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A Method for Fault Detection and Location in Distribution Networks in the Presence of Micro-Grids Based on Voltage Sequence and Network Flow

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ABSTRACT

With the development of energy and creation of different types of energy generation sources and their benefits, using these sources in electricity networks spread. These sources have caused disappearance of radial nature and coordination of protective equipment of distribution networks. With the purpose of better and more rational use of sources of distributed generation, micro-grids were formed. Therefore, the extensive research has been done and is done on this type of production and network. Fault detection and location is one of the major subjects in protection of power networks in which the accuracy and speed of operation is of particular importance. Much research has been done on fault detection and location, each of which has problems or shortcomings. In this study, a new method for detecting and locating faults in distribution networks in the presence of micro-grids using symmetrical components of voltage and current of network and their phase changes is proposed; a method that has the ability to detect and locate symmetric, asymmetric and high impedance faults. The proposed method is imposed to micro-grid in the presence of different kinds of faults in the network; the results of the simulation indicate the accuracy of the method.

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INTRODUCTION

The most important problems in the electricity distribution network of Iran are high power loss, unapproved voltage drop, and long power outages. Due to the high volume of investments in the network and the need for proper operation, finding ways to lower these outages is essential. Distribution networks have the highest percentage of outage in power network, 8% of all of outages happen in this part. The faults of distribution network are classified into two major categories of transient faults and permanent faults. 8% of the faults are transient and 20% of them are permanent faults. Permanent faults usually are along with mechanical damage of the line, which should be soon repaired and returned to service. Because physical presence is not possible for search and fault location in all parts of the distribution network, distance of fault can help find its place. In fact, fault detection is difficult without a general idea about where the fault is, and high accuracy in finding the fault location substantially reduces the time required to repair damage of the distribution network.

In the case of transient faults also fault location has crucial role, because they are significant weaknesses of the network. Although transient faults don't cause service outage, but repetition of them can harm the network and can result in permanent faults. There are many branches in the distribution network, and a lot of time and money is needed to restore the network in permanent faults. Exact fault location in distribution networks reduces outage time and repair time of the network, and thereby reduces the losses in factories, offices, various parts of the industry, and even subscribers [8]. Fault location in distribution networks has higher cost, lower accuracy, and more difficulty than transmission networks [6, 4, 15, 23, 24].

With the advancement of technology and advent of a variety of energy sources such as wind power plants, Photovoltaic panels, fuel cells, micro-turbines, a new kind of electricity production and distribution is proposed. According to this type of energy production technology, special places for plants are not required but these units can be placed near the places of consumption; they are called Distributed Generations (DG) [18]. Increasing presence of DGs in medium voltage (MV) and low voltage (LV) networks has created new challenges for engineers that have led to much research about them [16, 17, 1]. Of the results of these researches is the

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possibility of island performance of the network in the presence of DGs and continuous load feeding at LV level by them, which is called Micro-Grid (MG) and in MV level is called Grid Cell. Micro-grids are networks that are formed by coming together of LV network, loads, small production units, control networks, storage networks, and adapters, which provide a little load in their area; by connecting many smaller networks together they form a vast network that has the current network's performance and yet in times of crisis can be returned to their constituent small networks [11]. Due to the many benefits of micro-grids, it is expected in the near future that using them in electricity networks highly increase.

The presence of these materials and sources causes changes in the amplitude and direction of the short circuit currents. Thus distribution networks lose their radial nature and then, the coordination of protective equipment also collapses. Of the problems caused by this kind of sources are wrong trip of feeders, wrong trip of production units, the rise and fall of the short circuit, unwanted islanding and preventing from automatic reclosing [14]. The main purpose of this article is to propose a simple and accurate method for detecting and locating faults in the distribution networks in the presence of micro-grids which is not only a high-speed performance, but also has a high placement accuracy.

Literature and Theory:

With the development of distributed generation technology, problems such as high cost of DG independent connection to the network, difficulties of control, etc. appeared. With further investigation in 2001, the idea of micro- grids arose for a rational and effective use of the DGs. Because of the proximity of the micro-grids with load, compared with centralized power networks, micro-grids do not need high-voltage transmission over long distances. Micro-grids have two modes of connected to the network function and the island function. In most cases micro-grids start to work in the mode of connected to the network and its load is supplied via the micro-grid or the main power network. In the event of a fault in the power network, micro-grid immediately exits from the connected mode and works in island mode to prevent damage to sensitive loads. However, the connection of micro-grids substantially affects the distribution network's protection [13].

