VERIFICATION OF ADAPTIVE PROTECTION SCHEMES FOR DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATIONS USING A HARDWARE-IN-THE LOOP SIMULATION

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Abstract: This project focuses on the problems assigned with the integration of DG units with the power grid. The impacts of the DG are studied in this project and examined physically. IEEE 4-node distribution system with two wind generators used as distributed generations is modeled in MATLAB/SIMULINK software and it is evaluated for symmetrical faults at different locations using directional overcurrent relays as a protective device. Adaptive protection schemes are related to change in relay settings according to network topologies. The attempt has been made to verify the proposed dynamic strategy for adaptive protection considering various fault cases for the system integrated with DG units. The feature of directional overcurrent protection of SEL-351s relay is used in this investigation in order to get practical results. The algorithm for the adaptive protection scheme is provided in the references and it is implemented to update the TMS values of relays dynamically by observing the changes occurring in the system. With all the results in hand, conventional and adaptive schemes are compared.

Keywords: Distibuted Generations, Directional Over-Current Relay, SEL-351s, Adaptive Protection.

I. INTRODUCTION

Power system protection schemes plays a significant role in reliable and efficient operation of a distribution system. Distributed Generations (DG) are used in power system for supplying power to localized loads with effective cost reduction and reliability enhancements. However, the integrating Distributed Generations (DG) with a power system makes a positive as well as negative impacts on operation, protection and control of medium and low voltage power system. The DGs can work in two operating modes i.e. grid-connected and islanded mode. As DG units are depend on renewable energy sources, there are frequent chances of these units to get disconnected from the system due to environmental conditions which further changes the network topology. In case of faults, the DG units contributes to fault currents. The sensitivity and operating time protective relays are affected by presence of DG. The coordination of protective devices is necessary to ensure the performance of distribution system with the necessary reliability and sensitivity. During fault situations, DGs lead to protection miscoordination. In such cases the conventional protection schemes are insufficient for adequate protection and hence adaptive protection schemes has been active research area.

Overcurrent Relay

Under the fault situations, the distribution system is exposed to overcurrent flow into its components. Overcurrent is the situation in which excessive current than expected flows through the conducting parts of the system and causes the generation of heat. Overcurrent relay is used to protect the system from this case. As per the ANSI standards, number 50 is for an instantaneous overcurrent or Definite Time Overcurrent and number 51 is for Inverse Definite Minimum Time. Practically, overcurrent relays are used every power system component like transformers, motors, generators, transmission lines, motors, etc. Three different types of operating modes of overcurrent relay are:

Definite (Instantaneous)- Current Protection:

This relay operates instantaneously as soon as current reaches the predetermined values. There is no time delay is provided for its operation. The coordination of these relays is designed on the principle that the fault impedance changes with respect to the location of fault current. The relay which is far from the source is operated for low current value and as we move towards the source, the operating currents for the respective relays are increased.

Definite-Time Protection:

For the operation of this relay, two criterions must be satisfied i.e. the fault current must go beyond the setting value and the fault should be continue for the time equal to time setting of a relay. Its operation is not dependent of the magnitude of current over the pick-up value. As it operates for a definite time, the coordination of such relays is easy. These are also used for the backup protection of distance relays and differential relays

Inverse Definite-Time Protection:

The operating time is inversely proportional to the current. Hence, for high fault currents the relay operates faster while for lower currents it operates slower. The relay has the inverse time current characteristics at low fault currents while definite time characteristics at higher values. Depending on these characteristics, there are three types of IDMT relays i.e. Standard inverse, Very inverse, extremely inverse time.

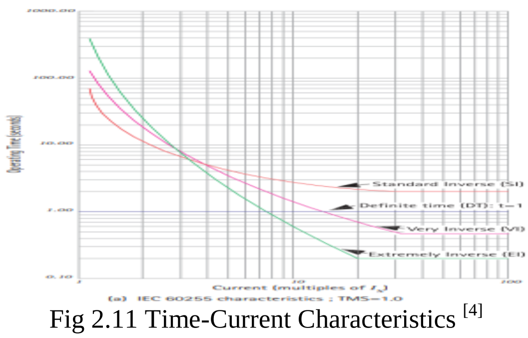


Fig 2.11 Time-Current Characteristics [4]

II. DISTRIBUTED GENERATION & MICROGRID

Distributed generations are advanced way of electrical energy generation and its storage performed by different small, grid-connected devices considered as distributed energy resources (DERs). Distributed generation is known as decentralized generation as the energy is generated and distributed using small technologies at consumer ends. Typically, renewable energy sources like solar power, biogas, wind power, geothermal power, and small hydro power are used as distributed energy resources (DERs). These small-scale generations are connected to the grid using power electronic devices or they can directly provide a power to small consumers. The basic of distributed generation is generating electricity close to the point of delivery. Distributed generation technology is decentralized, modular and more flexible which is close to the load. Distributed generation plants can be smallest like a solar panel installed on the rooftop supplying power to a single home or it can be a local based solar plant integrated with a grid. So basically, they can be operated in grid connected mode or islanded mode.

