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RELAY COORDINATION PLANNING FOR HIGH PHOTOVOLTAIC PENETRATION USING PRESET-TIME METHOD

Ahmed Abduljabbar Abdulkareem*, Madihah Md Rasid, Jasrul Jamani Jamian, Norazliani Md Sapari

Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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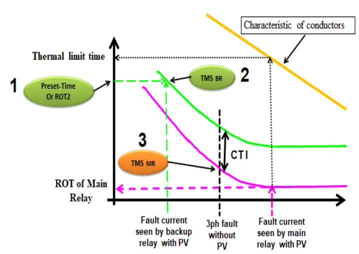
*Corresponding author
madihahmdrasid@utm.my

Graphical abstract



Abstract

In light of the advancement and technological development, electricity has become the main component of all areas of life. Photovoltaic (PV) systems are widely used within distribution networks. Despite all the advantages that PV possesses, it has some effects on the protection system. One of the most essential effects caused by PV is an increase in the relay operating time (ROT) of the backup protection relay during faults. Many studies have focused on improving the coordination of protection relays at high PV penetration, either by using current limiters or modifying the characteristics of the protection curves. However, they require a high cost and advanced relay. Therefore, the Preset-Time method is introduced in this study to shorten the ROT of the backup protection relay within the radial distribution networks which contributes to accelerating the removal of faults. The proposed method is tested on the Iraqi distribution network and is simulated using ETAP 19 software. The performance of the Preset-Time method is evaluated during the change in penetration levels. To validate the preset time method, its results are compared to the conventional method and the Max PSM method. From the results obtained by the Preset-Time method, the highest percentage of reduction in ROT was 33.20% and 29.23% compared to the conventional and the Max PSM methods, respectively.

Keywords: Protection system, backup protection relay, ROT, coordination of protection relays, photovoltaic

Abstrak

Dalam kemajuan dan pembangunan teknologi, elektrik telah menjadi komponen utama dalam semua aspek kehidupan. Sistem fotovoltaik (PV) digunakan secara meluas dalam rangkaian pengagihan. Walaupun PV banyak kelebohan, ia ada memberi kesan ke atas sistem perlindungan. Salah satu kesan ialah peningkatan masa operasi geganti (ROT) semasa kerosakan. Banyak kajian telah memberi tumpuan kepada meningkatkan penyelarasan geganti perlindungan pada penggunaan PV yang tinggi, sama ada dengan menggunakan pengehad semasa atau mengubah suai ciri-ciri lengkung perlindungan. Namun, kaedah ini memrlukan kos yang tinggi. Oleh itu, kaedah Praset masa diperkenalkan dalam kajian ini untuk memendekkan ROT geganti sandaran dalam rangkaian pengedaran jejari yang menyumbang kepada mempercepatkan pemulihan kerosakan. Kaedah ini di uji pada rangkaian pengagihan Iraq menggunakan perisian ETAP 19. Prestasi kaedah Pratetap-Masa dinilai semasa perubahan dalam tahap penembusan. Untuk mengesahkan kaedah masa pratetap, keputusannya dibandingkan dengan kaedah konvensional dan kaedah Max PSM. Daripada keputusan yang diperolehi kaedah Preset-Time, peratusan tertinggi pengurangan ROT ialah 33.40% dan 29.24% berbanding kaedah konvensional dan Max PSM.

Kata kunci: sistem perlindungan, geganti sandaran, ROT, penyelarasan geganti perlindungan, fotovoltaik.

1.0 INTRODUCTION

In the modern era, electricity has become the lifeblood. Almost no application in life is devoid of the use of electricity. Electricity reaches consumers after passing through three main stages, which are production, transmission, and distribution. The distribution stage is one of the most important stages, as it is the closest to consumers. With the increasing demand for electricity, the use of distribution generators (DG)s has spread significantly due to the advantages that these generators possess. DGs are divided into several types, some of which work on thermal fuels and others that work on wind or solar energy [1], [2].

