Protection Strategy for Distribution Systems with Reverse Power Relays in the Presence of DG Resources

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Abstract- The protection of distribution systems is an important issue without it, a power or distribution system cannot operate properly. Distributed generation (DG) is trendy nowadays, and therefore the protection of power systems with the presence of DG sources should also be considered. On the other hand, considering that distribution networks have a radial mode, scattered production sources disturb the coordination between the protective equipment in the network to be disturbed. With the existing methods, it isn't easy to perform this protective coordination. In this research, a new protection strategy for system tests with the presence of DG sources is investigated. Homogenization, despite the availability of resources, presents several technical issues: economic and regulatory questions. The system's radial structure is modified by the voltages coming from the source towards the feeder end. Therefore, in the reverse direction, when DG is added to the system, disturbances are introduced. That is, the strong pressure on the network causes the existing protection system of distribution networks to be against these changes. To maintain system stability, a reverse power relay (RPR) is recommended to protect the system from voltage fluctuations, and power (centralized). By adding a relay for each distributed generation, network protection is improved and network reliability is increased. The mentioned designs will be implemented on a sample distribution network using MATLAB software.

Keywords: Reverse power relay, protection of distribution systems, DG sources, protection strategies

1. Introduction

One of the important issues that has occurred in the electricity industry in recent years is the use of distributed generation resources in power networks [1-2]. DG sources can cause a decrease in the absolute amount of loads and, as a result, a decrease in the non-distributed energy of the network by creating island areas when a fault occurs in the network [3-4]. The distribution system establishes the connection between the transmission system and the final consumer, and the power sector system is the closest to the consumer system. If a power plant or a transmission line goes out of the circuit, generators, networks, and other transmission lines can usually be used so that the consumer does not lose electricity [5]. But in the distribution system, if a line is cut, the consumer will be without electricity. The major part of the initial investment cost for the provision of electrical energy, from the power plant to the place of consumption, is related to the distribution network. All the mentioned cases show the importance of the distribution system. The wide and growing use of electrical energy makes it necessary to raise the quality level of supplying this energy [6]. The errors that occur in the distribution network have two natures, transitory and permanent.[7] Transient errors are errors that are resolved after they occur, without the need to perform maneuvers and repairs at the feeder level, and the system returns to normal status. But persistent errors are errors that require maneuvers and repairs to restore the system after they occur. Statistics and surveys in distribution networks show that 80-90 percent of the errors that occur in air distribution networks are transitory in nature [8] and this is due to various reasons such as wind Wind, leaves of trees, birds, and animals collide with distribution lines, lightning, and malfunctions in equipment, etc. The percentage of these errors and the reasons for their occurrence depend on the geographical location and climatic conditions of the target area and can differ according to these conditions. One of the factors to reduce the number of subscribers affected by the error and as a result to reduce the number of subscribers who experience blackouts is the use of a protection strategy. Reverse Power Relay (RPR) is capable of protecting system fluctuations (voltage and power)[9]. RPR is a directional power relay that operates in parallel with a DG or power device[10]. RPR can be appropriate by disconnecting the DG from the grid under fault conditions. Therefore, it estimates the reverse power [11]. In reference [12], used for voltage protection in the presence of DG. It only uses the local voltage value to determine the relay operation time, hence, a low-cost protection method is presented.In reference [13], power flow, and contribute to fault current levels. This phenomenon can upset the balance of the current overcurrent protection devices and be effective in the permanent power outage of a large number of customers.

In reference [14], a new strategy is presented to provide an optimal solution for recloser-fuse coordination, which seems to have more influence on distributed generation sources in distribution systems. The core of this strategy is presented based on the classification of coordination status in error conditions as maintaining coordination and losing it. The main benefit of this classification process is that if a protection plan is in place, it can deal with the error and also deal with the additional measures that are needed. The last one is based on providing performance information of DGs during outage, the protection coordination can be regained.

In reference [15], overcurrent protection and coordination with the recloser are implemented at the beginning of the feeder with lateral fuses. The final conclusion is also drawn using this design on a test distribution system.In reference [16], A study based on real data describes with DG the operation of reclosers and increased safety in distribution systems. The favorable results of the research show that for fault currents exceeding 3 kA, it increases reliability.

In reference [17], to coordinate the performance of protective devices and scattered production resources, in this article, the combination of ant colony algorithm, sensitivity analysis, and multi-criteria decision-making method was used, so that with the placement and capacity of production resources at the same time scatter and protection devices improved.

