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Dynamic Model Of 400 Kv Line With Distance Relay

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ABSTRACT
A dynamic three phase model of 400 kV, 450 km Transmission Line Fault Simulator of the Lucknow- Sultanpur (UP India) transmission system with SCADA architecture was designed and constructed to demonstrate overhead transmission line maintenance using Digital Numerical Distance Relay (DNDR). Experiments were conducted to study the working of the relay for its efficacy, performance and procedures of usage by simulating different faults on the transmission line.

This dynamic model comprised three phase generator, transmission lines (representing 400 kV, 450 km in three sections each of 150 km) and Resistive and inductive loads. The system has the circuit breakers, reverse power relay, over current relay. DND Relay has become vital for the protection of modern transmission systems. Many of the existing transmission lines which do not have DND Relays are now being modernized by adding on these relays.

The dynamic model built here provides complete information and know how about usage of the DND Relay for modernizing the existing systems and contributes to efficient and reliable management of maintenance. This dynamic model can be used as a tool for training the students and field engineers. Apart from the study of the DND relay the

Model is provided with the UPFC devices and SCADA architecture making it versatile for power system laboratory training.

Keywords: *Distance Relay, EHV Transmission Model, Protection, SCADA*

CAPABILITY OF THE DYNAMIC MODEL CONSTRUCTED

This dynamic model of 400kV, 450 km is designed as a benchmark for the power system training laboratories and the experiments were performed using this dynamic model:

1. Fault Clearing in the Three Zones of the Transmission Line.
2. Obtaining Distance to Fault.
3. Power Flow in Grid Network
4. Control of Power in Transmission Lines using UPFC device.
5. Application of SCADA.

INTRODUCTION

A three phase dynamic model simulating 400 kV, 450 km Transmission line system was designed and constructed using scaled down parameters with base values to co-relate the parameters of the study obtained on the model to the real system. The model comprised 400 volts, three phase motor generator set provided with motor drives, reverse power relay, short circuit relay with circuit breakers for its protection. Metering was provided by using three phase digital Multi Function Meter (MFM) that display voltage, current, power factor, frequency, active and reactive power. The multifunction meter also has RS485 for communication with HMI (Human Machine Interface). The MFM (Multi Function Meter) and the PLC (Programmable Logic Controller) was used. The generator components were laid out on panel 1 of the model. Panel 2 of the model that is the middle panel simulates three sections of transmission lines; each section represents 150 km length. The data for the transmission line was taken from Sultanpur–Lucknow (UP) India, 400 kV Extra High Voltage line.

The transmission line is provided with Digital Numerical Distance (DND) Relay. It performs two functions: 1) Gives Protection to the transmission line 2) Provides distance to fault for all types of faults encountered in high voltages transmission lines maintenance. The DND Relay has software as its main components which can be programmed as per the requirement of the user and the information about the fault zone of the transmission line is automatically captured by it.

The transmission line (TL) is provided with the digital MFM with similar display and arrangements for communication features like the one used in the generator; over current relay and breaker arrangement. The TL configuration is in the form of a pi-section with RLC values represented as per the base value stated in equation 1, 2 & 3. One MFM is provided at the Sending end of the TL and another at the Receiving end of the last section.

THE RLC OF EACH SECTION OF 150 KM (Table no 1)

Parameter 150 KM TL	Resistance (R) per phase	Inductive Reactance (XL) per phase	C/2 per phase
Actual value in ohms	R1 = 4.17 Ohms	X1 = 50.4 Ohms	1.8 MFD (for pi 0.9 +0.9 MFD)

The Sultanpur – Lucknow transmission line has capacity to carry 900 Amps of current per phase that is equal to a total power of:
= V x I = 400 x1000 x 900 =360 MVA per phase.
The loads are mounted on panel 3 and comprise circuit breakers, short circuit relay and multifunction meters on each resistive and inductive load. The table 1 gives the values of RLC parameters of the loads calculated as per the base values.

SCADA (SUPERVISORY CONTROL AND DATA ACQUISITION)
The equipment is provided with PLC and Master Unit to acquire data from MFM and display it on the computer software. The supervisory command can be issued to this dynamic model as per the software shown in figure 5. The circuit layout of the model is given in figure 4. The special software has been developed for providing the display of MFM from all points of the three panels see figure 6.

