Planning and Retrofitting of ABB REF615 in 33KV Kachumari Easun Reyrolle Feeder Panel of APDCL

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Abstract*: Relays play a great role in power system protection and fault diagnosis. The present work deals with a retrofitting work on the feeder panel of 33 KV Kachumari and Short Circuit analysis of the same feeder at Moran 33/11 KV sub-station of APDCL under Sivasagar Electrical Circle. The system is integrated with ABB REF615 class numerical relays in series with the older generation of electro-mechanical relays. The mode of operations of the old and new systems, their circuit diagrams, CT and PT connections, among others have been explored. The whole process of retrofitting has been discussed in details. Investigations shows that the sensitivity of the new numerical relay is better and it is able to successfully isolate various faults viz. over current and earth faults and the existing electrical network elements can sustain the maximum fault level generated by the system. The fault event history after the installation of the numerical relay has been recorded and analyzed. The fault propagation to upstream grid side has been found to be considerably minimized after the retrofitting work. Since inception and commissioning, it is in service and helping in an improved customer experience.

***Keywords*: Numerical Relay, Retrofitting, ABB REF615, IEC 61850, Fault Detection, Short Circuit analysis, Over Current Earth Fault Relay.**

(Article history: Received: 24th May 2020 and accepted 20th December 2020)

I. INTRODUCTION

Assam Power Distribution Company Ltd. (APDCL) is a public limited company responsible for electricity distribution, trading and supply primarily in the state of Assam [1]. As it was formed by taking over the earlier Assam State Electricity Board (ASEB), thus, it has in possession all the previous equipment, transmission and distribution lines, feeder panel etc. Just like any other utility and service, providing secure and reliable supply to their customers is of utmost concern. However, the occurrence of short-circuit fault, broken conductor and other high impedance faults affects the reliability and quality of power supply [2, 3, 4]. The prevention of defects and faults in primary equipment of substation is considered a major differentiating factor in the quality of power delivered by utilities [5]. For this purpose, various power system protective devices have been around for over 100 years[6]. In modern days, relays are vital devices present in any power system. They not only protect various components in the power system from catastrophic damage during faults but also help in maintaining safe and reliable operation of the entire system [7].

Earth faults are one of the most common type of faults associated with power systems. According to data available in literature, in a distribution network the major fault is single phase-to-ground (70% to 80%), followed by phase-to-phase-to ground (17% to 10%), phase-to-phase (10% to 8%) and three-phase (3% to 2%) [8]. Traditionally fuses were employed as protective devices in circuits for the lower voltage and current sections of power networks as their operating time/current characteristics are similar in form to withstand the time/current characteristics of the protected circuits. Through their action, they enable circuits to be kept in service until times when faulted or overloaded parts of a network that must be disconnected to protect the healthy equipment from consequential damage [9]. One of the most commonly used protection schemes in the distribution network is the employment of over-current relays (OCRs) due to its low cost and simplicity in application. It is seen that the coordination of protection relays in a multi-source distribution network with different grounding systems is complex resulting in high operating time for fault tripping. But fast operation of OCRs is desired to minimize the damage to the equipment and to prevent the accidental disconnection of many healthy feeders. The high operating time adversely affects network stability and the power quality. Hence, fast operating time of OCRs is very crucial for dependable working of the distribution network [8]. Also another most common and very crucial fault associated is high impedance fault. They result when a primary circuit conductor makes an unwanted electrical contact with high impedance object. But detecting these faults with the existing facility is a challenge due to the low level of fault current associated [4]. This makes it an ever trending practical research problem which necessitates for newer technical capabilities and upgradation of existing system for better performance. People worldwide are adopting the technical capabilities available in IEC 61850 standard and upgrading the existing electro-mechanical protection system [10]. With the adaptation of microprocessors to protective relays came a new and better class of relays known as a microprocessor relay, a numerical relay, or a digital relay [6]. These new generation numerical relays are becoming increasingly popular due to various advanced and enhanced capabilities. Various advantages of numerical relays over old electromechanical relays have been reported, viz. lower cost, better protection, more information, reliability, flexibility, compactness, digital communication capability, higher sensitivity with great pickup ratio, auto resetting and self-diagnosis capability [6, 11].

The present work is carried out at Sivasagar Electrical Circle of APDCL. As common to many old systems, the panel is equipped with old generation electromechanical relays. But there are safety and performance related limitations associated with it. For instance, sometimes when there is a downstream fault in 33 KV line, the relays couldn't timely sense and actuate. Thus, the fault propagates to upstream affecting and tripping the whole line which otherwise could have been prevented and isolated only within a region. This causes unnecessary workload and delay in maintenance and resetting work. Also, when there is a snap in the distribution lines and conductors are hanging on the poles or arcing with the ground, it is not possible with the existing system to know and take preventive measures unless someone reports it from the other end. As the magnitude of the fault current is generally less than the adopted earth fault setting, it makes it unable to detect through conventional over current and earth fault protection devices [12,13]. These high impedance fault situations often occur when a conductor breaks and falls to the ground. It happens mostly during rainy and stormy season, when objects like tree or a branch falls on the line; leaving an energized conductor dangling or at ground level causing a public hazard [4]. Also, the knowledge of or narrowing down the fault location was another problem. All these problems translate directly in terms of customer experience and satisfaction, improvement of which is the ultimate goal.

In this situation, retrofitting of relays can help a great deal in increasing the lifespan of equipment as well as the quality of service as can be seen in [12, 14]. But no modification should be undertaken without carefully applying proper knowledge of High Voltage Alternating Current (HVAC) and control fundamentals to figure out the economic and technical feasibility of any proposed changes. [15] Incorrect relay settings and unknown system parameters can lead to relay mal-operation as can be seen in various case studies presented in work done by Das et al. [7]. Also, during actual practice, an upgrade is never as easy as it sounds. There are always various problems associated like non availability of original installation drawing, wires not well-labelled, fitting problem of the new relay in old relay's holes, cutting and making alteration in the panel, problem with flexibility of wire insulation among others.[6] All this situation has to be considered and overcome before and during the project. The following work describes the retrofitting work, its testing, short circuit analysis of the 33 KV feeder and evaluation carried out at the Moran 33/11 KV sub-station under Sivasagar Electrical Circle of APDCL.