In reference [18], the effect of scattered production with different technologies on the annual energy losses has been calculated. In addition, the effect of dispersed production with different technologies such as combined cycle, wind energy, photovoltaic, and solar cells on losses is investigated. In this article, it is shown that wind energy shows the worst behavior in reducing losses. It is also concluded from this reference that distributed generation units with the ability to control reactive power will have a greater effect in improving voltage level capability and reducing losses in the network. In reference [19], a new method for radial distribution networks is presented for protection.

The connection of distributed photovoltaic generation to the power system causes problems in the protection system based on overcurrent relays. Its impact on the optimal integration of the overcurrent protection system has been shown [20] to select the best type that improves the protection system.

A distribution system connected to a small system is studied. A neutral ground resistance (NGR) was introduced to increase the relay's operating time up to the delay limit and reduce the unwanted tripping of the non-faulted feeder connected to it. The overcurrent protection relay was simulated to analyze the operating patterns during the fault [21].

From the discussion in the previous sections, the following results can be inferred for relay or fuse coordination, because the issues arising from these coordinations are similar:

1- If these devices can handle the increased fault current due to DG penetration, there will be no problem regarding their coordination.

2- If the devices observe fault currents related to upstream faults, two situations are possible:

   - Coordination will be lost when the same current is observed for a downstream fault as for an upstream fault.

   - If the devices see different fault currents for downstream and upstream faults, then there is a margin for the synchronization to remain valid. If the difference in fault currents observed by the devices is greater than the margin, coordination is achieved. Therefore, if the DG fault injection is greater, the probability of maintaining coordination is greater.

3- There is also a margin for fuse and relay coordination. In this case, if the difference in fault current observed by these devices is less than the margin, coordination will be maintained. Therefore, if DG fault injection is less, the probability of maintaining coordination is higher.

The coordination effects in the above connection conditions can be summarized as follows:

If a pair of synchronized relays finds a different current for a downstream or upstream fault, there is a limit for the synchronization to remain valid. If the difference seen by the protective devices in the fault currents is more than the above limit, the coordination remains. The greater the share of distributed production resources in the injection, the greater the probability of coordination.

In the previous sections, some of the problems caused by the presence of scattered production sources in the performance of traditional distribution network protection schemes were mentioned. The methods of dealing with these problems are still one of the most important research fields in the discussions related to electrical energy distribution systems, and it cannot yet be claimed that a precise, complete and optimal solution has been provided for the problems caused by distributed generation sources for the protection of distribution networks. And the field of research in this field is very wide. In the following, after examining the importance of DG effects on the protection of distribution networks, we point out the most important solutions applied for protection coordination with and without the presence of scattered products.

A study of overcurrent coordination, comparison and selection of the type and operation times of protection devices to achieve the goals of the protection system in unusual system conditions.

- With the increase in the number of switches and distributed generation sources, various reliability, loss, and voltage profile indicators tend to improve; however, with the increase in the number of equipment beyond a certain amount, the change in the mentioned indicators becomes insignificant.
- DG sources are located near load centers and switches are also located near the sources, and in fact, on lines that are less at risk of tripping during a fault, to maximize system reliability parameters.
- To ensure the automatic shutdown of the power plant or whether a device is properly monitored, the operation of an alarm with audio or visual display, in case of failure of any of the power sources of the protective equipment prevents its proper operation.

2. Principle of Reverse Power Relay

When several generators are paralleled together, necessary measures must be taken to monitor the flow of these sources when abnormal conditions occur. The relay used for this purpose is the reverse power relay. During oscillations, the direction of the current changes from the busbar to the generator, and the power delivered is low. However, the stator current undergoes a 180° phase shift, which is shown in Figure 1, called the maximum torque angle (MTA). This indicates that if a relay is used then it can detect the loss of the primary because the current phasor reverses and enters the triplet region. However, the magnitude of this reverse current phasor is very small compared to the forward current, because the generator absorbs enough real power to meet the losses and drive the turbine. Hence, the directional relay for detecting the loss of the primary drive requires a high degree of sensitivity compared to the directional relays used for overcurrent applications [9-10].

