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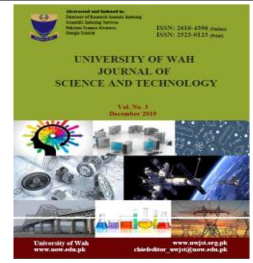

Numerical Relay Based 220 kV Transmission Line Backup Distance Protection at Pipri West Grid- A Case Study

Adnan Ali, Muhammad Ovais Raza, Muhammad Hammaduddin, Muhammad Saad Aslam, Abdul Moeed Saadat, Syed Saad Amin and Syed Muhammad Shakir

***Abstract*—This case study presents the working, testing and commissioning of the 220 kV backup distance protection schemes employed on the Pipri West Grid of Karachi Electric Limited (KEL). The paper discusses protection systems in transmission lines and the technical issues with electromechanical and static relays. Current status of relays in Pakistani transmission network and the need for their up gradation to modern numerical relays have been emphasized. The 220 kV backup distance project of Karachi Electric (KE) uses LZ96 static relay that has been replaced with Siemens Siprotec 4 7SA522 numeric distance relay. These newly replaced relays has features of telecommunication, monitoring, control, and power swing blocking functions. This paper also present the problems encountered in conventional distance protection. Desirable features of distance protection are obtained via tele-protection. Information transmitted from one end to the other end of the line via tele-protection is also analyzed. The parameterizing of numerical relays is done with Digitalizer Simulator (DIGSI) software and finally testing results are reported using Instrumentation System Automation (ISA) TEST SET.**

***Index Terms*—Transmission line, Distance protection, Numerical relay, Static relay, DIGSI Software, ISA Test Set.**

I. Introduction

TRANSMISSION lines play a vital role in electrical power system as they transfer the bulk electrical power from power plants to the electrical substations located near load centers. The transmission lines are tightly interconnected forming a transmission network known as Grid or national Grid. Pakistan transmission network comes under two utility companies WAPDA (Water and Power Development Authority) and KE. The transmission voltages in KE network are mainly 132 kV, 220 kV and 66 kV. All transmission lines are interconnected and any fault on the line can cause severe effect on the grid, resulting in larger area blackout. High voltage faults on 220 kV and 132 kV lines are so severe, that they not only cause black out in a large area but also result in severe damages to the equipment in case fault persists for long time span. A transmission line fault is specifically defined as an undesirable and unavoidable event that can disturb the stability of a power system [1]. In case of fault, all generators and even motors fault current increasing significantly to the full load current level. This fault current causes overheating, which may lead to fire. Overheating can also deteriorate the insulation. Moreover, faults also results in synchronization issues of electrical machines and electrical power drops rapidly. However, the mechanical input power during fault remains constant causing, the generator to accelerate due to which its rotor angle increases, which results in swinging of the generators with respect to each other. Thus, the faults in power system can affect the system stability. Therefore, the faults must be isolated as selectively and speedily as possible. So, it is the most common practice in transmission network, that not only primary protection system is employed but also a backup protection is employed in case primary protection fails, there is a backup protection to isolate the faulty line section. Normal clearing time of faults for primary protection is less than 160 ms and for backup protection is within 500 ms. However, it also depends on the particular technology of the circuit breaker [2].

Statistics of transmission line faults shows that failures are mainly caused by bad weather, equipment failures, human negligence, the percentage of line to ground faults

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A. Ali (email: adnanali@neduet.edu.pk) is currently serving as Assistant Professor in Electrical Engineering Department of NED University Karachi, Pakistan.

M. O. Raza (email: muhammadovais@gmail.com), M. Hammaduddin (email: mhammaduddin@gmail.com), M. S. Aslam (email: msaadaslam @gmail.com) and A. M. Saadat (email: abdulmoeed@gmail.com) are graduates of NED University in year 2015.

S. M. Shakir (email: mshakir@gmail.com) is currently serving as Sr. Executive Engineers in Siemens.

Corresponding author email: adnanali@neduet.edu.pk

and the dimensions of the line (specifically 60% in 220 kV lines to 97% for 735 kV lines) [3]. Transmission line faults can be categorized as shunt faults, series faults and simultaneous faults.

II. Distance Protection

The natural selection of relay for any type of fault will be an inverse time overcurrent relay if fault current increases threshold current and the relay tripping time should be in inversely proportion to fault current. However over current relays are actuated by one quantity only i.e. current, and in case of transmission lines other parameters such as source impedance, fault location and type of faults also affect the current measured by relay and results in unsatisfactory performance [4]. These relays may incorporate loss of selectivity, which is tolerated to some extent in low voltage (LV) distribution network, where the continuity of the supply is the main objective. However, in an extra high voltage (EHV) grid, loss of selectivity can lead to power system instability, in addition to large interruption to load. Therefore, over-current protection is usually not employed as a protection in EHV (i.e. 220kV) transmission line. Another line protection scheme known as "distance protection" offers much more accurate reach and gives satisfactory performance, because it is actuated by two quantities and the reach of distance protection does not depend on the source conditions and fault type. Hence, the most common protection scheme for transmission line faults is the distance protection. The working principle of distance relay is based on the effective measurement of impedance between the fault and the relay location. When the fault resistance is low, the impedance is in proportion to the distance between reach point of the relay and its location. Ideally, the relay will operate (instantaneously) in this zone and will remain stable for faults outside this zone [5, 6]. Numerous other advantages associated with distance protection include simpler and faster protection, allows high line loadings a widely used in carrier aided distance and auto-reclosing schemes. Distance protection scheme is a non-unit type of protection scheme which provides both primary and backup protection. There are three types of distance relays namely impedance relay, reactance relay and MHO (admittance) type distance relay.

While protecting any transmission line, the line is divided into different zones. A protection zone is a well-defined region extending along the transmission circuit between definite limits. Basic distance protection scheme comprises of one instantaneous tripping zone, and one or more than one-time delayed zones. In general, a distance protection scheme has a minimum of three protection zones. Careful selection of relay reach point and operating time allows correct protection coordination among the different zones. The different zones are obtained either by changing the taps on auxiliary voltage transformer or by using separate measuring element for each zone.

Relay reach and operating time settings for a standard three-zone distance protection on line LMO are shown in *Fig.1* [7]. Zone 1 is the instantaneous zone and covers around 80-85% of the line length LM. Zone 2 is delayed by coordination time delay and is set to protect 100% of the line LM, plus 20% of the adjacent line MO. Zone 3 is the remote backup for Zone 1 and is set to protect 100% of lines LM, MO, plus about 25% of the third line. Typical operating times are 20-40 ms for Zone 1 and 250 to 300 ms for Zone 2 [7]. Distance relays can be configured for different operating characteristics such as plain impedance, reactance, MHO and polygonal characteristics.

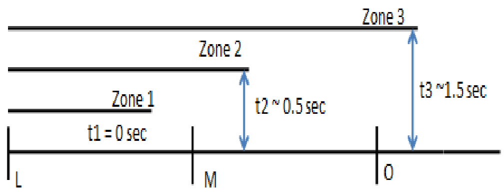

Fig. 1. Typical 3-zone Distance Protection.

MHO and Quadrilateral distance characteristics of relays are the most commonly used properties that have been explored under different circumstances [8]. MHO relay works perfectly for phase faults, therefore, self-polarized and cross-polarized MHO settings fail in case of earth faults, hence for earth faults quadrilateral MHO characteristic is used because this characteristic provides the best overall coverage out of any MHO type characteristics and it can provide higher resistive coverage. This becomes advantageous in case of protection for phase to earth faults on short transmission lines, lines with no earth wires, ineffectively earthed systems and for feeders having high tower footing resistance [9, 10].

The circular and straight-line distance relay characteristics are developed with the help of earlier electromagnetic relay technology. Further advancements led to the development of analog technology, which allowes relay characteristics other than circles or lines. Quadrilateral characteristics as shown in *Fig. 2* permits separate settings for reactance X and resistance R. Therefore, the resistance can be set for faults involving ground.

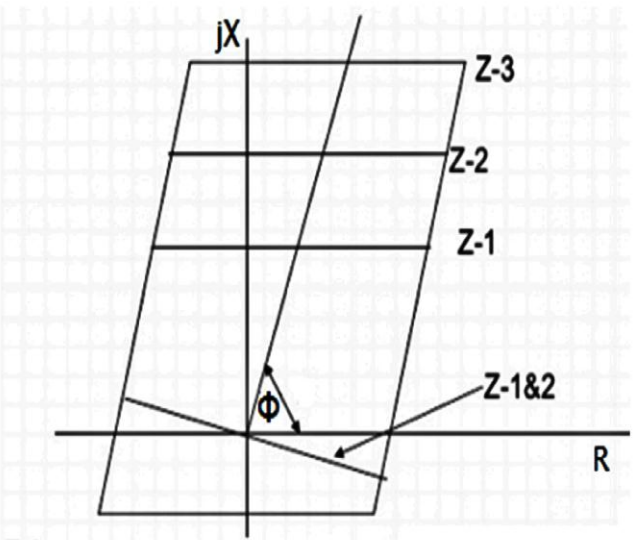

Fig. 2. Quadrilateral MHO characteristic.