FACTS Devices – UPFC (Unified Power Flow Control) device has been provided on the Analyzer to control
i) Voltage magnitude
ii) Phase angle
iii) Impedance
iv) Active and Reactive Power
v) To store energy in the capacitors where spare generator energy is available.

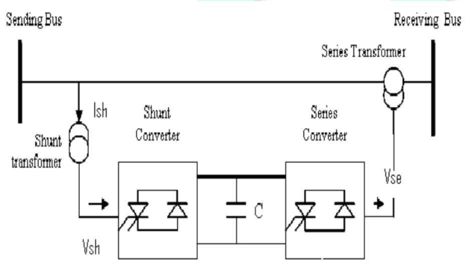

Figure 1 Basic Structure of an UPFC

It can be seen in figure 1 that the UPFC consists of a series and a shunt converter and it is connected back-to-back through a common dc link.

The benefits of utilizing FACTS devices in electrical transmission systems
• Better utilization of existing transmission system assets
• Increased transmission system reliability and availability.
• Increased dynamic and transient grid stability and reduction of loop

The UPFC Device is provided on the panel no. 2 along with the TL. This has plugging arrangement to connect or disconnect from the TL. The Controller comprises a shunt and series arrangement with converter and Inverter circuits (see figure 1). This controls the flow of Active and Reactive power in the TL

POWER FLOW
Figure 2 shows the diagram of a power system. Generators are connected at Buses (1) and (4) while the loads are indicated at buses (3) & (2)

Table 3 By Conversion through base values Grid Parameters obtained from table 2

Base values for the transmission system is: 20 MVA / per phase and 200 KV/per phase. The

transmission line data of Figure 2 give per unit series impedances and line charging susceptances for the normal-Π equivalents of the four lines identified by the buses at which they terminate. The **bus data** in table 2 lists values for P, Q, and V at each bus. The

values of load are calculated from the corres-ponding P vales assuming a power factor of 0.85. Check the Magnitude of Voltage and Phase angle (with reference to the slack bus) at each Generator and Load bus and also note Active and Reactive power in all Trans Lines
Keep 20 volts on Generator bus and load buses
Start the experiment by adjusting the R L C parameters of the Load and the regulating

Transformer tap position to achieve the flow of power in the Load as specified in the figure 2
and likewise adjust Transmission Line parameters & the regulating Transformer to achieve the flow of active & reactive power.
Table 2 Results of Experiment for Power Flow

Data on the Model

Bus Bar	Voltage (V)	I m A Current	Power Factor (Cos φ)
G1	20	75	0.89
G2	20	100	0.9
L1	20	100	0.8
L2	20	75	0.83
T1	20.4	40	---
T2	21	35	---
T3	21	60	---
T4	21	40	---

Bus Bar	MVA	Power Factor (Cos φ)
G1	150	0.89
G2	200	0.9
L1	200	0.8
L2	150	0.83
T1	80	---
T2	70	---
T3	120	---
T4	80	---

Figure 3 400 kV High Voltage Lines

The RLC parameters of 400 KV EHV lines per km
Table 4 Data taken from: Sultanpur – Lucknow line (UP India

Table 5 RLC Parameters of 400 kV line for 150 km

SULTANPUR-LUCKNOW LINE

Nominal Voltage	400 kV
Circuits per phase	1
Sub-conductors per phase	2
Span	400 meters
Conductor Name and Size	Moose,54/3.53 mm Aluminum 7/3.53mm Steel
Resistance per phase per km at 20 degrees	0.0274Ohm

Resistance	4.5 ohms
Inductance	150 mH
XL	46.8 Ohms
Capacitance	1.8 micro Farads (for pi 0.9 + 0.9)

Resistance	0.03 ohms / phase / Km
Inductance	1.00 m H / phase / Km
Inductive Reactance	0.33 ohms / phase / Km
Capacitance	12 n F / phase / Km
Y	3.7×10^{-6} / phase / Km