II. DESIGN AND INSTALLATION METHODOLOGY

The 33 KV Moran feeder of 132/33 KV Moran Grid Sub-Station feeds two 33/11 KV Sub-Stations namely Kachumari and Moran 33/11 KV Sub-Station. The 33 KV Kachumari feeder is tapped from the 33KV line, which enters into the 33/11 KV Moran Sub-Station. The Single Line Diagram of the system is shown later. The 33KV Moran Feeder of 132/33 KV Grid Sub-Station is protected with Siemens 7SR11 series of Numerical relays. On the other hand, the 33 KV Kachumari feeder is equipped with Easun Reyrolle (ER) 2 Over Current and 1 Earth Fault (2OC+1EF) non-directional Electro-Mechanical (EM) relay.

This retrofit project is a custom project. During the course of this work, all the parts of control and protection system, the necessary refurbishment/upgrade, is designed considering the specific project at the designated substation. This actually leads to a high level of customization requiring significant design effort, even when standard designs are used. For the purpose of addressing the issues of designing and installing field wiring, and for the selection of number of protective relays; scheme has been selected and designed conforming to IEC 61850 standard protocol. IEC 61850 standard protocol has three main powerful concepts contained within, which are self-description of data, peer-to-peer communications of data, and the publishing of sampled value data. [11,16]. This standard directly does not describe uses or designs, but rather outlines the formats, building blocks, ways for possible solutions.

For a typical distribution network when fault is at outgoing feeder, the incomer of that particular outgoing also senses the fault current like the outgoing feeder protection system. In that situation, it is very much necessary to block the protection system of Incomer and isolate the fault by using outgoing protection system to get rid of the tripping of Incomer and the other healthy outgoing feeders. With the help of GOOSE of IEC 61850 these difficulties could be overcome, enabling to block the incomer protection in the event when the fault is on outgoing feeder. Time taken to block the protection stage of incomer is around 15 to 20 msec. by using GOOSE. On the other hand, by using input filter of time 5 msec. at incomer and wiring from outgoing IED to Incomer IED, the time measured was around 47 msec. as can be seen in [16].

A. *Easun Reyrolle 33 KV Kachumari Feeder Panel prior to retrofitting work at Moran 33/11 KV sub-station*

The 33KV Kachumari feeder panel of Moran 33/11 KV sub-station operates on 110V DC. As stated earlier, the Control and Relay (C&R) panel has (2OC+1EF) Non-Directional Over current and Earth fault relay for over current and Earth fault protections. Their specification is enlisted in Table 1 and the C&R panel is shown in Fig. 1.

TABLE 1. Relay specification of the C&R panel

Make	Easun Reyrolle
Type	2TJM10*3
CT secondary	5 Ampere
O/C setting	50-200%(IDMT)

E/F setting	20-80%(IDMT)
Case Size	2 V
WD	H405W4057

Whenever any kind of over current fault or earth fault occurs during the 33KV transmission from Moran 33/11KV Sub-Station to Kachumari 33/11KV Sub-Station, the Over Current and Earth Fault (OCEF) relay (2OC+1EF) provides protection to the feeder. Its die-cast frame carries all the sub-assemblies viz. induction disc, electro-magnetic system, operating coil, plug bridge and the contact assembly. The relay follows the Inverse Definite Minimum Time Lag (IDMTL) characteristics. The Current Transformer (CT) connections along with the NO contacts of the OCEF relay is shown in Fig. 2.

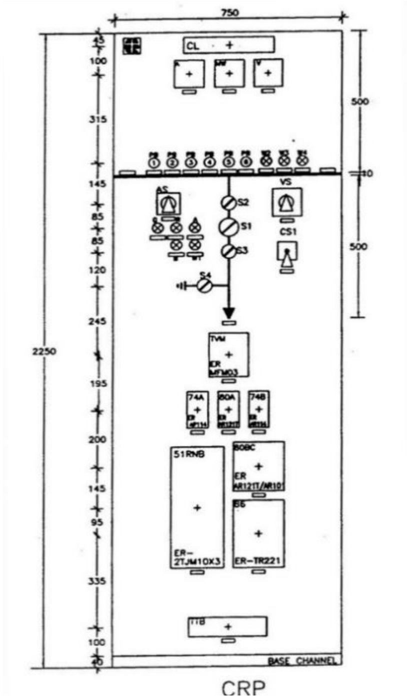

Fig.1. Control and Relay Panel

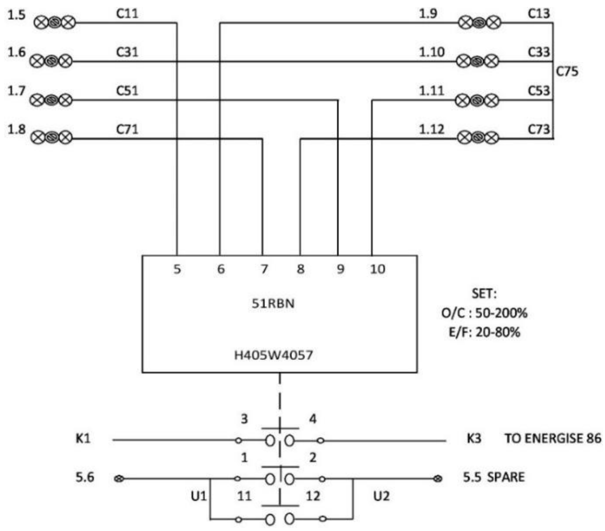

Fig. 2. OCEF relay CT connections

Apart from these, there are various other important auxiliary relays, switches and indicators; which works in a proper and harmonious way to protect the equipment, helps in continuous health monitoring and gives information about any fault. They are mainly: Master Trip Relay, Trip Circuit Supervision Relay, Trip Neutral Close (TNC) Switch, various indications like Breaker ON/OFF, Spring Charged, TCS Healthy and Push Button Switches. The Master Trip Relay gives the trip signal to the Circuit Breaker in order to isolate the fault. It actuates based on the signal sent by OCEF relay whenever it senses any fault in the 33KV line through 33KV CTs. The connection diagram of the Master Trip Relay with Normally Open (NO) and Normally Close (NC) contacts is shown in Fig. 3.