III. Conventional Distance Protection Issues

Major problem with conventional distance protection is that instantaneous tripping is not obtained for both ends of the entire line. In order to understand this problem of non-simultaneous tripping and to examine the protection coordination, a conventional distance protection scheme is used to protect line L. The relay 1 near the Bus L is associated with circuit breaker 1 while Relay 2 near Bus M is associated with circuit breaker 2. Both relays operate in two zones; Zone 1 with instantaneous tripping and Zone 2 in which tripping take place with a time delay as shown in *Fig. 3*.

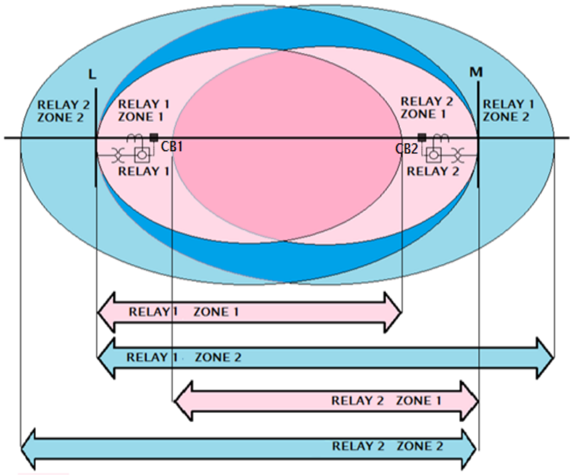

Fig. 3. Distance protection scheme for line LM.

A. Fault Occurring at the Middle of the Line LM

Consider a fault that occurs at the middle of protected line as shown in *Fig. 4*. Since the fault occurs in the middle of the protected line as shown in *Fig. 5*, it lies in the Zone 1 of both distance relays. Both relays will operate without any intentional time delay, sending a trip command to the associated circuit breakers. Hence, the complete faulty section is isolated within 40 to 70 ms. Total time taken in isolation of the fault at local end and remote end is shown in Table I.

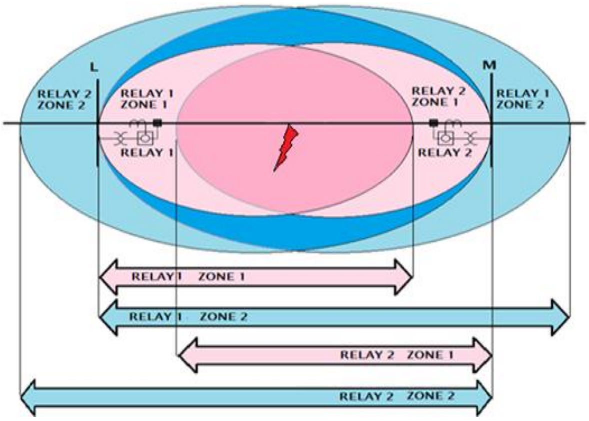

Fig. 4. Fault occurrence at middle of the Protected Line.

TABLE I
ISOLATION TIME FOR FAULT (MIDDLE)

Local End	Remote End
Relay 1 operating time=20~30ms	Relay 2 operating time=20~30ms
CB 1 opening time = 20~40ms	CB 2 opening time = 20~40ms
Total time = 40~70ms	Total time = 40~70ms

B. Fault Occurring near the Bus L

Consider a fault that occurs on the line LM near bus L as shown in *Fig. 6*. Since the fault lies in Zone 1 of relay 1 and Zone 2 of relay 2 as shown in *Fig. 7*. Hence, relay 1 will operate instantaneously while relay 2 will operate with a time delay. Line isolates at end L in 40 to 70 ms while isolation at end M takes 400 to 500 ms. Total time taken in isolation of the fault at local end and remote end is shown in Table II.

TABLE II
ISOLATION TIME FOR FAULT (BUS L)

Local End	Remote End
Relay 1 operating time=20~30ms	Relay 2 operating time=400~500ms
CB 1 opening time = 20~40ms	CB 2 opening time = 20~40 ms
Total time = 40~70 ms	Total time = 420~540 ms

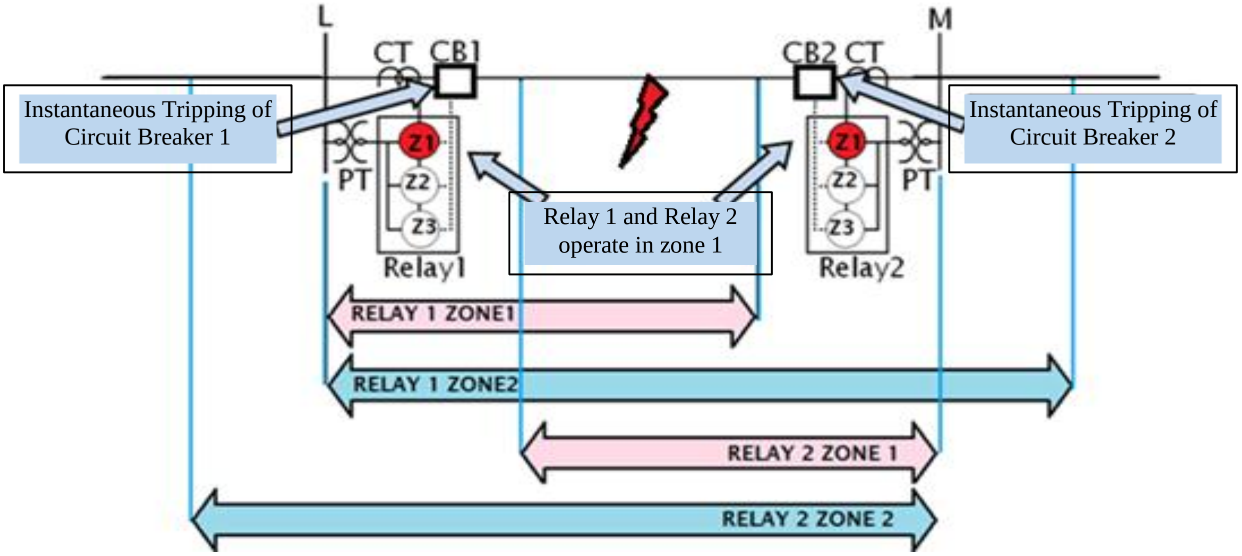

Fig. 5. Distance Relay coordination for a fault at middle of line LM.

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Fault remaining on the feeder M may cause the system to be unstable. For a high speed auto-reclosing scheme, the non-simultaneous opening of the circuit breakers at both ends may result in a transient fault which can cause permanent lockout of both circuit breakers [11]. Hence, the desirable features of distance protection as noted from previous observation are:

- The scheme should be able to discriminate between internal and external faults
- Circuit breakers present at the two ends of the transmission line must operate simultaneously for internal faults
- Simultaneous auto-reclosing of the circuit breaker at both ends.

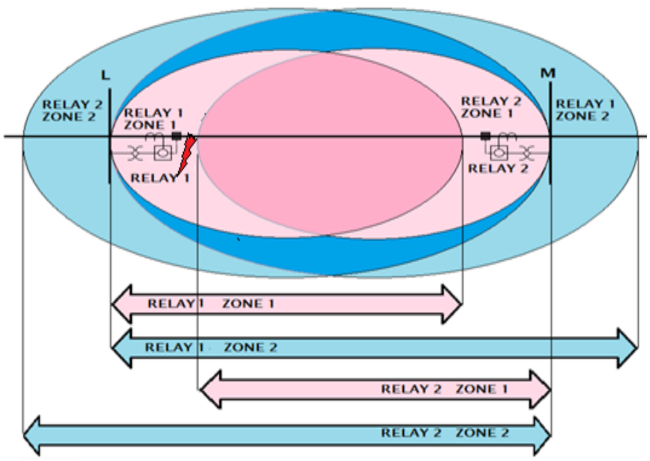

Fig. 6. Fault Occurring on Line LM near Bus L.

