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Adaptive Overcurrent Protection Scheme for Power Systems with High Penetration of Renewable Energy Recourses

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ABSTRACT. *Due to high penetration of renewable energy recourses in the existing distribution network, the protection system faced a new challenge. This paper presents an adaptive overcurrent protection scheme for active distribution network ADN enhanced by real time measurement gathered from micro phasor measurement unit μPMU. The μPMU measurement is used in this paper to estimate the network topology of the ADN. The proposed scheme has been tested and validated using MATLAB programing environment. The simulation results demonstrate the effectiveness of the proposed adaptive protection scheme.*

Keywords: Power System Protection, Adaptive protection, renewable energy recourses, active distribution network, optimization technique.

1. Introduction.

Nowdays, a high penetration of renewable energy in an electrical distribution network, this penetration lead to convert the passive distribution network to be an active distribution network[1-3]. The conventional distribution networks are a dual structure system that consist of substations and loads, with the power flowing from the grid to consumers. Since there are no distributed generations (DGs) connected into the grid, this kind of network can be called a passive distribution network (PDN) [4].

An active distribution network (ADN) is a ternary structure system, which consists of DGs, substations and loads, where a flexible network topology is employed to manage power flows and achieve the proactive regulation of DGs [5].

The increase in the short circuit level and change in fault current directions in the ADN influence the protection coordination between relays installed in the ADN, and disturb the functionality and the selectivity of those relays. Further, dynamically changing load, generation and topology cause a significant change in fault currents which sometimes results in a miscoordination of one or more primary - backup relay pairs.

Furthermore, blinding of protective devices and false tripping are the most common protection problems associated with integrating DGs in the DN [6].

Many researches have been presented in literature to deal these problems. Whereas, the non-adaptive protection scheme provides settings of relays, which can coordinate properly in both grid-connected and islanded modes. However, such a scheme cannot provide proper coordination when one or more lines in the system go out-of-service for any reason [7, 8]. On the other hand, adaptive protection scheme provides optimum settings for each operating topology and the circuit breaker status of DERs [9]. The adaptive protection provides much better coordination with relatively low operating times of all the relays [10, 11].

To reduce the possibility of the unwanted power outage, proper coordination among the direction overcurrent relays DOCRs is necessary. That's mean, the minimum coordination time interval (CTI) must be maintained between the operating times of primary and the corresponding backup relay pairs. Proper protection coordination can be achieved through optimum settings of the two parameters of DOCRs, namely, time multiplier setting (TMS) and plug setting (PS).

Normally, optimization-based approaches are used to obtain the optimum settings of the relays. In term of this, the problem is formulated as either a linear programming (LP) or a nonlinear programming (NLP) problem and various optimization techniques are applied to solve these problems. In LP formulation, the operating times of relays are expressed as the linear function of the TMSs of the relays whereas the PSs of the relays are assumed to be already known. A simple approach and its variants have been proposed to determine the TMS of the relays in [12]. In NLP formulation, the operating time of a relay become a nonlinear function of TMS and PS of the relay [13]. Subsequently, application of various metaheuristic optimization methods such as particle swarm optimization (PSO), genetic algorithm (GA), and evolutionary algorithm (EA) have also been proposed in the literature.

The proper adaptive overcurrent protection needs a real time information, this information generally obtained by s supervisory control and data acquisition (SCADA) system or intelligent electronic devices (IEDs). These data face two types of issues. The first one is a high time delay, whereas the second one is considerable measurement errors. From this point in this paper the phasor measurement unit PMU is used to enhanced the adaptive protection scheme. real-time monitoring and protection scheme of AC MGs by employing a synchrophasor at the point of common coupling (PCC) has been discussed [14]. The μPMU provides phasor measurements at very high-resolution, which is one of the most important requirements to use them at distribution level [15].

This paper proposed an adaptive overcurrent protection scheme enhanced with micro phasor measurement unit μPMU. The MATLAB program is used to solve the nonlinear optimization problem. The proposed scheme has been tested in an active distribution network. The micro phasor measurement unit μPMU is used in the proposed scheme to gathered the real time information from the network to the control center via suitable communication link.

The organization of the rest of this paper is as follows, In Section II, the proposed adaptive overcurrent protection is presented, which include the optimal relay setting calculation. In Section III, Simulation results and discussion is presented. Finally, the conclusion is presented in Section V.