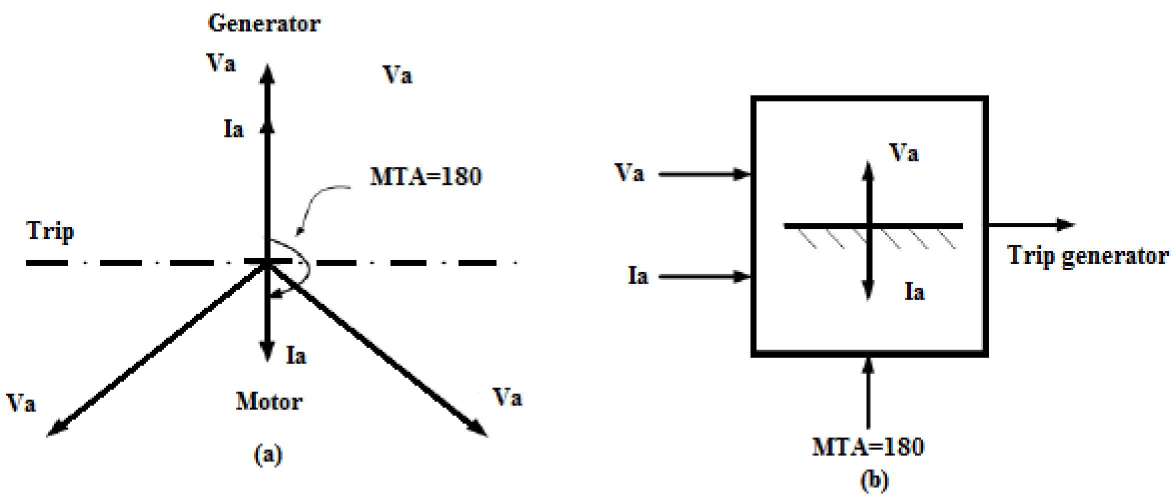

Figure 1. (a) Phase view (b) Block view of voltage and current

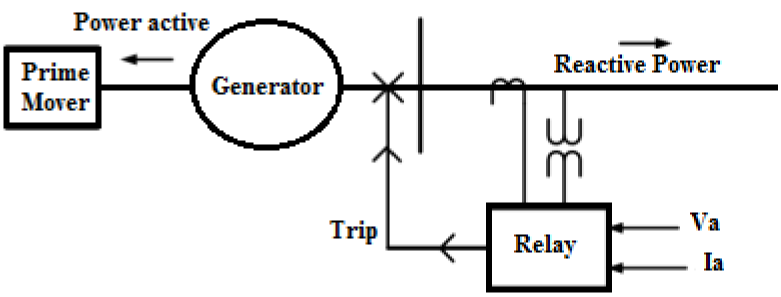

Figure 2. Reverse power relay in power system

However, this overlap is reduced to a low level in the case of reverse power flow, shown in Figure (3a-3b).