Inductive Reactance per phase per km	0.3321Ohm
Shunt Admittance per phase per km	3.2983*10-6
Current Carrying Capacity at 40 degrees	900A
Ground Wire	2Number, 7/3.66mm
Ground wire height at tower	30.4m
Tower height	30.4m
Conductor Height at tower	20.75m

BASE VALUES FOR REPRESENTING THE SYSTEM ON THE MODEL

BASE VALUES OF REAL SYSTEM ---- (1)

Base power: 20 MVA
Base Voltage: 200 KV

$I = \frac{20\ MVA \times 10^6}{200 \times 10^3}$ = Base Current: 100 Amps

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$Z = \frac{200\ KV\ x\ 10^3}{100}$ = Impedance: 2000 ohms

The Base Impedance of 2000 Ohms of Real System and the same value on the model co-relates conversion made to real as indicated in equation (2) (3) & (4)

BASE VALUES ON THE AC NETWORK ANALYZER MODEL ----- (2)
400 Volts of the 3 phase generator output is stepped down to 100 volts / phase for the 3 phase through a three phase transformer

BASE VALUES OF THE SCALED DOWN SYSTEM ------------ (3)
(ON THE MODEL)

Base Voltage: 100 Volts per phase
$I = \frac{100}{2000}$ = Base Current: 50 mA

50mA represents 20MVA Power in real system and 100 Volts represents 200KV of real system see equation (1)
Base Impedance: 2000 ohms
Frequency: 50 Hz

BASE VOLTAGE 50V/PHASE ON THE MODEL ------------- (4)

Base Voltage: 50V per phase
$I = \frac{50}{2000}$ = Base Current: 25 mA

25mA represent 20MVA Power in real system and 50 Volts represents 200KV of real system
Base Impedance: 2000 ohms
Frequency: 50 Hz
A comparison between the four equation shows that lower voltage is preferable as it permits the model to represent higher data of Generator, Transmission Line & Loads for power flow problems of a grid network. This gives the relationship between the Base values of Real System and the Model: It means the current of 50 mA on the model represents 100 Amps of the real system. At 100 volts, 50 mA represents 20 MVA of the real system.
Lab experiments were conducted in The MRPC Company laboratory on by simulating 400 kV for a 450 km TL length. The simulated RLC parameter of the transmission line was taken from Sultanpur - Lucknow line. Fault was created at the End of the line to verify the maximum current flowing through the line under a short circuit fault condition. The results were obtained on a three phase transmission line sending 415 volts and stepping down to 100 volts per phase for all the 3 phases. At Voltage = 100 volts, the current in the fault was measured 800 mA. As per the Base value the Fault current of 800 mA is equivalent to 320 MVA (because 50 mA at 100 volts on the above base value represent 20 MVA hence at 800 mA is equal to 320 MVA per phase of the real system). And the current flowing in the fault in the real system is equal to 1600 Amps per phase (as 50 mA represents 100Amps in the real system hence 800 milli Amps in the fault = 1600 Amps per phase in the real system).

COMPONENTS USED ON THE MODEL

Resistive Load 12A (3 KVA)	2
Inductive Load 12A (3 KVA)	2
Breaker (5 Amps)	12
Over Current Relay	6
Multifunction Meter	6
DC Motor	2
Drive for DC Motor	2
Synchroscope	2
Generator Protection	2
Generator (3 Phase, 2.5 KVA)	2
Numerical Distance Relay	1
Housing Panel with	2
150 km Pi Section	3
SCADA Hardware	1
SCADA Software	1
DC Source	1