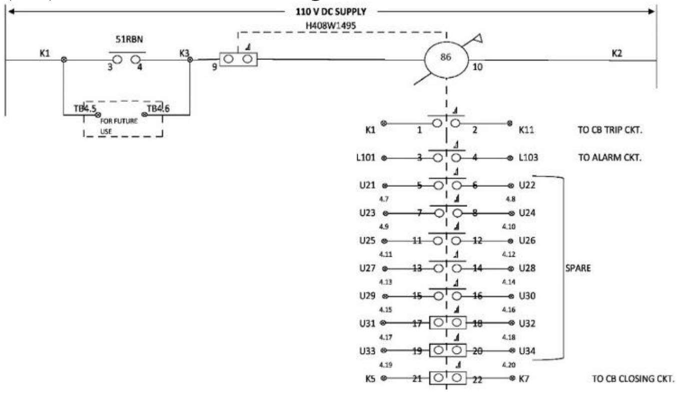

Fig. 3. Master Trip relay connections with OCEF relay along with NO & NC contacts

The Trip Circuit Supervision Relay monitors the health of the trip circuit or the protection system. Due to the special inter-locking, the circuit breaker will not close from Trip Neutral Close (TNC) switch unless the Trip Circuit Supervision provide signal of trip circuit healthiness. TNC switch provides the required signal to the Circuit Breaker in order to close or open (trip) the circuit. Fig. 4 depicts the TNC switch along with the connection diagram.

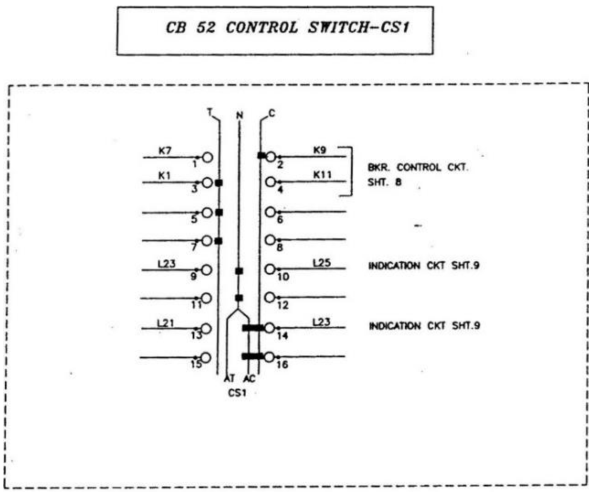

Fig. 4. TNC switch connection diagram

Also there exists multi-colored LEDs to provide the right information or status of the Circuit Breaker, Circuit Breaker Spring charging, Trip circuit etc.; viz. red LED lamp for circuit breaker ON, green for circuit breaker OFF, blue for Circuit Breaker spring charged and white LED for indicating Trip Circuit Supervision (TCS) healthy status. The supervision of Trip circuit healthiness during Circuit Breaker OFF condition is called as pre-close supervision and during Circuit Breaker ON condition is called as post-close supervision. Fig. 5 shows the circuit diagrams for indication in the existing Easun Reyrolle Feeder Panel and Fig. 6 shows closing circuit, tripping circuit, the post-close supervision and pre-close supervision of the existing Easun Reyrolle feeder panel. Apart from them, there are six NO/NC type push buttons (PB) in the feeder panel for Alarm Cancel (PB 1), Alarm circuit test (PB 2), TCS Healthy (PB 3), AC Fail Test (PB 4), DC Fail Test (PB 5) and DC Fail Accept (PB 6).

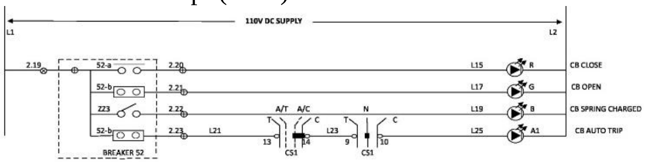

Fig. 5. Indication Circuit diagram

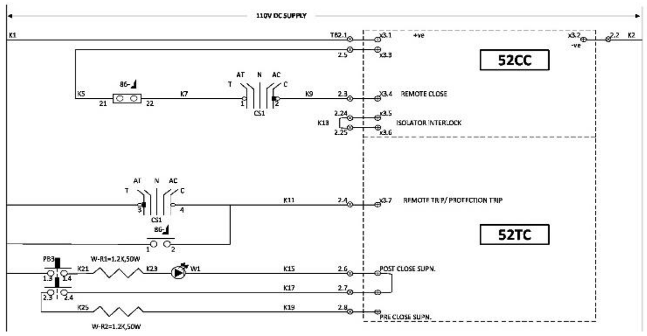

Fig. 6. Closing and Tripping Circuit with TCS connections

B. *ABB REF 615 OCEF (16 BI 6 BO 3HSO) Relay and its Parameter settings*

ABB REF 615 is a feeder protection and control relay. It is designed for protection, control, measurement and supervision of power system. It is capable of using the full potential of IEC 61850 standard for communication and interoperability between sub-station automation devices. The relay provides main protections for overhead lines and cable feeders in the distribution network. Its standard configurations can be altered by changing the signal matrix or the graphical application functionality from the Protection and Control IED Manager PCM600. The application functionality of PCM600 allows the creation of multi-layer logic functions using various logical elements, timers and flip-flops. The user can configure required specifications by combining protection functions with logic function blocks. PCM600 follows IEC 61850 protocol and can provide protection and control functionality in all voltage levels. It simplifies the IED (Intelligent Electronic Device) engineering and enables information exchange with other IEC 61850 compliant tools. PCM600 tool can be used to read and write all the configuration and setting data of an IED with a single command. It gives the privilege to monitor online about the status of Binary Inputs and Binary Outputs (BIBO) of different functional blocks via application configuration. Moreover, parameter setting of PCM600 enables viewing and setting of IED parameters both in offline and online moods. The parameters can be read from the IED to PCM600 and written from the PCM600 to IED[17].

The relay selected to be retrofitted is of "N" configuration with the order code of "HBFNAEFCNGC1BLA11G". It has 16 Binary Inputs,6 Binary Outputs (BIBO) and 3HSO for interfacing with the feeder panel. Though it is a directional Over Current and Earth Fault relay, it has been configured as Non-Directional (ND) relay by keeping the scope for Directional element in future. It is featured with current, voltage, frequency and power protections along with High Impedance Fault (HIZ) protection and Phase discontinuity protections as can be seen in [18].