When two or more distributed generations are connected together, it is called as microgrid. Microgrid can be defined as:

"A group of Distributed Energy Resources (DERs) integrated with local loads forming a local energy network, which can be operated by integrating with the grid or in a islanding mode in order to have a high reliability and resilience to grid disturbances." [10]

Impacts of Distributed Generation on Power System

- Voltage regulation: Switching capacitors, line regulators, load tap changers are used to maintain the desired voltage levels in the distribution system. Basically, voltage regulation depends on the radial flow of power from substation down to all loads. The integration of DG to distribution system alters the radial characteristics of the system and so power flows in different directions. Loss in radial characteristics and change in power flow affects the performance of the voltage regulation technique. Integrating DG units with the distribution system changes the maximum and minimum voltage level. This affects the voltage control functionality of the network.
- Power Quality: DGs working conditions depends on different operating characteristics which varies according to type to DG. Also, most of the DGs use power electronic devices which gives rise to power quality issues.
- Short circuit level of a network: Short circuit level of a networks gets affected by the penetration of DG units as it increases in fault current levels of a network. The integration of the DG units with power grid decreases contribution of the utility to faults but the fault current levels are still increased because DG units itself contributes to it. This contribution of the DG units to the fault depends on the placement of the DG. One centralized DG unit makes a significant impact on the short circuit level of a network. Location of DG units, types of DG, inverter are the factors contributing to faults currents.
- Impact of DG on Distribution Feeder Protection: Distributed generation depends on the renewable sources such as wind speed, solar radiations, etc. Hence, depending on the availability of such sources DGs can be connected and disconnected frequently. This leads to variation in power supplied by DGs in the grid and hence conventional protection schemes designed without considering the impact of DG are inadequate. Integration of small generators on distribution network will observe the blinding of protection, reduction of reach, sympathetic tripping, failed reclosing, miscoordination.
- Unintentional Islanding: The phenomenon is also called as Loss of Grid, in which the distribution generation gets separated from the main utility during fault condition. Even after the disconnection from the grid, if these distribution generators continue to supply the fault current then the fault may persist long causing severe damage to equipments. In such islanding condition, system losses the control over voltage and frequency which results in instability and low power quality.

Adaptive Protection Schemes

Considering the impacts of the DGs, the protection system must satisfy the following requirements:

- It must respond to not only grid connected but also to islanded mode of operation. If the fault occurs in the grid connected mode, then protection scheme should isolate the microgrid so that it can operate in autonomous mode and if fault occurs within the microgrid system itself, then protection system should disconnect it as soon as possible to avoid unnecessary power outages.
- Protection coordination has to be maintained in order to have the primary and backup protection for the device.

Integration of DG units depends on protection coordination and Decentralized energy source management which gives the optimized control and network configurations. The adaptive protection scheme is a kind of protection scheme which can solve the problems introduced by microgrid integration with the grid along with satisfying the above-mentioned requirements.

The adaptive protection can be defined as "an online technique that continuously updating relay settings with respect to system configurations change in a timely manner using communication or communication-less means." [5]

The algorithm used for the adaptive protection scheme is given below:

