date (mm/aa)	L (km)	Confirmed Location (km)	Calculated Location (km)	Error (km)	Relative error based on line length (%)
765 kV	04/20	231.40	32.436	32.390	0.046	0.020
765 kV	06/20	231.40	40.365	40.240	0.125	0.054
765 kV	07/20	240.00	239.100	239.010	0.090	0.038
765 kV	07/20	240.00	239.100	239.140	0.040	0.017
765 kV	08/19	361.00	0.000	0.000	0.000	0.000
765 kV	07/19	342.00	270.000	270.068	0.068	0.020
765 kV	08/20	240.00	238.700	238.760	0.060	0.025
765 kV	04/21	334.46	0.300	0.300	0.000	0.000
500 kV	05/08	248.28	206.000	206.220	0.220	0.089
500 kV	04/08	248.28	206.000	206.150	0.150	0.060
400 kV	04/21	216.00	47.750	47.180	0.570	0.264
400 kV	05/17	262.41	1.902	1.920	0.018	0.000
230 kV	20/09	325.73	122.430	122.560	0.130	0.040
230 kV	27/09	325.73	325.680	325.690	0.010	0.003
230 kV	10/09	325.73	99.510	99.550	0.040	0.012
230 kV	22/09	325.73	194.620	194.650	0.030	0.009
230 kV	09/09	325.73	156.960	156.990	0.030	0.009
230 kV	09/18	64.72	48.000	46.260	1.740	2.689
230 kV	06/21	140.59	40.000	39.920	0.080	0.057
220 kV	08/15	16.40	14.960	14.959	0.001	0.000
220 kV	08/15	16.40	13.098	13.160	0.062	0.378

Fault location results are based on 765 kV and 400 kV transmission lines in India, 220 kV from Spain, 230 kV in Mexico and 230 kV and 500 kV in Brazil, using some of the results from lines in Brazil that are shown in [3]. Most of the events are single-phase-to-ground faults, where about 3 to 4 cycles later there is a single-pole breaker opening operation. One second later, an Automatic Reclose attempt is made by sending the circuit breaker closing command for the faulted phase. In cases of temporary faults, a single breaker opening is sufficient to eliminate the disturbance. For cases of persistent faults, the line is opened again after an Automatic Reclose attempt. For faults where the Automatic Reclose attempt was not successful, the protection system performs the three-phase opening of the transmission line circuit breakers.

The TW fault location is performed with the records of the first TW event, which is the Trip event. The use of the Trip event records ensures greater reliability in the fault location compared to the reclose or three-phase opening records, as the wavefront peaks are better defined, and it eases the positioning of the timestamp reference for fault location calculation.

Regarding the results shown in the table, it can be seen that the system has an accuracy with relative errors below 0.5% for the majority of cases. It is noteworthy that this precision is achieved with the refinement of the parameters involved in the location of faults by traveling waves, notably the line length (*L*) and the wave propagation speed, in general related to the attenuation factor *k* that indicates the percentage of the speed of light at which the wave travels on the line.

To provide the accuracy shown in the fault location examples, notably applicable to the Double-ended method with synchronized measurements, it is necessary to carry out a previous calibration of the transmission line parameters. These factors are usually refined during commissioning or through regression methods after the first events. These events make possible to calculate the wave propagation coefficient on the transmission line (k factor) and the real line length of the line. Given the unavailability of the traveling wave parameters commissioning, the fault location system must use real fault data to ensure greater accuracy. If the system is not calibrated and standard parameters are used, the fault location error is generally within 1 km for every 100 km of line length. The confirmation of the location of faults is carried out through the field maintenance team that travels along the lines and certifies the result of fault locations.

The fault in Table 1 where there is an error greater than 1% in relation to the size of the line, refers to a high impedance event where the wavefronts do not have a discontinuity as clear as a low impedance fault, thus being more difficult to determine the time instant of the wavefront accurately. Despite the error from the actual fault location, the calculated location provides comparatively a better estimate of the region where the fault may have occurred compared to impedance-based location.

Figure 13 and Figure 14 show the Waveform and the Traveling Wave records for both transmission line ends for the second fault shown in Table 1, a typical fault for the 765kV line. This event occurred in June 2020 and it was a low impedance fault on phase A. The single-pole circuit breaker of phase A received the opening command and, around 3,3 cycles after the fault, the phase A is deenergized. The uppermost part of the graph show the three-phase currents, the middle of graph shows the three-phase voltages and in the bottom part are the high frequency TW signals.

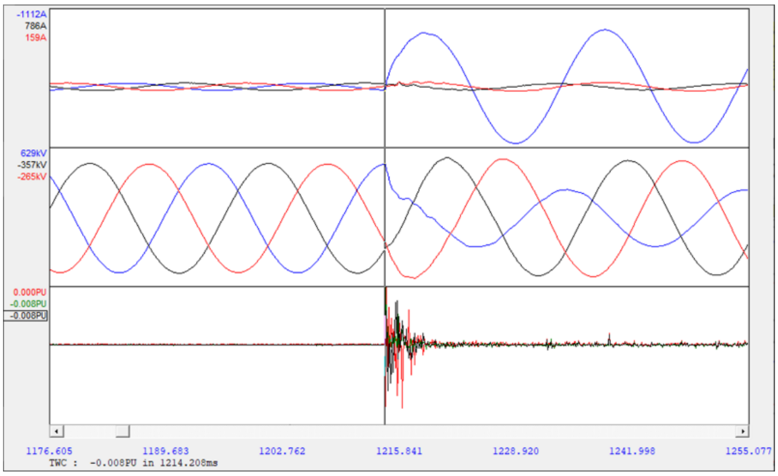

Figure 13 – Waveform record and TW record for terminal A.

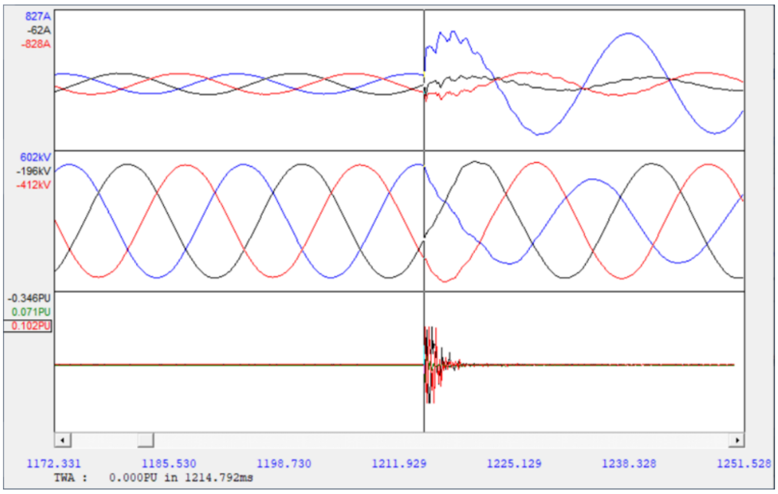

Figure 14 – Waveform record and TW record for terminal B.

It is possible to notice for the fault that, due to its low impedance characteristic, the current waveform quickly goes high, and the voltage waveform suffers an abrupt drop. The intensity of the TW wavefront for low impedance faults (bottom of the figures) is clear enough to identify the timestamps to be used to locate faults.

Another aspect to be analyzed is the way in which the accuracy of fault location methods by TW is compared. For example, the absolute fault error is based on the absolute difference between the actual location and the software-calculated location. When the line length is taken into account for the error calculation, the percentage error in relation to the actual fault location is drastically reduced [6].