Coinciding with the fuel crisis and the global warming problem that the world is suffering from these days, photovoltaic (PV) is at the forefront of the distribution generator scene [3]. The distinction that PV has gained is a result of the advantages that PV enjoys in terms of the absence of pollution and ease of installation and use [4]. The PV connection to the distribution networks is in several models, including those that are close to the loads, close to the sources, and between the sources and the loads [5]. With their various connection models, PVs contribute to reducing losses and increasing the stability of distribution networks. The effectiveness of PV depends on the level of penetration. As the penetration depends on the quantity of load connected to the electrical network. When the electrical load is equal or near to the power generated from the PV, the penetration of the PV is at its highest value.

However, there is a significant problem resulting from connecting the PV at high penetration with the distribution networks, which is the increase in the operating time of the backup relay during faults if the main relay does not respond to remove the fault and loss the coordination between the main and backup relays [6]. In addition, the problem of loss of coordination between the protection relays is likely to occur as a result of the difference in currents of the main and backup relays caused by PVs in some connection models. Therefore, the two problems of increasing the operating time of the backup relays and the loss of coordination in the protection system may lead to the collapse of large parts of the distribution network [1], [7]–[12].

There are two main strategies used to reduce the operating time of the backup relays [11]–[16], which are: 1) the strategy for minimizing the PV effect during a fault and 2) strategies for modifying the curves of protection relays. Most of the studies that concerned improving the performance of the protection system during high penetration of PV followed those strategies. The study presented in [3] discussed the separation of the PV through directional relays that determine the photovoltaic contributing to the fault current, as the study contributes to improving the performance of the protection system and ensures coordination between the relays. The method of using a fault current limiter placed in an active section of the meshed distribution network is declared in [8] to ensure that the PV does not contribute to the fault currents within certain distribution network fault locations. In [13], current limiters were used, which reduced the value of the photoelectric currents, ensuring coordination between the protection relays and reducing the operating time of the backup relay. The approach of employing several curves is stated in [14], with the appropriate curve. In [17], a very effective method is proposed to improve the coordination between the protection relays considering the maximum plug setting multiplier (Max PSM) incident when faulting. Therefore, to reduce the ROT of the backup relays and maintain the coordination between the main and backup relays during the fault at the high penetration of the PV, it is required to use additional expensive equipment such as fault current limiters (FCLs) and advanced protection relays. The FCLs have to be within specific locations in the distribution networks, which in turn will reduce the high current caused by the high penetration of the PV. As for using of advanced protection relays, which in turn must deal with a wide range of time multiplier setting (TMS) starting from low decimal places that to give the minimum operating time of the backup protection relays. In addition to this, the impacts of high PV penetration on backup relays have not yet adequately addressed in previous studies. The high PV penetration leads to a difference in the fault currents seen by the main and backup relays. As a result of this difference in current, the backup relay will take a longer time to clear the fault if the main relay does not respond for any reason.

Considering above-mentioned concerns, this paper proposes a method called the Preset-Time method to reduce the operating time (ROT) of backup relays at high PV penetration. In the preset-time method, the characteristics of the IEC curves of various types are exploited to achieve the minimum operating time for the protection relays in general and for the backup relays in particular. The operating time of the backup relays is reduced, taking into consideration the critical time interval between the curves of the main relay and the backup relay, and it also considers the priority of operation and preserves coordination between the relays. The Preset-Time method contributes to accelerating the removal of defects from the distribution network and thus increasing the reliability of the protection system for the distribution network.

The negative impact of a high PV penetration on a distribution network depends mostly on the capacity and location of the PVs within that network. The worst effect is when the location of the PV is between the main relay and the backup relay as shown in Figure 1. The PV contributes to increasing the fault current that is seen by the main relay, while it contributes to reducing the current seen by the backup relay [18].

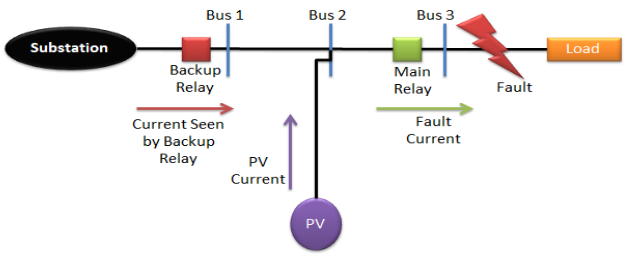


Figure 1 Currents during fault in the presence of PV

The change in the amount of current leads to a large change in the time required to remove the fault by each relay. The increase in the amount of PV penetration may lead to cases of destruction of the electrical network during faults [19]. The high penetration leads to an increase in the fault current, which in turn can lead to exceeding the thermal limit time of the electrical equipment as shown in Figure 2. The current seen by the main relay reaches its peak at the full penetration of PV, which in turn makes the ROT of the main relay reach its minimum. Consequently, if the main relay does not succeed in clearing the fault for any reason, reaching the thermal limit time is expected because the operating time of the backup relay is high due to its low current during the fault. The equipment's thermal limit time depends mainly on the type of metal that the electrical equipment is made from and on the cross-sectional area that passes the current during the fault.

