

Impact of Distributed Generation on Coordination of Protective Devices

تأثير التوليد الموزع على تنسيق أجهزة الحماية

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ملخص البحث:

مع زيادة نسبة اسهام التوليد الموزع في شبكات التوزيع فقد نشأ العديد من المشاكل والتحديات أمام مهندسي التشغيل في شبكات التوزيع. لذا فقد أصبح من الضروري بحث واستقصاء مجموعة من المفاهيم الجديدة الخاصة بربط مصادر التوليد الموزع مع الشبكة، وهذه المفاهيم تشمل مشاكل خاصة بتشغيل واقتصاديات الشبكات بالإضافة إلى مجموعة القوانين المنظمة.

هذا البحث يناقش موضوع ربط مصادر التوليد الموزع مع شبكات التوزيع من وجهة نظر نظام الحماية. حيث يتم دراسة حماية خط توزيع اشعاعي ضد زيادة التيار باستخدام مصهرات ومعدات توصيل اتوماتيكية Autoreclosers وذلك قبل وبعد اضافة مصدر توليد موزع. وقد تم استنباط نموذج حاسوبي باستخدام بيئة MATLAB-SIMULINK وتم تصميم موديل لتمثيل كلا من المصهر ومعد التوصيل حيث لا يوجد عنصر يمثلها في بيئة SIMULINK، وبعد ذلك تم عمل محاكاة مخصصة لدراسة تأثير اضافة مصدر توليد موزع على تنسيق coordination أجهزة الحماية بالخط. وكذلك دراسة مدى مناسبة منظومة الحماية التقليدية للعمل في وجود وحدات توليد موزع.

والدراسة المقدمة تثبت أن التنسيق بين المصهرات ومعدات التوصيل يمكن أن يتأثر في حالة اضافة قيم كبيرة من مصادر التوليد الموزع، وأن هذا التأثير يكون حساسا لكل من شكل المنظومة وحجم ومكان اضافة مصادر التوليد الموزع.

Abstract

The increasing penetration of distributed generation (DG) added to the distribution power system creates new technical and economical challenges. It will be necessary to investigate many issues concerning these challenges. In terms of physical integration, protection is one important topic of these challenges.

In this paper, the interconnection of DG units with power systems from protection point of view is discussed. The overcurrent protection of radial line using fuses and autoreclosers before and after integrating a DG source is analyzed. A MATLAB SIMULINK Model of the system is done.

Since there is not any element in SimPowerSystems (SPS) to represent the fuse or recloser, two models are designed for simulating the operation of both fuse and recloser. These models could be used for any other application. A detailed simulation is performed to study the impact of DG integration to the system from the prospective of protection devices coordination. Also, the suitability of the classical protection for the system after DG integration is investigated.

This study proves that coordination between fuses and reclosers in a distribution system can be disrupted with substantial penetration of distributed generation. The effect of DG on protective device coordination is sensitive to distribution system configuration, DG size and location.

Keywords:

Distributed Generation, Protection, Autorecloser, Fuse, Coordination.

1. Introduction

Distributed generation is a new concept in the economics literature about electricity markets, and is a result of the application of deregulation in the electric power sector [1]. DG has many definitions because it is a new trend in electric power system.

Generally speaking, it can be defined as *"the development of small, modular electric generation close to the point of consumption"* [2].

DG has been impacted the power system industry and these impacts can be categorized as, financial, technical, and regulatory impacts [1-6].

The increasing penetration of distributed generation (DG) in the power system creates new challenges and problems for network operators. It will be necessary to investigate many issues concerning technical, economical and regulatory problems.

Integration of DG in distribution networks may impact the network protection system [7-16]. The overall problem when integrating DG in existing networks is that distribution systems is a unidirectional system from the central generation downstream to the consumer. The conventional protection systems were designed in common Medium Voltage (MV) and Low Voltage level (LV) distribution networks for a passive paradigm, i.e. no generation are expected in the distribution network. For future distribution system, the networks get active and the conventional protection turns out to be unsuitable [7]. As a result, the additional fault current supplied by DG can cause relays to under-reach or overreach.

In [8], the authors have explored the effect of DG on protective device coordination such as fuse-fuse, fuse-recloser and relay-relay, depending on size and placement of DG. They concluded that problems related with protection devices and coordination schemes require a special attention since they may weaken the reliability of the system.

Doyle [9] has investigated the changes in fault levels with the addition of DG at the

various locations. The resultant impacts on the recloser and fuses were also discussed.