The existing OCEF Relay is operated for 2OC+1EF i.e. two phases are used for Over current faults and one phase (i.e. CT Secondary star point wire) is used for Earth faults. But the Numerical relays are operated 3OC+1EF which is a clear advantage. Also, the new numerical relay to be retrofitted is compact in size, just about 20 % of the size of the old EM relay but with greater functionality. The rear view of ABB REF 615 along with connection pins of respective BIBO cards such as X100, X110, X120 and X130 is shown in Fig. 7. Also, the signal descriptions with respective binary inputs, signal descriptions with respective binary outputs, programmable LEDs, CT and PT connections of the ABB REF 615 relay are shown in Table 2-Table 5 respectively.

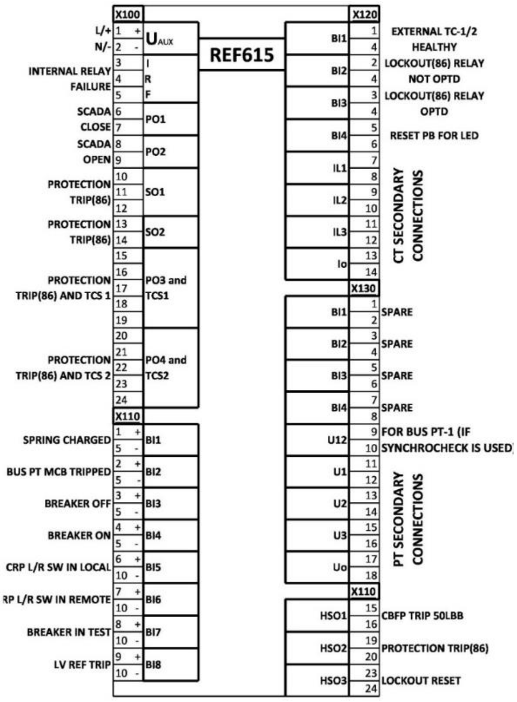

Fig. 7. ABB REF 615 connections on rear view

TABLE 2. Signals Descriptions with respective Binary Inputs of the ABB REF 615 relay

Signal Description	Binary Inputs	Connector Pin
Circuit Breaker Spring Charged	X110-BI1	X110:1+ve,5-ve
PT MCB Tripped	X110-BI2	X110:2+ve,5-ve
Circuit Breaker open condition (CB OFF Position)	X110-BI3	X110:3+ve,5-ve

Circuit Breaker close condition (CB ON Position)	X110-BI4	X110:4+ve,5-ve
CRP Local-Remote in Local	X110-BI5	X110:6+ve,10-ve
CRP Local-Remote in Remote	X110-BI6	X110:7+ve,10-ve
Breaker in Test	X110-BI7	X110:8+ve,10-ve
LV REF Tripped	X110-BI8	X110:9+ve,10-ve
External TCS relay Unhealthy	X120-BI1	X120:1+ve,2-ve
Lockout relay (86) not operated	X120-BI2	X120:3+ve,2-ve
Lockout relay (86) operated	X120-BI3	X120:4+ve,2-ve
LED Reset from external push button	X120-BI4	X120:5+ve,6-ve
Spare	X130-BI1	X130:1+ve,2-ve
Spare	X130-BI2	X130:3+ve,4-ve
Spare	X130-BI3	X130:5+ve,6-ve
Spare	X130-BI4	X130:7+ve,8-ve

TABLE 3. Signal Descriptions with respective Outputs of the ABB REF 615 relay

Signal Description	Outputs	Connector Pin
SCADA Close	X100-PO1	X100-6,7
SCADA Open	X100-PO2	X100-8,9
Protection Trip	X100-PO3	X100-15,16,17,18,19
Protection Trip	X100-PO4	X100-20,21,22,23,24
Protection Trip	X100-SO1	X100-10,11,12
Protection Trip	X100-SO2	X100-13,14
CBFP (50_LBB) Trip	X110-HSO1	X110-15,16
Protection Trip	X110-HSO2	X110-19,20
86 Reset	X110-HSO3	X110-23,24
Internal Relay Failure	X100-IRF	X100-3,4,5

TABLE 4. Programmable LED's incorporated with the ABB REF 615

LED Number	Indication Details
LED 1	Non-Directional Over Current Trip
LED 2	Non-Directional Earth Fault Trip
LED 3	Protection Trip
LED 4	Lockout (86) Relay Trip
LED 5	MET PT MCB Tripped
LED 6	CBFP (50 LBB) _Trip
LED 7	Beaker in Remote
LED 8	SCADA Close
LED 9	SCADA Open
LED 10	86 Reset
LED 11	TC 1/2 Unhealthy

TABLE 5. CT and PT connection terminals of the ABB REF 615 relay

ABB REF 615 rear view terminals	Connector Pin	Terminal Connection Details
X120:IL1	X120:7,8	X120:7-C11(R-Phase S2 of CT Secondary), X120:8,10,12,14 Shorted
X120:IL2	X120:9,10	X120:9-C31(Y-Phase S2 of CT Secondary) X120:8,10,12,14 Shorted
X120:IL3	X120:11,12	X120:11-C51(B-Phase S2 of CT Secondary) X120:8,10,12,14 Shorted
X120: Io	X120:13,14	X120:13-C71(Shorted S1's of CT Secondary) X120:8,10,12,14 Shorted
X130: U1	X130:11,12	X130:11-E11(R-Phase S2 of PT Secondary), X130:12 is connected to X130:13
X130: U2	X130:13,14	X130:13-E31(Y-Phase S2 of PT Secondary), X130:14 is connected to X130:15
X130: U3	X130:15,16	X130:15-E51(B-Phase S2 of PT Secondary), X130:16 is connected to X130:11

The Parameter Setting of the new numerical relay can be done both in offline mode as well as online mode via Protection and Control IED Manager PCM600.The details of Analog Inputs, current protections and voltage protections adopted are listed in Table 6., Table 7 and Table 8 respectively.