2. The Proposed Adaptive Overcurrent Protection.

The main aim of protection schemes is to limit the damage, by separating the faulted section from the healthy one as quickly as possible. There is a minimum time gap between the operating times of primary and its corresponding backup relay. This time gap is known as the coordination time interval (CTI) of the primary-backup relay pairs. The proper protection coordination is achieved through the optimum settings of the direction over current relays DOCRs. However, the settings need to be changed as the network topology changes.

The operating time of a DOCR is dependent on its two parameters for given fault current. These parameters are time multiplier setting (TMS) and pickup current setting (PCS). The value of TMS and PCS parameters is called settings of the relay. In numerical DOCRs, TMS and PCS parameters are considered as the continuous variable within their range. Also, these parameters can be modified remotely from the control centers through a suitable communication link.

The real-time measurements obtained from μPMUs can be used to estimate the correct topology of the network. On the other hand, the status of various CBs, DGs, and PCCs can be obtained through the μPMUs. All this information will send continuously to the main control center to determine the short circuit current. The time coordination of primary and backup relay also will check in the control center.

Figure.1 present the proposed adaptive protection scheme the data is collected by using μPMUs and send to the main control center. In the control center there are two main function. the first one is calculating the short circuit current in each branch in the system by using the information gathered from the μPMUs.

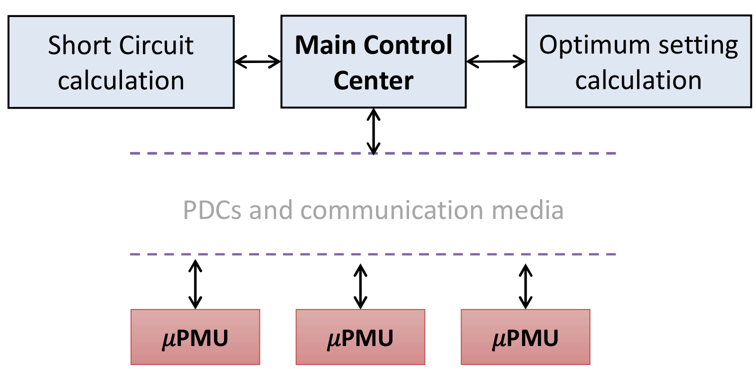

FIGURE.1 The proposed adaptive overcurrent protection

Whereas, the second function that must be done according to the proposed scheme is calculating the time coordination between the primary and the back-up protection relays, if the coordination time within the range the process well repeated. On the other hand, if the coordination time is out of range the optimum relay setting must to calculated and sent to the DOCRs.
The optimum setting of overcurrent relay is usually formulated as a constrained optimization problem. Several objective functions have been discussed in recent literature. The most common objective function used in literature is the minimization of the sum of the operating times of all the Directional Over Current Relays (DOCR) for the maximum fault current, this objective function is expressed as follows:

$$OF = \min \sum_{i=1}^{m} t_{op,i} \tag{1}$$

Where *m* is the number of relays, $t_{op,i}$ is the operation time for relay R_i . The operation time for relay R_i can be calculated by:

$$t_{op,i} = \frac{\mu\,.TMS_i}{(I_{F,i}/PS_i)^{\beta} - 1} \tag{2}$$

Where TMS_i is the time multiple setting for Relay R_i , $I_{F,i}$ is the maximum current flow through relay R_i. PS_i is the relay plug setting and μ, β is the relay characteristic constant as shown in table 1.

TABLE 1 . Overcurrent Relay Constant [16]

Relay type	μ	β
standard inverse relays	0.14	0.02
very inverse relays	13.5	1
extremely inverse relays	80	2

The objective function (1) minimizes the operating time only for primary relay without taking in account the backup relay operating time. To minimize the operating times of the backup relays along with those of the primary relays, the objective function in (3) can be used also:

$$OF_{i,j} = \sum_{i=1}^{m} (t_{op,i})^2 + \sum_{i=1}^{n} (t_{op,j} + MCT)^2 \tag{3}$$

Where, $OF_{i,j}$ is the summation of operating time for the primary relay R_i and the backup relay R_j. $t_{op,i}$, $t_{op,j}$ are the operating time for the primary relay R_i and backup relay R_j, respectively. MCT is the minimum coordination time between primary and backup relays. The objective function (3) is subjected to the following set of constraints:

1. If a primary relay R_i has a backup relay R_j for a fault at any line k, then the coordination constraint can be expressed as follows:

$$t_{op,j} - t_{op,i} \geq MCT \qquad (4)$$

Where $t_{op,i}$, $t_{op,j}$ is the operating time for the primary and backup relays, respectively.