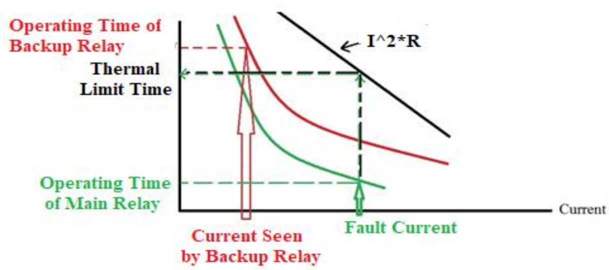


Figure 2 Times and current during faults in the presence of PV

The purpose of this research is to introduce an approach for reducing the ROT of backup relays and maintaining coordination between the main and backup protection relays in radial distribution networks at the significant PV penetration. The approach used in this study is called the Preset-Time method, and it works with ordinary protection relays. As a result, the Preset-Time method avoids the requirement for costly equipment such as advanced protection relays or FCLs. This study has tested a radial distribution network made up of five feeders, part of which contains PVs with a high penetration. The study uses the MATLAB software to implement the genetic algorithm (GA) to obtain the best TMS values. The obtained TMS and other data are entered to ETAP software to simulate the test system.

To ensure the validity and effectiveness of the Preset-Time method, its results are compared with the results obtained through the conventional and the Max PSM method when applied to the same test system.

2.0 METHODOLOGY

The main objective of the Preset-Time method is reducing the ROT of the backup protection relay and making it within the safe time while considering the preservation of coordination between the main relay and the reserve relay at different penetration levels.

In the Preset-Time method, the ROT of the backup protection relay is predetermined by the protection engineer during the setting of the protection relays in the planning stage. The basic concept of the predetermined time method is illustrated in Figure 3, which is summarized in three steps. After determining the currents seen by the main and backup relays with and without PV, the first step is to determine the ROT of the backup protection relay. In other words, the Preset-Time is determined while considering the time of the thermal limit of the electrical equipment. Therefore, given the availability of time and current, the second step to select the TMS of the main relay can be achieved.

The third step is to select the curve of TMS of the main relay. To determine the TMS value of the main relay, the current seen by the relay during the fault without the presence of the PV is adopted instead of the fault current seen by the main relay with the presence of the PV. After considering the critical time interval (CTI) between the main relay and the backup relay, setting the TMS value of the main relay becomes easy to accomplish. Choosing TMS based on fault current without the presence of PV ensures that the protection system works reliably with varying levels of PV penetration.

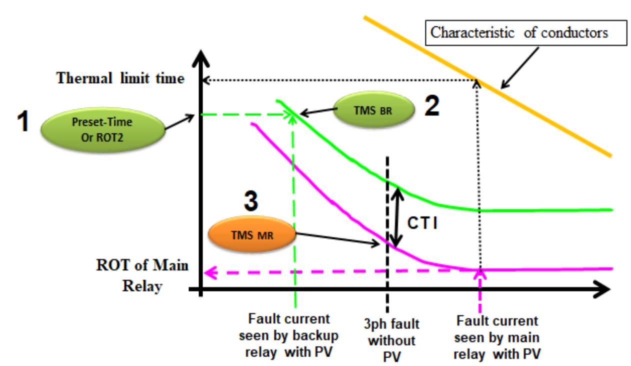


Figure 3 Steps and curves of the Preset-Time method

There are conditions and equations that must be followed in implementing the Preset-Time method to achieve the best results. Regarding the conditions, they are as follows.

- The setting of the protection system starts from the backup relay.

