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Adaptive Protection Scheme for Medium Voltage Systems with Distributed Generation and Islanding Detection

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ABSTRACT

Utilization of Distributed Generators (DGs) reduce the demand in both distribution and medium-voltage networks, without any need for transmission system expansion. Penetration of DGs into an existing power network have many impacts on the system, with the power system protection being one of the major issues. In this context, this paper proposes a novel adaptive protection scheme able to overcome protection problems associated with connection of DGs. The proposed protection scheme addresses the loss of coordination, bi-directionality, and islanding detection regardless of the type, number, location, and size of the connected DGs. The proposed method uses adaptive and communication relays. The used communication media is fiber optics. Offline load-flow analysis and short circuit calculation are required to determine both value and direction of the current in each relay for each connection case. The main processor receives signals from all relays to determine the connection status of the system and sends flags refer to the Current-Time Characteristics (CCT) to each relay. ETAP program is used to simulate the tested system, and to perform the required analysis.

Keywords:
Distributed Generators (DGs), Current-Time Characteristics (CCT), Fault Current Limiter (FCL).

1. Introduction

Renewable energy systems are booming with the deployment of reliable Distributed Generation (DG) technologies such as wind and solar energy that provides a lot of advantages for utilities. Introducing DGs into an existing power network reduces the demand for both distribution and medium-voltage network without any need for transmission system expansion. With DGs connected directly to the loads, both cost and power loss are significantly reduced, while supply reliability to customers is further increased [1]. On the other hand, connection of DGs has some drawbacks on stability, power quality, and protection of the system, depending on size, location, type, and number of DGs connected to the system, these drawbacks can limit both size and number of DGs connected to the system [2]. Additionally, insertion of DGs into a power network increases the short circuit current and the power network will not be radial because of the reverse current.

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Therefore, connecting DGs causes a lot of problems in system protection such as loss of coordination between protection devices (especially recloser-fuse mis-operation), bi-directionality due to reverse current, and islanding operation.

Over the recent years, a lot of efforts have been directed to investigate these protection problems. To solve the problem of loss of coordination between devices, some scholars suggested the utilization of microprocessor-based recloser [3], while others suggested performing an optimization problem to determine the maximum size, type, and location of DG so that the coordination between devices is not affected [4]. Further, disconnecting DGs during faults to return to the original connection was focused in [5]. Part of these studies have been directed to use Fault Current Limiter (FCL) to solve the problem of loss of coordination. FCL has negligible impedance during normal condition and has large impedance during short circuit condition. So, FCL is used to reduce the level of short circuit current. Different types of FCL and different locations have been proposed in [6] to reduce the short circuit current from DG and hence return to the original protection level. The author in [7] suggested using dual setting of directional overcurrent relay to overcome the bi-directionality problem in meshed system.

Islanding operation has some drawbacks on the system such as voltage and frequency control, power quality, lack of grounding, and out-of-phase reconnection [8]. Islanding detection techniques are categorized in two essential groups; local techniques and remote (communication based) techniques. The local techniques are divided into passive, active, and hybrid techniques. Communication based techniques use a continuous signal between grid and DGs, and are classified into power line signaling scheme and transfer trip scheme, where both schemes have an enhanced reliability compared to the local techniques, however, with a higher cost. The local detection techniques are based on measuring system variables, such as voltage, frequency, active power, reactive power, at DG location. Although these techniques have low cost, they give poor results in some cases, especially when a matching between load and DG occurs during islanding operation, resulting into a large non-detection zone [9]. Through extensive efforts, several studies have been oriented towards using passive techniques such as rate of change of frequency (ROCOF) [10], rate of change of voltage [11], rate of change of phase angle difference [12], voltage unbalance variation and total harmonic distortion [13], rate of change of output power of DG [14], balance of reactive power [15], support vector machine (SVM) based on many variables [16], an autoground system based on applying three phase to ground fault during islanding to ensure effective, fast, and correct decision [17], and neuro-wavelet method based on applying wavelet transform and artificial neural network on transient voltage signal [18].

Active detection techniques have significant advantages being able to define islanding situation, even if there is a matching between load and DG capacity. However, they introduce a disturbance to the system. Some active methods are reported in [19], such as reactive power export error detection, impedance measurement method, active frequency drift, and active frequency drift with positive feedback.