It is always important to have confirmation of the actual fault location by field personnel to feed back the system and ensure better accuracy of the TW fault location method for future events. The more data with confirmed real location, the more the method becomes adherent to the real model of the line and, thus, offers better accuracy in the locations. It should be noted that an accuracy of ±150 meters with respect to the actual fault location is generally considered good enough to accurately alert field personnel to repair.

Another point is the certainty of how the field personnel confirmed the actual location of the fault. When the short circuit is close to the substation or is in easily accessible areas, for example, the location confirmed by the maintenance team occurs faster and more accurately (up to meters), but when it comes to more remote parts or in places with difficult access, this confirmed location is sometimes estimated and has errors of up to hundreds of meters. However, this error becomes tolerable once the distance between towers on average is sufficiently accurate for the line inspection team, and this distance is usually greater than 400 m.

In other cases, when there is no real confirmation of the fault location provided by the line maintenance team, the fault location compared to the traveling wave system, as a way of consolidating the result, is usually given by single or double ended impedance methods. However, attention should be paid to these cases because the actual location of the fault confirmed in this way inherently has the imprecision of the impedance methods [13], [14], and this should not be a method to calibrate the locator by traveling waves. The fault impedance, fault distance to the measurement terminals and the type of modeling implemented in the equipment can negatively affect the result provided by the impedance location method, therefore, negatively affecting the performance of the TW fault location system when the actual fault location is provided by impedance methods.

Fault location using TW methodology is based both on software and user experience when the fault location software have manual location mode. Each fault event has a unique characteristic in the behavior of TW wavefronts. A solid short-circuit, for example, will result in a much more defined TW wavefront than a high impedance fault. It is in this aspect that the user experience comes in to identify cases where greater attention is required to define the best timestamp points within the TW record, as well as cases in which the field team should consider a bigger inspection range. The analyst's ability, in these more complex cases, is a vital part of determining the most appropriate timestamps for location and consequently ensuring better accuracy.

There are tools that perform traveling wave fault location automatically based on fault records of the fundamental frequency (50/60 Hz) and high frequency components (traveling wave records), once they are available. These tools save the user time by performing automatic location based on a pair of TW records and a pair of Waveform records at each end of the transmission line. For more complex cases where location does not occur automatically due to the fault characteristic, an analyst must be assigned for analysis. On the other hand, it is recommended in systems that have manual tools that the analyst performs a critical analysis of the automatic location, thus ensuring that the inspection team is directed to the correct location of the failure and is already aware of the possibility of the inspection range being greater or smaller, depending on the analyst's difficulty in locating it.

5 Conclusion

The article, in addition to presenting a brief review and history of fault detection by traveling waves, showed considerations, experience and practical examples accumulated in the last 13 years of the use of this technique in fault location, having applications in several transmission companies in Brazil and several countries in the world, mainly in Latin America, Europe and Asia. With this history of application in different parts of the world, quite diverse, it is possible to have a relevant history of the behavior of traveling waves in different types of faults, in different electrical systems and at different voltage levels.

Some practical examples of traveling waves records in different types of faults were shown, where it is explored how the protection engineer can obtain important information through these records to determine the precise location of a fault and, depending on the situation, the expected assertiveness for the location including in situations with fault location performed automatically by location algorithms. In these examples it was possible to observe the variability of the behavior of the traveling wave signals, which is a relevant topic to be considered and analyzed when applying technologies in the field, especially when applying automatic algorithms to detect these signals.

Practical examples of the technology in operation show that, for different types of faults, high or low impedance, line lengths of hundreds of kilometers, with or without reactive compensation, etc., the accuracy of the locations can range from hundreds to tens of meters – this being the result often obtained by the traveling wave fault location system. This is verified even in situations of automatic location, which is limited to factors that are normally under the control of the utilities, such as the correct selection of the signal to trigger the locators, correct calibration of the equipment, as well as the analyst's capacity in more complex cases to understand the traveling wave signals through the records to determine the most appropriate timestamp for the fault location.

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Discussion on TWFL

Limitations of Conventional Methods of Fault Location

Affected by Line Parameters

Effect of In-Feed/ Out-Feed and Mutual Compensation of Parallel Lines.

Accuracy of fault location in the range of kilometers.

Long outage durations and restoration time.

Accuracy affected by Series compensation and network complexity

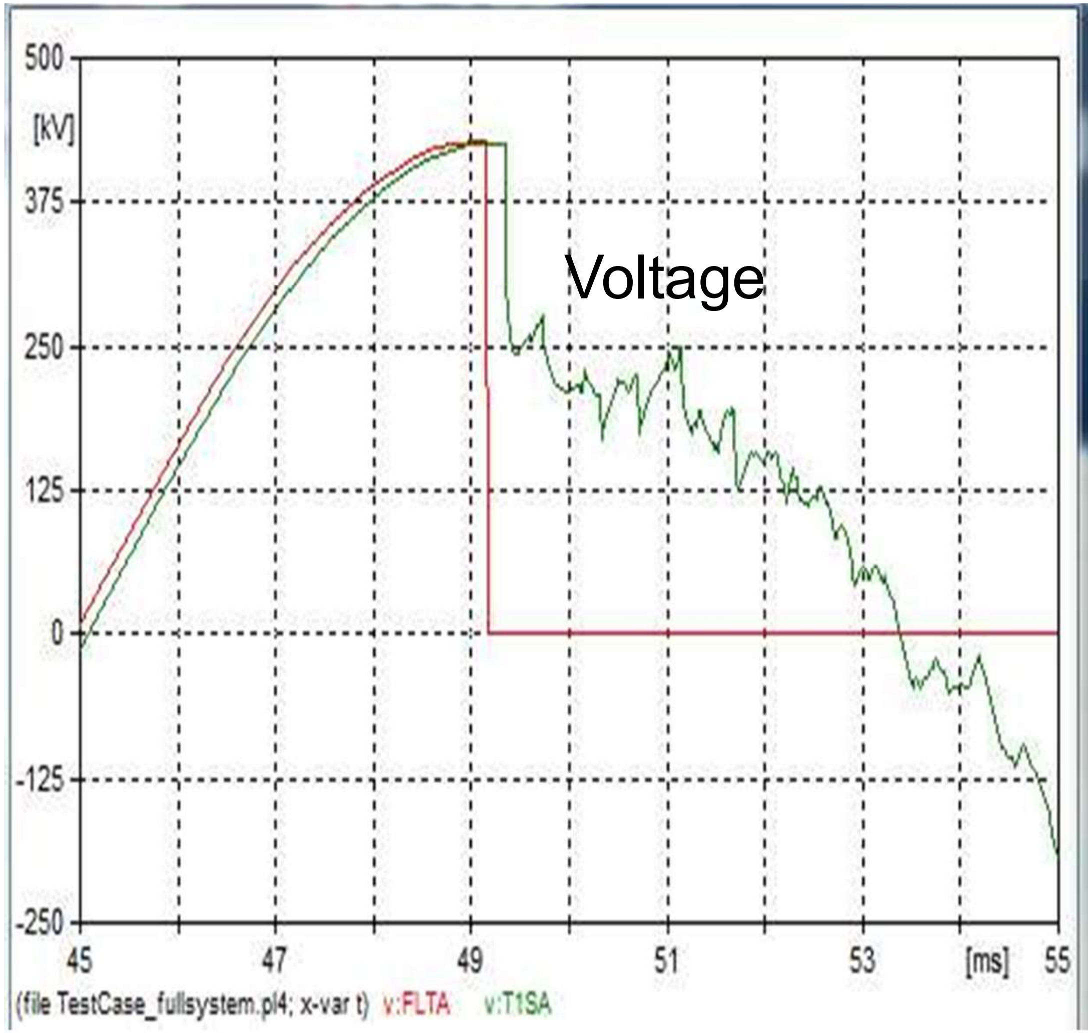
Significant effect of Fault Resistance on the accuracy of this method