TABLE 6. Analog parameter input

Analog Inputs	PC Value
Current (3I, CT)	Primary Current-100A, Secondary Current-5A
Voltage (3U, VT)	Primary Voltage-33000 V, Secondary Voltage-110 V, VT Connection- Delta
Voltage (3UB, VT)	Primary Voltage-33000 V, Secondary Voltage-110 V, VT Connection- U12
Voltage (U o, VT)	Primary Voltage-33000 V, Secondary Voltage-110 V
Current (Io, CT)	Primary Current-100A, Secondary Current-5A

TABLE 7. Details of Current Protections adopted

Current Protections	Start Value	Start value Mult.	Operating curve type	Time Multiplier
51_1: PHLPTOC1 (O/C Low set)	0.60×In	1.0	IEC Normal Inverse	0.05
50_1: PHHPTOC1 (O/C High set)	2.40×In	1.0	IEC Definite Time	Operated delay time:40 msec.
51N_1: EFLPTOC1 (E/F Low set)	0.20×In	1.0	IEC Normal Inverse	0.05
50N_1: EFHPTOC1 (E/F High set)	0.80×In	1.0	IEC Definite Time	Operated delay time:40 msec.
46PD: PDNSPTOC1 (Phase Discontinuity)	20%	Operated Delay Time: 7000 msec.		
HIZ: PHIZ1 (High impedance fault detection)	Security Level: 5			

TABLE 8. Details of voltage Protections adopted

Voltage Protections	Voltage selection	Start value	Operating Curve type	Operate delay time (msec.)
59_1: PHPTOV1(Over Voltage)	Phase to Phase	1.10×Un	IEC Definite Time	40
27_1: PHPTUV1(Under Voltage)	Phase to Phase	0.90×Un	IEC Definite Time	60

III. Retrofitting of ABB REF 615 Relay with 33KV Easun Reyrolle Feeder Panel

Once the connections and parameter setting are known and wires in the Easun Reyrolle Feeder Panel are selected properly, the retrofitting could be done. For the purpose of retrofitting, there are number of stages and operations involved. Initially the wires are ferruled properly and the existing Easun Reyrolle panel surface has been cut as per the dimension so as to accommodate the upcoming ABB REF 615 relay. Then the new relay is connected by selecting proper criteria and subsequently powered up. For this, the CT and PT connections have to done accordingly by properly emphasising on the previous connection and provisions available. Along with it, the binary input connections, Power output connections and TCS connections have to be done properly. Lastly the programming and parameter settings have to be loaded or write to the IED. Once everything is installed and ready, the feeder can be charged and loaded.

In the beginning, the naming or ferruling of the wires should be done properly to ease the retrofitting work of ABB REF 615. The wires are crimped with bottle lugs in one end (to be connected with ABB REF 615) and other end with U lugs (to be connected with Easun Reyrolle Feeder Panel). Proper documentation of ferruling is also important from maintenance and future upgradation/retrofitting point of view. Table 9 enlists the ferrules used in this retrofitting work.

TABLE 9. Ferrules made for the work

Ferrule Name	Numbers of wires (i.e. two ferrules per wire)	Ferrule Name	Numbers of wires (i.e. two ferrules per wire)
J1	1	K7	1
J2	3	K9	1
L19	1	K11	1
L17	1	K15	1
L15	1	TB 2.7	1
K1	4	TB 2.8	1
U32	1	C11	1
U22	1	C31	1
L101(1.3)	1	C33	1
L101(1.4)	1	C51	1
L102	1	C71	1
R	2	B	2
Y	2		

The new ABB REF 615 Relay to be retrofitted is connected in series with the Easun Reyrolle (2OC+1EF) OCEF Relay. For this the CT secondary terminals from the switchyard has to be connected to both Easun Reyrolle Relay and ABB REF 615 Relay in series. Once done, for the purpose of powering up the relay, the 110 V DC available on the Feeder Panel has to be connected to the relay in the terminals as shown in Table 10. Also, for the CT & PT terminal connections proper shutdown of the 33 KV Feeder should be ensured. As stated earlier, the CT connections is in series to both the Relays as shown in Fig. 8.

TABLE 10. Connections for powering up the relay

X100 of ABB REF 615	Connection to be done on Easun Reyrolle Feeder Panel
X100:1	J1 (TB 1.15) =Positive
X100:2	J2 (TB 1.16) =Negative

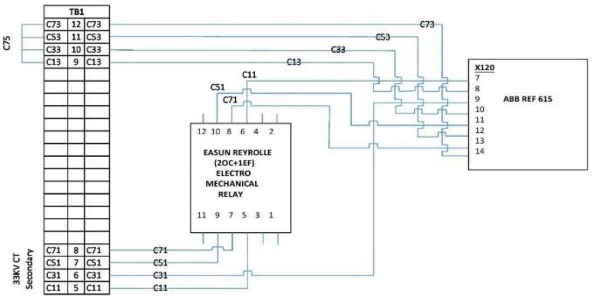

Fig. 8. CT connections to be made with existing Electromechanical relay

For the CT connections, initially the outgoing CT terminals of Easun Reyrolle Relay have to be disconnected. For this, ferrule no. C13(ER relay pin no.6), C73(ER relay pin no.8) and C53(ER relay pin no.10) are to be disconnected from ER relay and to be connected to X120:8,14,12 of ABB REF 615 respectively. Then the ER relay CT outgoing terminals are to be connected to ABB relay by using proper ferruled wires as enlisted in Table 11.

TABLE 11. CT connections of ER relay with ABB relay

Ferrules	Connection to be made
C11	Easun Reyrolle Relay pin no.6 to X120:7 of ABB Relay
C71	Easun Reyrolle Relay pin no.8 to X120:13 of ABB Relay
C51	Easun Reyrolle Relay pin no.10 to X120:11 of ABB Relay

As the existing ER relay is a (2OC+1EF) relay, its C31 terminal of CT secondary doesn't extend to ER relay. So, first of all the shorting of C31 of TB1.6(ER panel) and C31 of TB 1.10(ER panel) has to be removed. Now, TB1.6 of ER Feeder panel is connected to X120:9 of ABB relay by using C31 ferruled wire which has been prepared earlier. Finally, the X120:10 of ABB relay has been connected with TB1.10 of ER feeder panel by using C33 ferruled wire. The PT terminal connections are shown in Fig. 9 and connection details are enlisted in Table 12.

