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ENHANCEMENT PROTECTION COORDINATION FOR DISTRIBUTION NETWORKS CONNECTED WITH PV USING PRESET-TIME METHOD

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A project report submitted in fulfilment of
the requirements for the award of the
degree of Master of Engineering
(Electrical Power)

School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2022

DEDICATION

This report is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

In preparing this report, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main report supervisor, Professor Dr. Madihah Binti Md Rasid, for encouragement, guidance, critics and friendship. Without their continued support and interest, this report would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for their wonderful educational curricula, and also to the Iraqi government in general and the Iraqi Ministries of Electricity and Higher Education for funding my Master’s study. The librarians at UTM deserve special thanks for their assistance in supplying the relevant literature, I do not forget to mention the assistance and support of the *University of Technology-Iraq*, Department of Electrical Engineering.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

In the modern era, electricity is the lifeblood. There is almost no practice without electricity in daily life. Distribution systems are the most important parts of the electrical system because they deal directly with the consumer, and any problems with them will reduce the quality of the electrical system and thus reduce its reliability. At a time when the global warming problem is emerging, the demand for and promotion of renewable energy is increasing. The spread of photovoltaic (PV) within the distribution networks has become widely spread in many countries. Despite the advantages provided by PVs, they cause negative effects on the distribution networks. One of the most significant negative effects that PVs cause on the distribution networks is the significant impact on the protection system. The high penetration of PVs can lead to the destruction of important parts of the distribution network due to the loss of coordination between the protection relays or increase the operating time (ROT) of backup relays when a main relay does not respond for any reason during faults. Most of the studies concerned with reducing the negative effect of PVs on the protection systems followed two basic strategies: either reducing the current coming from the PVs during the fault or modifying the curve characteristics of the protection relays. Both strategies have satisfactory results in reducing the harmful effects of PVs during faults. However, both strategies followed in most studies either require equipment to be added to the electrical network, such as current limiters, or use advanced and modern relays through which the characteristics of the curves of the protection relays can be modified. In this study, a method called Preset-Time is used to enhance the performance of the protection system during faults at high PV penetration within the radial distribution networks. The method aims to achieve the lowest possible ROT for the backup relays in the event of a failure of the main relays. The database of a radial distribution network (11.5 kV) located in western Iraq is used as a test system for the proposed method. To ensure the correctness of the Preset-Time method, the performance of the protection system in the conventional setting with and without PVs is analyzed; the Preset-Time method is implemented at full and zero penetration of PVs at various locations on the test system; the performance of the Preset-Time method is evaluated for different operating conditions of PVs; and finally, the effectiveness of the Preset-Time method is validated by comparing it with the conventional and Max PSM methods. The Etap19 software is used for modeling, while the genetic algorithm is used to calculate TMS. The Preset-Time method has proven its quality and effectiveness in reducing the ROT of the backup relays for the whole test system compared with the conventional and Max PSM methods alike at an initial critical time interval (CTI) of 0.3s.

ABSTRAK

Dalam era moden, elektrik adalah nadi. Hampir tiada amalan tanpa elektrik dalam kehidupan seharian. Pada masa masalah pemanasan global semakin meningkat, permintaan dan promosi tenaga boleh diperbaharui semakin meningkat. Penyebaran fotovoltaik (PV) dalam rangkaian pengedaran telah tersebar secara meluas. Kesan negatif paling ketara yang ditimbulkan oleh PV pada rangkaian pengedaran ialah kesan ketara ke atas sistem perlindungan. Penembusan PV yang tinggi boleh menyebabkan kemusnahan bahagian penting rangkaian pengedaran disebabkan peningkatan dalam masa operasi (ROT) geganti sandaran. Kebanyakan kajian yang berkaitan dengan mengurangkan kesan negatif PV mengikut dua strategi asas: sama ada mengurangkan arus yang datang daripada PV semasa kerosakan atau mengubah suai ciri lengkung geganti perlindungan. Kedua-dua strategi mempunyai hasil yang memuaskan dalam mengurangkan kesan berbahaya PV. Walau bagaimanapun, kedua-dua strategi yang diikuti dalam kebanyakan kajian sama ada memerlukan peralatan untuk ditambah pada rangkaian elektrik, seperti pengehad arus atau menggunakan geganti maju dan moden yang melaluinya ciri-ciri lengkung geganti perlindungan boleh diubah suai. Dalam kajian ini, kaedah yang dicadangkan dipanggil Preset-Time digunakan untuk meningkatkan prestasi sistem perlindungan dalam rangkaian pengedaran jejari. Kaedah ini bertujuan untuk mencapai ROT serendah mungkin untuk geganti sandaran. Pangkalan data rangkaian pengedaran jejari (11.5 kV) yang terletak di barat Iraq digunakan sebagai sistem ujian untuk kaedah yang dicadangkan. Untuk memastikan ketepatan kaedah yang dicadangkan, prestasi sistem perlindungan dalam tEtapan konvensional dengan dan tanpa PV dianalisis; kaedah yang dicadangkan dilaksanakan pada pelbagai penembusan PV; prestasi kaedah yang dicadangkan dinilai untuk keadaan operasi PV yang berbeza; dan akhirnya, keberkesanan kaedah yang dicadangkan disahkan dengan membandingkannya dengan kaedah konvensional dan Max PSM. Perisian Etap19 digunakan untuk pemodelan, manakala algoritma genetik digunakan untuk mengira TMS. Kaedah yang dicadangkan telah membuktikan kualiti dan keberkesanannya dalam mengurangkan ROT geganti sandaran berbanding kaedah konvensional dan Max PSM sama pada selang masa kritikal awal (CTI) sebanyak 0.3s.