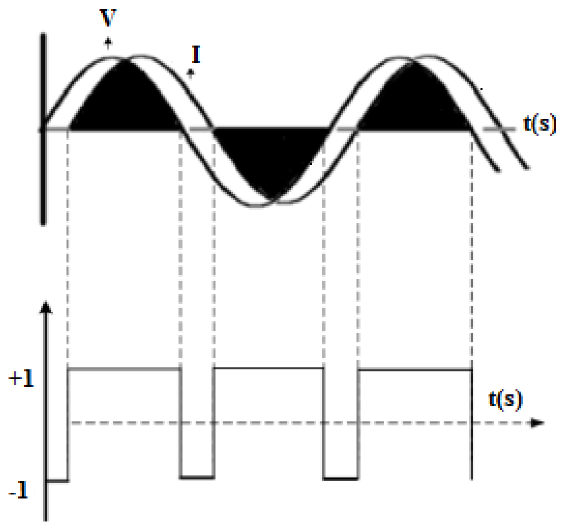

Figure 3a. Angle between voltage and current waveforms under normal conditions

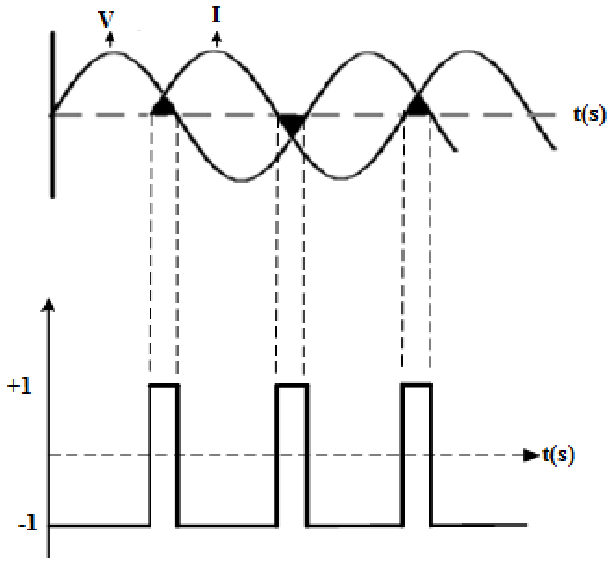

Figure 3b. Angle between voltage and current waveforms under fault conditions

Connecting a distributed generation source to a distribution network will undoubtedly cause local changes in the network characteristics. Connecting a generator to a distribution network has the effect of increasing the fault level in the network near the connection point. Therefore, connecting distributed generation to the network can cause a closed distribution network at its fault level to exceed this limit. The increase in the fault level can cause hazards, including damage to and destruction of the plant or even damage to personnel and circuit breakers. Therefore, as with other system protection changes, the current and fault settings must be calculated to apply this change to the protection coordination. Figure 5 shows a main distribution feeder fed by source S and protected by reverse overcurrent relays R1, R2, and R3. The coordination between these relays is shown in Figure (4).

The protection philosophy here is that for the maximum fault current in the bus (3) that occurs due to the occurrence of a fault in the bus (3), the operating time of relay R2 is greater than that of R3 (at least by a time interval known as CTI). Similarly, relays R1 and R2 are coordinated for the maximum fault current in the bus (2). As shown in the figure below, R1 supports relay R2 and R2 supports relay R3.

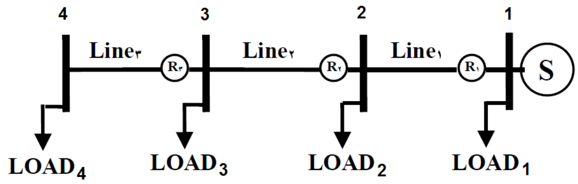

Figure 4: Relay coordination

The nature of the reverse overcurrent relay curve is such that if they are coordinated for maximum current, they will be coordinated for lower currents as well. As shown in Figure (5), R1 acts as a back-up for R2 and R2 acts as a back-up for R3.

Therefore, if the coordination of relays R2 and R3 is done for fault current in the bus (3), there is no need to check the coordination of these relays for fault in the bus (4) of a lesser short-circuit fault. So, to check the coordination of the main and backup relays, it is sufficient to check the coordination for short-circuit current in the bus near the main relay.

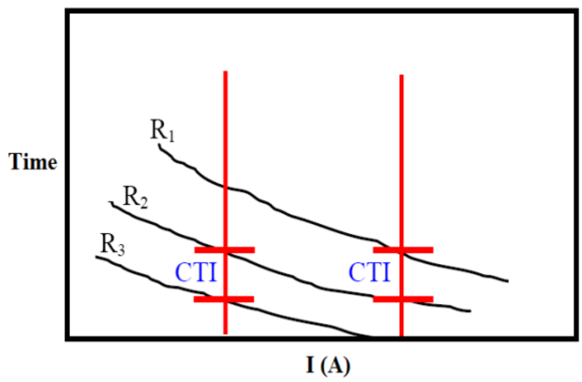

Figure 5: Relay coordination range

3. Main and backup protection

The main protection task is to cut off the power switch to the faulted section as quickly as possible. However, if the main protection does not work for any reason such as the relay, the relay failure, the current or voltage not reaching the relay, the supply circuit being cut off, the circuit breaker not working, the backup protection must work. If the protection of the support is located in the place of the main protection, it is customary to protect the local support and if it is far from the main protection, it is customary to protect the remote support. First, we must specify the meaning of support protection here:

A- Repetition of protection:

In the equipment that is very important, which can be due to its high price or the strong need to continue the exchange of electrical energy, etc., they use two similar protections, one of which is the main one and the other is the main two, both of which can have the same characteristic. And they also have a similar arrangement. Here, the meaning of repeated protection is the non-functioning of one relay due to an error, and the second relay sees that error and removes the defective part from the system. An example of this clause can be the use of two main distance relays that protect a line in the protection of power transmission lines.

B- Compensating for the weakness or defect of the main relay:

To protect a device, sometimes a relay is used which, although it is the main protection, but it protects a part of the protection area of that device, and if the fault occurs further than that percentage of the area, the relay is not energized and therefore does not work. Therefore, they consider the support relay to compensate for the weakness or protective defect of this device in this regard. An example for this band is the differential relay (main) and high current relay (backup) to protect the transformer.