2. The operating time for the relay R_i should be larger than the minimum operating time and less than the maximum operating time, this constraint can be expressed as:

$$t_{i,min} \leq t_{op,i} \leq t_{i,max} \qquad (5)$$

Where $t_{i,min}$, $t_{i,max}$ is the minimum and maximum operating time of the relay R_i.

3. The TMS and PS should be within relay rang:

$$TMS_{i,min} \leq TMS_i \leq TMS_{i,max} \qquad (6)$$

$$PS_{i,min} \leq PS_i \leq PS_{i,max} \qquad (7)$$

Where $TMS_{i,max}$, $TMS_{i,min}$ are the minimum and maximum limits of the time multiple setting, respectively. $PS_{i,min}$, $PS_{i,max}$ are the minimum and maximum limits of plug setting, respectively.

For numerical/digital type of relays, TMS and PS can have any continuous value within their ranges. Whereas, for static or electromechanical relays, TMS can be any continuous value but PS can only have certain fixed discrete value within their respective ranges. Anyway, numerical relay has been used to conduct this paper.

3. Result and Discussion.

To investigate the effectiveness of the proposed protection scheme, an active distribution system has been chosen. The single line diagram of the chosen distribution system is shown in figure.2. It has 4 buses and 4 lines. The distribution system is connected to the grid at bus 1. There are two 5MVA distributed generators DGs connected to the system at bus 2 and bus 4. The short-circuit rating of the grid is 250 MVA, whereas the generators have a short-circuit rating of 25 MVA. In simulation, the base voltage is taken as 11 kV and base MVA is 100. Each transmission line of the network has a resistance and reactance of 0.02 pu and 0.05 pu, respectively.

In order to provide proper protection system, the system has 8 directional numerical over current relay DOCRs, 2 relays at each line.

The current transformer CT for each relay based on the maximum loading current and short circuit current. Table 2 proposes the selected CT ratio for all relays, the load current at peak load, the maximum and the minimum short circuit currents for each relay in the system.

TABLE 2. Load Current, Fault Current And CT Raio

Line No.	Relay No.	I_{load} (A)	$I_{f\,min}$ (A)	$I_{f\,max}$ (A)	CT Ratio
L1	1	597	6543	8261	3000/5
	2	597	1701	2148	3000/5
L2	3	117	3412	4187	1200/5
	4	117	2271	2788	800/5
L3	5	178	3875	4735	1200/5
	6	178	1426	1742	1000/5
L4	7	62	3129	3810	1000/5
	8	62	1827	2225	600/5

Firstly, DG2 which is connected in bus 4 is assumed to be isolated from the network. after all measurements and topology information sent to the main control center, the short circuit current is calculated in each line, in order to determine the coordination time of primary-backup relay pairs.