Sorts of fault:

Generally, faults made in power networks, in terms of their lasting time, are classified into three categories [21]: Transient fault, Semi-permanent fault, Permanent fault.

Transient faults:

Transient faults are those faults which disappear after a short time and there are not any changes in the characteristics of network equipment. Usually in these faults, after a short electric arc and flow, the cause of the arc disappears itself, and with a brief power outage which is needed to deionize and remove the arc, we can re-live the network [20].

Semi-permanent faults:

In semi-permanent faults more time is needed for power outage. For example, if a tree branch fall on the power lines, causes power outage and will be burned at the time of electricity connection by the arc, and the line cannot be re-lived until the complete burning of the branch.

Permanent faults:

The faults whose time of elimination is relatively large and are often in need of repair are called permanent faults. These faults that occur because of cut of the conductors, fall of the high voltage towers, connection of lines with trees, fault in the ground cables, etc., cause the reclose and energizing the network become impossible until removing that fault.

A review on the micro-grids:

The power networks that use different sources of electricalload are known as Hybrid power networks. These networks are combinations of various components such as production networks, storage network, power management and control network, etc. The design of small power networks' components, with capacity of connecting and disconnecting the electricity grid, which are known as micro-grids, should ensure that it functions in both modes of operation, including connected to the network mode and island or independent from network mode [7]. Loads and energy sources in a micro-grid can disconnect from the electricity grid with the least outage and connect to it again, and therefore lead to increased reliability of supply of micro-grids' load. Distributed energy source can be Distributed generation or Distributed Storage (DS), and often both are used to supply energy in a micro-grid.

Parts of a micro-grid:

Micro-grids are islands that are purposefully formed in a facility or in an electricity distribution network and include at least one Distributed Energy Source (DER) and related loads [2]. Micro-grid is a small power network (typically on the scale of a few megawatts or less), which has three main characteristics: DG, independent load centers, possibility of independent and reliable operation to large electrical networks [3]. A micro-grid has the main parts of DG, DS, connection keys and control network. The connection key is the connection point of the micro-grid and the rest of the distribution network. Various technologies are necessary for the proper functioning of switching, including measurement, protection relays, telecommunication equipment, etc. During the opening of the key, sources of power generation in micro-grid should be able to load it with the appropriate frequency and maintenance of voltage levels.

The initial design of micro-grids:

The initial design of micro-grids should be such that during operation in island mode, the balance between production and consumption can be established. Distribution analysis should be done for various modes of design for the maintenance of proper voltage regulation and the ability of the sources of power to deal with inrush currents resulting from large loads be ensured. In island mode, management of generation and load is so important. Adequate reserve margin which is a function of load factor, load amount, load shape, required load reliability, and availability of power generation, and also suitable monitoring of operation for detecting the status of micro-grid should exist.

Micro-grid control networks:

Micro-grid control network is designed for reliable operation of the grid in different modes of connected and disconnected from the network. This network can be based on a central controller or be embedded as controller sections in each generator [2].When the connection is disconnected from the network, the control network must control the frequency and voltage and supply the real displacement of power and moment reactive between the production and consumption.

Electric energy generation and storage technologies:

Distributed energy sources which can be used in micro-grids include renewable sources such as wind, solar, hydro, etc. and also other nonrenewable sources such as diesel. Solar energy is a proven technology in terms of performance, but also costly. Problems of using it in the isolated networks are almost identical to the wind energy. Increase in the influence of the power these units in micro-grids, puts voltage and frequency stability at risk. That's why the designs of the hybrid networks containing wind turbines and solar panels require comprehensive investigate and detailed studies.

As in an independent power network, the balance between production and consumption of electrical power should be restored immediately, the difference between demand and supply of electrical power will be compensated with electrical power storage. Energy storage makes it possible to maintain the balance between supply and demand of energy. Energy can be saved in the form of mechanical, electrical, biological, thermal, energy and so on. Energy storage applications along with DG include [9]:

- maintaining stability in changing load;
- Power supply when the DG units are not available for reasons such as repair, maintenance or inadequate primary source of energy (such as Photovoltaic at night);
- Creating dispatching capability for DG units that are capable of dispatching.