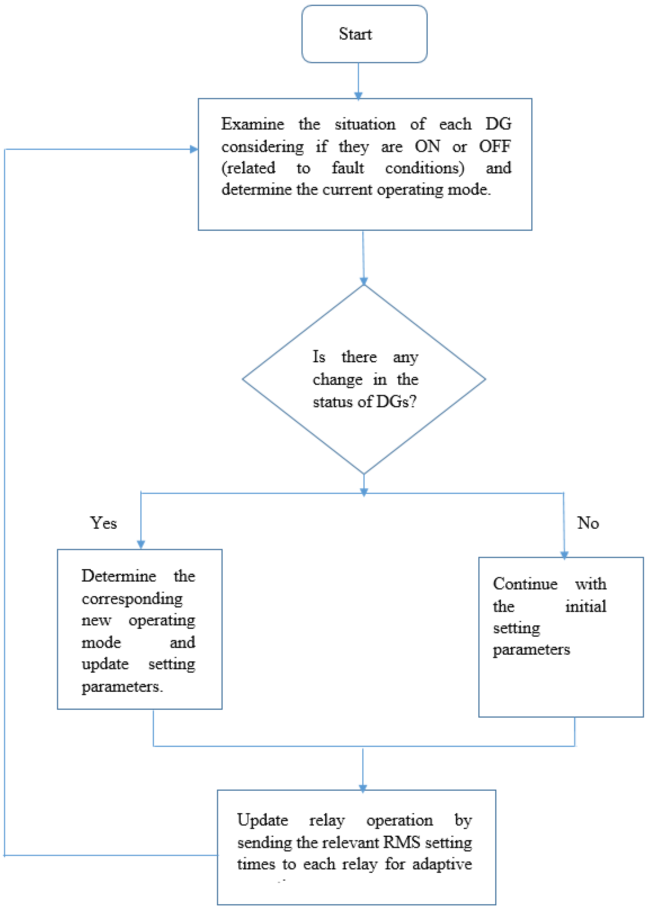


Fig 2. Algorithm for Adaptive Protection

SEL-351s in Hardware- in-the loop:
For implementing the proposed adaptive protection scheme in hardware system, microprocessor relay SEL-351s is used as a directional overcurrent relay. SEl-351s is a digital relay designed by Schweitzer Engineering Laboratories for protection, control, monitoring applications in power system. The function of directional and non-directional overcurrent is used for protection of power system feeders. SEl-351s has number of overcurrent elements like phase overcurrent, negative-sequence overcurrent, residual-ground overcurrent, neutral overcurrent. For inverse-time overcurrent element settings, a wide range of pickup current, continuous time dial settings and time-current curves specified from IEEE like Moderately inverse (U1), Inverse (U2), Very Inverse (U3) and IEC standards like Standard Inverse (C1), Very Inverse (C2), Extremely Inverse (C3), etc. In addition to these curves, the relay has 38 standard recloser curves which allows the coordination in between recloser and fuse.

Fig 3. SEL-351s Protection System.

III. IEEE 4 NODE TEST FEEDER SIMULATION AND RESULTS

To study the impacts of Distributed Generations on the system and for implementation and analysis purpose of adaptive protection scheme IEEE 4 node test system is considered. The original IEEE 4 node test system is shown in fig 4.

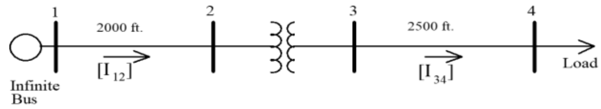


Fig 5. IEEE 4 Node Test Feeder

Three phase transformer data:

Connection	kVA	kVLL-High	kVLL-Low	R- %	X- %
Step-down	6000	12.47	4.16	1.0	6.0
Step-up	6000	12.47	24.9	1.0	6.0

Table 1. Three Phase Transfomer Data

Load Data:

	Balanced	Unbalanced
Phase-1		
kW	1200	850
Power Factor	0.9 lag	0.85 lag
Phase-2		
kW	1200	1200
Power Factor	0.9 lag	0.9 lag
Phase-3		
kW	1200	1583.33
Power Factor	0.9 lag	0.95 lag

Table 2. Load data

This is the original IEEE 4 node test feeder, however to examine the impact of Distribution system and implementation of adaptive protection, we need to modify the system with DGs. The DG units are added at bus 2, 3 & 4 and loads are also divided in between bus 2, 3 & 4.

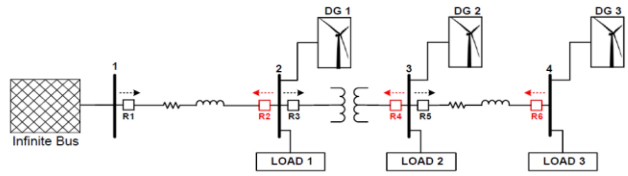


Fig 6. Modified Test system for IEEE 4 node test feeder. [1]

Balanced	Active Power (kW)	Reactive Power (kVAR)
Load -1	3500	1696
Load- 2	1000	485
Load- 3	900	434

Table 3. Adaptive system load data

The system is designed in MATLAB/SIMULINK and it is shown in fig. 7

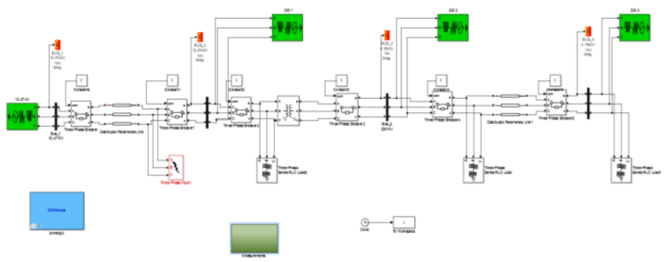


Fig 7. IEEE 3 node test system with 3 DGs in Simulink.

Short Circuit Analysis:

To study the effects of integration of DG on short circuit levels of the system, short circuit analysis is carried out for 4 different modes with 3 different fault locations. The results of short circuit analysis are shown in following figures. For each mode there is a variation in a short circuit current which shows that how the short circuit level of the system is affected by DG integration. Table 4 shows the values of the fault currents and it is observed that fault currents goes on increasing.

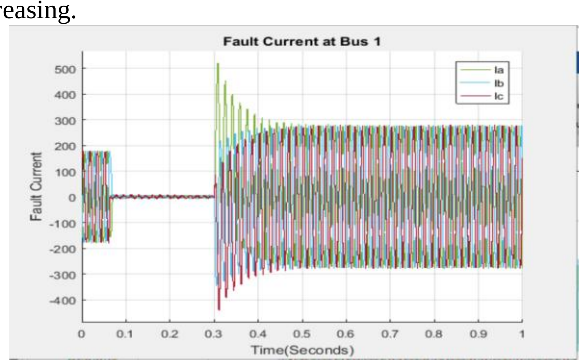


Fig 8. Short Circuit Current at Bus 1 with no DGs added to the circuit.