CIRCUIT LAYOUT

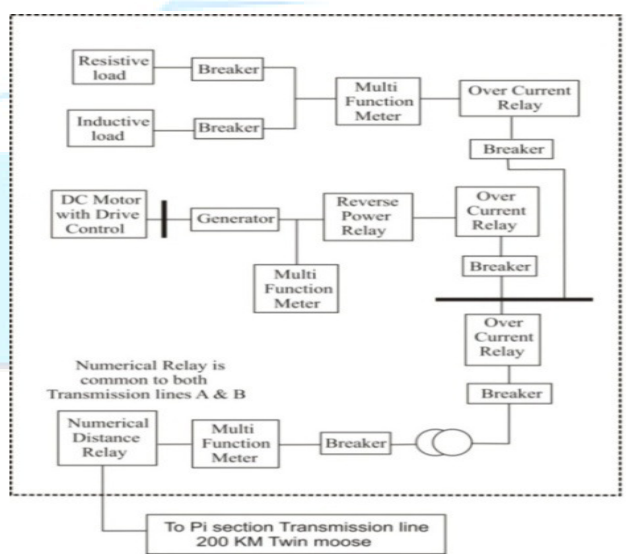


Figure 4 Shows circuit layout

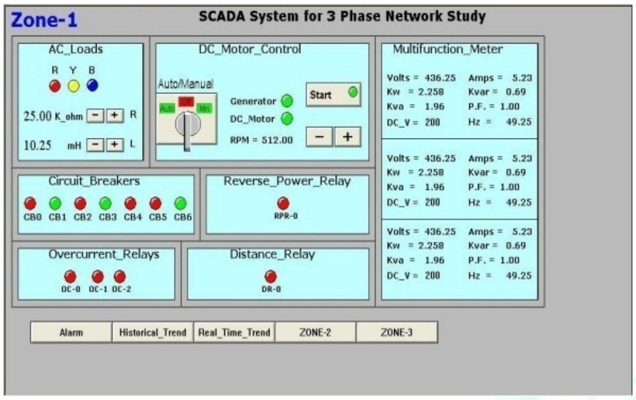


Figure 5 Software layout

DYNAMIC MODEL OF 400 KV TRANSMISSION LINE

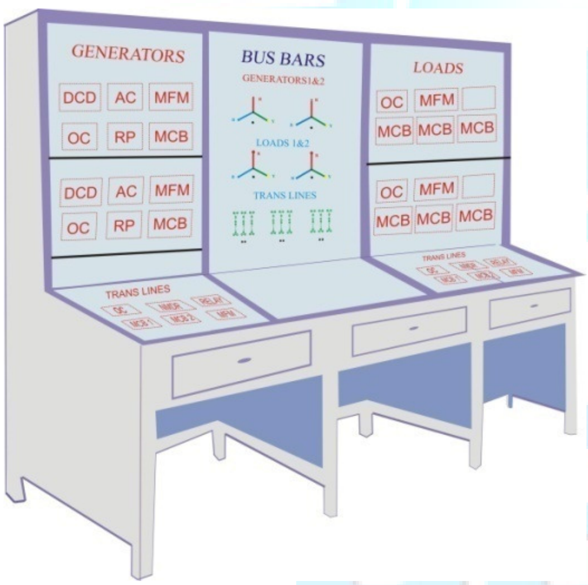


Figure 6 Shows the Equipment
Approx: Panel Size: Length 7.5 ft., height5.5 ft., depth 2.5 ft.
DCD- DC Drive, AC- Switch MFM- Multi Function Meter, OC- Over-current Relay, RP- Reverse Power Relay, MCB- Miniature Circuit Breaker, NDR- Numerical Distance Relay. The Sketch is Not to the Scale: shows 2 Generators, 2 Loads Transmission Lines as per the specifications

DYNAMIC MODEL OF 400 kV TRANSMISSION LINE WITH DISTANCE RELAY

The proposed equipment comprises three panels of the given dimensions see figure 6. It is mounted with the listed items as per the diagram.

PANEL 1
Panel1 has various components related to the two generators. The motor generator set also has a separate control panel with digital meters. A three phase dynamic model simulating 400 kV, 450 km transmission line system designed using scaled down parameters with base values to co-relate the parameters of the study obtained on the model to the real system.
The model comprises 400 volts, three phase motor generator set provided with motor drives, reverse power relay, short circuit relay with circuit breakers for its protection. Metering provided by using three phase digital Multi Function Meter (MFM) that display voltage, current, power factor, frequency, active and reactive power. The multifunction meter also has RS485 for communication with HMI (Human Machine Interface).