IV. TELE-PROTECTION

Tele-protection schemes help in achieving the desirable features of distance protection by interconnecting the distance relays at each end of the protected line through a signaling channel. The purpose of the signaling channel is to transmit information about the system conditions from one end of the protected line to the other and it can also be arranged to initiate tripping (also known as Transfer Trip Scheme) or prevent tripping (also known as Blocking Scheme) of the remote circuit breaker.

The signal is transmitted through one of the four channels i.e. power line carrier, radio link, microwave channel and fiber optic link. There are four common tele-protection schemes:

- Direct under-reach transfer trip Scheme (DUTT)
- Permissive under-reach transfer trip scheme (PUTT)
- Permissive over-reach transfer trip scheme (POTT)
- Blocking scheme

In KE project, the scheme utilized is PUTT, in which only a simplex signaling channel is required. The scheme is very secure as signaling channel only keyed for internal faults (Zone 1 initiation). PUTT scheme is shown in *Fig. 8.* In case of a fault near bus L, the Zone 1 element of relay 1 will operate to trip the associated circuit breaker and send a carrier signal to Relay 2. The instantaneous Zone 2 element of Relay 2 will also generate a signal, the AND logic output will be high which will issue a trip command to breaker 2. Total time taken in isolation of the fault at local end and remote end is shown in Table III.

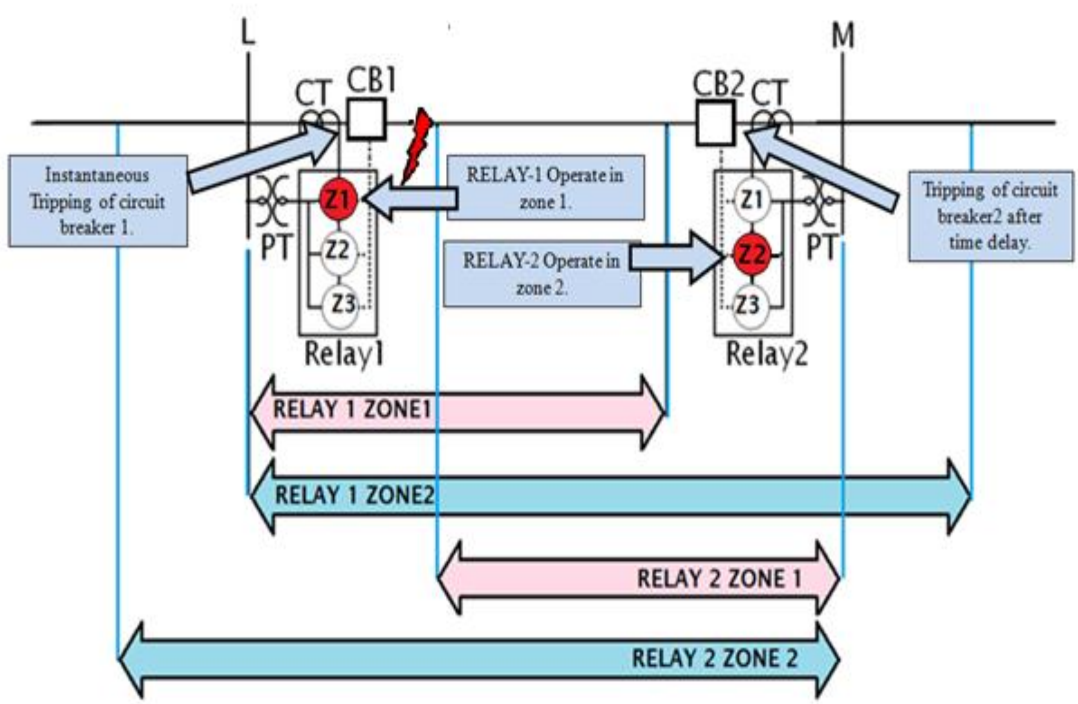

Fig. 7. Distance Relay Coordination for Fault on Line LM near Bus L.

TABLE III
FAULT ISOLATION TIME USING PUTT (BUS I)

Local End	Remote End
Relay 1 operating time=20~30ms	Signal transmission time=10ms
CB 1 opening time = 20~40 ms	Signal received time = 2 ms
	Decision time = 3 ms
	Trip Command = 5 ms
	Relay 2 operating time=20~30 ms
	CB 2 opening time = 20~40 ms
Total time = 40~70 ms	Total time = 60~90 ms

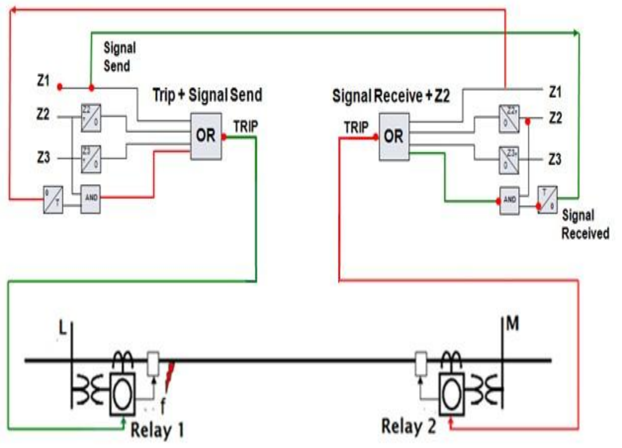

Fig. 8. Logic Diagram of PUTT Scheme.

V. RELAY TECHNOLOGY AND RECENT DEVELOPMENTS

The earliest relays used until 1940s were electromechanical relays [12]. However, the current trend is towards the replacement of older technology relays with new relays due to additional features and functionality. The electromechanical relays have a slower response time and do not have features such as condition monitoring, data communications, metering and self-diagnostics [12]. Field tests to check the performance of electromechanical relays are difficult and all the settings on relay are done through mechanical elements consisting of 'screw adjustment' which is quite sensitive as excessive torque may occur and cause damage [13]. Another drawback of electromechanical relay is that in case of fault, the fault current passes through the coil of relay in order to trip the contacts. This phenomenon increases the resistance, which results in increased burden on the current transformer. Therefore, to overcome this problem, the volt-ampere rating of current transformer (CT) is kept high when used with electromechanical relays, resulting in increased cost. In the light of these problems, electromechanical relays are continuously being replaced with modern relays. On the other hand, static relays have many benefits of self-diagnostic capability, such as, less coordinating interval, less maintenance and pick up accuracy [14]. Furthermore, with the development in microprocessor technology, the numerical relays have been introduced. Numerical relays exceed in performance compared to both electromechanical and static relays in accuracy, sensitivity and discrimination capability. These relays have features of data communications, multifunction, remote operation, disturbances immunity, metering and event archiving [12]. The maintenance requirement of these relays is low and several protection functions can be grouped in the same relay [15], resulting in space saving on panels.

Numerical relays increase the reliability as there is less direct wiring and interconnection wiring involved, also they have internal built in watchdog timer that alerts the user in case of problem in the relay [16]. Other benefits of numerical relays include economy, flexibility and improved performance [17]. Apart from above mentioned advantages, numerical relays are also important in case of system changes. When the transmission system changes, there is no need to change the whole relay setup, as these relays can be used with dynamic systems (smart grid protection and micro grids) where they can adapt accordingly [18]. A comparison of three relays is shown in *Fig. 9* [19].

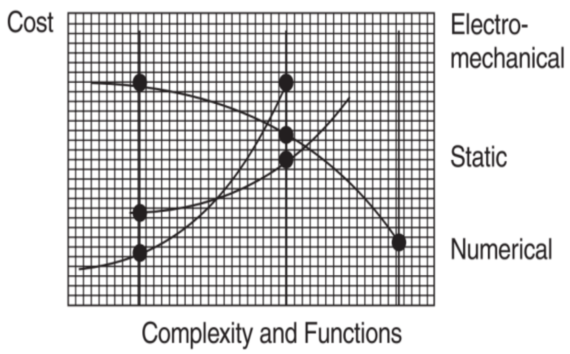

Fig. 9. Relay Comparison

Fig. 9 helps in selecting the least expansive relay for a given level of complexity and functions in power systems. It also shows that for same level of complexity and functions, electromechanical relays have the least expensive followed by static relays and the most expensive is numerical relays. But as the complexity and functions increase, numerical relay cost decreases drastically as shown. Hence, for the complex and multifunction environment in which the current power system works, numerical relay is the preferred choice. Also, since KE is planning towards the establishment of smart grid stations, Numerical relays would be the best choice for such systems.

Performance analysis of numerical relays was done using real time digital simulation for high voltage lines of Brazilian power system where it has been shown that these multifunction numeric relays assure the security and stability for transmission network [20]. The issue of CT burden is also solved using numeric relays as the current coming from CT passes through a sensing coil or a current transducer which senses the current and sends the signal to relay microprocessor to acts accordingly. Therefore, the resistance offered by this relay is very low as compared to electromechanical and static relays, so the burden of CT is very low. This allows the scheme designer to select CT of lesser rating which reduces cost and makes this scheme cost effective. This scheme uses a three core CT, so that if one of the cores is damaged, the other core is used. It increases the reliability of system.