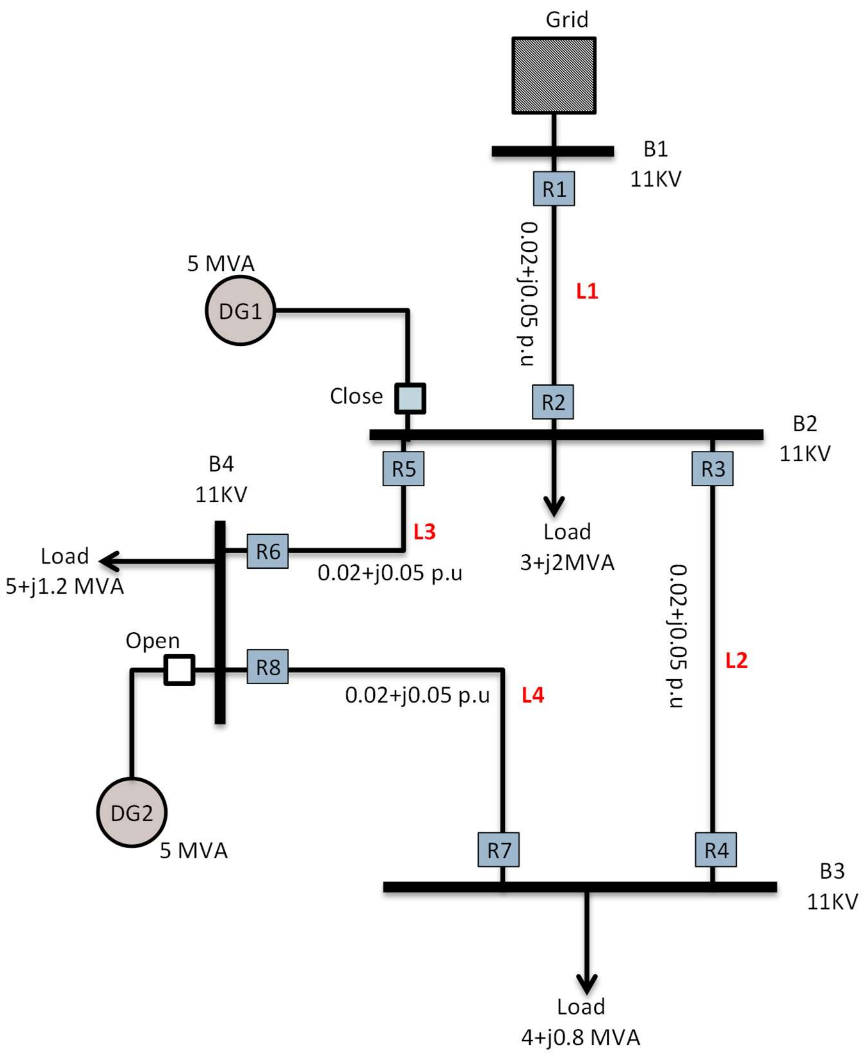

FIGURE. 1. Distribution system under study

Referring to the figure 2, there are 10 pairs of primary-backup protection relays in the system. So, the short circuit current for each pair is shown in table 3.

TABLE 3. Short Circuit Current For Primary And Backup Relays

Fault Location	Pair No.	R_{prim}	R_{Back}	I_{prim} (A)	I_{Back} (A)
L1	1	2	4	2527	1542
	2	2	6	2527	821
L2	3	3	1	4466	4627
	4	3	6	4466	465
	5	4	8	3048	436
L3	6	5	1	4987	4481
	7	5	4	4987	384
	8	6	7	1989	1874
L4	9	7	3	4066	1587
	10	8	5	2491	2369

After obtaining the short circuit current for all relays, the optimal setting is generated from the control center and sent to the relays. Figure.3 shows the PS and TMS setting for all relays. To ensure suitable setting for proper coordination between the primary and back up protection, the operating time for all pairs of primary and backup relays, the coordination time interval CTI for all pairs and the minimum acceptable coordination time MCT have been calculated and presented in figure.4. For example, if a fault is occurred at line L1, the primary protection is R2 and the Backup protection is R4, pair No. 2 in table 6.