- The default operating time of the backup relay under the worst conditions is assumed to be in the range of 300 to 1200 ms.
- The backup relays must be set with IEC normal Inverse Definite Minimum Time (IDMT) curve.
- The initial time margin or initial Critical Time Interval (CTI) between each relay is 300 ms.
- All relays located in the first stage have to be set with the IEC Extremely Inverse (EI) curve.
- The reference current that is adopted in determining the TMS of the backup relay is the lowest current that passes through it, which synchronizes with the highest current that passes through the main relay during the faults in the presence of the PVs.
- The reference current that is adopted in determining the TMS of the main relay is the three-phase fault current that passes through it without the presence of the PVs.

To ensure that the Preset-Time method works with different levels of PV penetration and to avoid tripping signals coming from the relay, the pickup current must be set to the highest value as shown in Equation 1[20]. Where I pickup1 is the pickup current without PV, while I pickup2 is the pickup current with PV.

$$I_{pickup} = \text{maximum}\,(I_{pickup1}, I_{pickup2}) \qquad (1)$$

To ensure that the setting of the relay will handle high temporal loads, the pickup current for both cases with and without the PV must be multiplied by 1.2. Therefore, $I_{pickup1}$ is set according to Equation 2 [20]. Where I load1 is load current without PV.

$$I_{pickup1} = I_{load\,1} * 1.2 \qquad (2)$$

To raise the sensitivity of the Preset-Time method in the presence of the PV, the value of the minimum fault current is reduced by multiplying it by 0.95, as shown in Equation 3 [3].

$$I_{Relay\,(min)} = I_{Fault\ with\ PV} * 0.95 \qquad (3)$$

To avoid saturation cases that may occur in the current transformer (CT), the accuracy limit factor (ALF) of the CT is preferably selected according to Equation 4 [21].

$$ALF = (\text{Max. fault current} / \text{Primary current of the CT}) \qquad (4)$$

To select the TMS for the backup relay, Equation 5 and Equation 6 are used [14].

$$TMS_{Backup} = [(A-1)/0.14] * \text{Preset Time} \qquad (5)$$

$$A = [I_{Relay\,(min)} / I_{pickup}]^{0.02} \qquad (6)$$

Setting the backup relay is according to the procedures shown in Figure 4. In the beginning, the backup relay is specified, followed by the load flow procedure using the ETAP 19 software. The load flow is for two cases, which are with and without the presence of the PVs, to discover the highest load flow seen by the relay, in order to set the pickup current of the relay according to Equation 2. After executing the load flow, the value of the fault current is obtained for the abovementioned cases in order to know the lowest fault current seen by the backup relay. Equation 3 is adopted in determining the fault current when the PVs are not present. Then the value of the ALF is determined. Then all the values obtained with and without PVs are filtered in order to choose the appropriate ones. Where the highest pickup current is chosen according to Equation 1 and the highest value of ALF, the lowest value of fault current is adopted. After that, the Preset-Time value is assumed, which is between 300 to 1200 milliseconds according to what is mentioned in the aforementioned conditions, and because the safe time of clearing the fault of distribution networks is located within that range. That is followed by selecting the value of the TMS through Equations 5 and 6. The GA is used to reach the lowest values of TMS. The MATLAB software is used to implement the GA in order to determine the best values of TMS. The TMS acquired from MATLAB is manually input into the ETAP software.

The objective function of the GA in this study is Equation 5, while the constraints of the GA are: 1) The minimum and maximum fault current seen by the backup relay during faults. 2) The minimum and maximum possible pickup current of the backup relay depends on the mentioned conditions of the Preset-Time method. 3) The minimum and maximum value of the Preset-Time which is from 300 to 1200 ms. 4) The minimum and maximum value of the CTI between every two curves which is from 300 to 500 ms. Then the values of the thermal limit time and the final CTI are checked. If they are within the permissible limits, the TMS and the pickup current are set; otherwise, the Preset Time is increased from 300 ms until the appropriate values are reached.