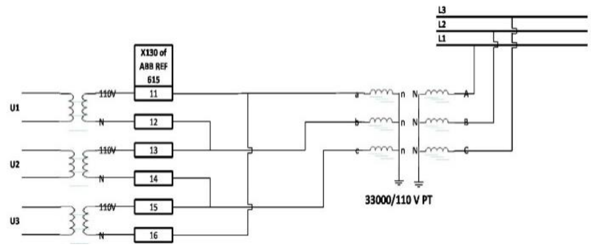

Fig. 9. PT Connections

TABLE 12. PT connections for ER relay with ABB relay

X130 of ABB REF 615	Connection to be done on Easun Reyrolle Panel
X130:11	E11 or TB 1.13 of ER feeder panel or E13
X130:12	E31 or TB 1.14 of ER feeder panel or E33
X130:13	E31 or TB 1.14 of ER feeder panel or E33
X130:14	E51 or TB 1.15 of ER feeder panel or E53
X130:15	E51 or TB 1.15 of ER feeder panel or E53
X130:16	E11 or TB 1.13 of ER feeder panel or E13

Also the power output as well as TCS connections need to be done for the new relay. For normal close operation of circuit breaker via ABB REF615 relay closing push button, SCADA Close command of the relay which is in X100-PO1 has been used. For closing circuit, the X100-PO1 connector pins need to be connected in parallel to the existing TNC switch connector pins. Similarly for normal open operation of circuit breaker via ABB REF615 relay tripping push button, SCADA Open command of the relay which is in X100-PO2 has been used. The X100-PO2 connector pins are connected in parallel to the existing TNC switch connector pins for tripping circuit. The detail connection for SCADA Close & SCADA Open is shown in Table 13 and can be visualized with reference to previous Fig. 6. Also the Binary Input X110 and X120 terminal block connections are described in Table 14.

TABLE 13. Detailed connections of X100 output terminal block

Signal Description	Power Output	Connector Pin	Connection to be done on ER Feeder Panel
SCADA Close (Breaker ON)	X100-PO1	X100: 6 (+ve)	K7 of Master Trip Relay or TNC switch from figure 6 above by using K7 ferruled wire
		X100: 7 (-ve)	K9 of TB 2.3 or TNC switch from figure 6 above by using K9 ferruled wire
SCADA Open (Breaker OFF)	X100-PO2	X100: 8 (+ve)	K1 of Master Trip Relay or TB 2.1 from figure 6 above by using K1 ferruled wire
		X100: 9 (-ve)	K11 of TB 2.4 or TNC switch from figure 6 above by using K7 ferruled wire

For Trip circuit Supervision and Protection Trip operations X100-PO3 connector pins of ABB REF615 are employed. Firstly, the connector pins X100:15 and X100:16 has been shorted and then X100:17 and X100:19 need to be shorted as shown in the Fig. 10. Then the X100:16 is to be connected to the 110 V positive DC supply i.e. K1 of TB 2.1 or Master Trip Relay. The X100:18 is connected to K15 of TB 2.6 from Fig. 6 and the K17 of TB 2.7 and K19 of TB 2.8 are disconnected from the TB2 of Easun Reyrolle Feeder Panel. Then an external Resistance of 22kΩ, 5W has been connected across it. When Breaker is in ON condition, X100-PO3 NO contacts and Breaker Auxiliary Switch NC (52a) and NO (52b) contacts remains in normal positions. For that instance, Trip circuit supervision is done through 52a (NC contact), which is called Post Close Supervision. On the other hand, during Breaker OFF condition, the Trip Circuit Supervision is done through 52b (becomes NC contact as CB is OFF), which is called Pre-Close Supervision. During normal tripping operations from TNC switch, if the breaker gets the tripping command continuously due to the fault in TNC switch or any other reasons, the trip coil may get damaged due to this continuous tripping pulse through 52b (becomes NC contact for pre-close supervision). To avoid this type of problem an external resistor is connected in series with 52b as shown in the Fig. 10.

TABLE 14. Binary Input X110 and X120 terminal block connections

Signal Description	Binary Input	Connector Pin	Connection to be done on ER Feeder Panel
Spring charged	X110-BI1	X110:1(+ve)	L19 from figure 5 above by using L19 ferruled wire
		X110:5(-ve)	Need to connect to J2 of ER panel or X100:2 of ABB relay
Breaker OFF	X110-BI3	X110:3(+ve)	L17 from figure 5 above by using L17 ferruled wire
Breaker ON	X110-BI4	X110:4(+ve)	L15 from figure 5 above by using L15 ferruled wire
Lockout (86) relay not operated	X120-BI2	X120:3(+ve)	U32 from figure 3 above by using U32 ferruled wire (Need to short K1, U21 and U31 in master trip relay of ER panel by using K1 ferruled wires)
		X120:2(-ve)	Need to connect to X100:2 of ABB relay
Lockout (86) relay operated	X120-BI3	X120:4(+ve)	U22 from figure 3 above by using U22 ferruled wire (Need to short K1, U21 and U31 in master trip relay of ER panel by using K1 ferruled wires)
Reset Push Button for LEDs	X120-BI4	X120:5(+ve)	1.4 of PB1 (NO contact) (Need to connect 1.3 of PB1 to L101 of ER panel)
		X120:6(-ve)	L102 of ER panel or any negative terminal of 110V DC

During Protection trip operation X100-PO3 NO contacts change its state to NC and hence the Trip Coil will get a 110V DC voltage pulse for a very short duration, which leads to trip the Circuit Breaker. The whole TCS and protection trip connection is shown in Fig. 10.

Now, after the proper hardwired installation and connection, the IED has to be configured by providing proper parameters to operate. For this, the IED is connected to the laptop through ethernet cable and the parameter settings are written (as discussed above) into the IED with the help of PCM600. Then a rechecking for these parameter settings is done with the Human Machine Interface (HMI) available on the ABB REF615 relay. Once all the installation and parameter settings are over, the relay is ready for operations. For initiation, the 33KV Kachumari Feeder of 33/11 KV Moran Sub-Station has been charged. After charging, the behaviour of the relay is found to be satisfactory. The final look of the 33KV Kachumari Feeder Panel is shown in Fig. 11.