Micro-grids' impact on the protection of distribution network:

After the connection of micro-grids to the distribution network, speed, selectivity, sensitivity, reliability and automatic reclosing of protection are affected. In addition, the unidirectional current of the traditional distribution networks transforms into two-way current and matching protection is no longer valid. The protection of micro-grids against all types of faults in both network-connected and island mode is important. The main problem that arises in island mode are the source-based inverter. Inverter fault currents by grade of silicon devices become limit up to two times the rated current. The fault current of the micro-grids including inverter in the island mode may not have sufficient over-current for protection trip. Therefore, protection of traditional distribution networks cannot be used for micro-grids, and we should look for new protection strategies. Current protection projects are investigated from two perspectives; on the one hand, to improve the protection of traditional distribution network to reduce debugging time, increase sensitivity and improve the quality of the feeder, and on the other hand, for the protection of transmission lines that are evolutionary theories and are used in power distribution networks, including distance protection and pilot protection [13]. The view of network protection is raised at the network level and unit level. Network-level protection is fitted at the point of common coupling (PCC) and unit-level protection within micro-grid is fitted with a ground fault detection technology. In order to avoid the possible consequences of island performance, relay protection network must act fast, detect the island state, and immediately separate the island part. Detection of island mode is divided into two categories which are active and passive island modes, each with specific detection methods.FCL fault current limiter is used in micro-grids, and according to the model and parameters of the network, adjusts the range for the impedance converters and reduces the fault current produced by the DG [22].

Using solar energy as the source for DG:

Solar energy is abundant and easy access to the proper use of it is possible. Given the proximity and access to the network, solar energy can be used as an independent unit or unit connected to the network. This energy will be very good to provide electricity in rural areas, where access to the power network is weak. Another advantage of solar energy is its portable operation at any time and at any moment. Photovoltaic modules, is the expression of the basic unit of the power conversion of the Photovoltaic production network. The output of photovoltaic module components depends on the amount of the solar radiation, temperature of solar cells and photovoltaic modules output voltage [10].

Storage Equipment:

When the micro-grid works in island mode, balance of the power is possible by means of energy storage by storing core installed at the MV / LV in the LV, and also by the batteries connected to the DC bus for distributed generation [11] and [12]. Flywheels are used as the main storing core of micro-grids, and unlike batteries, their life is independent of the discharge and work well in heavy discharges [19].Considering the period of analysis, storage equipment is modeled as constant DC voltage sources that are connected to the network by electronic converters (AC/DC/AC converter for the flywheel and DC/AC inverter for batteries).This equipment as an AC voltage source is controllable and the output characteristics act very quickly to changes [11].

Inverters:

In micro-grids, inverter models can be derived from two control strategies: PQ inverter control and logic of control voltage source inverter (VSI). In the first type, for providing the active and reactive power, the inverter runs at the set point given to it. In the second type, the inverter can be controlled to load power with a predetermined amount of voltage and frequency. Based on the amount and type of load, active and reactive power output of VSI is determined.

Simulation and Analysis of Fault in the Sample Network:

Due to the constant enlargement of the electricity network and the arrival of new and complex components and also the need to carry out various studies, either immediately or not immediately, testing the full model with all the details require to spend money, time and special hardware that is not economic. Therefore, the need for network simulation is strongly felt. In order to simulate, the MATLAB software is used in this thesis.

The proposed sample network:

The network studied in this paper, includes a DG source and a storage battery. Photovoltaic panel is used as the DG source. This source can function in island mode. In table 1 the information of the micro-grid under study is expressed.

Table 1: Information of the studied micro-grid.

description	amounts
Line length	2 km.
Line resistance	0.0012 ohm
Line inductance	0.00009337 Hanry
Line Capacitance	0.00000001 Farad
load	10 kw
PV capacity	100 kw
Network voltage	6 kw
Micro-grid voltage	41.5 kw
Network frequency	60 hertz

Studied micro-grid is shown in Figure 1 and Photovoltaic panel used in the simulation is shown in Figure 2.

The structure of fault detection protective algorithm:

Fault detection:

To protect the studied micro-grid, fault detector systems that record amounts of voltage sequences and current of the network and phase of these sequences, are installed at the beginning and end of each feeder at suitable places. Fault detector systems precisely examine voltage sequences and current of the network and also the phases of these sequences before and after the fault occurred.