Hybrid techniques combine both passive and active methods, with some of them depending on voltage and reactive power shift while others depending on positive feedback and voltage unbalance [20]. Some authors are concerning on avoiding or estimating the nondetection zone and other authors solve the islanding detection problems using advanced methods or methods used only for a certain type of DGs [21-22]. Different adaptive methods are proposed to solve the bi-directionality problem or loss of coordination problem [23]. At the end of this review, it can be shown that most of the reviewed protection methods are focusing on solving only one protection problem. This paper presents an adaptive method to solve all protection problems resulting due to connection of DGs.

2. Proposed Algorithm

Nowadays, a large scale of DGs are added to the grid so that the proposed method uses adaptive and communication overcurrent relays, every feeder has two relays, one of them at the beginning of the feeder and the other one at the end of the feeder (Ex: R34 represents the relay between bus 3 and bus 4 at the end of bus 3 and R65 represents the relay between bus 5 and bus 6 at the end of bus 6).

First of all, we have to define all connection cases for the system (i.e. case 1: grid alone, case 2: grid + DG1, case 3: grid + DG2, and so on), then perform the load flow analysis and short circuit calculation for each case to determine the value and the direction of the current in each relay. According to these results, each relay has N number of currents; N is equal to the number of connection cases. So, each relay has N number of CCT or may less than this number if there are equal currents in different cases. All CCT of relays can be defined by the value of actual current and short circuit current.

All relays are connected to the main processor so that the main processor receives a connection signal (connected or disconnected) from all relays in the system (i.e. feeder's relays and DG relays) to define the connection of the system. The media of communication between relays and the main processor is fiber optics which has a lot of advantages such as vendor availability, high communication speed, high reliability, and can be used in overhead systems and underground cables. The required communication time is 48.9 microseconds / 10 Km length, so maximum communication time for a system consists of 14 relays is less than 1.4 ms, which is less than 0.1 power cycle, so the protection process will not affected by the total time for communication and programming. According to the connection case of the system the main processor sends flags refer to the CCT to every relay. The proposed method is applied on two different systems, Simple five steps of the proposed method are shown in Figure 1; these steps are applied to any system regardless of the size, number, location and type of the added DGs.

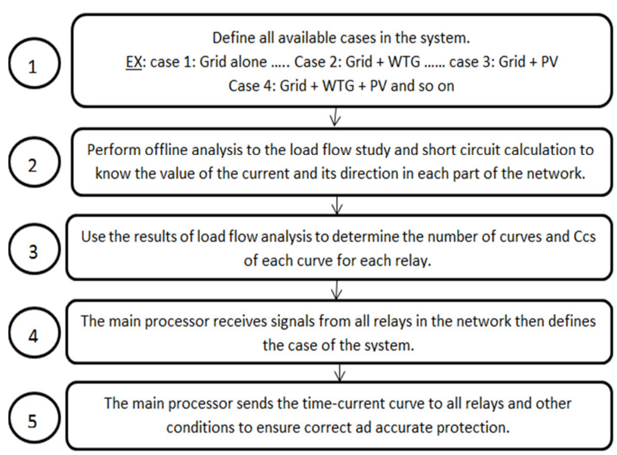

Fig. 1. The main steps of the proposed method

3. Tested System

The tested system consisting of grid with rated voltage of 34.5 kV and short circuit level of 1000 MVA, it is connected through 20 MVA transformer with turns ratio of 34.5/4.16 kV, seven main buses, six loads of 5, 3, 1, 1.2, 1.4, and 1.6 MVA are connected at buses 2, 3, 4, 5, 6, and 7 respectively, three capacitors banks of 2, 1.2, and 1.3 MVAR are connected at buses 2, 5, and 6 respectively, the sizes and locations of these capacitors are chosen to keep the voltage at accepted values with any formulation of the system, five main feeders have cross section area of 400, 400, 300, 400, and 240 mm^2 respectively, the number of conductors per phase for each feeder are 3, 2, 2, 1, and 1 respectively, the feeder lengths are 1, 1, 1, 1, and 0.3 Km respectively, wind farm consisting of four wind turbines of 600 kW each (WTG_{1-4}) is connected at bus 4 through 4 MVA transformer with turns ratio of 0.6/4.16 kV, another wind farm consisting of three wind turbines of 600 kW each (WTG_{5-7}) is connected at bus 6 through 2.5 MVA transformer with turns ratio of 0.6/4.16 kV, and six PV arrays of 85 kW each are connected at bus 7 through 1 MVA transformer with turns ratio of 0.22/4.16 kV. Relays R1, R23, R34, R45, R56, and R67 are called the forward relays and R32, R43, R54, R65, and R76 are called the reverse relays. Figure 2 shows the details of the simulated system using ETAP program.