Due to all these features and advantages mentioned above, current back up static relays at KE grid station are being replaced with modern numeric SIEMENS SIPROTEC 4 7SA522 relay. This relay is a non-switched distance protection with six measuring systems [21]. Full scheme non-switched numerical distance protection relays take six separate elements (3 ground and 3 phase) as input calculate the positive sequence impedance from the received voltage and current samples which are derive from instrument transformers through antialiasing filter and sample and hold circuits after quantization. Non switched numerical distance relay uses full cycle discrete Fourier transform (FCDFT) to extract fundamental frequency information using current and voltage samples [22].

Many new techniques have been researched for the purpose of transmission line protection including fuzzy logic, neuro fuzzy logic, artificial neural network (ANN) and phasor measurement unit (PMU) based techniques [23]. ANN can identify any noisy patterns by learning any complex input/output mapping [12]. Similarly, by using PMU data from various grid stations, wide area backup protection systems can be proposed for detection of fault in transmission lines [24].

A. Relays in Pakistan Transmission Network

Protection system for transmission lines both in WAPDA and KE, use all three relays i.e. electromechanical, static and modern numerical relays. However electromechanical relays and static relays are being replaced with modern numeric relays. An old electromechanical distance relay at 220KV grid station, Faisalabad is shown in *Fig. 10*. It is in operation since 1960 in WAPDA network.

Fig. 10. Distance Relay at 220 kV Gird Station Faisalabad.

Pakistan has been hit by a few blackouts in the past that led to vast areas without power. A systematic study of all blackouts is not carried out in the country yet and resulting in lack of data in this direction that hinders academic researchers to venture into this area. In blackout study of Pakistan most of the lines tripped under overloading conditions. The tripping of relays under these conditions are also evident in other blackouts. Analysis of blackouts in general sheds light on the importance of distance relays and their applications under complex operating scenarios. In August 14 2003, blackout of North America and European disturbances of 2006 reveal that one of the reasons behind these blackouts was the undesired operation of numerous distance relays. Hence there is a need for improvement in it regarding how these relays are used [26]. Advanced methods of distance protection have been investigated that can detect load encroachment and out of step conditions which do affect the operation of electromechanical and static relays [26].

Further new projects have been investigated involving numerical distance relay which resulted as integration of renewable energy into the system. Out of these, Uzbekistan supports project CASA-1000 has an additional element of High-voltage direct current (HVDC) converters [27]. The importance of FACTS devices was also highlighted for transmission capability improvement and as blackout remedial measures. All these projects requires sophisticated study of the complete grid and are better suited for advanced protection methods of numerical relays employing advanced protection algorithms.

VI. NEED OF CURRENT PROJECT

As discussed above, the modern numerical relays are multifunctional and have many desirable features for the current complex power networks. Hence old relays are being replaced with modern numerical relays and also in all new grid station projects, the default choice is numerical relays.

The primary requirement is that the 220 kV line should not be affected as it is further divided into a number of 132 kV lines which provides service to many areas of the city. A parallel protection scheme in which both primary and backup relays work is needed for protection purpose. For high voltage lines it is common practice to have protection redundancy.

A. Project Description

The location of 220kV transmission line is at KE Pipri West Grid Station where a transmission line from Pipri West to KDA-1 is to be protected as shown in *Fig.11*.

B. Functional Overview of 7SA522 Relay

In this project, the LZ96 static backup distance relay is replaced with SIEMENS SIPROTEC 4 7SA522 numeric distance relay. 7SA522 relay provides full scheme distance protection in a single unit. It has utilized all functions scheme (advanced protection and monitoring) with high degree of reliability and sensitivity required for the protection of power transmission lines. 7SA522 relay can be programmed to show separate characteristics for different types of faults e.g., MHO characteristics in case of phase faults and quadrilateral characteristics in case of earth faults. The 7SA522 relay consists of a well proven phase selection algorithm which ensures the following two points:

- Single pole tripping which increases poor system protection reliability.
- Measurement of distance up to fault location with little error.

This relay contains selectable load encroachment characteristics, six distance zones, fault locator feature, built in tele-protection function for simultaneous clearance of faults from both ends of transmission line, power swing detection function, weak in feed protection, directional earth fault protection, switch onto fault overcurrent protection, auto-reclosure, breaker failure protection. It also performs the monitoring function in terms of measured value supervision, fault logging and oscillographic fault recording. 7SA522 relay can be programmed or reprogrammed to perform variety of functions without manipulating the hardware. This is implemented by using DIGSI 4 software provided by Siemens to set the relay for different operating conditions. The circuit diagram of the modified scheme of protection for transmission line is shown in *Fig. 12*.

C. *DIGSI-4 Software*

DIGSI-4 software is a copyright software of Siemens. It provides user friendly parameterization and settings for all Siprotec protection devices. It also provides easy analysis and documentation of system faults. In this paper, DIGSI-4 software is used for setting and configuration of Siprotec 4 7SA522 distance relay for PIPRI- KDA 1 line.

In the device configuration block of DIGSI-4 software 7SA522 relay is configured according to the project. Device configuration settings of relay are shown in the *Fig. 13*.

Similarly, power system attributes are added in power system data-1 block. The block consists of three groups namely Transformer group**,** Power system group and circuit breaker group. After insertion of this data, next comes the settings of group that includes the distance protection zone settings and characteristics as shown in *Fig. 14*. The settings for different zones have been inserted into the software as shown in *Fig. 15* and a .rio file is generated by the software that includes all the settings of relay. This file is needed in test set software for testing of relay. Rio file is used to replicate distance zone settings into ISA or any other testing software.

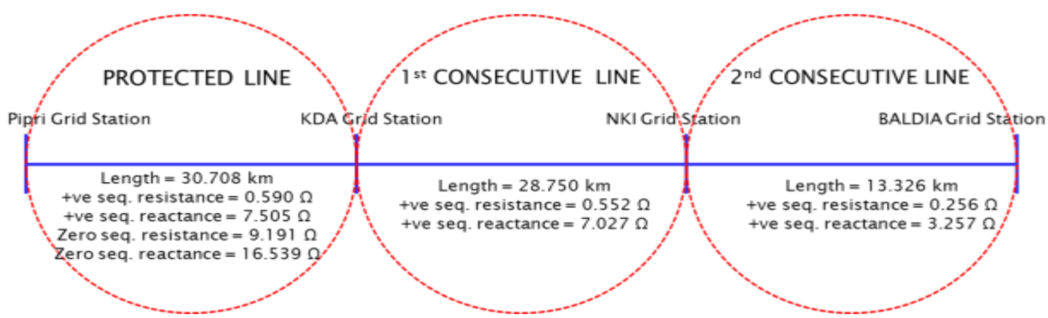

Fig. 11. Transmission Line Layout

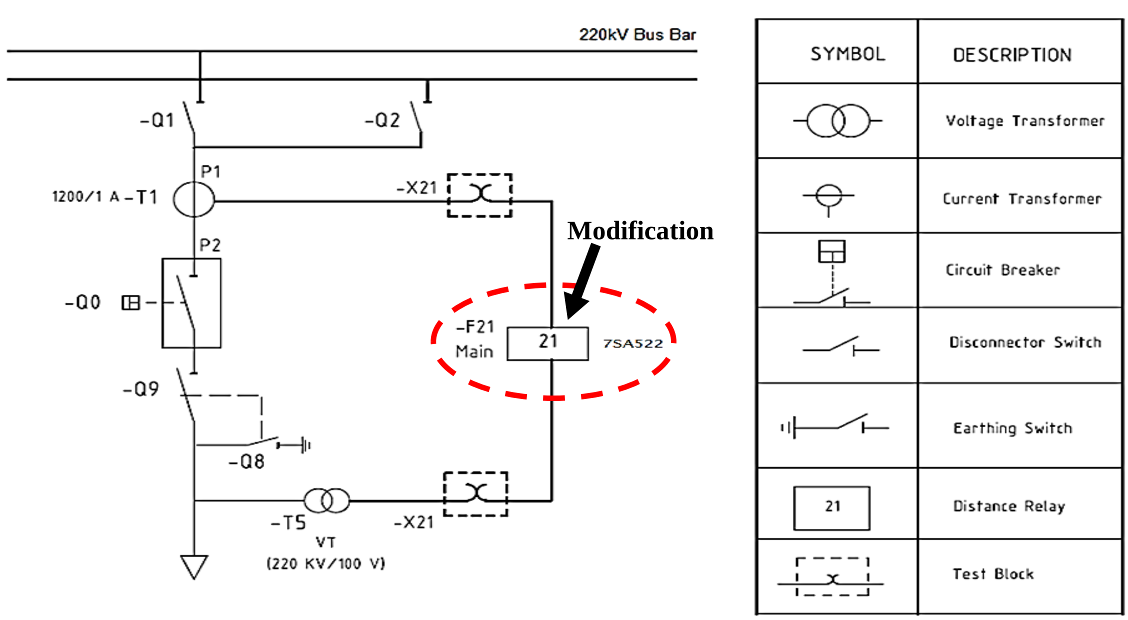

Fig. 12. Circuit Diagram of Modified Scheme.