4. Weakness of Security System and Security Coordination with DGs

- Non-coordination of protective relays: In fact, when an accident occurs at one point of the network, it is expected that the relevant protective relays will operate and disconnect the defective part from the network and the rest of the network will continue its normal operation.
- Protective relay defects: A protective device can be defective before an accident occurs and no one knows about it, and after the connection and operation of other relays occurs, its defects can be determined by analyzing the incident report. Also, a protective relay can malfunction during an accident, and this can be due to the design, and a relay can not have the necessary accuracy or be sensitive to transient states.
- Existence of protective relays without directional control: such as ground connection relays without direction and high current without direction, these relays can have unwanted operation in some cases and cause wrong command to be sent.
- Design problems of protective relays: the presence of problems in the relay of protective systems can cause disturbances in the normal use of the network and in accidents, for example, suppose the power source of a distance relay is constantly malfunctioning or the distance relay of a line is out of circuit. Operate by the induced voltages of the adjacent line.

5. Importance of DG Effects on Distribution Network Protection

The effects of DG on security coordination are so great, such that it was not easy to provide a comprehensive security coordination solution at the beginning and the articles only investigated the effects of DG on security coordination. [21-23] As a preliminary answer, we should say It is true that the DG is added only on one or more points of the distribution network, but there are different devices in the entire distribution network, and placing the same DG or DGs can affect the amount of fault currents everywhere in the network and therefore on the protection settings. Almost all protective devices are affected. The effects of DG in one place affect the fault currents of many places and therefore the settings of many protective devices. In the following, some potential problems of the presence of scattered production sources on the performance of the distribution network protection system are explained with examples.With the presence of distributed generation sources in the distribution networks, the equivalent circuit of the fault point changes. In the simplest case, each DG can be considered as a series voltage source with a constant impedance. By adding this model to the distribution network model, it can be easily understood that the level of short circuit changes in all points of the network for all errors. This change in different conditions can cause different problems for the protection system, which can generally be divided into the following three categories [24]:

- Increasing and decreasing the fault current seen by protective devices
- Creating a difference between the fuse current of the faulted branch and the reclosure coordinated with it
- Change in the direction of the fault current in some protective devices

When a large generating unit or several different small generating units are connected to the medium pressure network, when a fault occurs along the feeder, the fault current that the overcurrent relay sees at the beginning of the feeder may decrease, which can prevent the relay from operating. [25]. This issue can be theoretically justified in such a way that when a production unit is connected to the medium pressure feeder and close to the upstream post, if an error occurs at the end of the feeder, the error current is provided in two ways. The amount of current decrease depends on the location of the DG and its size, so it is possible that this current decrease will cause the initial relay of the feeder to not sense the fault current and not trip.

6. The System Under Study

To test and simulate the designed relay, a 200 MVA and 11KV synchronous machine is used, which is connected to the 220 kV network through a 220/11 kV transformer. For the DG source, a photovoltaic system is connected to the common bus with a capacity of 250 KW. The simulation system is shown in Figure (6), the reverse power relay model is shown in Figure (7) and the details of the system are shown in Table (1).

With the presence of DGs in electric distribution systems, the uncertainties of both generation and load have a great impact on the system voltage stability. Moreover, in the presence of several DG units, the optimization and placement of these units is increasingly important to maintain the stability and reliability of the power system. Based on this, it is very important to consider the voltage adaptability of the distribution system for the combination of DG units.

Table 1: Details of the studied system

Resource	Values
Generator	VL-L=11kV f=50Hz S=200MVA
Transformer	VP/VS (L-L) =11kV/220kV f=50Hz S=210MVA
Network	VL-L=220kV f=50Hz S=1000MVA
Photovoltaic	VP/VS (L-L) =11kV/220kV f=50Hz S=250KW