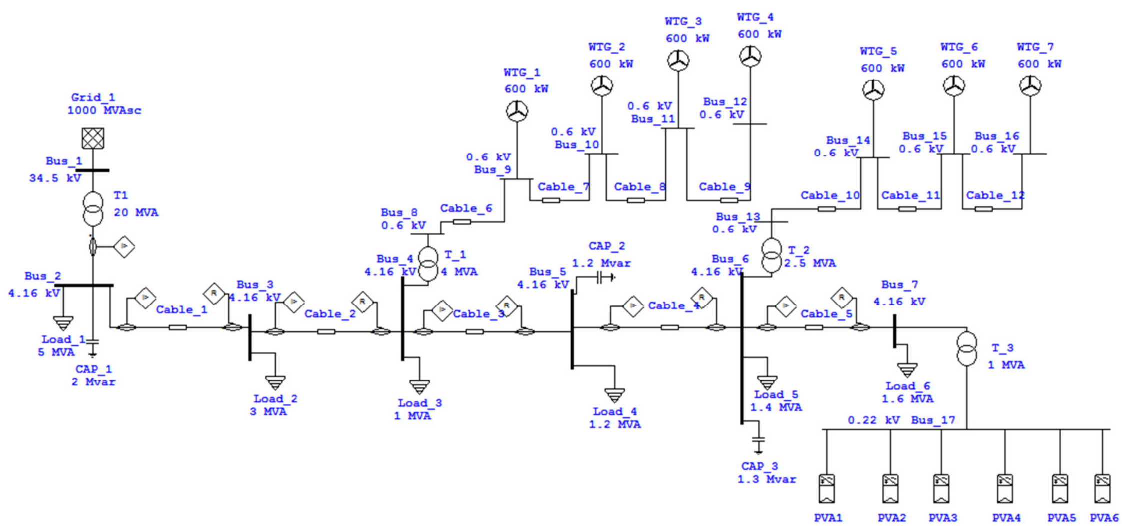

Fig. 2. Details of the tested system in ETAP

This system has nine possible connections and they are listed in Table 1.

Table 1
Possible connections for the tested system

Case	connection
1	Grid alone
2	Grid + WTG_{1-4}
3	Grid + WTG_{5-7}
4	Grid + PV
5	Grid + WTG_{1-4} + WTG_{5-7}
6	Grid + WTG_{1-4} + PV
7	Grid + WTG_{5-7} + PV
8	Grid + WTG_{1-4} + WTG_{5-7} + PV
9	Islanding operation (WTG_{1-4} + WTG_{5-7} + PV)

The main processor defines the connection case of the system according to the received signals from all relays. This process described in Figure 3.

Then the main processor sends a flags refer to the CCT for each relay and handles the special condition for each case. This idea is explained in the next two examples:

1- When the connection is case 2, if R32 or R43 get trip, the main processor sends trip signal to the relay of WTG_{1-4} to prevent islanding operation of WTG_{1-4} (the allowable islanding is connection of WTG_{1-4} + WTG_{5-7} + PV).
2- When the connection is case 9, a capacitor bank of 0.8 MVA is connected at bus 4 to prevent disallowable occurrence of voltage drop, disconnect R34 and R43 and if any DG becomes out of service, then the main processor will send a trip signals to other DGs.

Figure 4 shows the data which the main processor sends to each relay and the special condition for each case.