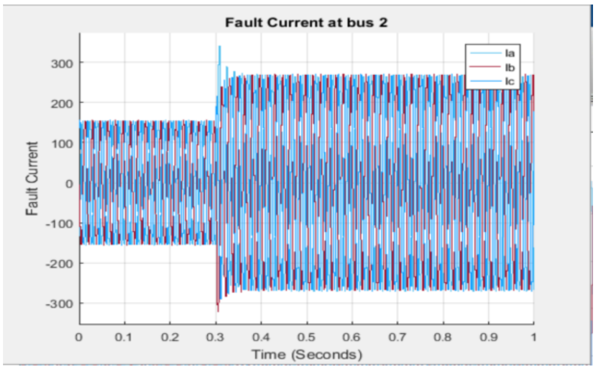


Fig 9. Short Circuit Current at Bus 2 with 1 DGs added to the circuit

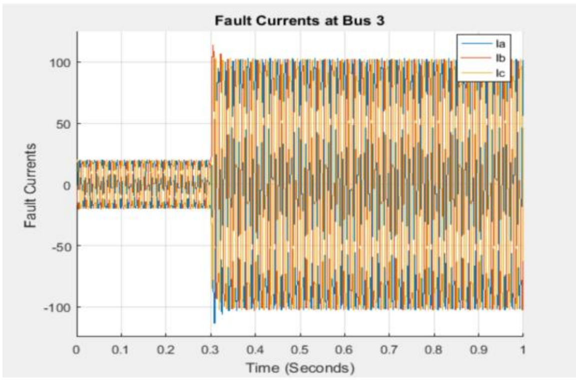


Fig 10. Short Circuit Current at Bus 3 with 3 DGs added to the circuit

Operating Mode	I_a (A)	I_b (A)	I_c (A)
Mode 1	484.3	480.7	478.9
Mode 2	577.6	580.8	563
Mode 3	607.4	602.4	583.7
Mode 4	607.9	609.2	599.7

Table 4. Short Circuit Currents for different operatinng modes

Overcurrent Relay Model in MATLAB/SIMULINK:

Overcurrent relay is designed in a Simulink. The primary fault current and nominal operating currents are measured at different locations for different operating modes for three phase faults. The operating time for relay is calculated using the equation,

$$t = TMS * \frac{0.14}{\left(\frac{If}{PS}\right)^{0.02} - 1} \quad (1)$$

Where, t = Operating time of relay.

TMS= Time Setting Multiplier, is considered as 0.05.

I_f = Fault current.

PS = Plug Setting Multiplier is considered as 1.25

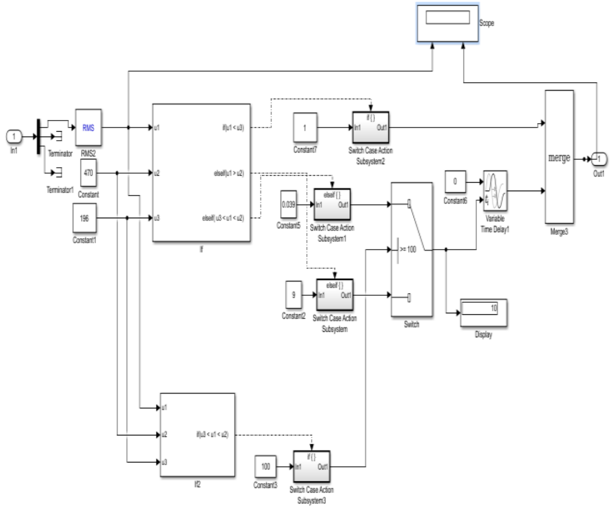


Fig 11. Overcurrent relay model in Simulink.

The following figure shows the operation of relay for different operating modes. For operating mode 1 i.e. without any DGs, the maximum fault current observed is 214 A while normal operating current observed is 108A. Using the equation (1), the operating time is calculated as 0.065s and hence relay trips at 0.065s after applying fault at 0.3s.

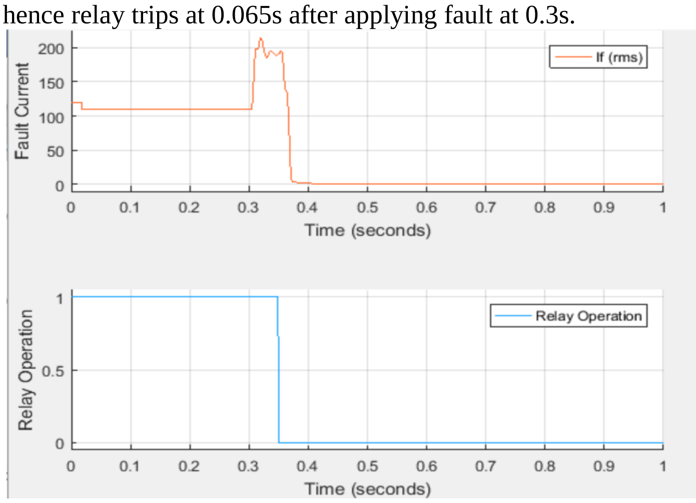


Fig 12 Relay Operation for Operating Mode 1

As explained earlier, the integration of the DG to the grid changes the short circuit level of the system and it is also observed by short circuit analysis of the system. As seen in the fig 13, the relay operates at different operating time than expected time of operation.