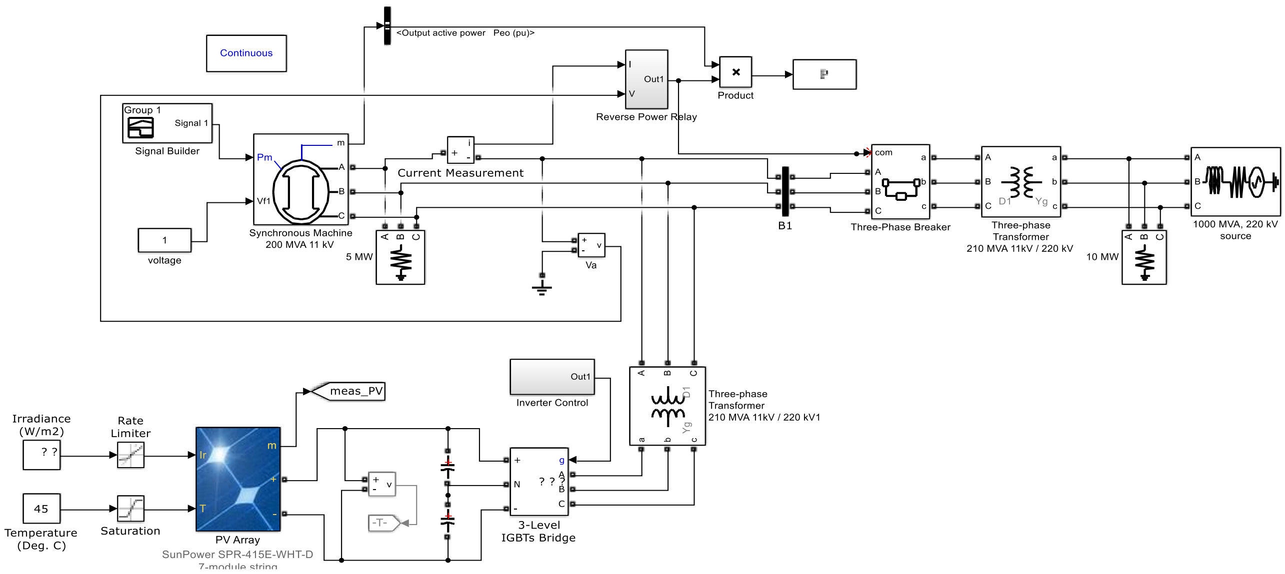

Figure 6: Simulated system

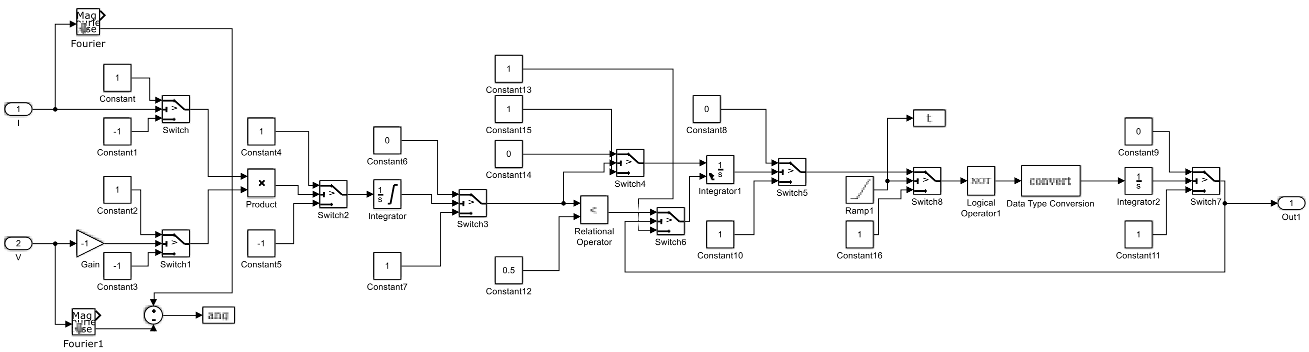

Figure 7: Reverse power relay model

The main purpose of the relay is to prevent the wrong signal from being sent to the breaker during transient or temporary fault conditions. The output of the direction element is sent to a breaker decision block whose output is '0' in normal condition and '1' in abnormal condition (inverse power). The integral value is compared to the threshold level 'T' whose value is set equal to the desired time delay value. When the integral value is less than the T level, the output of the delay element will be 1 which indicates normal condition. Unstable condition, since it receives the integrator data input '0'. So the integrator value will always be '0' less than the value 'T', so the output of the delay element will be 1 respectively. But in a permanent abnormal conditions, the input to the integrator will be '1' and after 'T'. In seconds, the integral value exceeds T, causing the delay element to produce an output of 0 to indicate an error condition. If a temporary error or transient condition occurs for less than "T" seconds, the integrator is reset to "0" by the relational operator after the error disappears. With the presence of distributed generation sources in distribution networks, the Thönen equivalent circuit changes from the fault point. Each DG can be considered in the simplest case as a series voltage source with a constant impedance. By adding this model to the distribution network model, it can be easily seen that for all faults, the short circuit level changes at all points in the network.