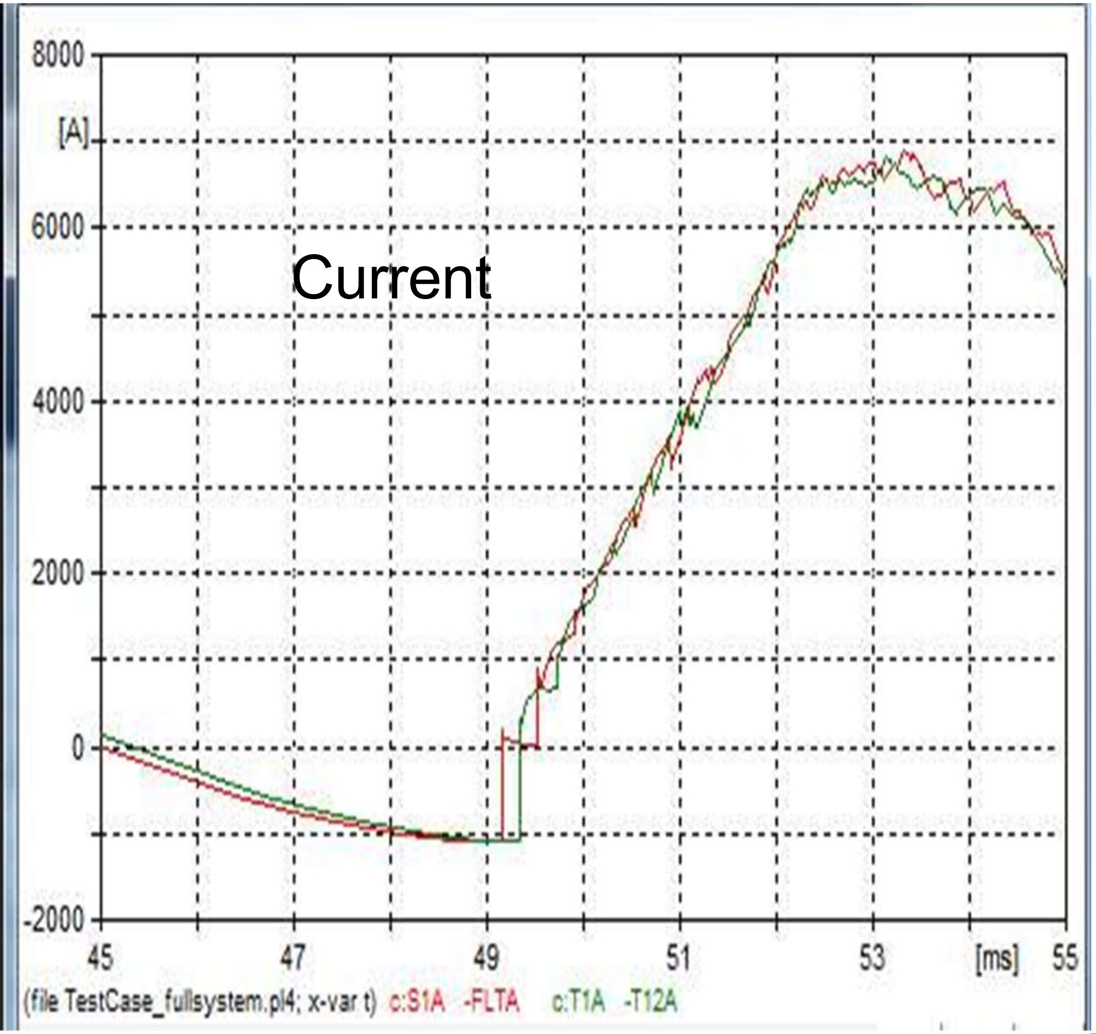
TWFL Working Principle

पावरग्रिड POWERGRID

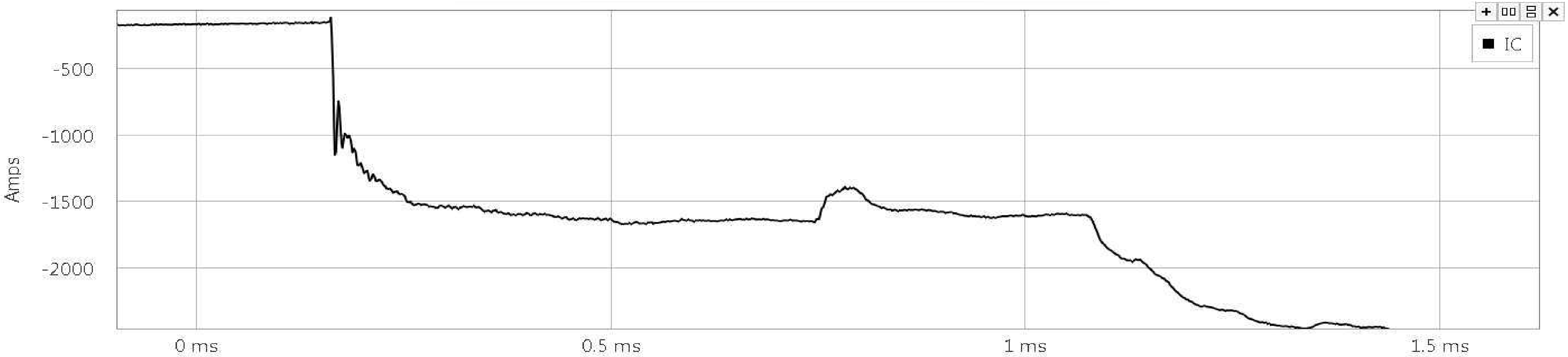
1. Fault inception generates high-frequency electromagnetic travelling waves
2. Waves propagate in both directions along the line at nearly the speed of light
3. Arrival times of waves captured at line terminals using GPS time synchronization
4. Central processor correlates time tags and compute fault distance using line length and wave velocity
5. Automated, real-time, and highly accurate fault location