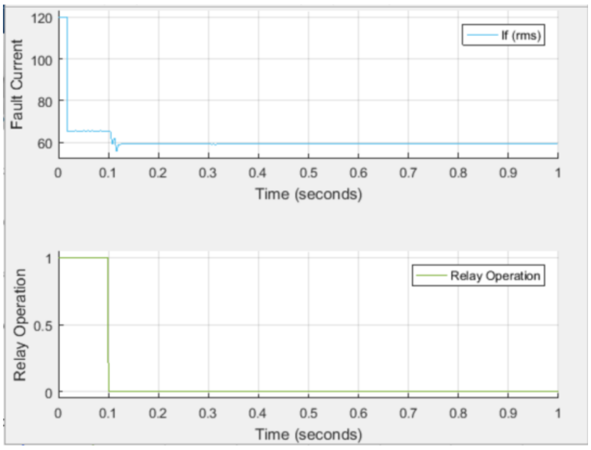


Fig 13 Relay Operation for Operating Mode 3

Along with this blinding of the protection is also observed for operating mode 3 as relay doesn't sense its pickup current.

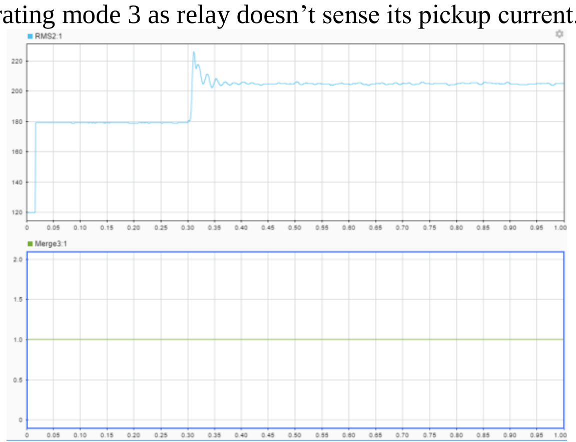


Fig 14. Blinding of Protection observed for mode 2

Hardware-in-the loop Simulation;

The microprocessor relay SEL-351s is integrated with the system modeled in Simulink and the attempt has been made to physically examine the function of relay and the effects of the DG unit integration on the performance of the relay. The protection system SEL-351s has the different group of settings where one can choose the elements and settings an be made for it.

This is the mechanical sub-model of induction motor from the balance equations and neglecting viscous friction, the rotor speed is shown in the below figure along with T_e as the input.

These microprocessor relays work on the firmware designed and embedded inside the relay. ACSELERATOR QuickSet is a software used for simplifying the relay settings and analysis support. This is a special software developed by SEL which is compatible with all the protection systems. Using proper communication with the PC, we can read or change the relay settings.

Phase Time-overcurrent element is used for the setting purpose. The event report function shows the details of every settings and details of every event occurred during relay operation. Fig 15 shows the global settings made in the experiment. However, fig 16 shows the settings for the group 1.

```
Global Settings:
PTCONN  = WYE      VSCONN  = VS       TGR     = 0.00
NFREQ   = 60       PHROT   = ABC      DATE_F  = MDY
FP_TO   = 15       SCROLD  = 2        FPNGD   = IG
METHRES = Y        LER     = 30       PRE     = 5         FLTDISP = MAX
DCLOP   = OFF      DCHIP   = OFF
IN101D  = AC       IN102D  = 0.50     IN103D  = 0.50      IN104D  = 0.50
IN105D  = 0.50     IN106D  = 0.50
EBMON   = Y        COSP1   = 10000    COSP2   = 150       COSP3   = 12
KASP1   = 1.20     KASP2   = 8.00     KASP3   = 20.00     ESTRT   = 50
ESCLT   = 120      MSTRT   = 50       MSCLT   = 120
LED12L  = Y        LED13L  = Y        LED14L  = Y         LED15L  = Y
LED16L  = Y        LED17L  = Y        LED18L  = Y         LED19L  = N
LED20L  = N        LED21L  = N        LED25L  = Y         LED26L  = Y
RSTLED  = Y
PB9D    = 0.00     PB10D   = 0.00
EPMU    = N        EVELOCK = 0        DNPSRC  = UTC       BOOPTCC = SET
BOOPPUL = SET      IRIGC   = NONE     UTC_OFF = 0.00
DST_BEGM= NA

PARTNO=0351S7XHB3E54X2
```

