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High Impedance Fault Modelling on 11Kv Feeder Using Matlab Simulink

Shyam Salona

M Tech Scholar, Department of Electrical Engineering, National Institute of Technology, Agartala, India

Abstract: ***High impedance faults (HIFs) are serious and troublingdisturbancesonpowerdistributionsystemsbecause the conventional power system protection devices are usually not designedtosenselowfaultcurrent levels. In order to develop a HIF detection algorithm, we first need a HIF model.Thispaperpresents a detailed model of HIF. Several institutions have already performed staged HIF tests in the past. Extracted characteristics from those tests has been used to design this HIF model. The proposed HIF model could replace staged faults which are quite tough to perform in order to get HIF data.***

Keywords: High impedance fault, Distribution system protection,Modeling, Fieldtests

1. Introduction

Distribution feeder conductors are prone to physical contact with neighboring objects such as overgrown vegetation, building walls, or any surfaces below them. This condition raises the electric potential of tangible objects around us and may result in death by electrocution, severe electrical burns, or fires ignited by arcing and heating of materials. The occurrence of such conditions also constitutes a loss of energy to the power companies as not all of the produced electrical power is delivered to their appointed loads.

Power is lost on the way of delivery and dissipated through foreign objects which should not be in contact with the line. Conventional relaying schemes monitor short-circuit conditions where a significant amount of the energy supplied by the power company flows directly into the ground and never reaches its load. This condition is more critical for normal system operation than the one in this study. Diverse and effective solutions have already been found for this type of fault. The type of faulted condition in this study is the one that appears "invisible" to conventional fault detection methods and is caused by a leakage or small current that flows through surrounding objects that present high impedance in the current path to ground. These kinds of faults are hard to detect by monitoring equipment because their presence result only slight increases in load current; thus can be confused with a normal increase in load. To develop algorithm for detecting high impedance fault it is necessary that we study the fault nature at both fault location and measuring end as substation but it's very dangerous to perform such experiment at fault end. So it's very much important that we develop a model of high impedance fault which perfectly imitates high impedance faults.

In this paper a new model is proposed which will imitate a real high impedance fault. For developing algorithms to detect a high impedance fault it's necessary that we know the signatures associated with Hif faults because we can't perform staged high impedance every time in order to collect data for Hif .

By their nature all gases are normally good electrical insulators, but it is well known that the application of a sufficiently high electric filed may cause a breakdown of the insulating properties, after which current may pass through the gas as an electric discharge. The term arc is usually applied only to stable or quasi-stable discharges, and an arc may be regarded as the ultimate form of discharge; it is defined as a luminous electrical discharge flowing through a gas between two electrodes. Electric discharges are commonly known from natural phenomena like sparks whose lengths can vary. Discharges can occur not only in gases, but also in fluids or solids or in almost any matter that can turn from a state of low or vanishing conductivity to a state of high conductivity, when a sufficiently strong field is applied. According to [1-4], starting with a uniform distribution of ions when the current and voltage are zero, the increase in voltage will cause space charge sheaths to form next to the electrodes and, because the mobility of the electrons is much greater than that of positive ions, most of the applied voltage will be across the space charge sheath at the anode as seen in Figure 1. The current densities in this sheath are very small and in order to „restrike" the arc, the space charge sheath must be broken down. If there are no ionizing agents, the breakdown must be ionization by collision; it will therefore require a minimum of several hundred volts. Under the action of the electric field strength, electrons are emitted from the cathode spot. These collide with neutral molecules, thereby ionizing them electrically. The ions in the arc column fly now under the effect of the field strengthtowards both electrodes and heat them by impact to high temperature. The negative electrons hit the anode, and the positive ions hit the cathode. In this way new electrons are liberated within the arc column and at the electrodes, and the process starts again. According to [7] the dynamic characteristics of arcs may be represented as in Figures 2 and3.