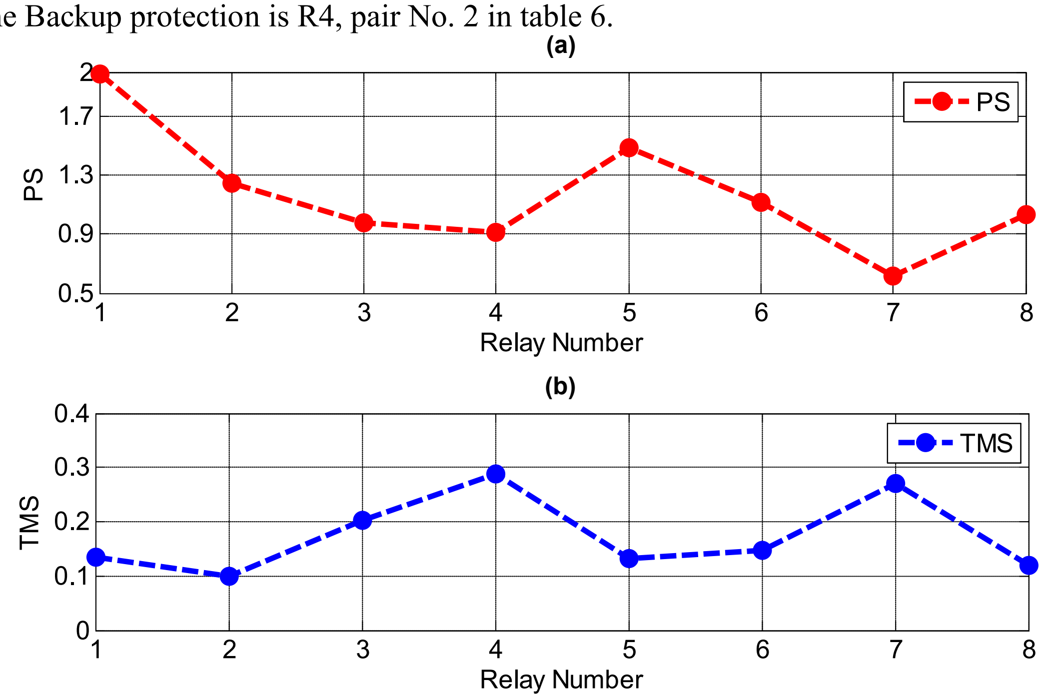

FIGURE. 2 Relay setting from control center for all relays (a) Pluge setting PS (b) Time multiple setting TMS.

Figure.4 (a), shows the operating time of the primary protection (R2) is about 0.5 seconds. The operating time for the backup protection (R4) is about 0.7 seconds. The coordination time exactly equals 0.2 seconds. Similarly, the coordination time for pair No. 3 is about 0.22 seconds, and for pair No. 4 is about 0.9 seconds, and so on. So, there is no pair of primary and backup relay has a coordination interval less than 0.2 sec.

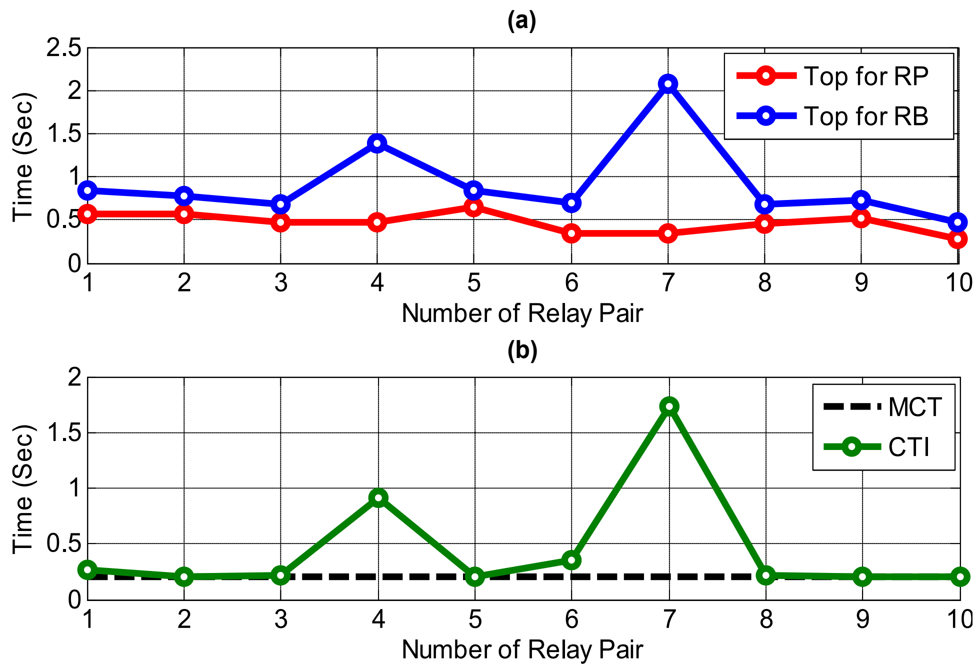

FIGURE. 3 (a) operating time in second for primary and back-up relay (b) Coordination time interval CTI and Minimum coorination time for all pairs of primary and back-up relays

With integration of DG2 at bus 4 the short circuit must be recalculated; this is done in the control center. All measurements and topology information are sent to the control center to calculate the short circuit current for the entire network in order to determine the optimal relay setting to ensure the proper coordination between primary and backup protection. The short circuit calculation is shown in table 4. Must to be noted, the short circuit current increased in some line after DG integration.