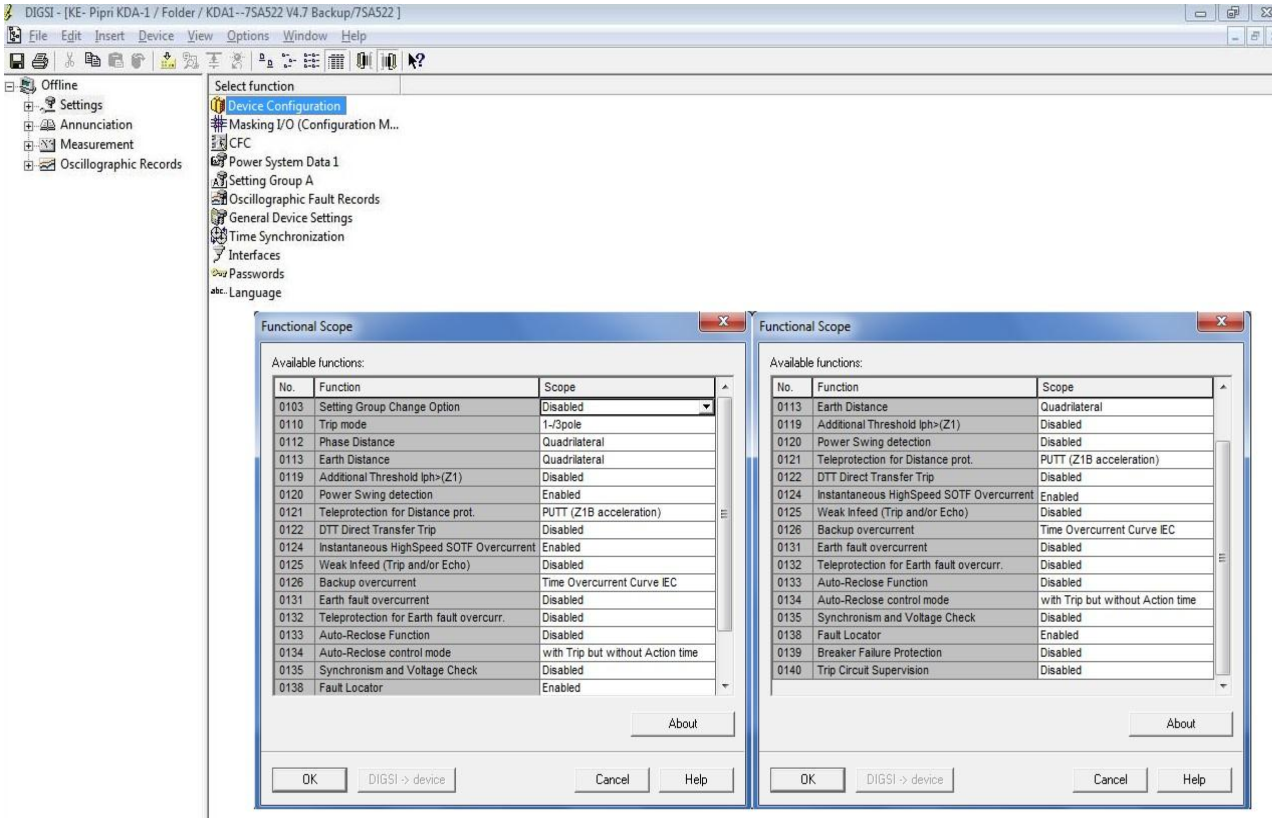

Fig. 13. Device configuration.

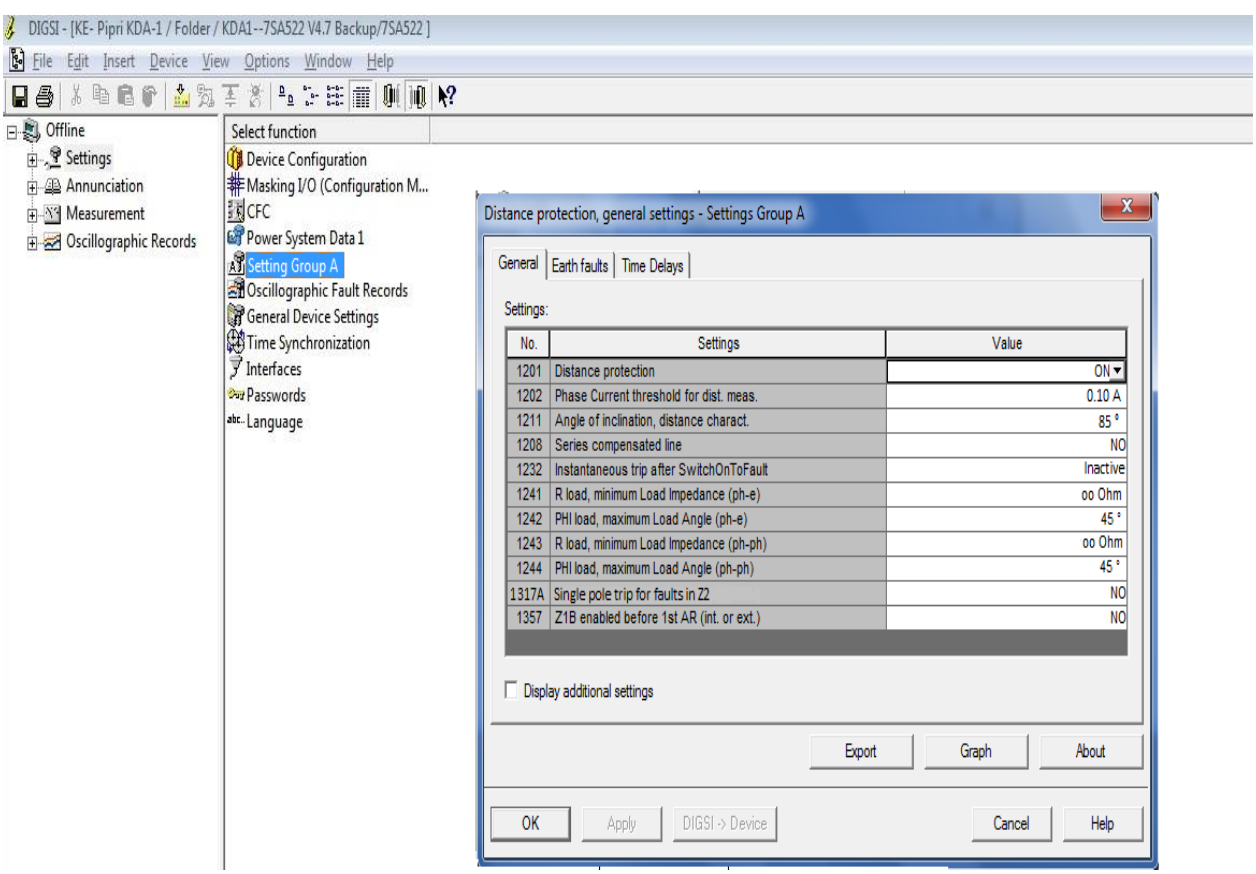

Fig. 14. Group distance protection; general settings.