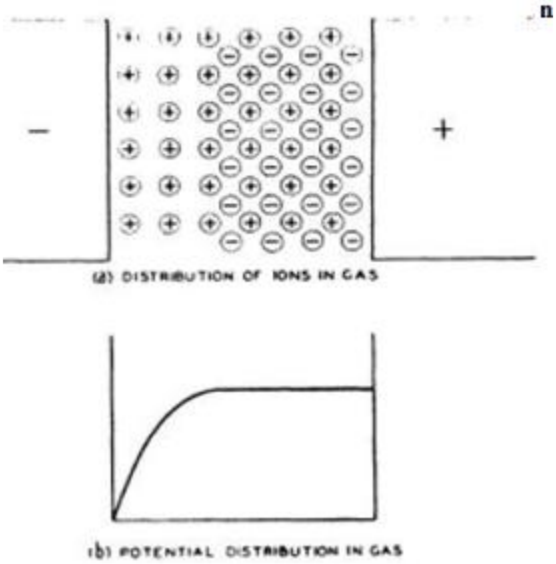

Figure 1: Ions and potential distribution in arc discharge through Gas[1]

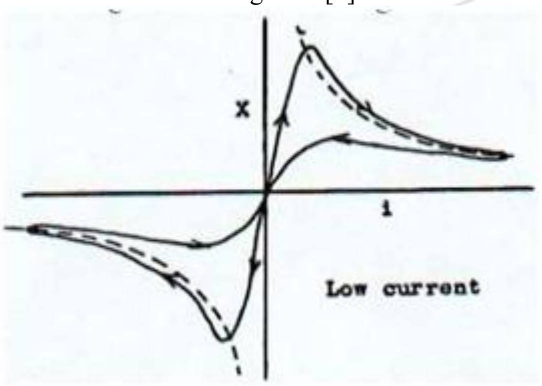

Figure 2: Voltage and current during electricarc [1]

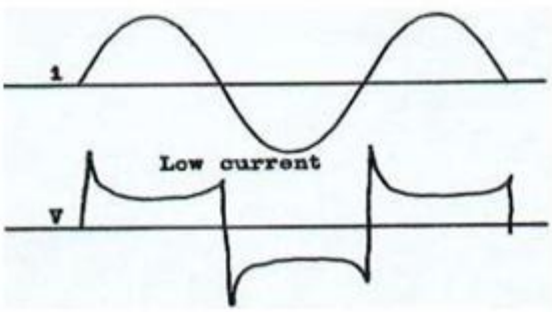

Figure 3: V-I characteristics duringarc [1]

2. Review of HIF Models

The Arcing associated with the HIFs results in energy dissipation in the form of heat that turns the moisture in the soil into steam and burns the grass into smoke. In the arcing phenomenon associated with downed power lines, due to the existence of air between ground and conductor, the high potential difference in such a short distance excites the appearance of the arc. Also, arcing often accompanies these faults, which poses a fire hazard. Therefore, from both public safety and operational reliability viewpoints, detection of HIFs is critically important. High impedance fault is a difficult case to model because most HIF phenomena involve arcing, which has not been perfectly modeled so far. Some previous researchers have reached a consensus that HIFs are nonlinear and asymmetric, and that modeling should include random and dynamic qualities of arcing. Emanuel model is based on laboratory measurements and theoretical components [1] suggested two dc sources connected anti-parallel with two diodes to simulate zero periods of arcing and asymmetry as seen in Figure4.

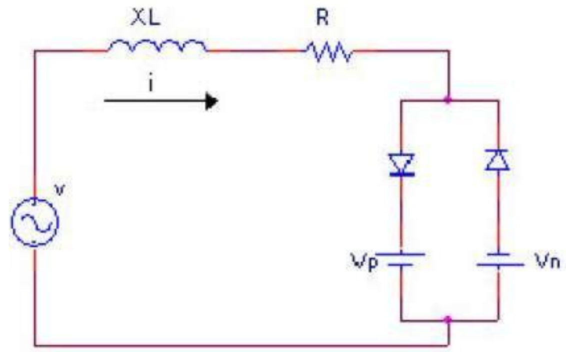

Figure 4: The Emanuel arcmodel [1]

In [4] for consideration of nonlinearity in earth impedance the arcing high impedance fault was modeled as two sets (positive and negative) of diodes in series with a resistance and a dc source Figure 5 illustrates thatmodel.

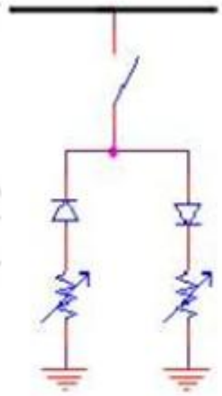

Figure 5: HIF model introduced by [4]

A simplified Emanuel model was introduced in [5]. As shown in Figure 6 the model has two unequal resistances that represent asymmetric fault currents. The two resistances, Rp and Rn, represent the fault resistance: unequal values allow for asymmetric fault currents to be simulated.