In the report [10], the authors have investigated some protection issues include: protective device coordination problems due to infeed and bi-directional current flow; effects on synchronizing and autoreclosing; the potential for forming small islanded systems; and issues related to ground fault detection.

In [11] Sukumar, et al suggested an adaptive protection scheme to investigate effect of high DG penetration on protective device coordination. They explored the effect of size, type, and placement of DG on the devices coordination.

In [12], Jager et al., have investigated ring networks with numerous DG units and radial network. They concluded that the use of inverse time characteristics can lead to significant shorter delay times ensuring selectivity simultaneously.

In his research [13], Maki et al., investigated the effects of DG on the feeder protection of a distribution network in a ring operation mode.

S. Chaitusaney [14], has analyzed and derived a set of equations to represent protection coordination and operating range constraints. The paper suggested a method to determine the maximum sizes of DG sources to maintain the existing protection scheme.

In [15] the authors have studied the effect of DG on automatic reclosing and suggested telecommunication based protection to solve the problem of integrating DG with electric systems

In [16] Salman and Rida concluded that there is a significantly effect of DG on the clearing time of protective devices installed at distribution feeders.

Most of these surveyed researches didn't simulate the operation of protective devices to explain the operation and performance of the system under study. Also, they didn't investigate the coordination problem in their work. By means of they didn't design no models for both fuse and recloser, just simple calculation.

This research will focus on over current protection of radial line and its protection devices coordination in DG environment. Two control circuits are designed for simulating the operation and performance of both fuse and recloser. These simulation models are used to investigate the impacts of DG on fuse-fuse and recloser-fuse coordination.

2. Overcurrent Protection of a Radial Feeder

2.1. Protection of Classical Distribution Systems

Protection of three phase distribution transformer in radial distribution system using fuses is considered to be classical protection system. It is general practice to install a fuse on the primary (incoming) line side of each distribution transformer. This may be a transformer internal fuse or an external fuse installed in a cutout. Automatic circuit reclosers are applied to protect the entire system against temporary faults; they should be installed on the main feeders due to economic considerations. Figure 1 shows a part of a classical distribution system with distribution transformer and recloser-fuse explanation [17].

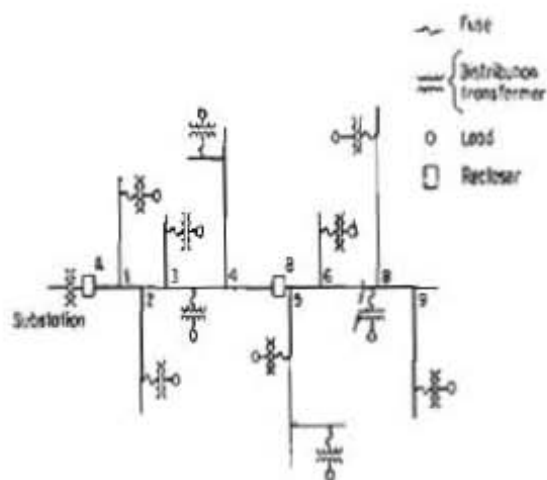


Figure 1 Classical distribution systems [17]

Correct protection of distribution transformer against overloads and short circuits has an essential influence on

consumers supply continuity and safety of people. Many years of domestic maintenances experiences proved that the cheapest as well as effective distribution transformer protection against results of overloads and short circuits are properly selected fuses. Rated current and breaking capacity of a fuse are selected according to the basic rules taking into consideration permissible transformer overloads or the maximum rating of the transformer.

Nowadays the nature of distribution system is changed due to the addition generating units to the distribution network. Comprehensive studies are required to explore the problems related to integrating DG with the classical distribution networks

2.2. System under Study

The characteristics of short circuit current and hence the ratings of the protection devices are depending on the network structures [12]. In this study we propose a system composed of radial feeder, a distribution transformer, and two secondaries ended with two loads. Figure 2, shows a schematic diagram of the proposed system in case of using reclosers to protect the main feeder, and fuses to protect the secondaries.