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LIST OF ABBREVIATIONS

TMS / TD	-	Time Multiplier Setting / Time Dial of Protection Curve
PS	-	Plug Setting of Protection Relays
PSM	-	Plug Setting Multiplier of Protection Relays
I_{set}	-	Setting Current of Protection Relays
PR	-	Protection Relays
MR	-	Main Relays
BR	-	Backup Relays
CT	-	Current Transformer
VT	-	Voltage Transformer
CB	-	Circuit Breaker
PV	-	Photoelectric
GA	-	Genetic Algorithm
ROT	-	Relay Operating Time
IDMT	-	Inverse Definite Minimum Time Curve of IEC
SI	-	Standard Inverse Curves of IEC
VI	-	Very Inverse Curves of IEC
EI	-	Extremely Inverse Curve of IEC
CTI	-	Critical Time Interval or time margin between curves
F1, F2, Fn	-	Feeder 1, Feeder 2, Feeder n
fc1, fcn	-	Fault Current on feeder 1, Fault Current on feeder n
ALF	-	Accuracy Limit Factor of a current transformer
pc	-	Pickup Current of a Protection Relay
ALF_F1CT1	-	Accuracy Limit Factor of Current Transformer Number 1 in Feeder 1
S.CR1R2F1	-	Fault Current seen by Relay2 when the fault on Relay 1 of Feeder1

LIST OF SYMBOLS

51N / I_N >	-	Earth Fault Relay
51 / I>	-	Overcurrent Relay
50N / I_N >>	-	Instantaneous Earth Fault Relay
50 / I>>	-	Instantaneous Overcurrent Relay

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The development that takes place in the field of electricity has changed the nature of life. There is almost no practice without electricity in daily life. Electricity reaches consumers after passing through several stages, starting with production, followed by transmission, and ending with the distribution system. The electricity distribution stage is considered one of the most important stages that electric power passes through because it deals with millions of consumers, thousands of secondary stations, and millions of kilometres of medium and low-voltage distribution lines that deliver electricity to consumers. From all of the above, distribution networks are the backbones of the electrical system, so any defect in them will negatively affect the electrical system in general and thus reduce its reliability, which will negatively affect consumers. Distribution networks are divided into several topologies, including radial, parallel, and meshed. Most of the networks are of the radial type for many considerations, including economic, technical, ease of maintenance, and speeding up the location of faults.

With technological development and the increasing demand for electricity, there has been an unprecedented use in recent years of the use of distribution generators, which can be divided into diesel generators and renewable energy sources [1]. The ease of obtaining an adequate source of sunlight and the availability of sufficient space to install silicon panels that convert solar rays into electrical energy has led to make PV energy an important source of electricity. Photovoltaic (PV) systems are a crucial alternative in many nations' energy profiles since they are a free source of electricity, environmentally beneficial, and secure [2, 3]. Nowadays, the world expects that a major climate change will occur, which will lead to destabilizing energy security, and therefore, most governments and countries consider the trend towards using renewable energy from various sources in order to reduce the impact of the problems caused by traditional energy sources. PV power has many advantages, including low price, ease of installation, and rapidity of installation, so it is considered the most important alternative energy source [4, 5]. The PV industry is a key promoter of renewable energy sources as a source of global energy The capacity of PV systems in the United Kingdom reached 15 GW by the end of 2019 [6]. By the end of 2018, renewable energy production had achieved a total capacity of over 505 GW throughout the world [7].