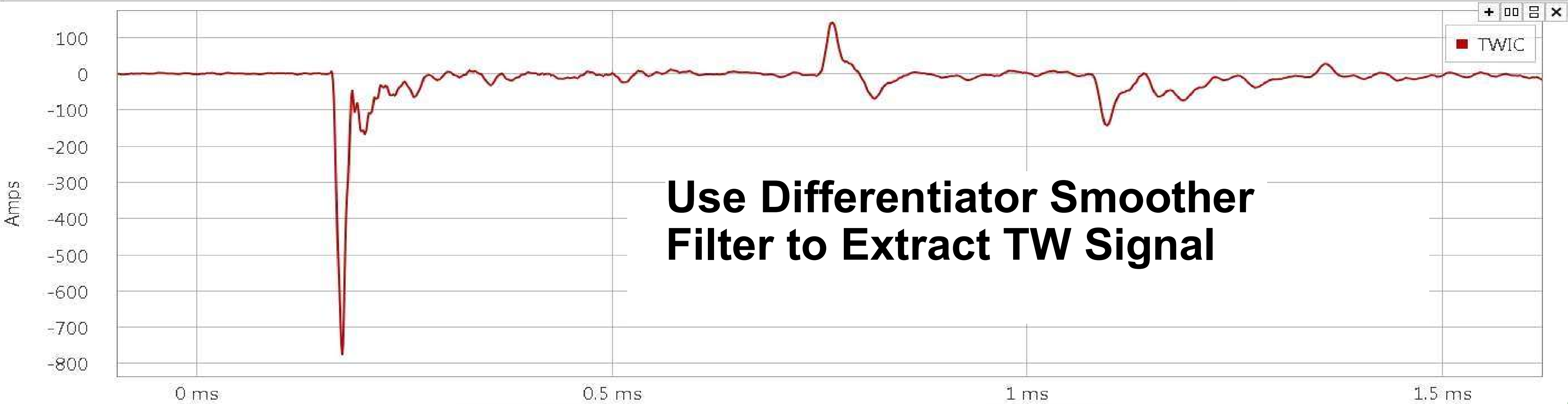
TWFL Working Principle



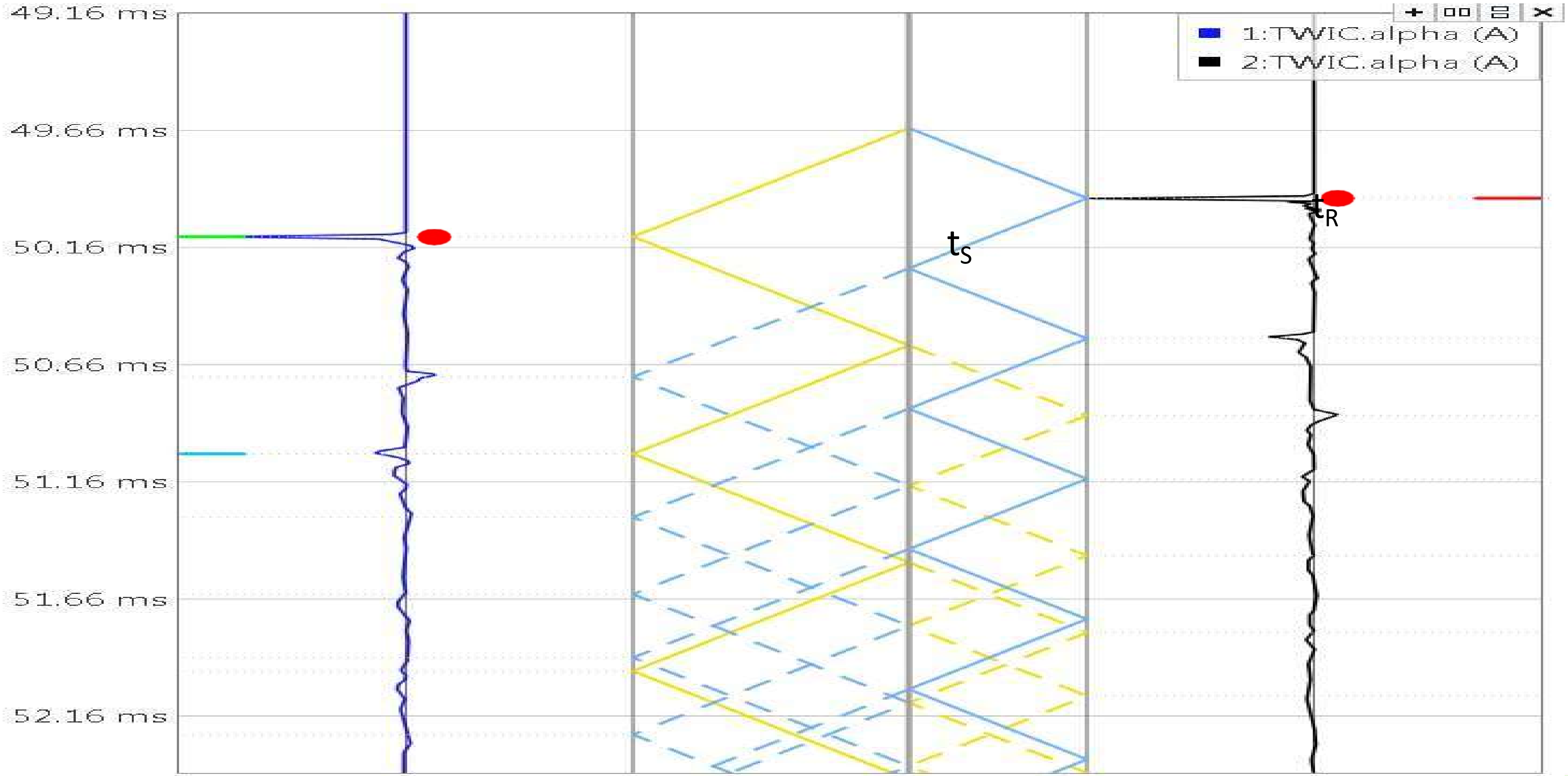


TWFL Working Principle

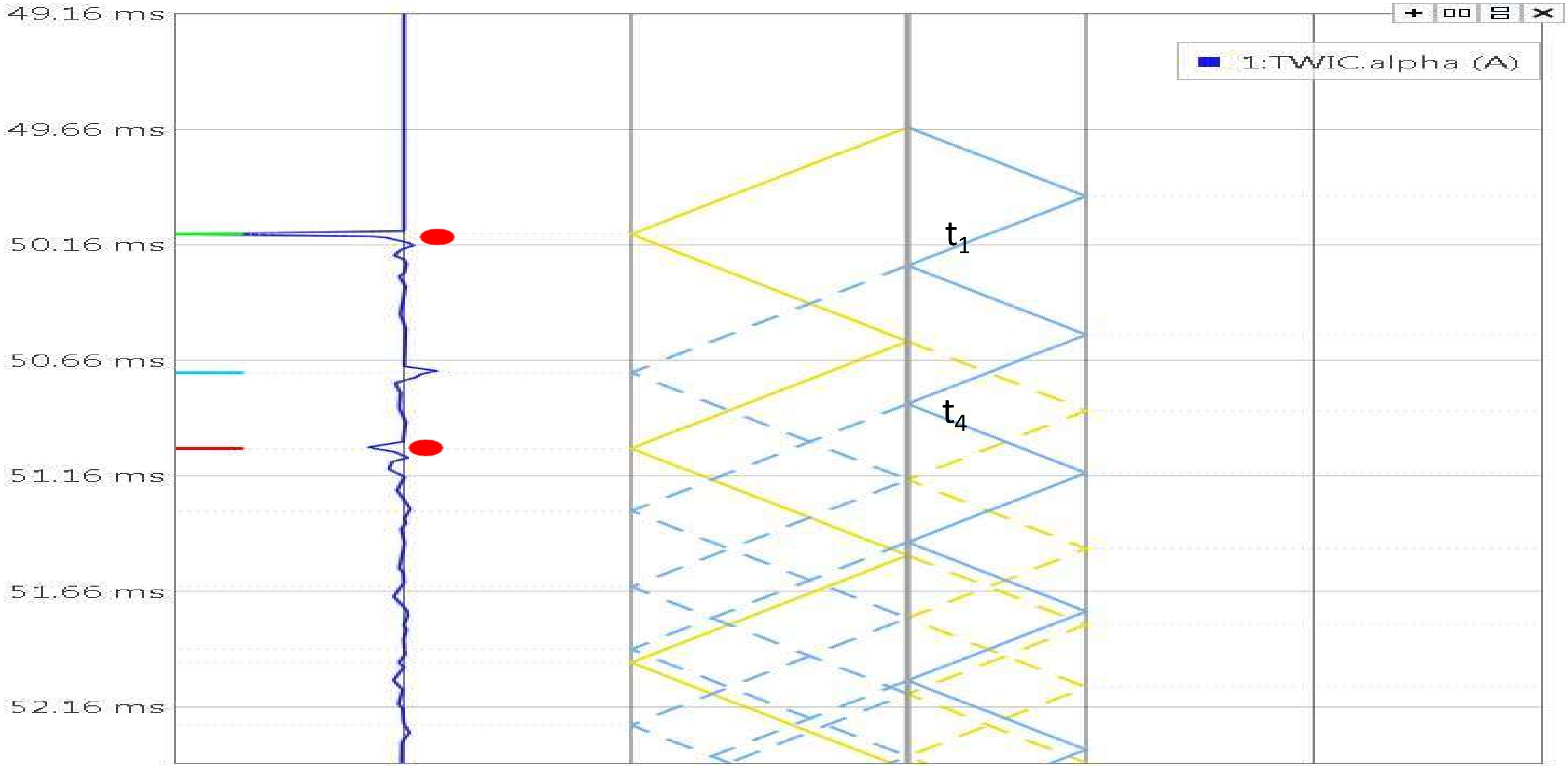