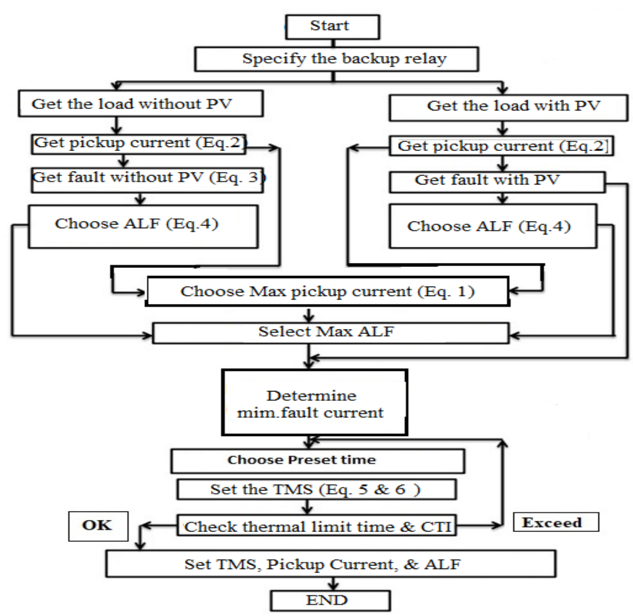


Figure 4 Flowchart of Preset –Time method to set the backup relays

Regarding the main relay setting, its ROT is determined according to Equation 7 [1]. In addition, TMS is selected for it according to Equation 8 [4].

$$ROT_{Main} = ROT_{Backup} - CTI \quad (7)$$
$$TMS_{Main} = ROT_{Main} * [B^{Y}-1] / Z \quad (8)$$

Where Y=2 for the relays located at the end of feeder, Y= 0.14 for the rest locations of relay. Z= 80 for the relays located at the end of feeder, Y= 13.5 for the rest locations of the relay. The setting procedures are as shown in Figure 5.

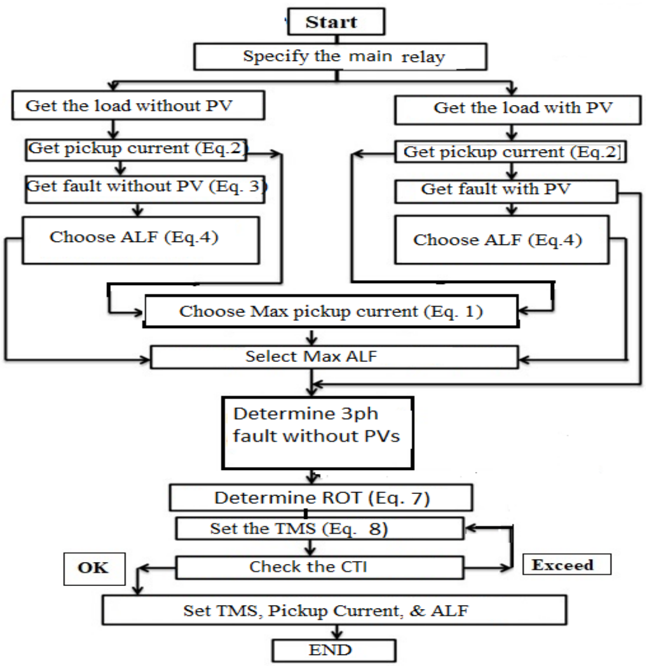


Figure 5 Flowchart of Preset–Time method of the main relays

They are the same procedures followed in setting the backup relay except that the fault current adopted in setting the main relay is a three-phase fault without any PV presence. The ROT is determined according to Equation 8, and TMS is specified according to Equation 9. In order to ensure that the Preset-Time method will operate with different levels of PV penetration, a fault without any PV has been adopted.

3.0 RESULTS AND DISCUSSION

The results of this study are structured into four sections. Section 4.1 shows the data for the test system. The case studies are explained in the second 4.2. Section 4.3 explains the results of setting in three methods, which are the Preset-Time method, the conventional method, and the Max PSM method. The modeling and the comparison of the results are explained in Section 4.4.

3.1 Test System Data

In order to evaluate the performance of the preset-time method, an 11.5 kV distribution network located in the west of Iraq was tested, which is shown in Figure 6. The system as a whole consists of 26 buses. The system contains a substation consisting of a 33/11.5 kV power transformer with a capacity of 31.5 MVA. The transformer is fed from the grid. The data for the grid and substation is shown in Tables 1 and 2, respectively. Five feeders come out of the substation. Six PVs each with a capacity of 2.3 MW are distributed on the first, third, fourth, and fifth feeders, while there is no PV on the second feeder. Table 3 until Table 8 show data for the five feeders.