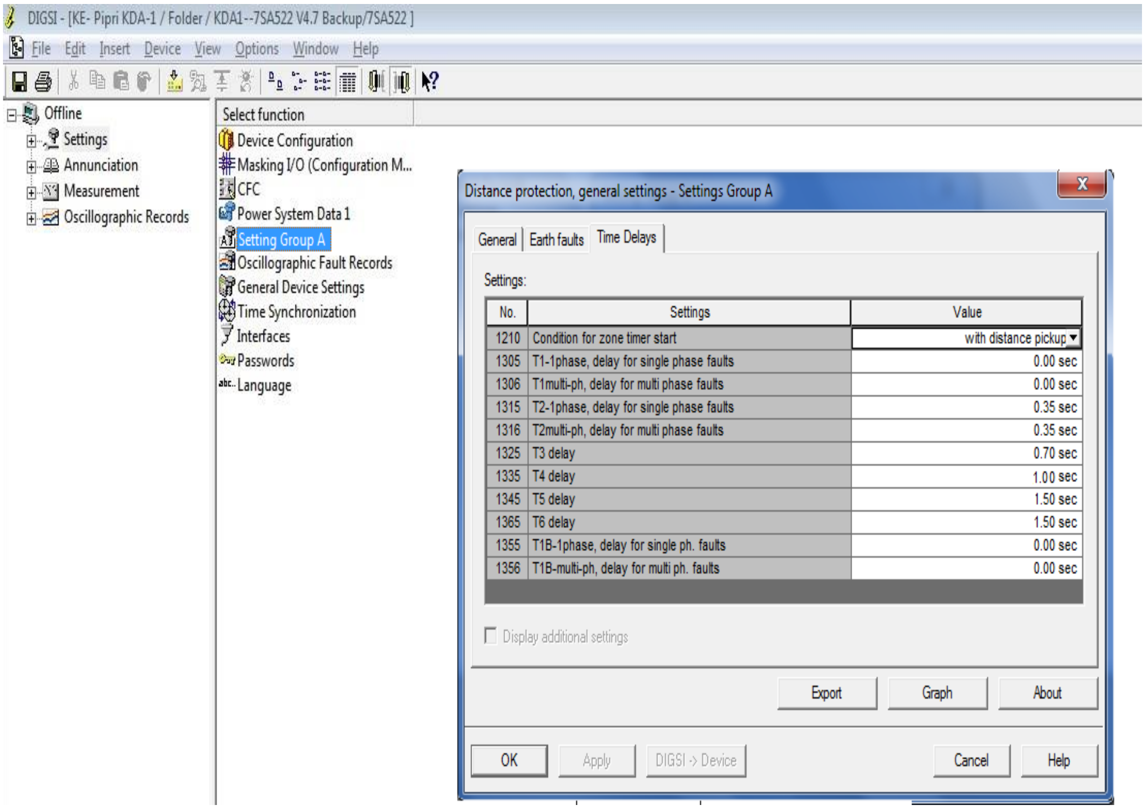

Fig. 15. Group distance protection: general settings.

VII. Testing Of The Relay

The relay performance during the commissioning is tested using ISA Automatic 3-phase protective relay test set, Digital Relay Test System (DRTS-6) [21]. The fault current and fault voltage injection system is designed to fulfill all the needs associated with commissioning, maintenance and testing of protective devices. Some of the features of this powerful commissioning tool are [28];

- Automatic test set generates faults current and voltage magnitudes by itself.
- Output: 4 x 300V, 1 x 260 VDC, 6 x 15A.
- Accuracy: 0.1% to 0.05%.
- RS-232 and USB port.
- Easily controlled by laptop

A. Testing Procedure

First of all, secondary CT is shorted, and then a test plug is inserted between CT, VT and relay which electrically disconnects the relay from the line. The current and voltage outputs from the test set are injected relay through the test plug. The horizontal pairs of terminals (i.e. 1-2, 3-4, etc.) are electrically isolated from each other. When this plug is inserted in the relay panel, it breaks the connection between instrument transformers and relay. The odd numbered terminals are towards the relay, which are used to inject current and voltages into the relay.

B. Testing Software

The DRTS-6 test set is connected with a laptop and ISA is opened. System parameters, line parameters, test mode, CT side, zone tolerance and time delays, nominal and maximum values of current and voltages, CT and VT ratios are fed into the software settings. Now the .rio file that has been generated in DIGSI is imported in order to get the relay settings and inject fault currents and voltages accordingly. Once the .rio file is loaded, all the zone R-X characteristic curves according to the settings appear on the ISA GUI.

Fig. 16. A typical test plug.

The zone with red boundary is Zone 1B which is used for Tele-protection, while remaining three zones are instantaneous Zone 1, time delayed Zone 2 and time delayed Zone 3. On the top left of the screen there are various options available. Test selection is clicked followed by test options selection for zone fault testing. When this option is selected, a new window appears.

Now moving towards the pointer, clicking any zone will create a fault in that zone. The test set will calculate the fault current and fault voltage with respect to fault impedance at the point in the zone where fault is created.

VIII. Test Results

After parameterizing the relay for correct grid settings, the test results are obtained for the distance relay 7SA522 installed on the Pipri west grid station to protect Pipri-Karachi development authority (KDA) 220 kV transmission line for different faults in various zones. The description of different symbols used in this research work are shown in Table IV. The test results includes all four types of faults including line-ground, line-line, line-line-line and line-ground with tele-protection settings. The procedure is same for all faults; they have been created in each case in different zones as shown by points in the *Fig. 17, 18,19 and 20*. The relay is tested and corresponding to each point, test values are generated that show the performance of relay under these faults as shown in Table V, VI and VII. As per settings, the relay operates correctly within the protected zone.

TABLE IV
DESCRIPTION OF DIFFERENT SYMBOLS USED IN PROJECT

Symbol	Description
Z (Ω):	Magnitude of Fault Impedance measured by Relay.
Φ(°):	Angle of Fault Impedance measured by Relay.
Err. Abs:	Absolute error between Nominal (Ω) and Z (Ω).
Err %:	Percentage error between Nominal (Ω) and Z (Ω).
T (s):	Tripping time
R (Ω):	Fault resistance measured by Relay
X (Ω):	Fault reactance measured by Relay
Pass/Fail:	Test result, either relay passed the test or not.
Zone:	Zone in which the fault is inserted.
Nominal (Ω):	Fault impedance created by Test Set.

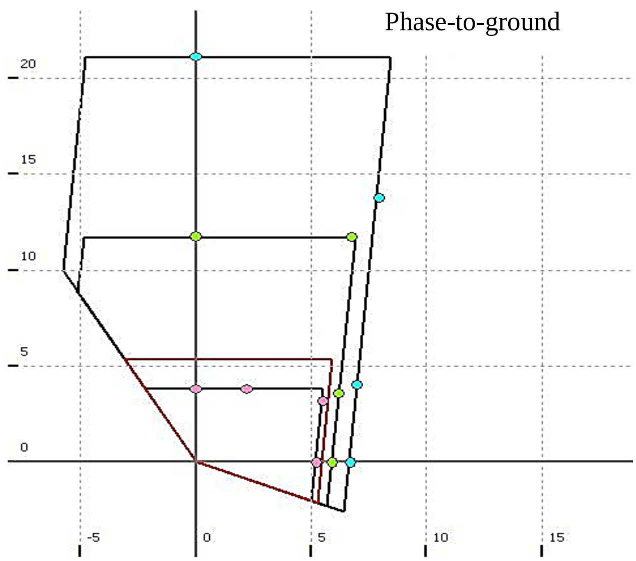

Fig. 17 L1-G fault injections in various zones of the protected line.

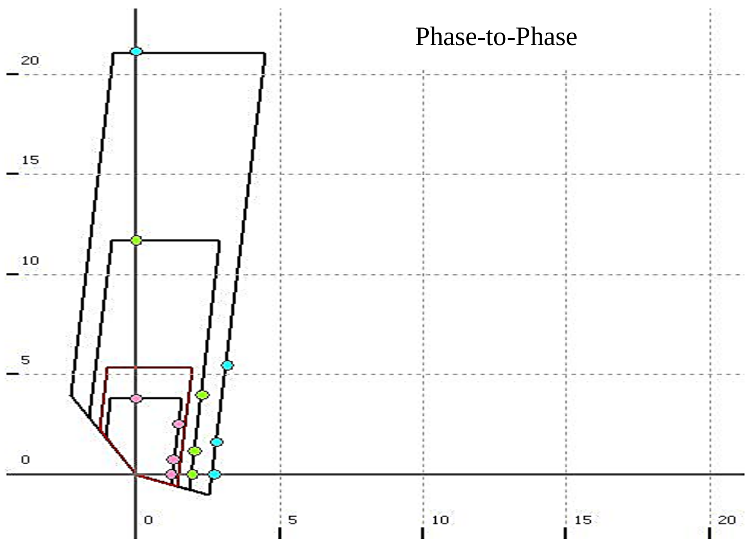

Fig. 18 L1-L2 fault injections in various zones of the protected line.