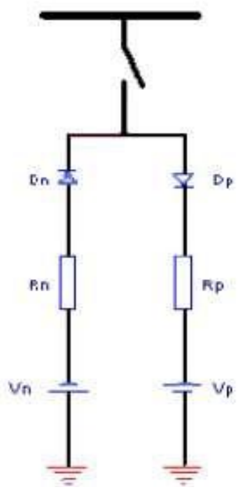

Figure 6: The Introduced HIF model in[5]

A simplified 2-diode HIF model was introduced in [6], as shown in Figure 8. This model consists of a nonlinear resistor, two diodes and two dc sources that change amplitudes randomly every halfcycle.

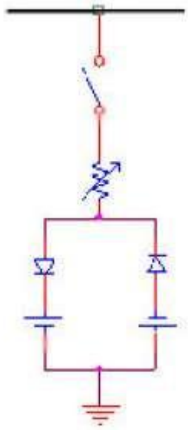

Figure 7: The HIF model proposed by[6]

Several other model has been proposed in recent years using dynamic arc modelling [2]. In this paper I have taken the Emmanuel model [1] as base and effort has been made to perfect the model.

3. Suggested HIF Model

3.1 Base of high impedance model

The base for propose model is related to model proposed by A. E Emanuel in 1990[1]. One part of the model comprises of two anti-parallel diodes with two opposite DC voltage source representing arc voltage of the ground or tree. Two resistive elements and two inductive element in parallel connected in series with arc voltage source and diode as shown in fig.4.1.Resistive and inductive elements are taken to limit the fault current and provide non linearity to the voltage current relationship as explained in reference [1]

Ratio of reactance and resistance is taken 0.1 in this case. Value of Emanuel parameters are given in table 4.1 Inductance value is calculate by considering Tan (θ) value 0.1.

Tan (θ) =2*pi*f*L/R=0.1

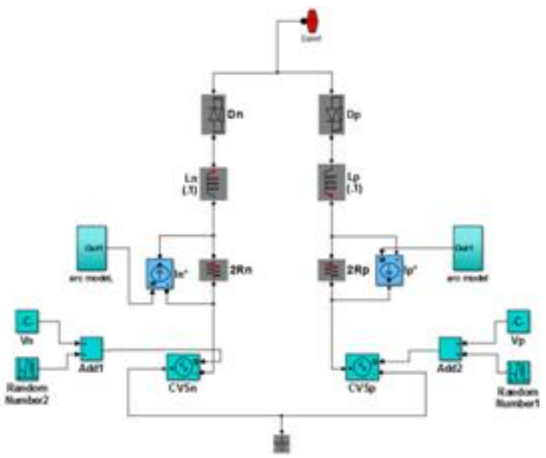

Figure 4.1: Overview of the proposed fault model

Table 4.1: Value of Emanuel parameters [9]

	Rp	Rn	Vp	Vn
1	208	212	3588	3847
2	215	223	4075	4626
3	235	225	5472	4783
4	244	227	6092	4911
5	245	245	6180	6155
6	247	271	6348	8011
7	255	280	6883	8634
8	267	286	7729	9059
9	269	289	7894	9249
10	272	290	8092	9358

Second part of the model contains a variable current source connected with the fault resistance in series. Basically fault current is divided in two part one directly through the fault and second through the current source.

3.2 Fault current build up circuit model

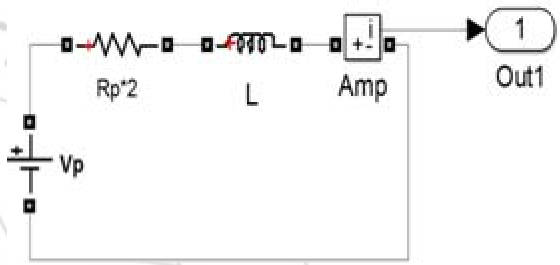

Figure 4.2: Fault current build up circuit

Circuit output current can be defined by below equation

$$I(t) = \frac{V}{R}(1 - e^{-R\frac{t}{L}})$$

Time period of the circuit is defined by

$$T = \frac{L}{R}$$

Circuit reaches its final steady state value in five time periods. Considering the fault current reaches its final value in 10-15 cycles, we can calculate the value of inductance connected in series with the fault resistance.