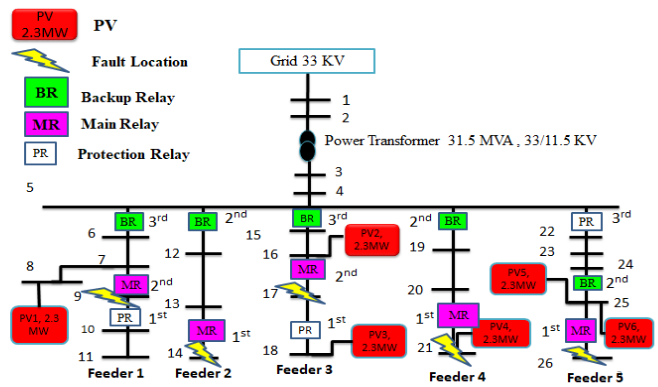


Figure 6 Test System

Table 1 Data of grid

Line to line Voltage (KV)	F (Hz)	Short Circuit Capacity (MVA)	Ratio of X/R	Type and Size of Conductors (mm²/phase)	
				Grid to Bus1	**Bus1 to Bus2**
				XLPE CU CABLE 1*400	XLPE CU CABLE 1*400
33	50	1000	10	**Length (m)**	**Length (m)**
				10	50

Table 2 Data of the substation

Capacity and Voltage of Power Transformer	Group	NGR Size ohm	No. of Feeders	Type and Size of Conductors (mm²/phase)	
				Power Tran. to Bus3	**Bus3 to Bus4**
31.5 MVA 33/11 KV	Dyn11	21.2	5	XLPE CU cable 1*400 mm²	XLPE CU cable 3*400 mm²
				Length (m)	**Length (m)**
				15	40

Table 3 Data of feeder 1

Type and Size of Conductors (mm²/phase) (From Bus to Bus)					
5 to 6	**6 to 7**	**7 to 8**	**7 to 9**	**9 to 10**	**10 to 11**
XLPE CU cable 1*150	Overhead ACSR 1*120/20	XLPE CU cable 1*150	Overhead ACSR 1*120/20	Overhe-ad CU 1*42	Overhead CU 1*42
Length (m)	**Length (m)**	**Length (m)**	**Length (m)**	**Length (m)**	**Length (m)**
510	490	245	1100	758	847

Table 4 Data of feeder 2

Type and Size of Conductors (mm²/phase) (From Bus to Bus		
5 to 12	**12 to 13**	**13 to 14**
XLPE CU cable 1*150	Overhead AAC 1*124	Overhead AAC 1*124
Length (m)	**Length (m)**	**Length (m)**
245	3010	97

Table 5 Data of feeder 3

Type and Size of Conductors (mm²/phase) (From Bus to Bus			
5 to 15	**15 to 16**	**16 to 17**	**17 to 18**
XLPE CU cable 1*150	Overhead AAC 1*124	Overhead AAC 1*124	Overhead AAC 1*124
Length (m)	**Length (m)**	**Length (m)**	**Length (m)**
255	2110	987	53

Table 6 Data of feeder 4

Type and Size of Conductors (mm²/phase) (From Bus to Bus		
5 to 19	**19 to 20**	**20 to 21**
XLPE CU cable 1*150	overhead AAC 1*124	overhead AAC 1*124
Length (m)	**Length (m)**	**Length (m)**
252	2998	80

Table 7 Data of feeder 5

Type and Size of Conductors (mm²/phase) (From Bus to Bus)				
5 to 22	**22 to 23**	**23 to 24**	**24 to 25**	**25 to 26**
XLPE CU cable 1*150	Overhead AAC 1*124	Overhead AAC 1*124	Overhead AAC 1*124	Overhead AAC 1*124
Length (m)	**Length (m)**	**Length (m)**	**Length (m)**	**Length (m)**
256	2030	2005	1009	58

Table 8 Data of loads

Feeder	Loads	
	kW	**kVAR**
Feeder1	2354	1362
Feeder2	3331	1466
Feeder3	5100	1900
Feeder4	3308	1475
Feeder5	4441	2032

3.2 Case Studies

To find out the effective impact of PV on the test system, the fault locations that most affect the operation of the protection relays were selected. All fault currents and current differences between main and backup relays obtained from the ETAP software are shown in Table 9.