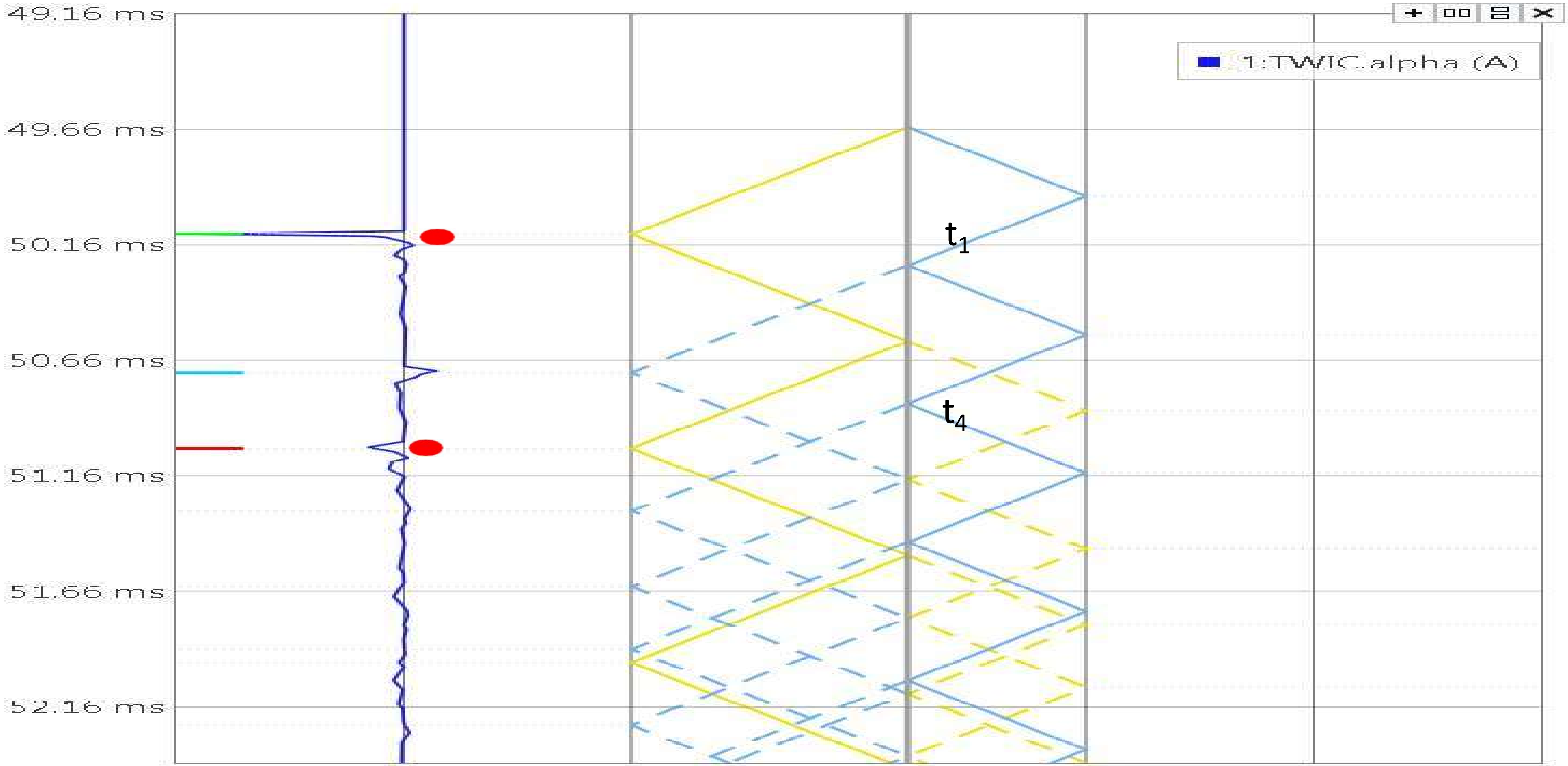
TW Fault Location (TWFL) Principle Double-Ended



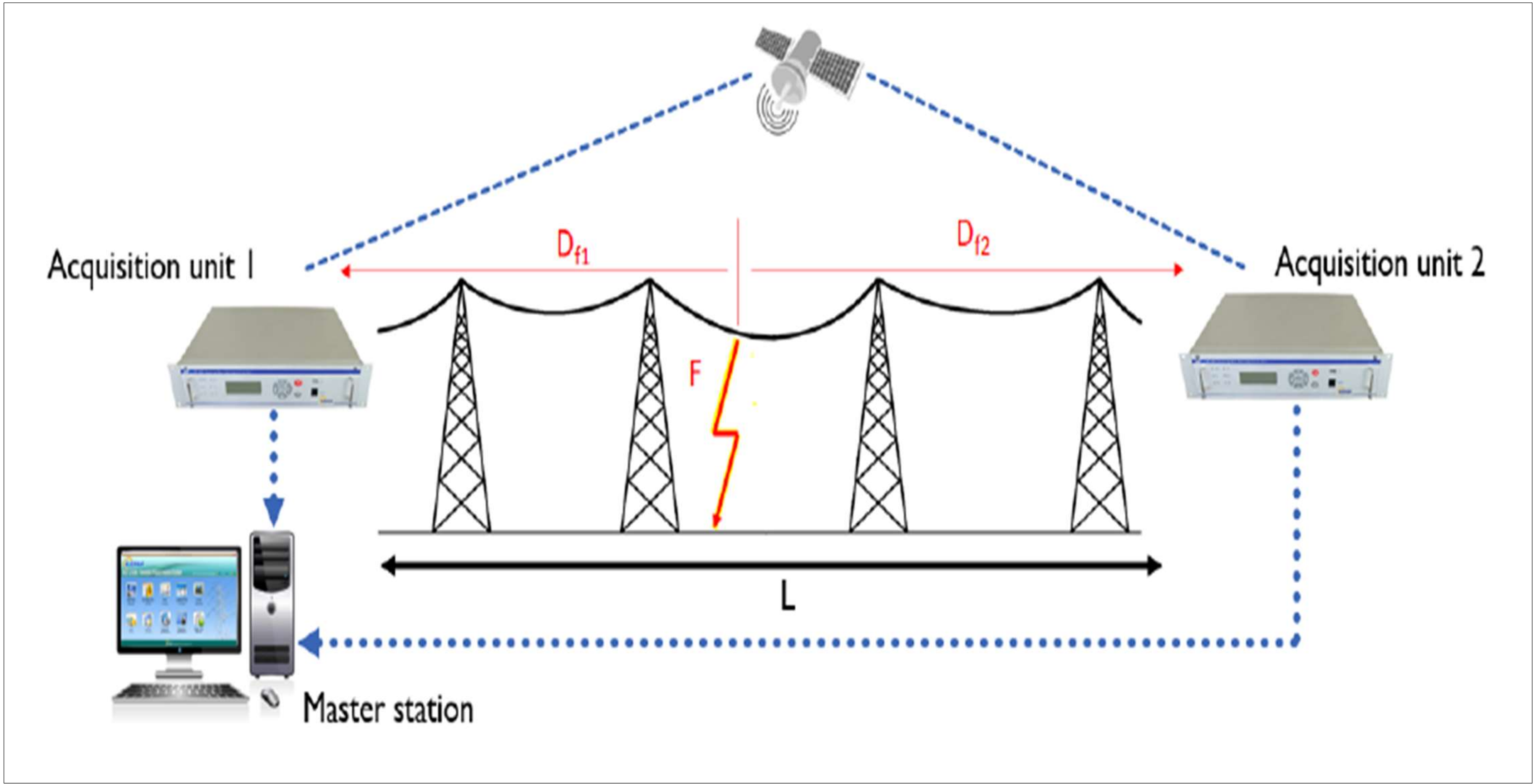
TW Fault Location (TWFL) Principle Single-Ended