For example,
If fault reaches its final value in 10 cycles, then time taken for reaching final value on 50 Hz system will be (0.02*10=0.2sec) 0.2 seconds. Also build up circuit should reach its final value in 0.2 sec; means that time period of circuit will be 0.2/5=0.01sec. Now if value of resistance is 500 ohm, then inductance value should be 50 Henry.

Fig 4.3 shows the output of build-up circuit.

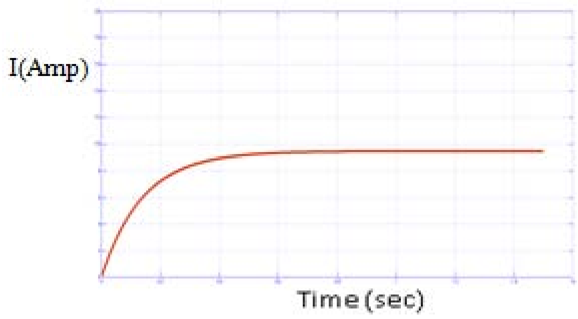

Figure 4.3: Output of build-up circuit

3.3 Addition of randomness in fault current

Study of staged high impedance faults gives the mean value and the variance. Testing on a 13.8 kV, 8 mile feeder in Mexico concluded that the mean value of amplitude and variance in high impedance fault is 10 & .149 respectively. [7]

This fault model utilises that data with the help of a random number generator of 100 Hz frequency. Output signal of the build-up circuit, when multiplied with the sinusoidal signal (50 Hz), results in an exponentially building sinusoidal signal. Passing the signal further through an absolute function block generate a signal of 100 Hz. The resultant signal multiplied with a random number generator signal with amplitude of 1 & variance of 0.15 results in a random amplitude sinusoidal signal whose negative side curve is shifted to positive side due to the absolute function implementation.Fig.4.

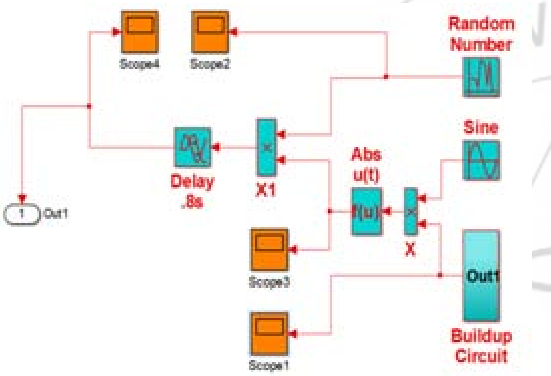

Figure 4.4: Simulink block (input of current source)

Current sources added on the left and right limb in fault model are identical in modelling except for the values of Emanuel parameters.

One transportation lag block is also added in the current source input signal to ensure that building up of the fault current doesn't start before the switching of the fault in main circuit. It is mandatory that the switching tome of fault is same as the transportation lag block setting. This concludes the modelling of high impedance fault.

4. Analysis and Results

4.1 Fault testing distribution network

As study of high impedance fault is mostly limited to low voltage distribution network, so to analyse the proposed model a 15 bus distribution network has been taken into consideration. Operational voltage of the network is 11 kV at 50 hertz frequency. It typically represents a rural Indian distribution network. Line data and bus data for the network has been taken from the reference [10].