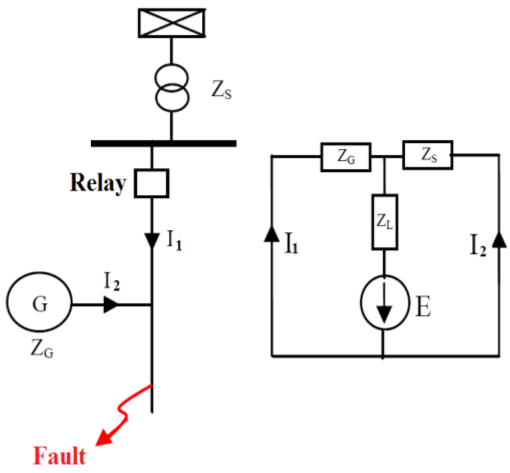

Figure 8: Preventing Overcurrent Relay Operation

When a large generating unit or several different small generating units are connected to the medium voltage network, when a fault occurs along the feeder, the fault current seen by the overcurrent relay at the beginning of the feeder may decrease, which can prevent the relay from operating . This can be theoretically explained by the fact that when a generating unit is connected to a medium voltage feeder close to the upstream substation if a fault occurs at the end of the feeder, the fault current is supplied in two ways, partly by the network (I1) and partly by the generating source (I2). This situation is shown in Figure (8).The amount of current reduction depends on the location of the DG and its size, so it is possible that this current reduction will cause the relay at the beginning of the feeder not to sense the fault current and trip.

7. Simulation and Analysis Results

Test conditions, results and discussion are given in two scenarios.

First scenario:

This is a normal situation where the power of the line changes from 90 kW to 125 kW in 25 seconds as shown in Figure (9) and in this case, the relay does not cut off (Figure 10). In figure (11) voltage and current changes are shown. This is a normal condition where the generator mechanical input changes from 0.2 pu to 0.8 pu in 20 seconds.

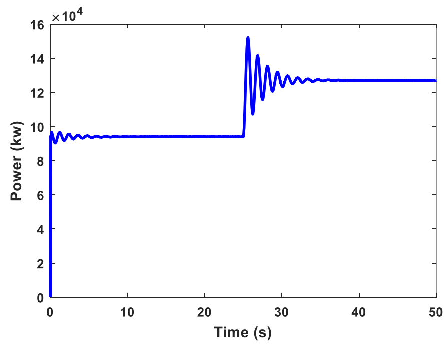

Figure 9: Line power

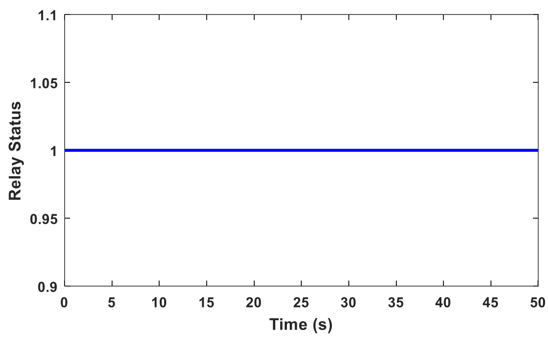

Figure 10: Relay operation, relay status

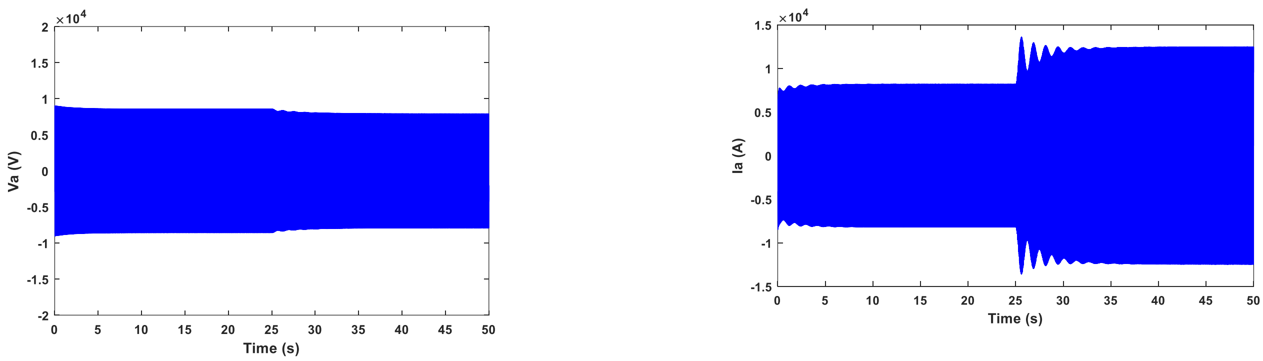

Figure 11: Voltage and current changes

In **Second scenario:**

It can be seen here that the relay movement occurred about 100 seconds after the error (Figure 12). This is a cumulative case to show the operation of the reverse power relay under different conditions. Line power changes also changes and the relay operates in this mode (Figure 13). From the figure, it can be seen that this system works safely in all mechanical crossings and isolates the power of the line safely after 100 seconds. In figure (14) the voltage and current of the line are also shown. It can be seen that there is zero current and voltage drop.