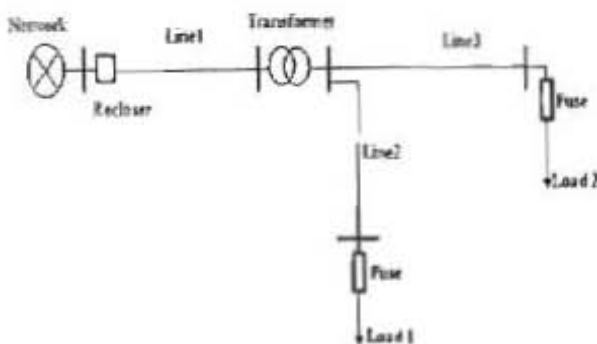


Figure 2 Schematic diagram of the proposed system

2.3 Coordination Scenarios

To tackle coordination problem we have to do two steps. The first step is to determine the appropriate protective devices size (fuses, reclosers), to do that we have to compute the normal current in the system branches. Based on those currents, the appropriate sizes of protective devices are chosen. Second step is to perform a short

circuit analysis to explore the coordination between protective devices. After that we have to investigate whether each fuse (recloser, fuse1, fuse2) will isolate only the faulted section, or there is a mis-coordination and some non-faulted sections are isolated. Figure 3 shows the different locations of proposed faults used in this study to explore the coordinations between different fuses.

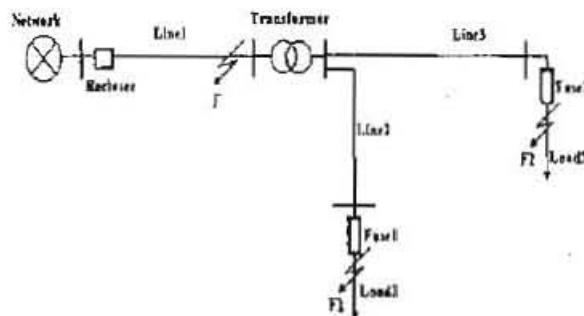


Figure 3 Fault locations on the proposed system

3. SIMULINK Model

The studied system is modeled using SIMULINK and SimPowerSystems (SPS) toolbox of MATLAB 7.5 [18, 19]. SIMULINK is used as an environment to simulate the whole system, but SPS is used to simulate the individual components of the system. As described in SPS manual, not all power system components could be modeled using that toolbox [19]. In SPS, there is not any element to represent the fuse or recloser. SPS models only the switch element (ideal switch, breaker). The switch model can work in two ways; first it could be set to a specific time to respond. Second it could be respond to external signal which has to be achieved using *external control circuit*.

To simulate the operation of different protective devices using the switch model, we have to design an external control circuit. This means that the switch model will respond externally. That control circuit will determine the required time to activate a protective device according to its TCC (Time Current Curves) and to sends the open signal to the switch that opens the circuit.

The structure of the simulated protective device using external control circuit and switch model is shown in Figure 4, where I_1 and I_0 are the currents passing through the protective device. The TCC curves for all fuse and recloser used in the feeder are attached in a table inside the control circuit.

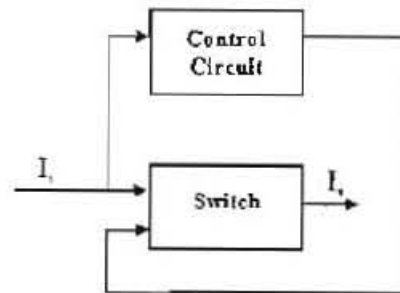


Figure 4 The Protective device model

The circuit will be used to implement the fuse and reclosers models. The fuse and reclosers models are explained in details in the following section.

3.1 Fuse Model

The fuse can be represented either by an ideal switch and an external control circuit, or a breaker block with an external control circuit. The ideal switch is preferable in this case since it takes no time to operate, which is a case similar to the fuse operation. The fuse is blown up according to its TCC time only. The breaker can be used to represent the recloser since it has mechanical characteristics similar to a circuit breaker.

A control circuit has been designed to represent the operation of a fuse so that it can open and isolate the fault according to its TCC. The proposed control circuit, shown in Figure 5, composed of: an *RMS block* and a *Gain block* to measures the root mean square value of the instantaneous current passing through the fuse, and obtain its peak. A *Function block*: the output of this block is a time corresponding to the passing current, which have an inversely proportional relation. A *Variable Time Delay block*: this block has two inputs: a data input and a time delay input and it delays the input by a variable amount of time. The block's output at the current time step equals the value of its

data input at a previous time equal to the current simulation time minus a delay time specified by the block's time delay input. The input data to the block is a zero signal so that its output will be the same signal after the delayed time (i.e. to open the fuse circuit after the delayed time). *Triggered Subsystem block* receives the output signal of the Variable Time Delay block as an input. It is a subsystem that execute each time a trigger event occurs. A falling trigger is used so that the subsystem execution occurs, when the control signal falls from a positive or a zero value to a negative value (or zero if the initial value is positive). For normal operation, the output of the triggered subsystem is always zero. *Logic NOT block* is used to invert the output signal, so that the ideal switch still close. Otherwise, when a fault occurs, triggered subsystem is executed and its output is 1, this output will be inverted to 0, which cause the ideal switch to open.