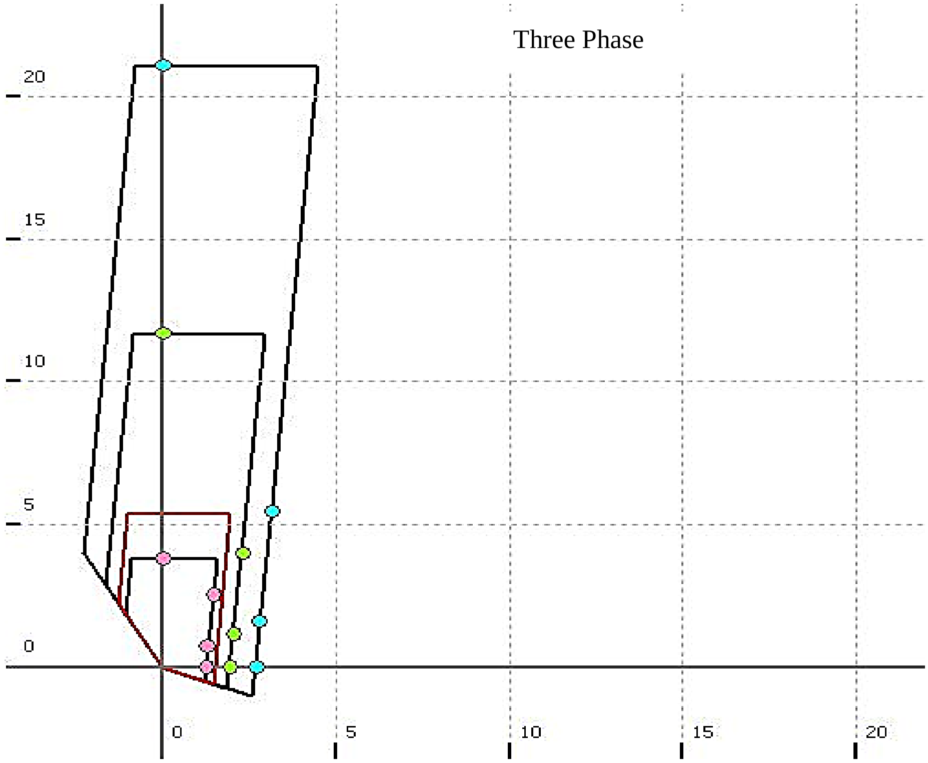

Fig. 19 L1-L2-L3 fault injections in various zones of the protected line.

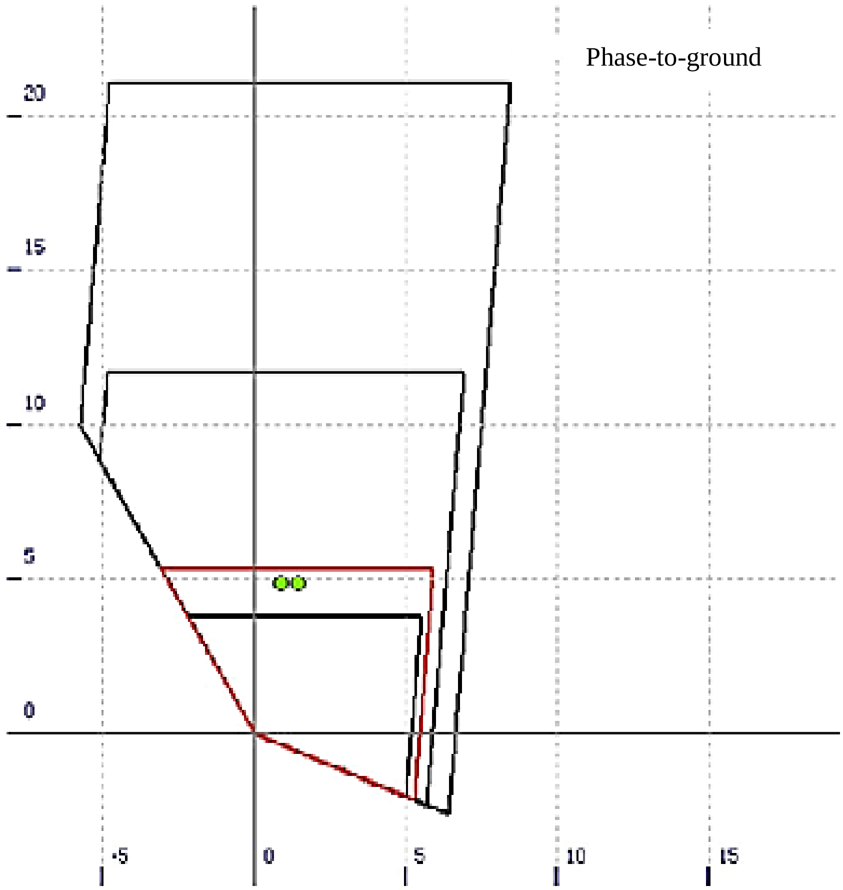

Fig. 20 L1-G fault injections in various zones of the protected line with tele-protection setting.

TABLE V
TEST RESULTS OF L1 FAULT (VARIOUS ZONES)

ZONE	Nominal(Ω)	Z(Ω)	Err. Abs.	Err %	T(s)	R(Ω)	X(Ω)	Pass/Fail
1	5.199 ± 0.19	5.215	0.016	0.3	0.0175	5.215	0	Pass
2	5.881 ± 0.586	5.918	0.037	0.6	0.3844	5.918	0	Pass
3	6.619 ± 1.058	6.702	0.083	1.2	0.7344	6.702	0	Pass
1	6.323 ± 0.19	6.353	0.03	0.5	0.0177	5.502	3.176	Pass
2	7.152 ± 0.586	7.152	0	0	0.39	6.194	3.576	Pass
3	8.049 ± 1.058	8.048	-0.001	0	0.7349	6.97	4.024	Pass
1	4.38 ± 0.19	4.387	0.007	0.2	0.0176	2.193	3.799	Pass
2	13.49 ± 0.586	13.532	0.042	0.3	0.3844	6.766	11.719	Pass
3	15.602 ± 1.058	15.892	0.29	1.9	0.7392	7.946	13.763	Pass
1	3.793 ± 0.19	3.811	0.018	0.5	0.0169	0	3.811	Pass
2	11.683 ± 0.586	11.756	0.073	0.6	0.3849	0	11.756	Pass
3	21.071 ± 1.058	21.127	0.056	0.3	0.7347	5.215	21.127	Pass

TABLE VI
TEST RESULTS OF L1-L2 FAULT (VARIOUS ZONES)

Zone	Nominal(Ω)	Z(Ω)	Err. Abs.	Err %	T(s)	R(Ω)	X(Ω)	Pass/Fail
1	1.222 ± 0.19	1.212	-0.01	-0.8	0.0174	1.212	0	Pass
2	1.904 ± 0.586	1.951	0.047	2.5	0.3889	1.951	0	Pass
3	2.642 ± 1.058	2.714	0.072	2.7	0.7396	2.714	0	Pass
1	1.486 ± 0.19	1.493	0.007	0.4	0.0174	1.293	0.746	Pass
2	2.315 ± 0.586	2.343	0.028	1.2	0.3891	2.029	1.171	Pass
3	3.213 ± 1.058	3.218	0.005	0.2	0.7345	2.787	1.609	Pass
1	2.881 ± 0.19	2.912	0.031	1.1	0.0171	1.456	2.522	Pass
2	4.488 ± 0.586	4.599	0.111	2.5	0.3849	2.299	3.983	Pass
3	6.228 ± 1.058	6.316	0.088	1.4	0.7346	3.158	5.47	Pass
1	3.793 ± 0.19	3.798	0.005	0.1	0.0339	0	3.798	Pass
2	11.683 ± 0.586	11.71	0.027	0.2	0.3844	0	11.71	Pass
3	21.071 ± 1.058	21.169	0.098	0.5	0.7392	0	21.169	Pass

TABLE VII
TEST RESULTS OF L1-L2-L3 FAULT (VARIOUS ZONES)

Zone	Nominal(Ω)	Z(Ω)	Err. Abs.	Err %	T(s)	R(Ω)	X(Ω)	Pass/Fail
1	1.222 ± 0.19	1.237	0.015	1.3	0.0168	1.237	0	Pass
2	1.904 ± 0.586	1.952	0.048	2.5	0.384	1.952	0	Pass
3	2.642 ± 1.058	2.708	0.066	2.5	0.7338	2.708	0	Pass
1	1.486 ± 0.19	1.486	0	0	0.0174	1.287	0.743	Pass
2	2.315 ± 0.586	2.343	0.028	1.2	0.3843	2.029	1.172	Pass
3	3.213 ± 1.058	3.211	-0.002	-0.1	0.7342	2.781	1.605	Pass
1	2.881 ± 0.19	2.935	0.054	1.9	0.0171	1.467	2.541	Pass
2	4.488 ± 0.586	4.599	0.111	2.5	0.3839	2.3	3.983	Pass
3	6.228 ± 1.058	6.302	0.074	1.2	0.7347	3.151	5.458	Pass
1	3.793 ± 0.19	3.803	0.01	0.3	0.0346	0	3.803	Pass
2	11.683 ± 0.586	11.711	0.028	0.2	0.3896	0	11.711	Pass
3	21.071 ± 1.058	21.121	0.05	0.2	0.7344	0	21.121	Pass

TABLE VIII
TEST RESULTS OF L1-G FAULT WITH TELE PROTECTION (VARIOUS ZONES)

	Zone	Z(Ω)	R(Ω)	X(Ω)	T(s)
Without tele-protection	2	4.966	0.875	4.888	0.3742
With tele-protection	2	5.096	1.44	4.888	0.038

Table VIII shows that the trip time is considerably reduced by employing the Tele-protection scheme. Initially the trip time is 0.3742s and with Tele-protection it is reduced to only 0.038s.