By assuming the relays' setting remains without any change. Then, by the short circuit current, which is presented in table 4, and relays setting presented in figure3, the operating time for primary and backup protection pairs and the coordination time interval CTI are shown in figure 5.

TABLE 4. Short Circuit Current After Dg2 Is Integrated

Fault Location	Pair No.	R_{prim}	R_{Back}	I_{prim} (A)	I_{Back} (A)
L1	1	2	4	3207	1693
	2	2	6	3207	1373
L2	3	3	1	4840	4523
	4	3	6	4840	465
	5	4	8	3382	919
L3	6	5	1	5074	4457
	7	5	4	5074	505
	8	6	7	2866	1595
L4	9	7	3	4091	1741
	10	8	5	3342	2111

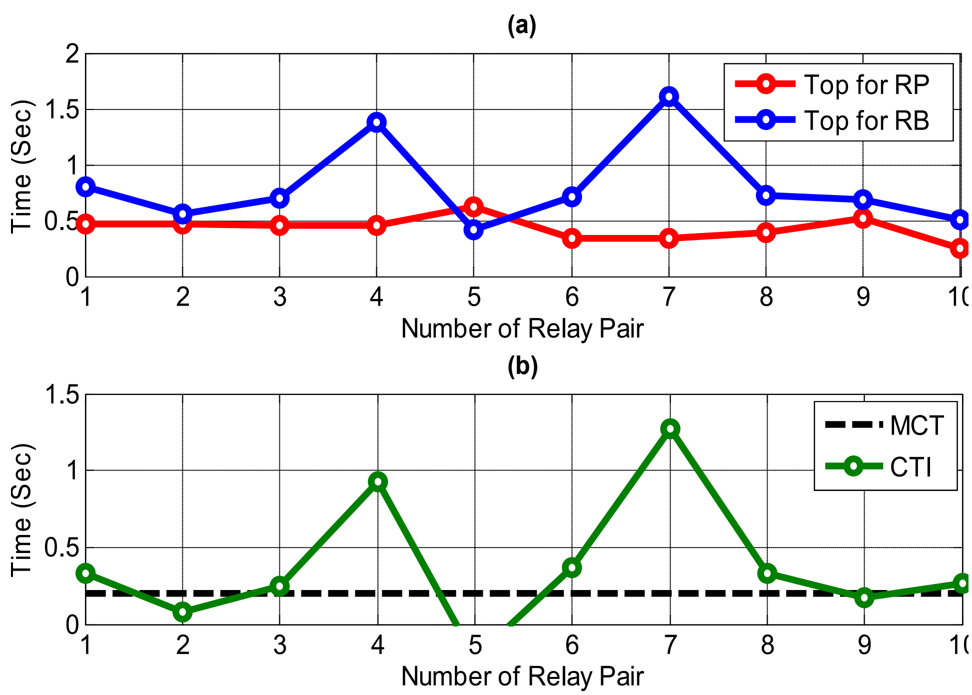

FIGURE. 4 (a) The operating time for all relay pairs after DG2 is integrated without change the relay setting (b) The coordination between primary and backup protection without change the relay setting.

Figure.5 (b) clearly shows the coordination time is failed in pairs 2, 5, and 9, i.e. the coordination time between primary and backup protection relay less than 0.2 seconds. Based on the proposed scheme when the coordination time out of range the optimum setting should be calculated and sent to the relays.