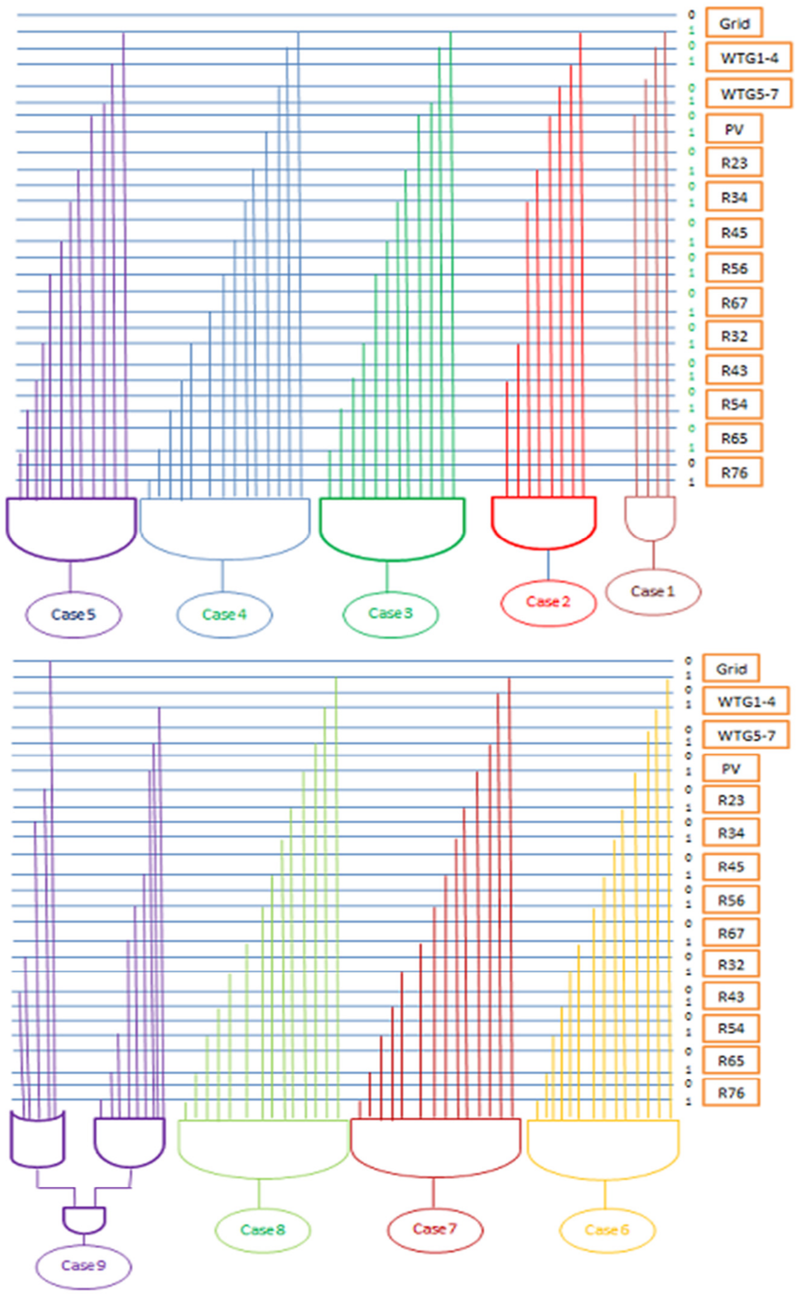

Fig. 3. The input signals to main processor to define the connection case

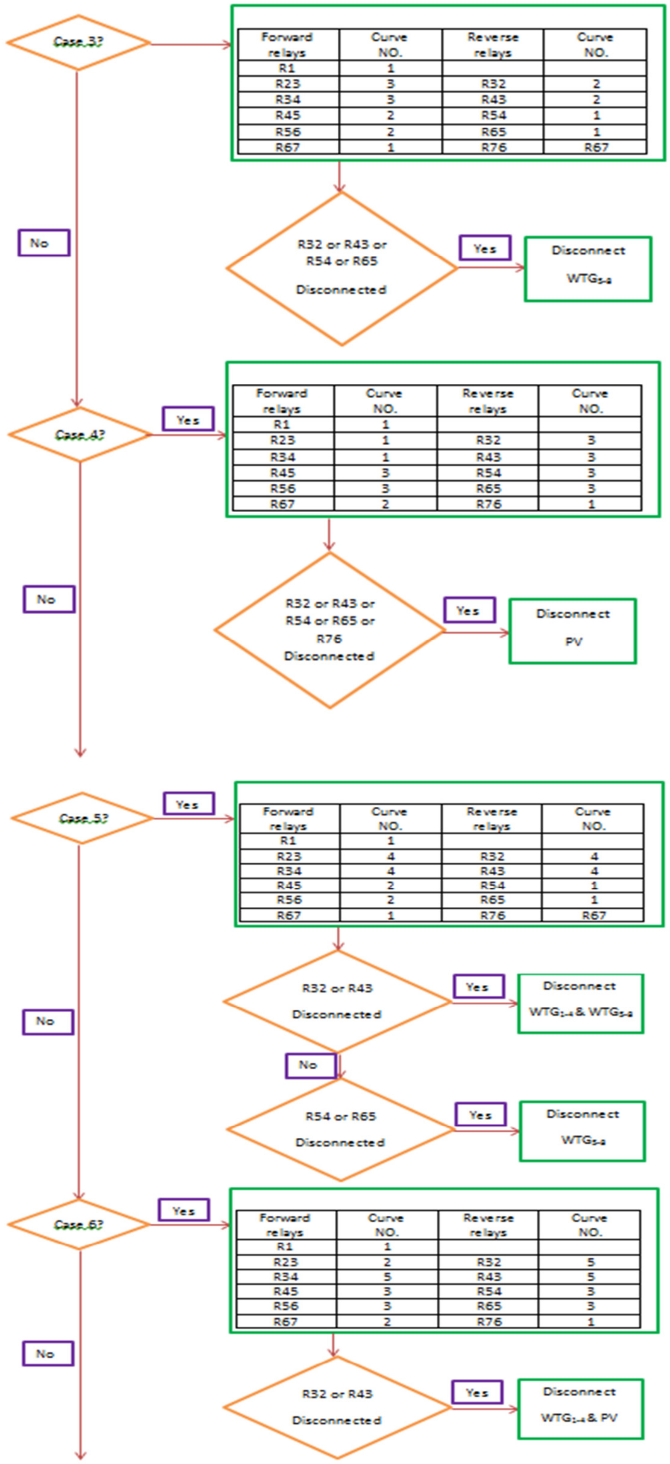

Fig. 4. Data which the main processor sends to each relay and the special condition for each case

4. Applying the Proposed Method on the Tested System and Results

Perform offline load analysis and short circuit calculation using ETAP to know the value and direction of current in each relay in each case, some results of this step are listed in Table 2.

Table 2
Results of load flow analysis and short circuit calculation

Case 1: Grid alone					
Forward relays			Reverse relays		
Relay	Actual current (A)	3ϕ SC current (KA)	Relay	Actual current (A)	3ϕ SC current (KA)
R1	2776	27.8			
R23	974.1	27.8	R32	No reverse	No reverse
R34	609.8	21.1	R43	No reverse	No reverse
R45	475.2	15.2	R54	No reverse	No reverse
R56	339.6	11.4	R65	No reverse	No reverse
R67	211.5	7.9	R76	No reverse	No reverse
Case 8: Grid + $WTG_{1\text{-}4}$ + $WTG_{5\text{-}7}$ + PV					
Forward relays			Reverse relays		
R1	2776	27.8			
R23	439.6	27.8	R32	---	2.4
R34	---	21.1	R43	100.1	2.5
R45	225.9	16.7	R54	---	1.08
R56	235	12.2	R65	---	1.2
R67	171.7	9.4	R76	---	0.095

Then we move to the next step, the pickup current of each relay for each case can be determined using the load flow results, the forward relays are chosen to be inverse definite minimum time overcurrent relays, the current-time characteristics curve of these relays is described by the following equation