3.3 Comparison of TMS by Three Different Methods

To validate the preset-time method, the TMS setting for the relays obtained by proposed methods are compared with conventional method and the Max PSM method. After applying the conditions for each of the three methods, the TMS setting values for the relays are obtained as shown in Table 10 and are illustrated in Figure 7. The result shows that the lowest values of TMS are those obtained by the Preset-Time method. The decrease in TMS values for the Preset-Time method comes from an important factor; that is, the Preset-Time method requires that the main relays located at the end of the feeder be set with extremely inverse (EI) curves. This type of curve is characterized by fast response at high faults and slow response at low fault currents, which contributes to preserving the value of the CTI between the main and backup relay when the fault occurs at high PVs penetration.

Table 9 Fault and difference current seen by relays

Feeder	Relay type	Fault Current (A)	Difference of Current (A)
Feeder1	Main Relay	2223	187
	Backup Relay	2036	
Feeder2	Main Relay	2692	0
	Backup Relay	2692	
Feeder3	Main Relay	2098	313
	Backup Relay	1785	
Feeder4	Main Relay	2673	0
	Backup Relay	2673	
Feeder5	Main Relay	3585	392
	Backup Relay	3193	

Table 10 Comparison of TMS settings for all feeders by three different methods

Feeder	TMS OF BACKUP RELAYS		
	BY PRESET-TIME METHOD	**BY CONVENTIONAL METHOD**	**BY MAX PSM METHOD**
Feeder1	0.1693 SI	0.2197 SI	0.18 19SI
Feeder2	0.1088 SI	0.16 24SI	0.1348 SI
Feeder3	0.1519 SI	0.19 37SI	0.1705 SI
Feeder4	0.1087 SI	0.162 SI	0.1471 SI
Feeder5	0.1239 SI	0.1827 SI	0.1654 SI

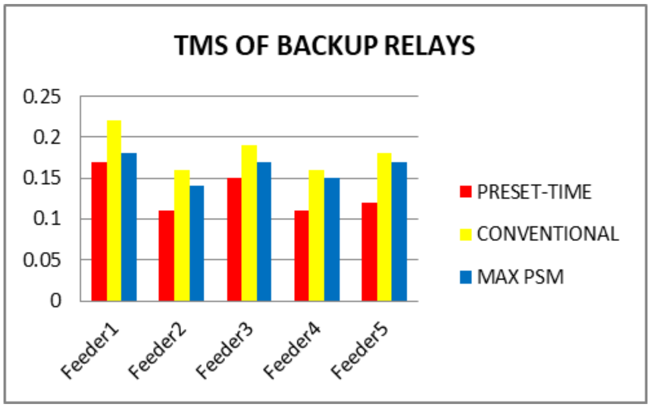


Figure 7 TMS of Backup Relays by Three Methods

3.4 Performance Evaluation of Preset-Time Method

By entering all the setting values of the relays and the data of the test system into ETAP 19 software, the results of modeling for the ROT values of the backup relays of the test system are obtained. All ROT values at full and zero PV penetration are obtained by the three methods as shown in Table 11 and Table 12. The result shows that the lowest ROT is provided by the Preset-Time method in both full and zero PV penetration levels. The ROT obtained by the Preset-Time method is shortened in comparison with ROT provided by another 2 methods. From the results obtained by modeling, it is clear that the ROT of the backup relays depends primarily on two main factors, which are the value of the TMS and the penetration levels. Because all the TMS obtained by the Preset-Time method are the lowest values, the ROTs by the Preset-Time method are lower than those obtained by the conventional and Max PSM methods.

When the Preset-Time method is used, the decrease in the ROT of the backup relays at high penetration is considered to represent the achievement of the study's purpose. The enhancement percentage of the Preset-Time method is the difference between the ROT of the comparative methods and the ROT of the Preset-Time method divided by the ROT of the comparative methods. The data tabulated in Table 11 are utilized to compute the percentage of enhancement gained.