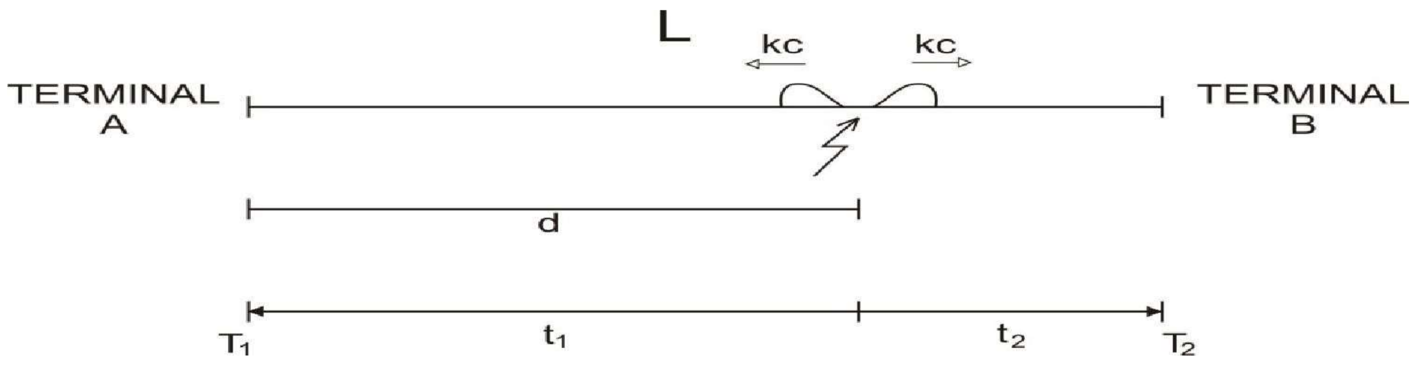
TW Fault Location (TWFL) Principle Single-Ended



TWFL Working Principle



TWFL Working Principle



where k is reduction factor

$kct_1 = \text{d}$

c is velocity of light

$kct_2 = \text{L- d}$

t_1 is time taken to travel from fault

t_2 is time taken to travel from fault d is distance of fault from end A

L is total length of transmission line

TWFL Working Principle

$kct_1 + kct_2 = \text{L}$

$t_1 - t_2 = \text{T}_1\text{-T}_2$

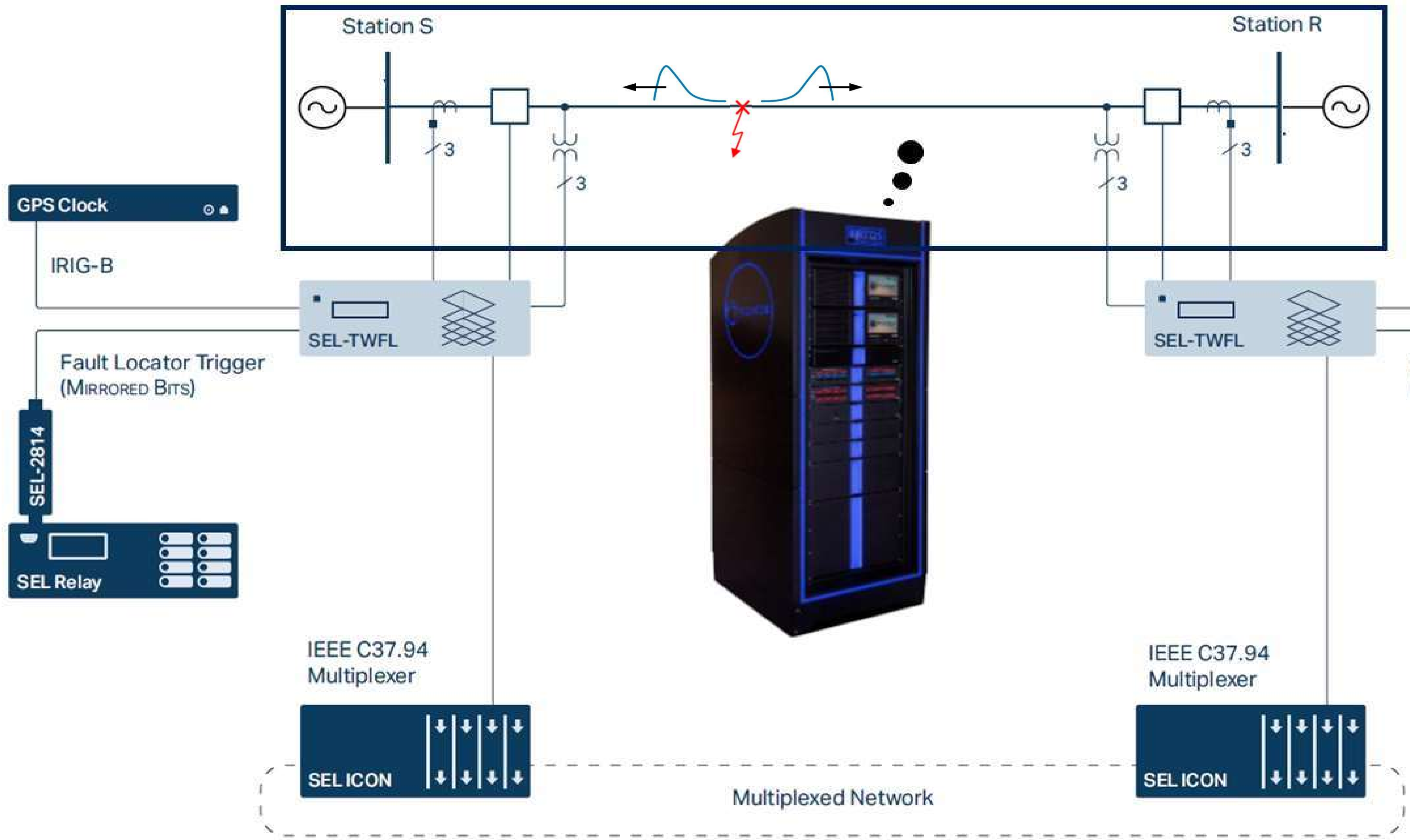
(T1 and T2 are time stamping of travelling wave at End A and End B respectively)