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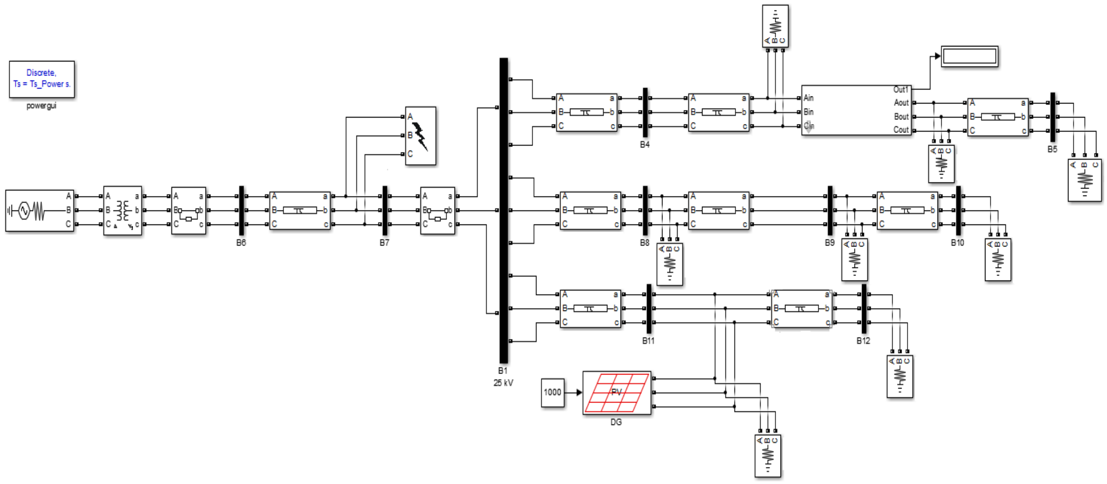

Fig. 1: Studied micro-grid.

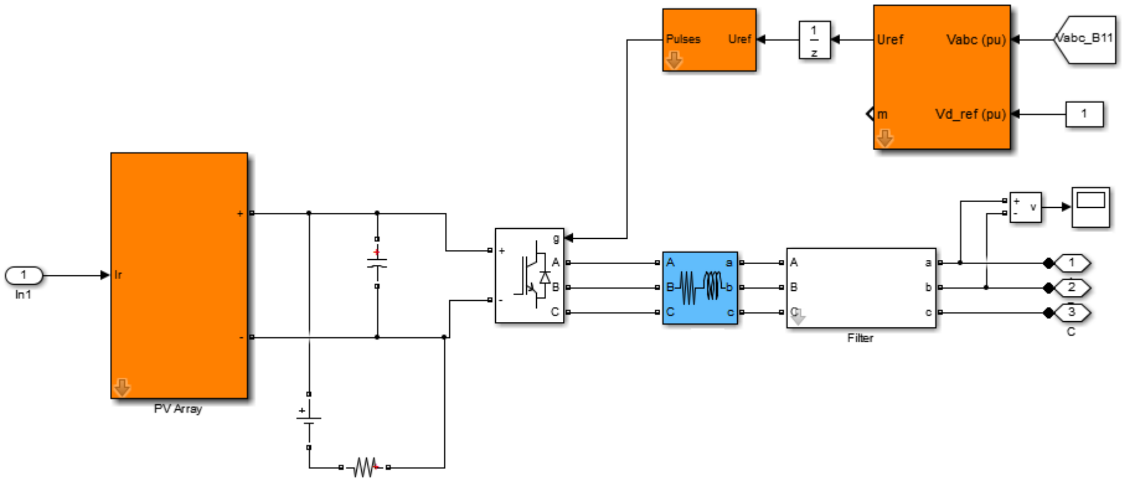

Fig. 2: Photovoltaic Panel used in simulation.