Even with all the unique advantages that characterize renewable energy, there are problems and obstacles that renewable energy sources cause when they are connected to distribution networks. These problems are summed up by 1) increasing the voltage of the distribution networks at certain conditions. 2) Impacting the stability of the distribution system. 3) Large changes in the flow of the fault current, which negatively affect the performance of the protection relays [8, 9]. It is clear from the foregoing that the performance of the protection system will be greatly affected by the presence of PVs. The biggest impact on the performance of the distribution system connected with PV sources is when faults occur.

Faults in the electrical system are defined as anything that causes a breakdown in the electrical insulator between the conductors. Breakdowns occur in insulators for several reasons, including mechanical or electrical reasons. In distribution networks, usually, the breakdown of electrical insulators is accompanied by sharp voltage sag and a severe current that may reach tens of times the rated current.

Generally, most of the problems faced by distribution networks are summarized by the external effects that surround or do not surround them those cause power outages, such as severe storms, lightning strikes, traffic accidents, harmful birds, harmful animals, breakdown of insulators, and cutting in wires due to high loads or due to high temperatures. Each of the effects mentioned can occur on any site in the distribution network. All the aforementioned conflicts cause a significant increase in the fault current, which leads to the formation of one of those common and well-recognized faults. There are five common types of faults, which are three phase (3L), three phase to ground (3L-G), line to line (L-L), two line to ground (2L-G), and line to ground (L-G). In general, the percentage of faults occurring on the distribution networks is as shown in Table 1.1 [10].

Table 1.1 The percentage of occurrence fault in distribution networks

Fault's type	Occurrence (%)
3L or 3L-G	2-3
L-L	8-10
2L-G	10-17
L-G	70-80

The method adopted for sensing these faults is a set of protection equipment, which generally consists of current transformers and protection relays, which provide a signal to the circuit breakers in order to isolate the faulty line [11].

The protection system in the electrical power system is considered one of the most important and interesting issues, as it guarantees protection for equipment, buildings, working staff, and those close to the electrical network.

The protection system consists of many equipment and sensitive electronic devices, which are mainly divided into high-voltage equipment and low-voltage devices as shown in Figure 1.1. Among the high-voltage equipment are Current Transformers (CT), and Circuit Breakers (CB). As for the low voltage devices, they are Protection Relays (Relay 51), DC source, and various sensors. The main controller within the protection system is the relay. The relay is considered the brain of the circuit breakers. Without the relay, the circuit breaker is a deaf and blind machine. The link between the high voltage network and the relay are the current transformers and the voltage transformers [10].

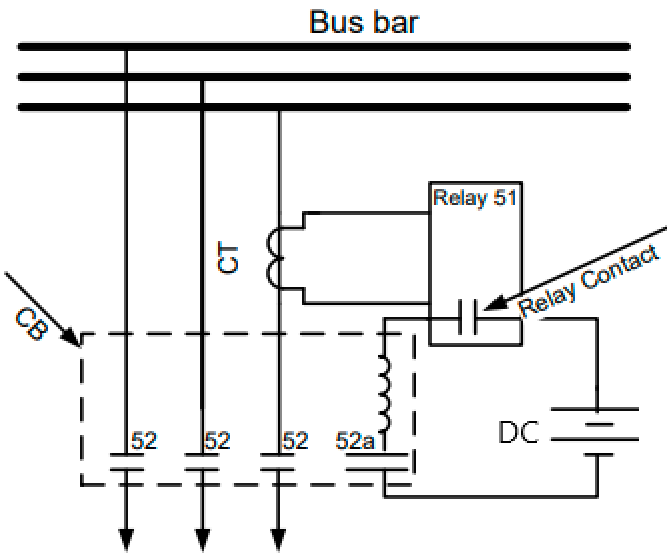

Figure 1.1 Protection system with HV and LV equipment

There are many types of protection relays, which include over or under voltage relays, overload relays, and overcurrent relays [11]. Voltage relays operate in cases of decreasing or increasing voltages on the electrical network. Concerning overload relays, they operate when the current is slightly increased above the specified value [12]. As for overcurrent relays, they are divided into two basic types: the first operates when a huge increase occurs above the specified value of the current, and the second type operates when ground faults occur on the electrical network.

As mentioned earlier, current and voltage relays are fed by CT and VT, respectively. The current CT consist of two coils, the first detects the high currents on the high voltage side, the second transforms the high currents in the first coil to low currents in order to be sensed by the protection relays. With regard to voltage transformers or potential transformer, they transform the voltages of the electrical network into low voltages that can be sensed by the protection relays. Through the features possessed by the protective equipment, the protection system can function correctly if its operation is programmed and coordinated in the correct technical way [13].