$$T_{op} = \frac{K \times \beta}{\left(\frac{\mathrm{Isc}}{\mathrm{Ip.u}}\right)^{\alpha} - 1} \qquad (1)$$

where: T_{op}: operating time, K, α, and β: relay constant, Isc: short circuit current, Ip.u: pick up current, α and β are chosen so that the relay curve is very inverse.

The pickup current is chosen to be 1.05-1.2 of the actual current. Now every relay has nine different values of actual current resulting nine different values of pickup current, in this paper the values of actual currents which have small different between them are resulting only one pickup current, so each relay may have three or four or five pickup currents but not nine values. For example, R56 has only three CCT instead of nine. The instantaneous current is chosen to be 5-20 times the pickup current. Table 3 shows the resulting curves of some relays.

The reverse relays are chosen to be definite time overcurrent relay to ensure high speed and correct decision, Table 4 shows the resulting curves of some relays. In some cases there is no reverse current from DGs in the load flow analysis but a reverse current appears in the short circuit condition, so the reverse relay pickup current is chosen to be a percentage of the rating of DG.

Since all relays are connected to the main processor, when a relay disconnect the circuit the main processor sends a trip signal to the relay in the same feeder to ensure complete and fast isolation to the faulted feeder. For example, if R34 trips, then the main processor sends trip signal to R43.