$t_2 = \{t_1 - (\text{T}_1\text{-T}_2)\}$

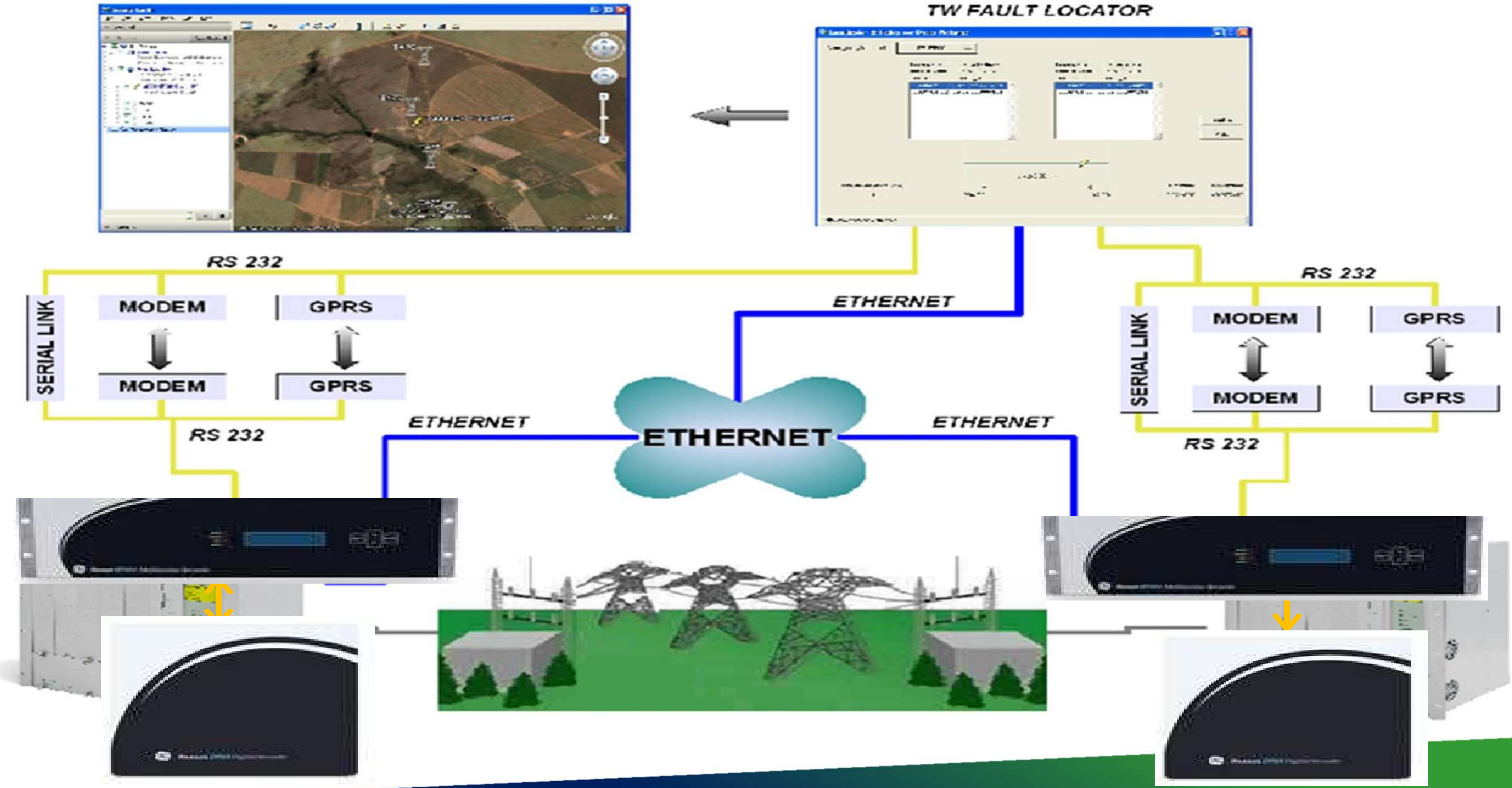
$kct_1 + kc\{t_1 - (\text{T}_1\text{–T}_2)\} = \text{L}$