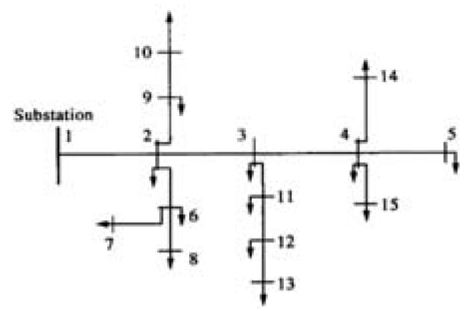

Figure 4.1: single line diagram of a 15 bus distribution network

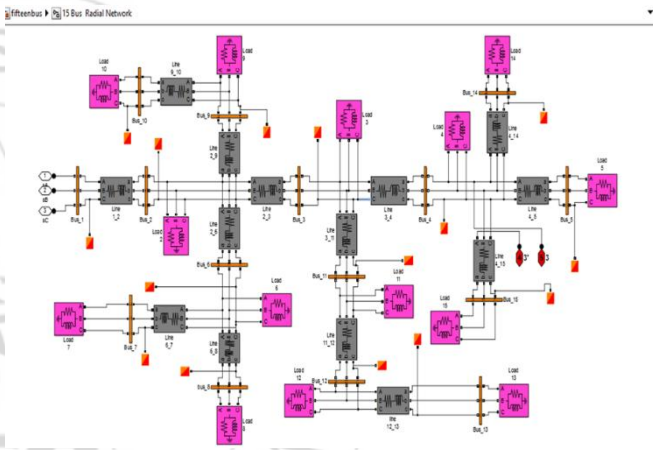

Figure 4.2: MATLAB/SIMULINK model of distribution network

4.2 Model Arrangement

Figure 4.3 shows the models arrangement for analysis of proposed fault model. Two cases has been considered to analyse the fault model. In first case line is intact and fault is touching the line & in second case line is broken and fallen on ground. Both cases present a high impedance fault scenario. Fault simulation time is [0.8 1.5].

For fast Fourier transform analysis substation voltage & current, fault location voltage & current is connected to the respective measurement devises. Also for analysing power fluctuation at substation a RMS block is connected through a multiplier having inputs from voltmeter and ammeter. Figure 4.3 represents case A in which conductor is still connected to the system. Simulation running time is [0 2] seconds.

AC voltage source connected to bus 1 is taken as swing bus. Power flow result in case of no fault is shown in figure 6.2. Power flow results is matched with the results from reference [10], which ensures us that modelling of 14 bus distribution system and the parameters selected is correct.