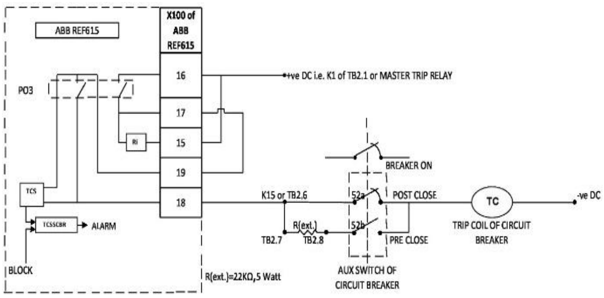

Fig. 10. TCS and Protection Trip Connection

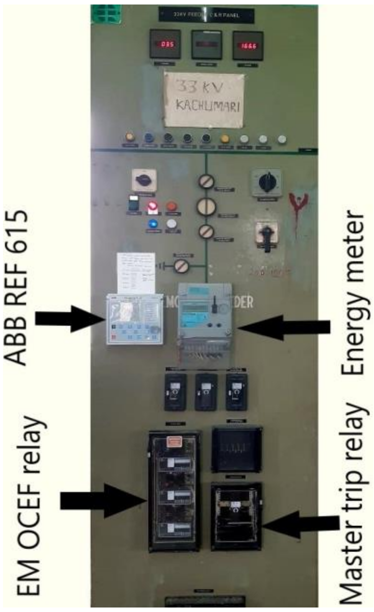

Fig. 11. 33KV Kachumari Feeder C & R Panel after completion of the relay retrofitting

IV. SHORT CIRCUIT ANALYSIS FOR 33 KV KACHUMARI FEEDER

It is well known that for a far end of generator the most severe fault is L-L-L fault (or L-L-L-G) or 3-Phase fault. To analyze the fault level of 33KV Kachumari Feeder and to ascertain the sustainability of the electrical network a fundamental approach has been employed. Hence, the fault level of 3-Phase fault is calculated and compared with the respective Circuit Breakers' Current Breaking Capacities (CBC) and Short Time Current (STC) characteristics of Current Transformers, Circuit Breakers and Isolator Switches. For that, the Single Line Diagram of Moran 132/33 KV Grid Sub-Station to the Kachumari 33/11 KV Sub-Station (Load) has shown in the Fig. 12. The respective details of the Power Transformers, Circuit Breakers, Current Transformers, and Isolator Switches have been shown in the Table 15.

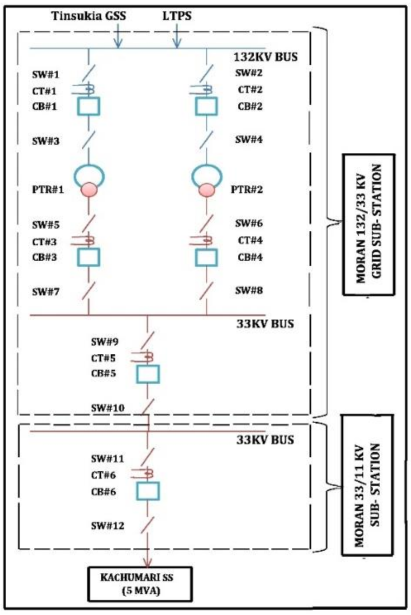

Fig.12. Single line diagram of electrical network in the field

TABLE 15. Details of various components from the Single Line Diagram

Sl. No.	Component	Abbreviation	Ratings
1.	Power Transformer	PTR#1	16 MVA, 132/33 KV, Vector Group= YNyn0, %age Impedance(%Z_1) =9.91%
		PTR#2	16 MVA, 132/33 KV, Vector Group= YNyn0, %age Impedance(%Z_2) =9.884%
2.	Circuit Breaker	CB#1 and CB#2	145 KV, 1250 A, Breaking capacity= 40KA, STC=40 KA for 3 Seconds, CGL
		CB#3 and CB#4	36 KV, 1250 A, Breaking capacity=25 KA, STC=25 KA for 3 Seconds, CGL
		CB#5	36 KV, 1250 A, Breaking capacity=26.3 KA, STC=26.3 KA for 3 Seconds, ABB
		CB#6	36 KV, 1250 A, Breaking capacity=25 KA, STC=25 KA for 3 Seconds, SIEMENS
3.	Current Transformer	CT#1 and CT#2	145 KV, 4-Core, CTR= 200-100/1-1-1-1, Short Time Current (STC)=31.5 KA for 1 Second, Accuracy Class:0.5,5P10, PS, PS.
		CT#3 and CT#4	36 KV, 4-Core, CTR= 400-200/1-1-1-1(for CT#3) & CTR= 600-300/1-1-1-1(for CT#4), Short Time Current (STC)=20 KA for 1 Second, Accuracy Class:0.5,5P10, PS, PS.
		CT#5	36 KV, 3-Core, CTR= 200-100/1-1, Short Time Current (STC)=20 KA for 1 Second, Accuracy Class:0.5,5P10, PS.
		CT#6	36 KV, 3-Core, CTR= 200-100/5-5, Short Time Current (STC)=16 KA for 3 Second, Accuracy Class:0.5,5P10, PS.
4.	Isolator Switch	SW#1 to SW#4	145 KV, Short Time Current (STC)=31.5 KA for 3 Second
		SW#5 to SW#12	36 KV, Short Time Current (STC)=25 KA for 1 Second

The Full Load Current (I_{FLA1}) of the Power Transformer#1 (PTR#1) and Full Load Current (I_{FLA2}) of the Power Transformer#2 (PTR#2) at the LV side (33 KV side) can be calculated as follows:

We know, $S= (\sqrt{3}) \times V_{L-L} \times I_{FLA}$

Where, S= Power Transformer Capacity or Apparent Power
V_{L-L} = Line Voltage of the system; and
I_{FLA} = Full Load Current of the system

For PTR#1, $16000= (\sqrt{3}) \times 33 \times I_{FLA1}$ => $I_{FLA1}=279.927$ A
For PTR#2, $16000= (\sqrt{3}) \times 33 \times I_{FLA2}$ => $I_{FLA2}=279.927$ A

Since, PTR#1 and PTR#2 both are in parallel.

Therefore, the Total Full Load Current of the system will be,

$$(I_{FLA}) = (I_{FLA1}+ I_{FLA2}) = 559.854 \text{ A}$$

Now, the total percentage impedance of the parallel system will be,

$$\%Z_{TOTAL} = \frac{(\%Z1)\times(\%Z2)}{(\%Z1)+(\%Z2)} = \frac{(9.91)\times(9.884)}{(9.91)+(9.884)} = 4.95\ \%$$

Let, a L-L-L fault or 3-Phase fault occurs in the 33 KV Kachumari feeder between Moran 33/11 KV Sub-Station and Kachumari 33/11 KV Sub-Station near the sending end of the of the feeder.

Then the maximum fault level or short circuit current will be,

$$(I_{SC}) = \frac{\text{I FLA}}{\text{\%Z TOTAL}} \times 100$$

$$= \frac{559.854}{4.95} \times 100$$

$$= 11310.18 \text{ A}$$

$$= 11.31 \text{ KA}$$

Now, the maximum fault level of the system has been compared with the Breaking Capacities and the Short Time Currents of all the 33KV Circuit Breakers, Short Time Currents of both the 33 KV Current Transformers and Isolator Switches from the table. From the comparative analysis, it can be visualized that the existing electrical system can sustain the maximum fault level of the system. Or, in other words it can be considered as a reference value for proper selection of circuit components' ratings for operational safety and sustainability.