To find out the value of the enhancement percentage at high PV Penetration obtained by each of the feeders of the test system as a result of applying the Preset-Time method, it is necessary to find the time difference of the ROTs and their percentage at using the conventional method or the Max PSM method. Therefore, to find out the percentage of enhancement obtained on the Feeder 5 compared to the conventional method, the time difference for the ROT through Table 11 is as below: 500-334=166 ms. Where 500 ms is the ROT by conventional method and 334 ms is the ROT by Preset-Time method. The percentage of enhancement obtained by Preset-Time method is (166/500)*100=33.2%.

To find out the percentage of enhancement obtained on the Feeder 5 compared to the Max PSM method for the Feeder 5, the time difference for the ROT through Table 11 is as below: 472-334=138 ms. Where 472 ms is the ROT by the Max PSM method and 334 ms is the ROT by Preset-Time method. The percentage of enhancement obtained by Preset-Time method is (138/472)*100=29.23%. And so on for the remaining feeders. The enhancement percentages for all feeders at full penetration are obtained as shown in Table 13 and are illustrated in Figure 8.

Table 11 ROT of backup relays at full penetration by three methods

Feeder	ROT OF BACKUP RELAYS AT FULL PENETRATION (ms)		
	BY PRESET-TIME METHOD	**BY CONVENTIONAL METHOD**	**BY MAX PSM METHOD**
Feeder 1	611	790	646
Feeder 2	313	454	438
Feeder 3	647	819	733
Feeder 4	314	456	427
Feeder 5	334	500	472

Table 12 ROT of backup relays at zero penetration by three methods

Feeder	ROT OF BACKUB RELAYS AT ZERO PENETRATION (ms)		
	BY PRESET-TIME METHOD	**BY CONVENTIONAL METHOD**	**BY MAX PSM METHOD**
Feeder1	604	782	640
Feeder2	310	452	437
Feeder3	644	816	730
Feeder4	311	453	424
Feeder5	329	494	466

Table 13 Enhancement Percentages of the Preset-Time method at full PV penetration

ENHANCEMENT PERCENTAGE AT FULL PENETRATION		
FEEDER NO.	**IN COMPARISON WITH THE CONVENTIONAL METHOD**	**IN COMPARISON WITH THE MAX PSM METHOD**
Feeder1	22.65%	5.41%
Feeder2	31.05%	28.53%
Feeder3	21%	11.73%
Feeder4	31.14%	26.46%
Feeder5	33.20%	29.23%

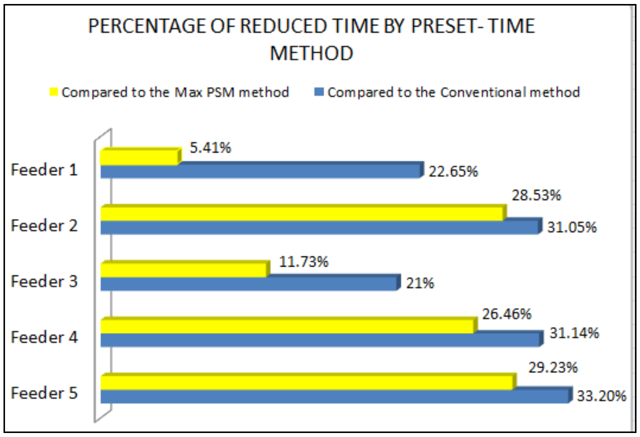


Figure 8 Percentage of Reduced ROT of Backup Relays at Full Penetration

4.0 CONCLUSION

The main objective of this study is to reduce the ROT of the backup relays at high PVs penetration on radial distribution networks using the Preset-Time method while considering the preservation of the value of the CTI around 300 ms between the main and backup relay. The Preset-Time method has been implemented at full and zero penetration of PVs at various locations. The effectiveness of the Preset-Time method has been validated by comparing it with the conventional and Max PSM methods. From the results obtained, the Preset-Time method has proven its quality in reducing the ROT of the backup relays for all feeders compared with the conventional and Max PSM methods alike. The highest enhancement percentages in the tested system was at full penetration of feeder 5 with its total load of 4441 kW and power generated from PVs on bus 25 was 4600 kW, then the ROT of backup relay was reduced by the maximum enhancement percentages of 33.20% and 29.23%, respectively, as compared to the conventional and Max PSM methods.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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