PANEL 2
Panel 2 has interconnecting arrangement linking generator, load and transmission lines. It can be referred to as Bus Bars. The transmission line (TL) is provided with the digital MFM with similar display and arrangements for communication features like the one used in Panel.
The TL configuration is in the form of a pi-section with RLC values represented as per the base value stated in equation 1, 2 & 3. One MFM is provided at the Sending end of the TL and another at the Receiving end of the last section. The transmission line is provided with Distance Relay. It performs two functions: 1) Gives Protection to the transmission line 2) Provides distance to fault encountered in high voltages transmission lines maintenance.

PANEL 3
Panel 3 has the load representing components as per the list to represent the resistive and inductive loads of the specified values and MFM, MCB, Relays. The SCADA items comprise PLC, Master Unit, Wireless Unit, and Software on the computer for capturing the data and exercising the Supervisory Control.

DISTANCE PROTECTION BASIC PRINCIPLES

The distance protection relay measures line voltage and line current at the relay location & evaluates the ratio between these quantities. Consider the relay at the area 1 in Figure 4.

When a fault occurs on the protected line the fault current If and voltage Uf is fed into the relay. The relay should trip for faults within a fractional distance k, which is called “the reach setting” of the distance relay, of the total distance between buses A and B. The reach given in distance unit, thus, is a tripping threshold.
Considering a solid fault at the threshold point C, we calculate the voltage drop along the line,

$V_f = kZ_L I_f$ (2.1)

Where Z_L = total line impedance from A to B. The impedance Z_k seen by the relay is computed as follow:

Zk = Vf / If = KZL (2.2)

Equation (2.2) expresses the threshold or the impedance characteristic of the relay. During normal system operation, the impedance seen by the relay is approximately equal to the load impedance that is much larger than the line impedance.

If the fault is within the fraction *k*, then the measured impedance at the relay is Z *less than* $Z_k = kZ_L$ (2.3)

The impedance to the fault point is now within the impedance protection characteristic and the relay will operate. Obviously, the relay will not trip for the fault beyond the fraction *k*.
The impedance characteristic of the relay can be chosen so that the reach is different for different phase angles of the apparent impedance.

Distance relays are categorized in two major schemes; switched scheme and full scheme. In a switched relay, the start elements detect a fault. These elements together with logic blocks determine the correct input signals with respect to the fault type. Zones of operation are decided by timer block. Measuring elements and directional elements decide if the impedance is inside a certain zone and the direction to the fault, respectively. The full scheme relay does not have the start elements. It has measuring elements for each phase, each zone and both phase to phase and phase to ground faults.

NUMERICAL DISTANCE RELAY

A numerical relay consists of the following main subsystems:

- Microprocessor
- Analog input system
- Digital output system
- Power supply

Numerical relays operate on sampled signals and adopt digital computations. Sampling is the process of converting analog input signals, such as current and voltage, into digital input signals. These analog input signals, in case of electromechanical and static relays, are directly fed into the electromagnetic winding or electronic circuits. In order to protect the relay from large transients of the input signals a surge filter is used. The A/D converts the sample values that represent the analog input signals into the digital input signals. However, the conversion is not instantaneous, and for this reason, the A/D system typically includes a sample and hold circuit. The sample-and hold circuit provides ideal sampling and holds the sample values for quantization by the A/D converter. The microprocessor containing the relay algorithm is the controller of the numerical relay. The microprocessor performs all control, computation, self-test, and communication functions. The algorithm functions as a digital filter to extract the fundamental component of the input signal, based on which the relay operation is carried out. The signal from the digital filter is compared with the pre-set threshold in the digital output system. The relay operation is decided based on this comparison.

TRANSMISSION LINE MODEL

The line model consists of 3 identical pi-sections, each corresponding to 150 km of a 400 kV line. The sections can be connected arbitrarily in series or in parallel.
In these experiments, the pi-sections have been connected in series, and the line model has been supplied by a strong grid.
The data for the real 150 km section of the 400 kV line are,
X_r = 50.4 ohms
R_r = 4.17 ohms
C_r = 1.8 MFD

TRANSMISSION LINE PROTECTION

Types of relays provided
1. Short Circuit & Earth Fault Relay
2. Distance Relay
Demonstration of Relays on the model. All the above relays are provided with the banana sockets output on the model which can be plugged in to the Generator or Transmission Line sockets as required.