3.2 Recloser Model

The recloser can be represented by a breaker block with an external control circuit. For a reclosing device, the control circuit also sends the closing signal to the switch when the reclosing time is achieved. A control circuit has been designed to represent the operation of a recloser which

automatically trip and reclose a preset number of times to clear temporary faults and isolate permanent faults. The proposed control circuit, shown in Figure 6, composed of: *RMS block* and a *Gain block* with the same functions explained in the fuse control circuit. The peak value will pass to two blocks; the first is a *Function Block* parameter which contains the fast curve of the recloser (TCC). The output of this block is a time corresponding to the passing current. The second is a *Relay Block* which allows its output to switch between two specified values (0, 1). If the current is less than a specific value (reclosers setting) the relay output will stay at zero value, if the current value is greater than that specific value and more the output of the relay will be stick with 1. *Variable Time Delay block* receives the output of the previous two blocks as an input. The output of that block will be either 0 or 1 after a delayed time. If a fault current is passed through the relay; its output signal is 0, and this signal will be delayed (by the variable time delay block) for a short time inversely proportional to the fault current value. The output of the last block is a signal that opens the breaker switch. If the fault is a temporary one, the relay output will be 1, so that the breaker switch closes.

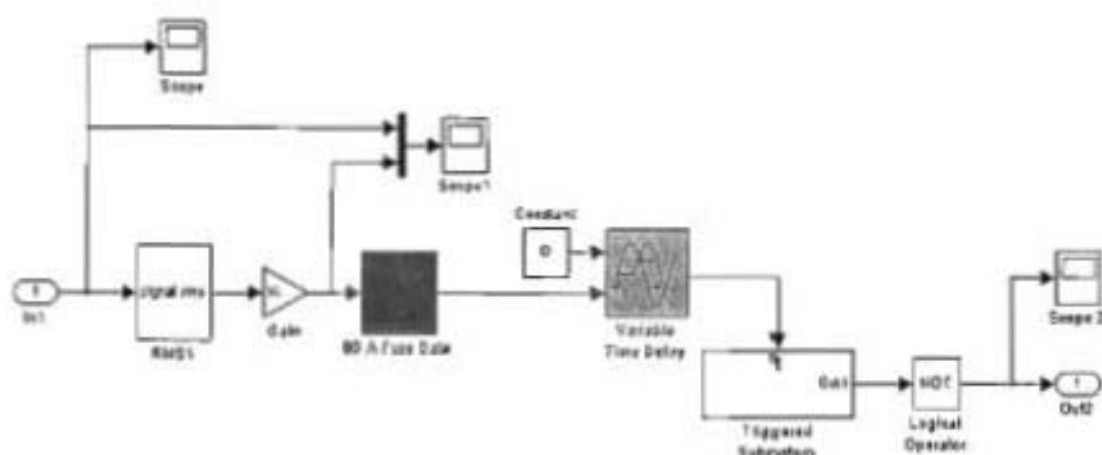


Figure 5 The proposed control circuit for a Fuse

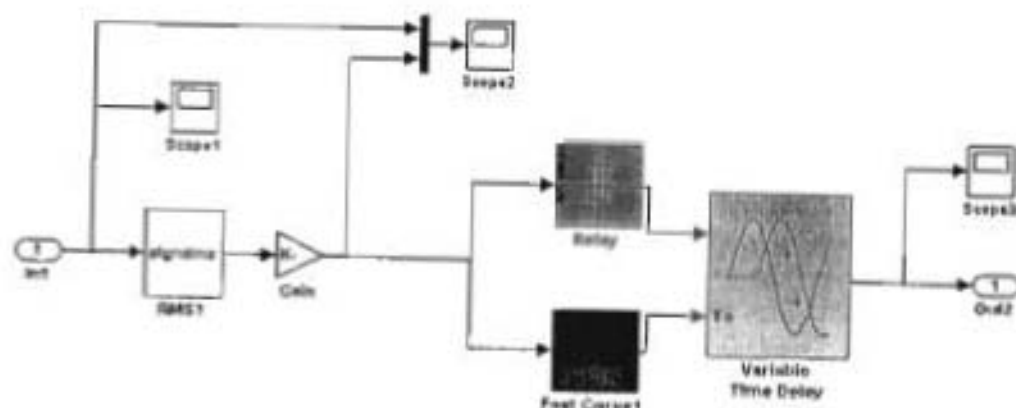


Figure 6 The proposed control circuit for a Recloser

These two models can completely simulate the operation of both fuse and recloser in Simulink environment and can be used for any other system.