Fig 15. Global Settings for SEL-351s

```
Group 1
Group Settings:
RID     =SEL351S_2  (SETTING GROUP 1)   TID    =JD1590
CTR     = 10        CTRN    = 1         PTR     = 1.00     PTRS    = 1.00
VNOM    = 67.00
Z1MAG   = 2.14      Z1ANG   = 68.86     Z0MAG   = 6.38     Z0ANG   = 72.47
LL      = 4.84
E50P    = N         E50N    = N         E50G    = N        E50Q    = N
E51P    = 1         E51N    = N         E51G    = N        E51Q    = N
E50BF   = N         EHBL2   = N         E32     = N        ELOAD   = N
ESOTF   = N         EVOLT   = N         E25     = N        EFLOC   = Y
ELOP    = N         ECOMM   = N         E81     = N        E81R    = N
E79     = N         ESV     = 8         EDEM    = THM      EPWR    = N
ESSI    = N
51P1P   = 6.00      51P1C   = C5        51P1TD  = 0.70     51P1RS  = N
51P1CT  = 0.00      51P1MR  = 0.00
DMTC    = 5         PDEMP   = 5.00      NDEMP   = 1.500    GDEMP   = 1.50
QDEMP   = 1.50
TDURD   = 9.00      CFD     = 60.00     3POD    = 1.50     50LP    = 0.25
SV1PU   = 0.00      SV1DO   = 0.00      SV2PU   = 0.00     SV2DO   = 0.00
SV3PU   = 0.00      SV3DO   = 0.00      SV4PU   = 0.00     SV4DO   = 0.00
SV5PU   = 0.00      SV5DO   = 0.00      SV6PU   = 0.00     SV6DO   = 0.00
SV7PU   = 0.00      SV7DO   = 0.00      SV8PU   = 1.00     SV8DO   = 0.00

SELogic group 1

SELogic Control Equations:
TR      = 51P1T
TRQUAL  = 0
TRCOMM  = 0
TRSOTF  = 0
DTT     = 0
ULTR    = !(51P1 + 51G1)
PT1     = 0
LOG1    = 0
PT2     = 0
LOG2    = 0
```

Fig 16.Group 1 Settings for SEL-351s

The event report is available for every cycle. As observed in the figure the relay observes the normal current under normal operation and there are no output signals generated in the output column. The fig.17 show the event reports for the operating mode 1 and mode 2.

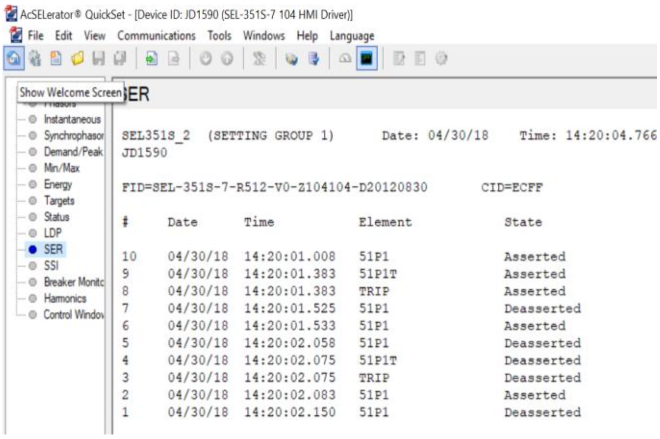
```
SEL351S_2  (SETTING GROUP 1)      Date: 04/15/18    Time: 14:00:46.341
JD1590

FID=SEL-351S-7-R512-V0-Z104104-D20120830       CID=ECFF
Event Number=14638

                                                                 Out  In
     Currents (Amps Pri)              Voltages (kV Pri)          1357 135
   IA    IB    IC    IN    IG     VA     VB     VC     VS Vdc Freq  246A 246
[1]
   60    -0    -0     0    59   -0.0   -0.0   -0.0   -0.0   1 60.00 .... ...
 -114    -0    -0     0  -114   -0.0   -0.0   -0.0    0.0   1 60.00 .... ...
  -60     0     0    -0   -59    0.0    0.0    0.0    0.0   1 60.00 .... ...
  114     0     0    -0   115    0.0    0.0    0.0    0.0   1 60.00 .... ...
[2]
   59    -0    -0    -0    58   -0.0   -0.0   -0.0   -0.0   1 60.00 .... ...
 -114    -0    -0     0  -114   -0.0   -0.0   -0.0   -0.0   1 60.00 .... ...
  -59     0     0     0   -59    0.0    0.0    0.0    0.0   1 60.00 .... ...
  114     0     0    -0   114    0.0    0.0    0.0    0.0   1 60.00 .... ...
[3]
   65    -0    -0    -0    64   -0.0   -0.0   -0.0   -0.0   1 60.00 .... ...
  -60    -0    -0     0   -60   -0.0   -0.0   -0.0    0.0   1 60.00 .... ...
  -35     0     0     0   -34    0.0    0.0    0.0    0.0   1 60.00 .... ...
    3     0     0    -0     3    0.0    0.0    0.0    0.0   1 60.00 .... ...
[4]
    0    -0    -0    -0    -1   -0.0   -0.0   -0.0    0.0   1 60.00 .... ...
   -0    -0    -0    -0    -0   -0.0   -0.0   -0.0   -0.0   1 60.00 .... ...
   -6     0     0    -0    -6    0.0    0.0    0.0   -0.0   1 60.00 .... ...
  -43     0     0     0   -43    0.0    0.0    0.0   -0.0   1 60.00 .... ...
[5]
   17    -0    -0     0    16   -0.0   -0.0   -0.0    0.0   1 60.00 .... ...
   51    -0    -0    -0    51   -0.0   -0.0   -0.0    0.0   1 60.00 .... ...
  -52     0     0    -0   -51    0.0    0.0    0.0   -0.0   1 60.00 .... ...
   43     0     0     0    43    0.0    0.0    0.0    0.0   1 60.00>.... ...
[6]
   71    -0    -0     0    71   -0.0   -0.0   -0.0   -0.0   1 60.00 .... ...
 -107    -0    -0    -0  -108   -0.0   -0.0   -0.0   -0.0   1 60.00 .... ...
  -59     0     0     0   -58    0.0    0.0    0.0   -0.0   1 60.00 .... ...
  114     0     0     0   114    0.0    0.0    0.0    0.0   1 60.00 .... ...
```