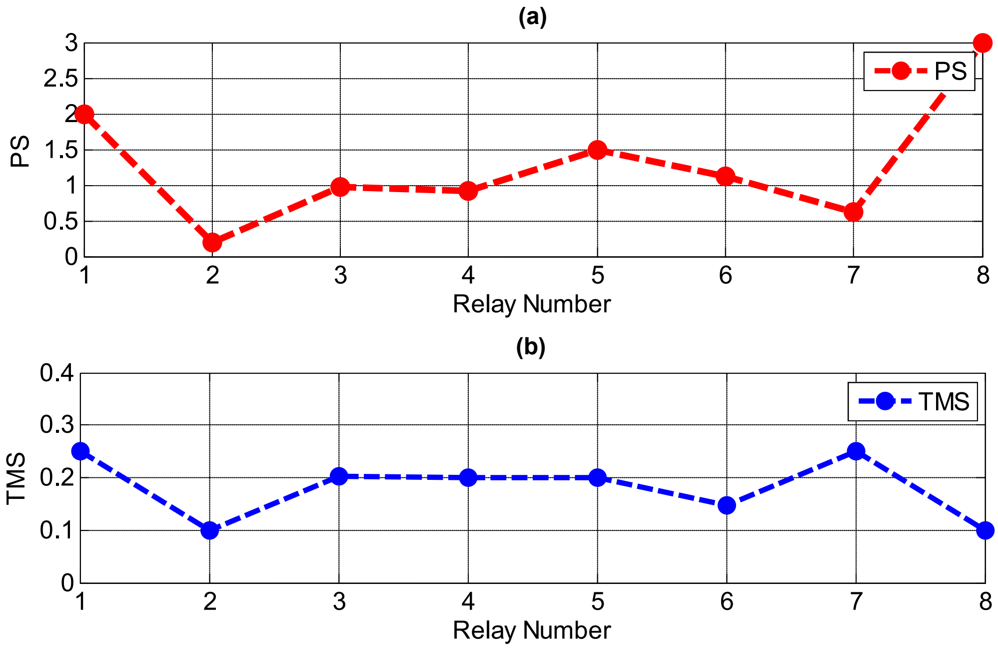

FIGURE. 5 (a) Plug Setting PS, (b) TMS for all relays, by proposed scheme after the communication link return to the service.

Figure. 6 shows the new setting od relays generated by control center after the DG2 is integrated. It is clear that all relays have been properly optimized. By applying the short circuit current given in table IV for the new relays setting, the operating time for each relay can be obtained. Figure. 7 shows the operating time of the relay pairs after applying the new relay setting. Figure 7 (b) clearly shows that there is no coordination time interval CTI less than MCT (0.2 sec.). Where, the coordination time between the primary relay R6 and the backup relay R7 in pair No. 8 is about 0.27seconds, and similarly between R2 and R6 is about 0.34 seconds.

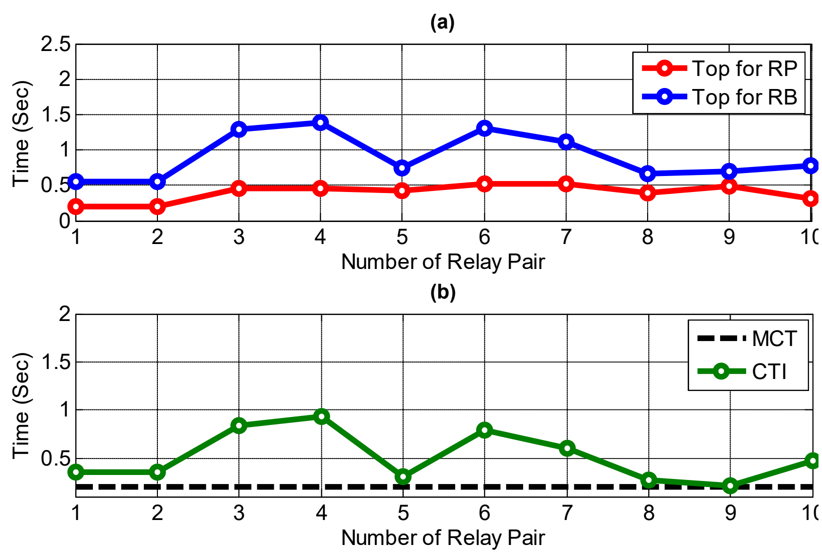

FIGURE. 6 (a) Operating time relay pairs (b) CTI and MCT for all for all relay pairs, by using optimal setting form the proposed scheme

4. Conclusion.

In this paper an adaptive protection scheme based on a micro phasor measurement unit μPMUs is proposed. The proposed scheme used the μPMUs to obtain the accurate measurement form the network to the control center. The coordination time between the primary and back-up protection relay is calculated continuously in the proposed scheme. The settings of all relays have been optimized to maintain the coordination time between the primary and the back-up relay. The simulation result shows that the proposed scheme is effective and sufficient to overcome the negative impact of distributed generation DGs in the distribution network.

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