$$\boxed{d = \frac{\text{L} + \text{kC}(T1 - T2)}{2}}$$

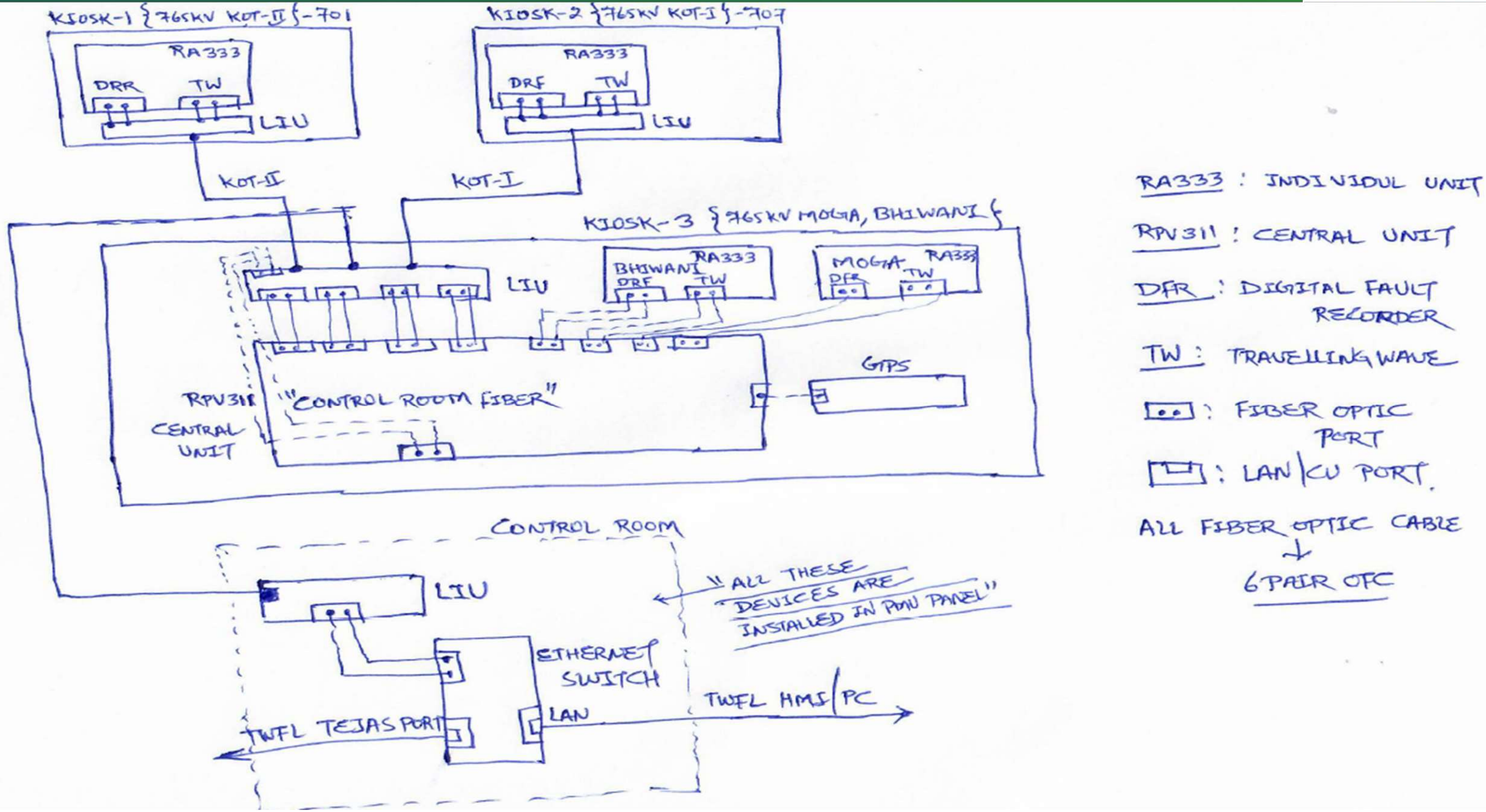
Architecture of SEL TWFL



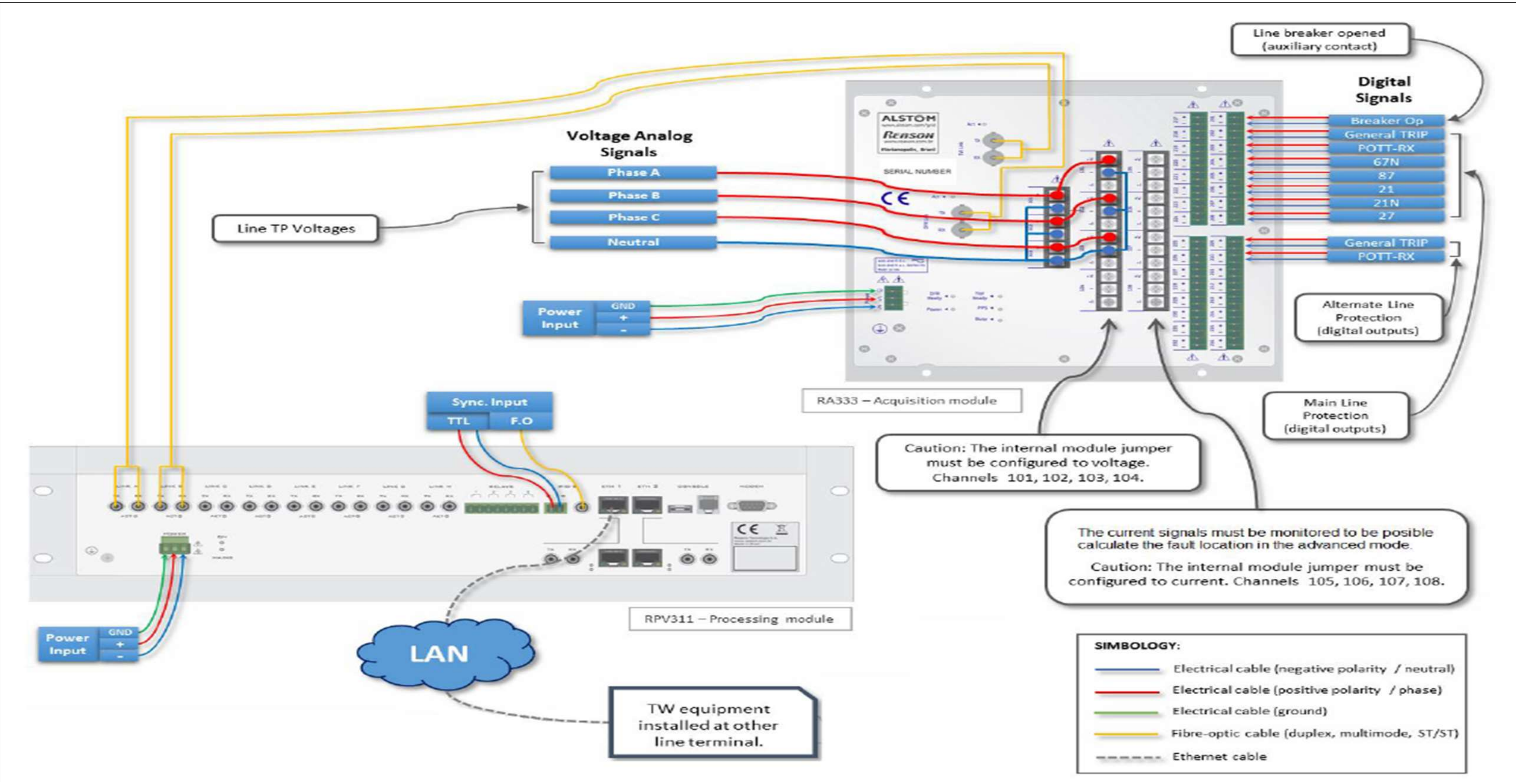
Architecture of GE TWFL



Architecture of GE TWFL



Architecture of GE TWFL



765kV Transmission Line			
S.No.	**Line Name**	**Length in km**	**Reason**
1	765kV Ajmer-Bhadla2 Line-1	272	765kV, RE
2	765kV Ajmer-Bhadla2 Line-2	272	765kV, RE
3	765kV Moga-Bikaner-1	351	765kV, RE
4	765kV Moga-Bikaner-2	351	765kV, RE
5	765kV Bhadla-2-Fatehgarh-2 Line-1	183	765kV, RE
6	765kV Bhadla-2-Fatehgarh-2 Line-2	183	765kV, RE
7	765kV Bhadla-2-Fatehgarh-2 Line-3	204	765kV, RE
8	765kV Bhadla-2-Fatehgarh-2 Line-4	204	765kV, RE
9	765kV Bhadla-1-Fatehgarh-2 Line-1	180	765kV, RE
10	765kV Bhadla-1-Fatehgarh-2 Line-2	180	765kV, RE
11	765kV Banaskantha-Chittorgarh-1	311	765kV, RE
12	765kV Banaskantha-Chittorgarh-2	311	765kV, RE

400kV Transmission Line			
S.No.	**Line Name**	**Length in km**	**Reason**
1	400kV Dehradun-Baghpat	164.0	Hilly
2	400kV Dehradun-Roorkeee	65.0	Hilly
3	400kV Jaipur(S)-RAPP D	228.182	More than 200kM
4	400kV Kankroli - RAPP ©	198.64	Nuclear
5	400kV Kota - Merta	257.9	More than 200kM
6	400kV Roorkee-Kashipur-1	150.892	Hilly
7	400kV Roorkee-Kashipur-2	150.892	Hilly

220kV Transmission Line			
S.No.	**Line Name**	**Length in km**	**Reason**
1	220kV RAPP(B)-Debari	204	Nuclear

Annexure-C

765kV Transmission Line			
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2	765kV Ajmer-Bhadla2 Line-2	272	765kV, RE
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5	765kV Bhadla-2-Fatehgarh-2 Line-1	183	765kV, RE
6	765kV Bhadla-2-Fatehgarh-2 Line-2	183	765kV, RE
7	765kV Bhadla-2-Fatehgarh-2 Line-3	204	765kV, RE
8	765kV Bhadla-2-Fatehgarh-2 Line-4	204	765kV, RE
9	765kV Bhadla-1-Fatehgarh-2 Line-1	180	765kV, RE
10	765kV Bhadla-1-Fatehgarh-2 Line-2	180	765kV, RE
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