Fig 17. Event report under normal operation.

However, when the fault is applied in the system, the relay generates the trip signal which is indicated as '1' in the event report as shown in fig 18.



```
AcSELerator® QuickSet - [Device ID: JD1590 (SEL-351S-7 104 HMI Driver)]
File  Edit  View  Communications  Tools  Windows  Help  Language
Show Welcome Screen  SER

SEL351S_2  (SETTING GROUP 1)       Date: 04/30/18    Time: 14:20:04.766
JD1590

FID=SEL-351S-7-R512-V0-Z104104-D20120830       CID=ECFF

#     Date       Time          Element         State

10    04/30/18   14:20:01.008  51P1            Asserted
9     04/30/18   14:20:01.383  51P1T           Asserted
8     04/30/18   14:20:01.383  TRIP            Asserted
7     04/30/18   14:20:01.525  51P1            Deasserted
6     04/30/18   14:20:01.533  51P1            Asserted
5     04/30/18   14:20:02.058  51P1            Deasserted
4     04/30/18   14:20:02.075  51P1T           Deasserted
3     04/30/18   14:20:02.075  TRIP            Deasserted
2     04/30/18   14:20:02.083  51P1            Asserted
1     04/30/18   14:20:02.150  51P1            Deasserted
```

Fig 17. Event report under Fault condition.

The same kind of operation of the relay is observed for other fault locations also and it is listed in the table below.

Fault Location	Normal Operating Current (A)	Fault Current (A)	Pickup Value 51P1P (0.25-16.00)	Time Dial Setting (TDS) 51P1TD (0.05-1.00)	Time of Operation (Seconds)
Bus 1	87	147	6.0	0.5	0.37
Bus 2	82	129	5.9	0.5	0.29
Bus 3	65	116	6.2	0.5	0.31

Table 5. SEL-351s Relay Settings

Now for operating mode 3 i.e. with 2 DG Units, if we keep the same settings for the relay then it doesn't work properly and doesn't send the TRIP Signal. The fig 18 shows the Sequential Event Report where trip signal is not asserted for the fault condition.

```
FID=SEL-351S-7-R512-V0-Z104104-D20120830      CID=ECFF
Event Number=12793

                                                              Out  In
     Currents (Amps Pri)           Voltages (kV Pri)          1357 135
   IA    IB    IC    IN    IG    VA    VB    VC    VS Vdc Freq 246A 246
[1]
   30     1     1    -0    31   0.0   0.0   0.0  -0.0   0 60.00 ....  ...
   -9     0     0    -0    -8   0.0   0.0   0.0   0.0   0 60.00 ....  ...
  -24    -1    -0     0   -26  -0.0  -0.0  -0.0   0.0   1 60.00 ....  ...
  -26    -0    -0     0   -27  -0.0  -0.0  -0.0   0.0   1 60.00 ....  ...
[2]
   41     1     0    -0    42   0.0   0.0   0.0   0.0   0 60.00 ....  ...
   47     0     0    -0    47   0.0   0.0   0.0  -0.0   0 60.00 ....  ...
  -93    -1    -1     0   -94  -0.0  -0.0  -0.0  -0.0   1 60.00*....  ...
  -23    -0    -0     0   -23  -0.0  -0.0  -0.0   0.0   1 60.00>....  ...
[3]
   93     1     1    -0    94   0.0   0.0   0.0   0.0   0 60.00 ....  ...
   22     0     0    -0    23   0.0   0.0   0.0  -0.0   0 60.00 ....  ...
  -93    -1    -1     0   -95  -0.0  -0.0  -0.0  -0.0   1 60.00 ....  ...
  -25    -0    -0     0   -25  -0.0  -0.0  -0.0  -0.0   1 60.00 ....  ...
[4]
   93     1     1    -0    94   0.0   0.0   0.0   0.0   0 60.00 ....  ...
   24     0     0    -0    25   0.0   0.0   0.0   0.0   0 60.00 ....  ...
  -93    -1    -1    -0   -94  -0.0  -0.0  -0.0   0.0   0 60.00 ....  ...
  -23    -0    -0    -0   -24  -0.0  -0.0  -0.0  -0.0   0 60.00 ....  ...
```

Fig 18 SER with Previous Settings.