In ordinary distribution networks that do not contain PV sources, the protection relays are coordinated in a classical way. The highest fault current is adopted in calculating the operating time of the main protection relays that are operated with Time Multiplier Setting (TMS) pre-determined by the protection designer. Then a Critical Time Interval (CTI) is added between the main relay and the backup relay, and finally, the TMS for the backup relay is calculated. The classical methods are useless and ineffective when there are PV generators connected to the distribution network because the PVs change the nature and value of the current flowing within the protection relays. As a result, confusion in the coordination process between the relays leads to incorrect and sympathetic isolation of circuit breakers [14].

The high currents flowing in the electrical network during faults may lead to the destruction of major parts of the distribution network. When those currents exceed the thermal time of the major parts, the consequences will be dire. Therefore, in the presence of PV generators and with no professional coordination, those devastating consequences will be inevitably present. [15, 16]. When those currents exceed the thermal time of the major parts, the consequences will be dire. Therefore, in the presence of PV generators and with no professional coordination, those devastating consequences will be inevitably present.

Generally, electrical substations deal with ordinary or advanced overcurrent protection relays, depending on the make- date of a substation. Therefore, this project takes into account those types of overcurrent relays. Among the advantages of advanced relays is that they have the ability to operate with a CTI of 0.2 to 0.3 seconds, while ordinary relays can handle a CTI of 0.35 to 0.5 seconds.

In this study, work will be done to find a method that ensures the correct coordination between the protection relays and ensures that the thermal time of the electrical network equipment is not exceeded when there are PV sources connected to the distribution networks for different penetration rates of PV sources.

1.2 Problem Statement

Distribution networks are one of the most important stages in the electrical system then their strength and reliability depend on the sensitivity and reliability of their protection systems. At a time when the global warming problem is emerging, the demand for and promotion of renewable energy is increasing. Consequently, the spread of PV generators within the distribution networks has become widely used.

Unfortunately, despite all the benefits that are obtained when PV generators are connected to the distribution networks, there are problems that appear in the protection system as a result of that connection. Often, when faults occur, PV generators cause an increase in the current at the main relays and a decrease in the current at the backup relays. Therefore, if the main relay does not respond for any reason, the backup relay will take a long time to operate, which may exceed the thermal limit time of the electrical equipment.

Improving the performance of the distribution network protection system is a concern of many researchers. Several studies have been conducted to improve the coordination between the main and backup relays within the high penetration of PV sources. However, reducing the operating time of the backup relays while taking into account the CTI between the main and backup relays to achieve the best coordination is still improving and expanding for a lot of studies and investigations.

In this study, a method called the Preset-Time Method will be used to reduce the operating time of the backup relay and enhance the performance of protection.

1.3 Research Objectives

The objectives of this study are as follows:

i. To analyze the performance of the protection system when the setting of relays is conventional with and without the presence of the PV generators.

ii. To propose a Preset-Time method that preserves coordination between relays and contributes to reducing relay operating times

iii. To implement the Preset-Time under various operation and location conditions of PVs.

iv. To evaluate the performance of the Preset-Time method at various PV penetration levels.

v. To validate the effectiveness of the Preset–Time method by comparing it with the conventional and the Maximum Plug Setting Multiplier (Max. PSM) method.

1.4 Project Scope

In general, connecting PV generators to distribution networks negatively affects the performance of the protection system. To diagnose weaknesses that impede access to a reliable protection system, this project is implemented in testing a protection system for a radial distribution network with and without the presence of PV generators and coordinating protection relays to operate with all penetration rates. Therefore, the main scopes of this project are as follows:

- The project is focused in testing the protection system of a radial distribution network located in the west of Iraq.
- Six PV source units, each with a capacity of 2.3 MW, are installed in the test system.
- The system is simulated using Etap 19 software.
- The TMS of the main and backup relays are obtained by MATLAB.

1.5 Report Organization

This report is divided into six chapters. The introduction, project background, problem statement, objectives, and report organization are all covered in chapter 1.

Chapter 2 shows the literature review that dealt with the distribution network and its protection in order to give an expanded understanding of the topic of this study. In addition, the chapter shows the most important published studies that deal with the topic of improving the coordination of protection system and reducing the operating time of backup relays at high penetration of PVs.

In chapter 3, the methodology for this project is discussed in detail. The chapter explains the flowchart of the entire project and illustrates the important equations used in setting the main and backup relays. In addition, the chapter shows the flowchart for setting the main and backup relays using the Preset-Time method.

In chapter 4, the results and discussion of this project are covered in detail. The chapter shows the results obtained by the conventional method, the Max PSM method, and the Preset-Time method. In addition, the comparison of the results is done in the chapter.

The overview of project management with Gantt Chart form and financial expenses is presented in chapter 5.

Finally, chapter 6 provides the conclusion and future work for this study.

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