1. SHORT CIRCUIT & EARTH FAULT

This is a Digital Relay and it has arrangement for setting the current at which it should operate for the purpose of disconnecting the supply. The Circuit Breaker part is also built in the relay.

2. DISTANCE RELAY

This is known as Impedance Relay/ Numerical Distance Relay. It has gained importance in last few years for protection and obtaining distance to fault in HV overhead lines. As the numbers of long over head lines are large this relay has got importance in the field application and several features have been added on to the relay. The Impedance Relay is customized for use of simulated Transmission Line on the model. The relay provides following information.

i) Impedance value (Z) ii) Distance to fault in Kilometers (Converting by a factor of 0.33 reactance per km). The relay has an attachment which will trip the circuit when current exceeds the programmed value set for the relay. A high voltage 400 KV Transmission Line is simulated on the model & fault can be created at the end of Transmission line to demonstrate the working of the relay.

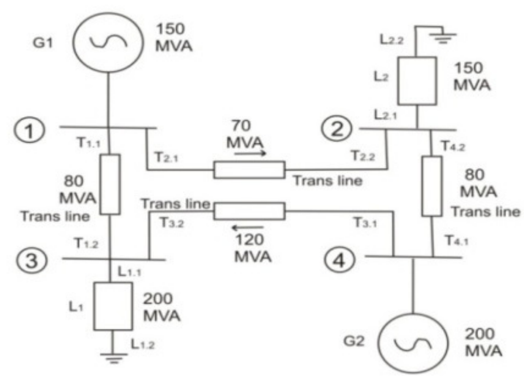
CONCLUSIONS

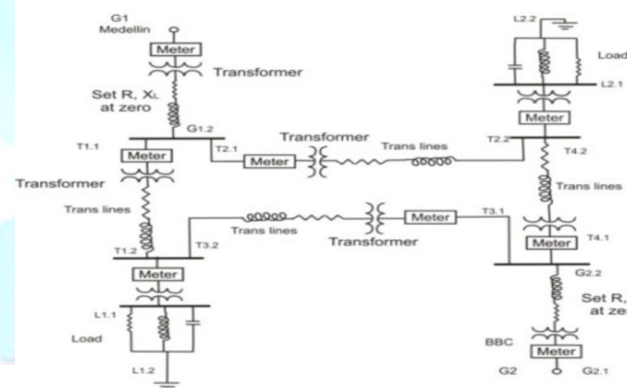
The Dynamic Model of 400kV, 450 km is designed as a Benchmark for power system laboratories. Experiments were performed using this dynamic model:

1. Fault clearing in the three sections of the simulated transmission line.
2. Obtaining distance to fault.
3. Power flow in Interconnected Grid network.
4. Control of power in the transmission lines using UPFC Device.
5. Data Acquisition and Supervisory Control using the SCADA architecture provided on the model.

Distance protection function provides fast and reliable protection for overhead lines and power cables in all kinds of power networks. For each independent distance protection zone, full scheme design provides continuous measurement of impedance separately in three independent phase-to-phase measuring loops as
well as in three independent phase-to-earth measuring loops. Phase-to-phase distance protection is suitable as a basic protection function against two-and three-phase faults in all kinds of networks, regardless of the treatment of the neutral point. Independent setting of the reach in the reactive and the resistive direction for each zone separately makes it possible to create fast and selective short circuit protection in power systems. Phase-to-earth distance protection serves as basic earth fault protection in networks with directly or low impedance earthed networks. Together with independent phase preference logic, it also serves as selective protection function at cross-country faults in isolated or resonantly earthed networks.

Independent reactive reach setting for phase-to-phase and for phase-to-earth measurement secures high selectivity in networks with different protective relays used for short-circuit and earth-fault protection.
The distance protection zones can operate, independently of each other, in directional forward or reverse or non-directional mode. This makes it suitable, together with different communication schemes, for the protection of power lines and cables in complex network configurations, such as double-circuit, parallel lines and Multi-terminal lines. Zone 1, 2 and 3 can issue phase selective signals, such as start and trip. Basic





distance protection function is generally suitable for use in non-compensated
Networks

Figures 2A & B below show the power system studied.

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