In order to have the correct operation of the relay we have to change the settings for the relay. The table 6 shows the new settings for the relay and the fig 19 & 20 shows the modified operation of the relay.

Fault Location	Normal Operating Current (A)	Fault Current (A)	Pickup Value 51P1P (0.25-16.00)	Time Dial Setting (TDS) 51P1TD (0.05-1.00)	Time of Operation (Seconds)
Bus 1	93	168	4.5	0.5	0.533
Bus 2	91	153	4.6	0.5	0.547
Bus 3	83	134	4.6	0.5	0.538

Table 5. New Settings for SEL-351s

```
SEL351S_2  (SETTING GROUP 1)       Date: 04/30/18    Time: 14:14:47.493
JD1590

FID=SEL-351S-7-R512-V0-Z104104-D20120830       CID=ECFF

#     Date       Time          Element         State

10    04/30/18   14:07:51.103  51P1            Asserted
9     04/30/18   14:07:51.619  51P1            Deasserted
8     04/30/18   14:07:51.636  51P1T           Deasserted
7     04/30/18   14:07:51.636  TRIP            Deasserted
6     04/30/18   14:07:51.644  51P1            Asserted
5     04/30/18   14:07:51.894  51P1            Deasserted
4     04/30/18   14:07:51.903  51P1            Asserted
3     04/30/18   14:07:52.153  51P1            Deasserted
2     04/30/18   14:07:52.169  51P1            Asserted
1     04/30/18   14:07:52.244  51P1            Deasserted
```

Fig 19. SER with new Settings.

```
                                                              Out  In
     Currents (Amps Pri)           Voltages (kV Pri)          1357 135
   IA    IB    IC    IN    IG    VA    VB    VC    VS Vdc Freq 246A 246
[1]
  170    -1    -0     0   169  -0.0  -0.0  -0.0  -0.0   0 60.00 1...  ...
 -107    -0    -0    -0  -107  -0.0  -0.0  -0.0   0.0   1 60.00 1...  ...
 -169     1     0     0  -168   0.0   0.0   0.0   0.0   1 60.00 1...  ...
  105     0     0    -0   106   0.0   0.0   0.0  -0.0   1 60.00 1...  ...
[2]
  168    -1    -0    -0   167  -0.0  -0.0  -0.0   0.0   1 60.00 1...  ...
 -106    -0    -0    -0  -106  -0.0  -0.0  -0.0   0.0   1 60.00 1...  ...
 -169     1     0     0  -168   0.0   0.0   0.0  -0.0   1 60.00 1...  ...
  107     0     0     0   108   0.0   0.0   0.0   0.0   1 60.00 1...  ...
[3]
  168    -1    -0    -0   167  -0.0  -0.0  -0.0  -0.0   0 60.00 1...  ...
 -105    -0    -0    -0  -105  -0.0  -0.0  -0.0  -0.0   1 60.00 1...  ...
 -169     1     0     0  -168   0.0   0.0   0.0   0.0   1 60.00 1...  ...
   72     0     0    -0    73   0.0   0.0   0.0  -0.0   1 60.00 1...  ...
[4]
   90    -1    -0    -0    89  -0.0  -0.0  -0.0   0.0   0 60.00 1...  ...
  -21    -0    -0    -0   -22  -0.0  -0.0  -0.0   0.0   0 60.00 1...  ...
   56     1     1    -0    57   0.0   0.0   0.0  -0.0   1 60.00 1...  ...
  -35     0     0     0   -34   0.0   0.0   0.0  -0.0   1 60.00 1...  ...
[5]
   32    -1    -1     0    30  -0.0  -0.0  -0.0  -0.0   0 60.00 1...  ...
  -19    -0    -0    -0   -19  -0.0  -0.0  -0.0  -0.0   1 60.00 1...  ...
 -177     1     0    -0  -176   0.0   0.0   0.0  -0.0   1 60.00 1...  ...
  107     0     0    -0   107   0.0   0.0   0.0  -0.0   1 60.00*1...  ...
[6]
```

Fig 20 Event report showing correct operation of relay.

IV. CONCLUSION

The methodology proposed in the paper gives the necessary steps to carry out the adaptive protection scheme considering requirements, influences and remedial actions for the power system with DG penetration. This proposed method can be implemented physically using intelligent electronic devices (IEDs) like microprocessor based digital relays having the features like processing, decision making, data storage, communication channels, etc. In this study, the adaptive protection scheme works well to maintain the protection coordination in between protective relays.

If the conventional system is considered the tripping times are longer however with the adaptive scheme the optimum TMS times are provided for relay coordination. The microprocessor relay SEL-351s is used for the verification of the adaptive algorithm and it is observed that microprocessor relays with the communication feature are useful for implementation of the protection schemes.

From future study perspective, the adaptive protection scheme along with the appropriate protection coordination between the relays and it can be implemented on the large-scale distribution systems having actual DG units. However, a research study is required to analyze the effects of the actual DG units on the system with physical relays in the loop.

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