V. RESULT AND DISCUSSION

In our day to day observations, it has been found that whenever an earth fault of low current (approximately 1.3-1.6×In) occurs during rainy weather, the 33KV Kachumari feeder of 33/11 KV Moran Sub-Station doesn't trip in time; rather the 33KV Moran Feeder of 132/33 KV Moran Grid Sub-Station trips even after the proper coordination between the relays is achieved. To understand the characteristics of the Electro-mechanical relay and to investigate whether their performance is a probable cause of tripping of 33KV Moran Feeder of 132/33 KV Grid Sub-Station, the existing Electro-mechanical relay is tested. The new numerical relay is also tested for checking its applicability and comparison purpose. For this, Omicron CMC 256-6 testing kit has been used and the results obtained are comparatively shown in Table 16.

TABLE 16. Relay test results

Relay Type	Relay Settings adopted		Injected Current (A)		Calculated Tripping time for both Overcurrent and Earth fault for IEC Normal Inverse Curve (msec.)	Measured Tripping time during test (msec.)		Remarks
	For Overcurrent fault test	*For Earth fault test*	*For Overcurrent fault test*	*For Earth fault test*		*For Overcurrent fault test*	*For Earth fault test*	
Electro-mechanical Relay	In =2.5 A TMS = 0.09 s	In=0.5 A TMS=0.09 s	1.3×In = 3.25	1.3×In = 0.65	2395	4652	3172	Took 2257 msec. more for OC and 777 msec. more for EF
ABB REF 615	In = 2.5 A TMS = 0.09 s	In=0.5 A TMS=0.09 s	1.3×In = 3.25	1.3×In = 0.65	2395	2184	2443	Approximately in range
Siemens 7SR11	In=1 A TMS=0.1 s	In=0.1 A TMS=0.05 s	2×In = 2	2×In = 0.2	For OC Fault=1003 For EF=502	1018	504	Approximately in range

From the testing results, it has been observed that the Electro-Mechanical Relay existing before the retrofitting takes longer Relay operating time than the calculated value. On the other hand, Siemens 7SR11 series of numerical relay (of 132/33 KV Moran Grid Sub-Station) trips within the calculated time for IEC Normal Inverse Curve. Due to which, when a fault occurs in the 33KV Kachumari feeder the up-stream relay of 33 KV Moran feeder of 132/33 KV Moran Grid Sub-Station trips before the down-stream protection. For this kind of tripping in the up-stream relays increases the interruptions of the 11 KV healthy feeders of 33/11KV Moran Sub-Station. From ABB REF615 Relay Testing results, it can be concluded that the upcoming relay ABB REF615 is more sensitive than the existing Electro-Mechanical Relay and its use is justified.

After several initial test runs, the newly retrofitted system has been found to work satisfactorily and duly commissioned for continuous service. The fault event record log shows considerable improvement in sensing and isolating the fault without letting it propagate to upstream. The fault event log of 33KV Kachumari Feeder for the month of March 2020 from the day of commissioning is shown in Table 17. From the log of 132/33 KV Grid Sub-station, it is observed that after the retrofitting operation, not a single trip due to fault is recorded for 33KV Moran Feeder of 132/33 KV Grid Sub-Station upto 30th March 2020. This implies that the newly retrofitted relay system is successfully isolating the fault of 33KV Kachumari feeder without affecting the Grid Sub-Station or other healthy feeders from 33/11KV Moran Sub-Station. Moreover, from the comparisons of the maximum fault level with the ratings of the CBs, CTs and Isolating Switches depict about the sustainability of the system.

Table 17. Fault events after numerical relay installation

Date	Trip time	Charged time	Duration (mins)	Remarks
13.03.2020	13:00	14:26	86	Earth Fault
15.03.2020	11:56	12:16	20	Over Current Fault
22.03.2020	16:55	17:10	15	Over Current Fault
22.03.2020	17:21	17:35	14	Over Current Fault

22.03.2020	23:45	23:50	5	Over Current Fault
24.03.2020	08:00	08:06	6	Over Current Fault
27.03.2020	09:35	09:40	5	Over Current Fault and Earth Fault
27.03.2020	12:16	12:20	4	Over Current Fault
27.03.2020	17:16	17:21	5	Over Current Fault
27.03.2020	20:30	20:35	5	Over Current Fault
29.03.2020	00:20	01:25	90	Over Current Fault
29.03.2020	4:35	4:45	10	Over Current Fault
29.03.2020	14:41	14:46	5	Earth Fault
30.03.2020	07:45	07:50	5	Over Current Fault
30.03.2020	13:43	13:46	3	Over Current Fault

VI. CONCLUSION

In this work, retrofitting of a new class numerical relay in the old feeder panels of the Moran 33/11 KV sub-station of APDCL has been described. The specification and connections of existing Easun Reyrolle feeder panel and new ABB REF 615 numerical relay have been discussed. The associated works related to the relay retrofitting like ferruling of wires and cutting of works have been shown. The new relay has been connected in series with the existing relay which enables a second backup layer of protection. The parameter settings, new connections and their CT, PT, TCS circuit connections have been explained in details along with the short circuit analysis of the 33KV Kachumari Feeder. The project has been successfully completed and commissioned on March 12, 2020, and since then serving the valued customers. From the fault event log, it has been seen that the newly retrofitted system is more sensitive. Since its inception, most of the faults can be isolated at the sub-station itself; thereby not allowing it to propagate upstream and affect the grid. This relay retrofitting is expected to increase the customer experience and satisfaction. Also, in the long run, it will be saving cost to company by protecting and keeping the various equipment healthy, thereby increasing their service life. Also, from its smart capability of Event and Disturbance recording, it will provide valuable data for analysis of the fault patterns through wavewin ABB software and thereby help in future planning of the network. On the other hand, its Load profile Recorder can record the specified electrical quantities for a said time interval and hence the perfect power scenario of the feeder could be analysed. And by using its fast communication capabilities we can plan for the sub-station automation in future.

ACKNOWLEDGMENT

The authors would like to acknowledge the invaluable discussion with ABB, India during the course of this work.

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