IX. CONCLUSION

The current grid structure from protection point of view in Pakistan is a mix of old and new technology. However, there are issues with old technology of electromechanical and static relays in coping with complex situations. Further, as new projects of FACTs, HVDC and renewable energy integration will be undertaken in the country, they will require sophisticated study of grid, advanced algorithms and settings for distance protection of transmission lines to avoid cascading faults. Hence there is a need to upgrade the technology of relay protection and explore the areas of ANN, fuzzy logic and PMU (phasor measurement unit) based techniques to avoid these wide area blackouts. Further as the network of numerical relays will expand the capacity of event logging and Oscillographic record will further help to understand the dynamics of the grid and expand opportunities for further research. This case study shows the results of one such implementation in KE network and the results obtained with software are promising. With the implementation of this project, the additional features of operational flexibility, better efficiency, fault logging, time stamping, and carrier aided protection and numerous other features which are unavailable currently will be realized for grid and helpful for the protection engineers.

REFERENCES

[1] W.P. Davis. Analysis of faults in overhead transmission lines, M.S. thesis, California State University, California, 2012.
[2] A. Haddad and F. W. Doug. Advances in High Voltage Engineering, IET, 2004.
[3] R. J. Marceau, T. Donald, M.C. Gillis and R. Sana. Asymmetric Operation of AC Power Transmission Systems the Key to Optimizing Power System Reliability and Economics, Presses inter Polytechnique, 2006.
[4] A.T.M. Yesansure and T. G. Arora. Numerical quadrilateral distance relay, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2(7), pp. 2920-2927, 2013.
[5] S.H. Horowitz and A.G. Phadke. Power system relaying, 4th edition, John Wiley and Sons, 2014.
[6] M. Eissa. Ground distance relay compensation based on fault resistance calculation, IEEE Transactions on Power Delivery, Vol. 21(4), pp. 1830-1835, 2006.
[7] A. Stosic, A. Marusic and J. Havelka. Transmission lines protection using siprotec numerical relays, Energija, Vol. 66, pp. 165-183, 2017.
[8] M.J. Domzalski, K. P. Nickerson and P. R. Rosen. Application of MHO and quadrilateral distance characteristics in power systems (relay protection), 7th International Conference on Developments in Power System Protection, 2011, pp.555-558.
[9] D.G. Philip and A. Rajendran. Development of a multi-characteristic distance relay, International Conference on Advancements in Power and Energy, 2015, pp. 176-181.
[10] M. Harikrishna. Performance of quadrilateral relay on EHV transmission line protection during various faults, International Journal on Control System and Instrumentation, Vol. 1(1), pp. 1-6, 2010.
[11] Alstom Grid. Network Protection and Automation Guide. Available online at http://rpa.energy.mn/wp-content/uploads/2016/07/network-protection-and-automation-guide-book.pdf on March 24, 2018.
[12] A. Abdelmoumene and H. Bentarzi. A review on protective relays developments and trends, Journal of Energy in Southern Africa, Vol. 25(2), pp. 91-95, 2014.
[13] L. A. Esteves, G. Caicedo and F. Murcia. Field tests for assessing electrical protection performance regarding electromechanical protection relays, Ingenieria e Investigacion, Vol. 32(3), pp.71-75, 2012.
[14] D.S.Baker. Application considerations of static overcurrent relays a working group report, IEEE Transactions on Industry Applications, Vol. 33(6), pp.1493-1500, 1997.
[15] J. Polimac and A. Rahim. Numerical relays–where are we now, 19th International Conference on Electricity Distribution, 2007, pp.1-4.
[16] D.L. Ransom. Upgrading relay protection: be prepared for the next replacement or upgrade project, IEEE Industry Applications Magazine, Vol. 20(5), pp. 71-79, 2014.
[17] F.M.A. Hussain, N. Khan, N. Mariun and S. Mahmod. Microprocessor based distance relay, National Power Engineering Conference, 2003, pp.43-46.
[18] D.G. Philip and A. Rajendran. Numerical conic distance relay, International Conference on Innovations in Information, Embedded and Communication Systems, 2015, pp.1-5.
[19] Bharat heavy electrical limited, Handbook of switchgears, Tata McGraw Hill Education Private Limited, 2005.
[20] A.L.P.d. Oliveira. Numerical distance protection performance analysis in short and long transmission lines using real time digital simulation, IEEE/PES Transmission and Distribution Conference and Exposition Latin America, 2008, pp. 1-6.
[21] Siemens, IPROTEC 7SA522 Distance Protection Relay for Transmission Lines. Available online at https://www.buildingtechnologies.siemens.pl/Images_IC/Images_SG/7SA52en.pdf on March 24, 2018.
[22] A.Venkatesh, K. S. Swarup. Investigating the performance of a symmetrical component distance relay, Proceeding of National Power Systems Conference, 2012, pp. 1-7.
[23] D.K. Singh, A.K. Singh and S.R. Mohanty. An adaptive transmission line protection and modelling of numerical distance relay with analog antialiasing filter, International Conference on Industrial Technology, 2017, pp. 388-393.
[24] A. Saber, A. Emam and H. Elghazaly. Wide area backup protection scheme for transmission lines considering cross country and evolving faults, IEEE Systems Journal, Vol. 99, pp. 1-10, 2018.
[25] M. Younas and S. Qureshi. Analysis of blackout of national grid system of Pakistan in 2006 and the application of PSS and FACTs controllers as remedial measures, International Conference on Electrical Engineering, 2007, pp.1-6.
[26] Damien, S.R. Tholomier. Improving the Performance Of Distance Protection During Wide Area Disturbances. Available online at https://www.pacw.org/fileadmin/doc/DistanceProtectionWAD.pdf on March 24, 2018.
[27] S. Zafar, Y.R. Fizzah, H. Haider and Sana. analysis of the awareness of present day undergraduate electrical engineering students about contemporary technologies, 2nd International Electrical Engineering Conference, 2017, pp. 31-35.
[28] I.A. Group, DRTS-6 Automatic Three-Phase Relay Test Set Manual. Available online at http://www.isatest.com/upload

/prodotti/DRTS%206/pdf/inglese/SIE10156-DRTS6.pdf on March 24, 2018.

Adnan Ali has completed BE and ME in Electrical Engineering from NED University of Engineering and Technology Karachi, Pakistan in 2009 and 2013 respectively. Currently he is working as Assistant Professor in NED University. His research interest includes power systems, transmission systems engineering and energy conversion systems.

Muhammad Ovais Raza completed his BE in Electrical Engineering from NED University of Engineering and Technology Karachi, Pakistan in 2015. Currently, he is working in electrical protection department of Siemens, Pakistan.

Muhammad Hammaduddin completed his BE in Electrical Engineering from NED University of Engineering and Technology Karachi, Pakistan in 2015. His research interest includes electrical power system protection and relays.

Muhammad Saad Aslam completed his BE in Electrical Engineering from NED University of Engineering and Technology Karachi, Pakistan in 2015. His research interest includes electrical power system protection and relays.

Abdul Moeed Saadat completed his BE in Electrical Engineering from NED University of Engineering and Technology Karachi, Pakistan in 2015. His research interest includes electrical power system protection and relays.

Syed Saad Amin completed his BE in Electrical Engineering from NED University of Engineering and Technology Karachi, Pakistan in 2015. He has got experience of working in K-Electric and Schneider.

Syed Muhammad Shakir completed his MS in Energy Management from NED University of Engineering and Technology Karachi, Pakistan in 2015. Currently, he is working as Executive Engineer in electrical and electronic manufacturing industry. His research interest includes power system protection and control, HMIs, Data Communication and protocols.