Table 3
Current-time characteristics for forward relay

Curve No.	Actual current (A)	Pickup current (A) =1.05-1.2I	Inst. Current (A) =5 $I_{P.U}$	Inst. Time (sec)	Curve type
			R23		
1	974.1 913.1	1025	5125	0.08	Very inverse K=3
2	649.2 586.9	690	3450	0.08	Very inverse K=3
3	785.4 736.3 439.6	825	4125	0.08	Very inverse K=3
4	475 410	500	2500	0.08	Very inverse K=3
			R56		
1	339.6 342.8	380	1900	0.02	Very inverse K=1
2	237 237.3 236.5 235 232.4	260	1300	0.02	Very inverse K=1
3	277.6 281.2	310	1550	0.02	Very inverse K=1

Table 4
Current- time characteristics for reverse relays

Curve No.	Actual current=pickup current(A)	Inst. Time (sec)	Curve type
	R65		
1	294 294	0.06	Definite time
2	270 270 270	0.06	Definite time
3	50 50	0.06	Definite time
	R54		
1	222 222	0.04	Definite time
2	180 180 180	0.04	Definite time
3	33 33	0.04	Definite time

Finally, in the last step, the processor has flags refer to the current-time curve for each relay and also has the connection case of the system. So, it sends the suitable flag for each relay as shown in Figure 4.The resulting curves of relays will be coordinated correctly. Figure 5 Shows CCT of forward relays for case1 and case 9 and Figure 6 shows CCT of reverse relays for case 3 and case 7.

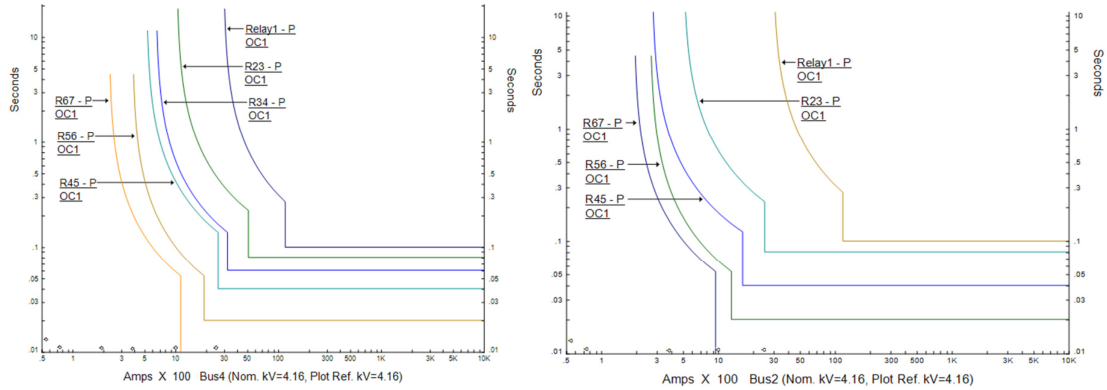

Fig. 5. CCT of forward relays for case 1 and case 9 respectively

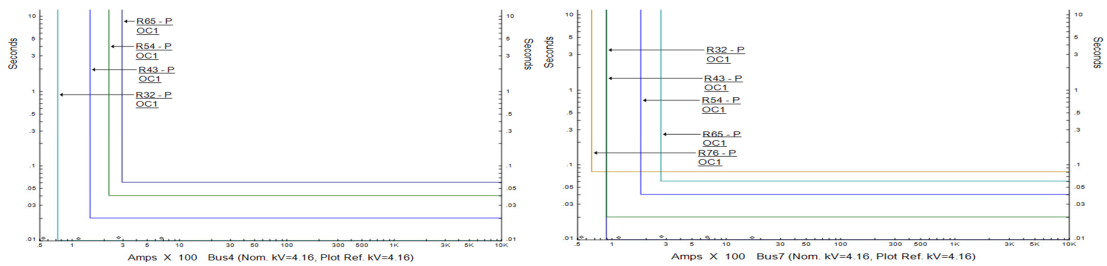

Fig. 6. CCT of reverse relays for case 3 and case 7 respectively

4. Conclusion

Connecting a large scale DGs in the distribution and medium voltage networks causes problems in the protection of the system such as loss of coordination, bi-directionality and islanding operation. This paper presents a novel adaptive method to overcome all protection problems regardless of the size, type, location, and number of connected DGs. The proposed method is tested on two systems with different location and size of connected DGs, the contribution of DGs on the system reaches to 40% of the maximum demand. The results reveal that, the proposed method effectively solves all protection problems. In the proposed method, a load flow analysis and short circuit study are done using ETAP program for all possible connections. Then time-current curves for each relay are defined. The main processor receives signals from all relays in the system through fiber optics medium, and then it defines the connection case and hence sends flags refer to the CCT for each relay.

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