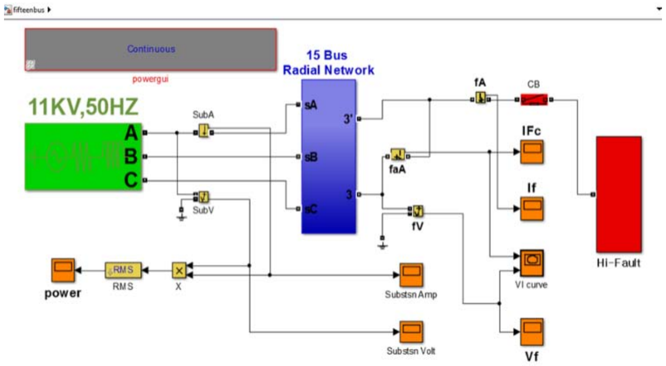

Figure 4.3: Arrangement of model for testing high impedance fault

4.3 Analysis

Simulation time 0-2sec
Fault time 0.8-1.5sec

4.3.1 Voltage and current profile at fault location& substation

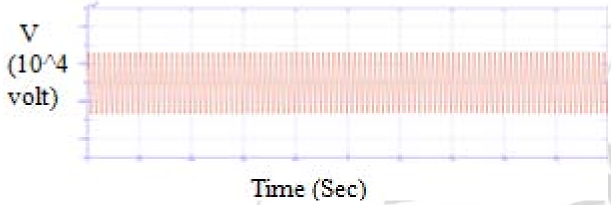

Figure 4.4: voltage at fault location

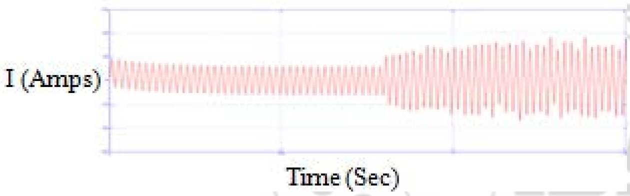

Figure 4.5: current at fault location

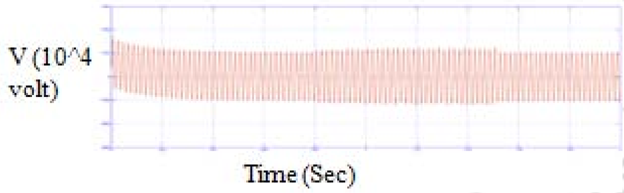

Figure 4.6: voltage at substation

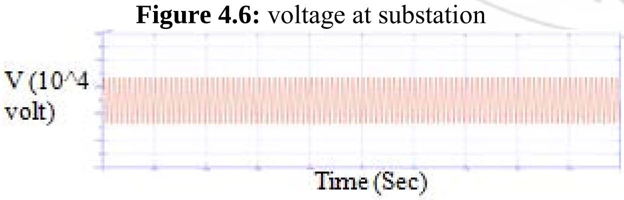

Figure 4.7: Current at substation

Current graphs from figures 4.5 & 4.7 shows represent that fault current are very less if compared to a ground fault. There is a very small rise in current at substation, which couldn't possibly be detected by a conventional over current relay. Random current spikes show the uncertainty in amplitude in case of high impedance fault.

4.3.2 Voltage current relation at fault location

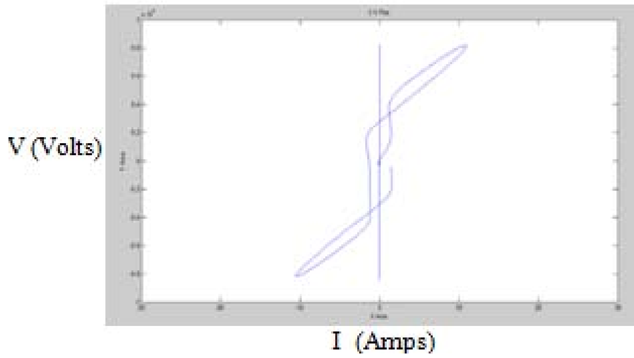

Figure 4.8: voltage current characteristic at fault location

Above V-I curve represents nonlinearity in the fault current.

4.3.3 Harmonic analysis of substation and fault current

FFT tool from powergui block has been used to perform harmonic analysis of current waveform, at substation and fault location. Percent magnitude and third harmonic phase angle with respect to fundamental voltage phase angle determines if the existing fault is a high impedance fault or not.

Angle of different harmonic content at substation and fault location is given in table 6.1. These values of harmonic angles are taken when the reactance to series resistance value is 0.1. As stated by Emanuel, third harmonics angle and magnitude is a function of tan (θ) and difference in positive and negative arc voltages.

Table 4.1: Angle of different harmonics at substation and fault location for one and thirty cycles

	Fault location Angle in degrees		Substation Angle in degrees	
	For 1 cycle	Average of 30 cycles	For 1 cycle	Average of 30 cycles
2nd harmonic	239.2	238.1	235	232.8
3rd harmonic	143.4	142.5	133.3	132.4
5th harmonics	126	121.4	109	104.5

4.3.4 RMS power at substation

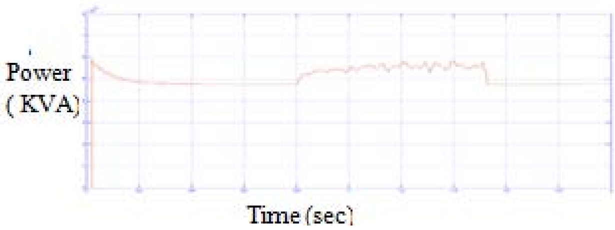

Figure 4.9: KVA power at substation

5. Conclusion

As in case of a high impedance fault, very less fault current is generated, detection of such faults are quite difficult by conventional fault detecting methods and unsuccessful detection of high impedance faults are very hazardous for both personal lives and property damage due to the fire. Several previous models of high impedance faults are discussed in this thesis. Model proposed in this thesis is based on Emanuel model [1].

Analysis results show that this model approximately imitates a high impedance fault. Along with the asymmetry and nonlinearity in fault current this model is able to produce randomness in amplitude with a buildup.

Harmonic analysis of fault current results gives us a specific signature of high impedance fault. Third harmonic phase angle with respect to fundamental voltage phase angle is in a specific range. This signature could be used to program high impedance fault detection algorithm.

At substation RMS value of power graph concludes heavy fluctuations, which represents arcing. As we already know that arcing is nothing but burst of energy in form of light and heat.

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Author Profile

Shyam Salona, born in Gaya, Bihar, India on 5th of January 1991. I am perusing my masters in technology in power systems specialization from National Institute of Technology Agartala, India