4. Coordination Analysis

To simulate the proposed model we use a hypothetical system described at Figure 2. This system is composed of a three phase Y-Y, 1.5 MVA, 15000/400 V, 50 Hz distribution transformer, a 10 km lumped primary feeder connects the transformer to a substation represented by a 10 MVA, 15 kV three phase source. The transformer supplies two 3- phase RLC loads (30 and 50 kW) through two 0.5 km secondaries. The simulation stages can be summarized as:

- Simulate the system under normal operation to determine the appropriate sizes of fuses and recloser
- Simulate the system at different fault conditions before integrating DG, to explore the protective devices' coordination of the original system.
- Simulate the system at normal operation with DG to explore the impact of DG on normal operation of the system.
- Simulate the system at different fault conditions after adding DG to explore the impact of DG on the protective devices coordination.

The simulation is done as follows:

4.1 Determination of Appropriate Sizes of Fuses and Recloser

The system is modeled and simulated in normal case before adding any protective device. The simulation is done to measure the currents flow in each branch of the proposed system. Based on these currents, the appropriate sizes of fuses and recloser are chosen.

The results of this simulation show that the following current passes in each feeder: Line1 = 12.67A, Line2 = 66.52A, and Line3=110A. Based on that measured values ratings of the recloser and fuses [20] are chosen as: 15A, 80A and 125A respectively.

4.2 Exploring the Protective Devices Coordination before Adding DG

The system is then simulated without DG for a three phase to ground fault at the three proposed faults locations (F, F1, and F2) as previously shown in Figure 3. The simulation is performed to validate the operation of the proposed system and to the adaptability of the designed control circuits. The fuse-fuse and reclosers-fuse coordination are then investigated for different cases. The analysis is done for many faults on many locations in the proposed circuit and many case studies are performed. The following item explains the protective devices coordination analysis.

4.2.1 Recloser-Fuse Coordination

The recloser automatically trips and recloses a preset number of times and isolates permanent faults. We will investigate both permanent and temporary faults to validate the operation of the proposed control circuit of the recloser. The coordination between recloser and both fuses (fuse1, fuse2) will be achieved if the fuse1 clear a fault near load1 faster than the recloser, and fuse2 clear a fault near load2 faster than the recloser. Table 1 gives the fast curve used in this study for the recloser [21]:

Table 1 Recloser fast curve

Time (sec)	Current (A)
0.36	275
0.20	300
0.10	350
0.06	458
0.05	527
0.04	650
0.033	800
0.03	1100
0.02	1900
0.01	3900

A. Temporary fault at the end of the primary feeder

To validate the control circuit design, the model is simulated for a temporary fault at the end of the primary feeder before transformer; the fault duration is 0.04 sec (starts at 0.02 and ends at 0.06). Figure 7 gives the output of the simulation. The fault current passes through the recloser; it trips and opens the circuit to clear the fault. When it recloses the circuit for the first time given fault cleared, it will not open again.

Figure 7 shows that the normal current passes through Load1 and Load2 before fault starts. During the fault there is no current passes in both loads. When the recloser recloses again finding that there is no fault it will allow the load currents passing normally. This means that the control circuit doing well and this is a good validation of the control circuit.

B. Permanent fault at the end of primary feeder

The model is simulated for a permanent fault at the end of the primary feeder to validate the operation of the proposed control circuit of the recloser in case of a permanent fault. The results are shown in Figure 8.

C. Permanent faults near load1 and load2

This case investigates the coordination between the recloser and Fuse1. The fault current passes in both of them. Fuse1 clears the fault before the recloser open the circuit, which means that the recloser-fuse coordination is achieved. After clearing the fault the load1 is isolated and normal currents passes in other branches. The same behavior of the system occurred for a permanent fault near Load2.

From simulation results explained in this section, the system behaves as expected for both temporary and permanent fault and the recloser-fuse coordination is achieved, which means the targeted recloser or fuse operates at the suitable time to isolate the fault.

4.3 Impact of DG on normal operation of the system

The impact of DG on normal operation of the system can be investigated by integrating a DG source to the system. There are two scenarios of this integration :

- First scenario is to integrate many DG to the system. At that scenario add-remove DG and measure branches currents will be the case.
- Second scenario is to integrate one DG at a specific busbar, change the DG values and DG location to get branches currents.

At this research we stick with this second scenario. The system is simulated for different penetrations of a DG source connected to specific bus bar. DG source is connected to three distribution buses: bus L1, bus L2, and transformer bus Tr respectively. Figure 9 shows the circulation of current in different branches of the system with DG connected to bus L2.

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