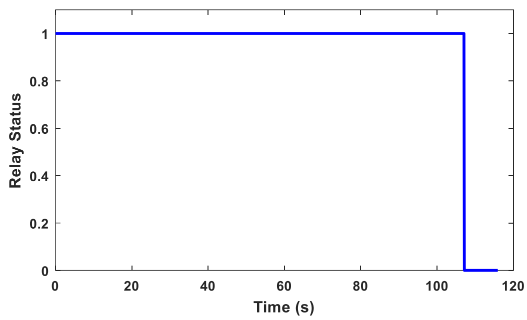

Figure 12: Relay operation, relay status

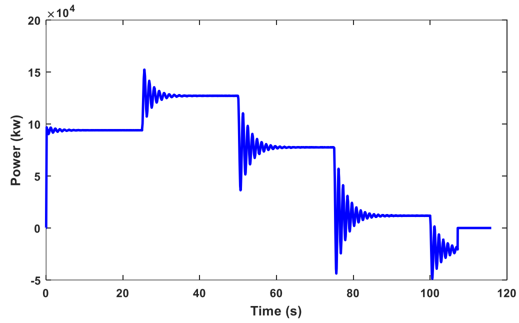

Figure 13: Line power

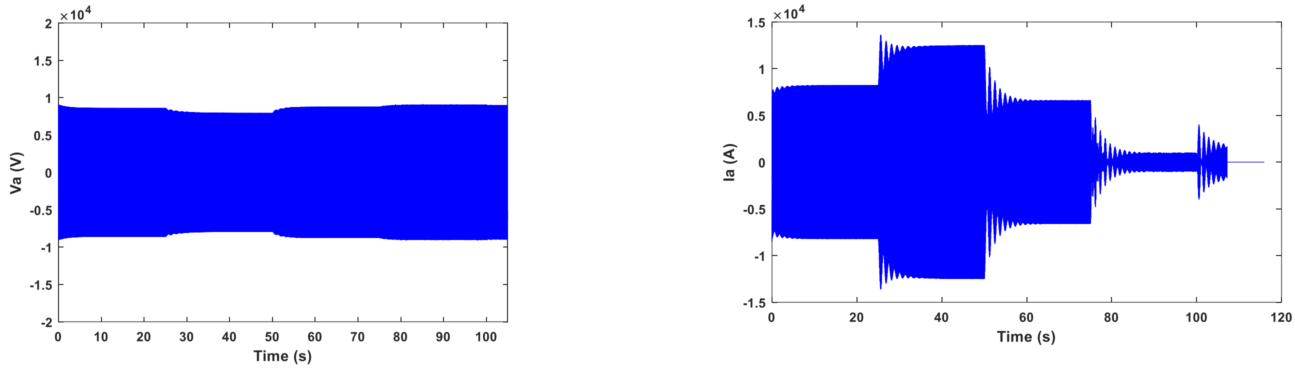

Figure 14: Voltage and current changes

8. Conclusion

In this research, modeling and simulation of reverse power relay using Simulink/MATLAB has been presented. The proposed relay model has been demonstrated in two case study scenarios. Compared with other power relay models, in the existing power system software, MATLAB has an advantage in terms of flexibility. Researchers are able to change test parameters and relay design. In this research, the synchronous generator with DG sources was modeled and investigated. The RPR is one of the most important protective devices of synchronous generators that comes into action when the input mechanical power of these generators is suddenly interrupted and prevents the motor operation and power return of these devices. The problem of improving the protection of synchronous generators against power direction changes was studied. The main goal of this research process is to improve the design of reverse power relays, in such a way that it improves the protection system against the motorization of synchronous generators. The effectiveness of the proposed method has been tested by creating different scenarios of power changes, and the effectiveness of the proposed method in improving the effectiveness of the protection of synchronous generators has been investigated and analyzed. Therefore, the existence of a protection system is mandatory throughout the power grid. The measurement of various quantities such as current, voltage, power, frequency, power factor, etc. is converted into quantities visible by the operator, and in these cases, these quantities are converted into control and command signals.

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