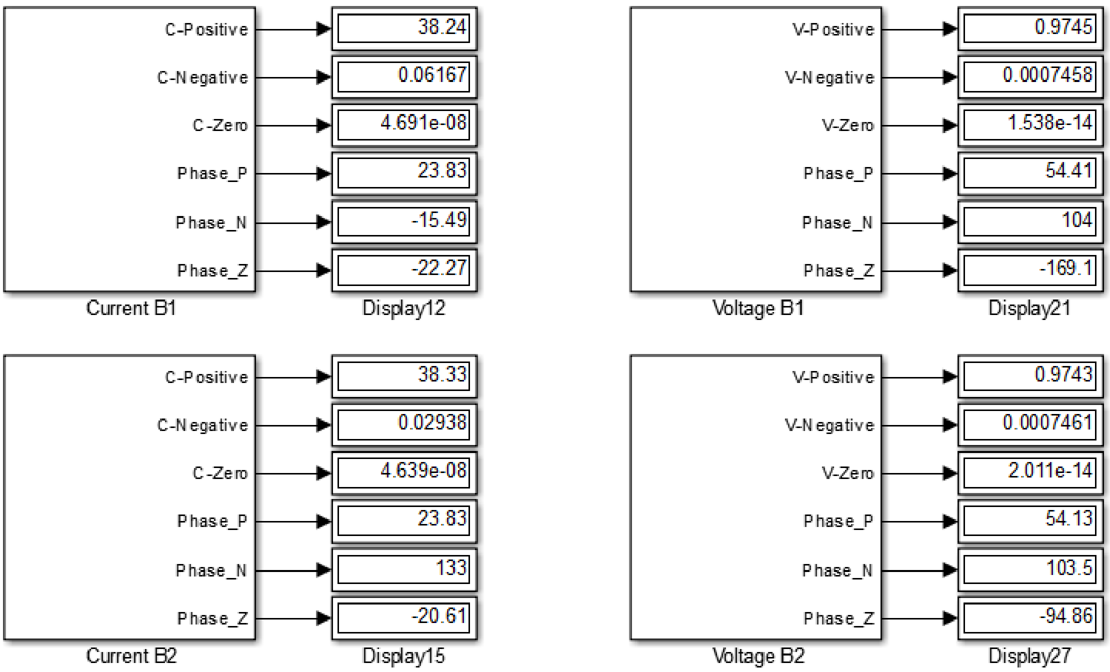

Fig. 3: Values of positive, negative and zero sequences of voltage and current and the phase of these sequences at the beginning and end of the feeder.

Central protection:

Each feeder's diagnostic systems record data to a central protection system (CPS). Information sent by fault detector systems at the beginning and end of each feeder has been examined and compared with the information of the central protection system. In the case of fault in each feeder, central protection system diagnoses it and procedure for removal of faulty feeder out occurs. Therefore, the algorithm presented in this paper is able to analyze data from fault detector networks quickly identify the faulty feeder to protective function be done through central protection system.

No fault condition:

In no fault condition and until there is no fault in the network, just the positive sequence of voltage and current have values and negative sequence and zero sequence of voltage and current should be ideally equal to zero. However, it is possible that because of the harmonics caused by inverters, the exact values are not equal to zero, which can put a filter in appropriate sites to minimize the amount of harmonics. Values of sequences of positive, negative and zero of voltage and current and the phase of these sequences, at the beginning and end of the feeder (B_1 and B_2) are shown in Figure 3.

It is clear that only the positive sequence of voltage and current at the beginning and end of the feeder, have higher values of zero and in terms of security algorithms, this item acknowledges no fault in the micro-grid. In the case of harmonic in the micro-grid (due to inverters) the negative and zero sequences of voltage and current values may be between zero and one. It can be concluded that in no fault condition:

Equation 1:

$$I_{-1} \cong I_{01} \cong 0$$
$$I_{-2} \cong I_{02} \cong 0$$
$$\text{phase}(I_{+1}) \cong \text{phase}(I_{+2})$$

Equation 2:

$$V_{-1} \cong V_{01} \cong 0$$
$$V_{-2} \cong V_{02} \cong 0$$
$$\text{phase}(V_{+1}) \cong \text{phase}(V_{+2})$$

In which:
L_{-1} & L_{-2}: Negative sequence of current at the beginning and end of the feeder;
L_{01} & L_{02}: Zero sequence of current at the beginning and end of the feeder;
V_{-1} & V_{-2}: Negative sequence of voltage at the beginning and end of the feeder;
V_{01} & V_{02}: Zero sequence of voltage at the beginning and end of the feeder;
$phase\ (I_{+1})$ & $phase\ (I_{+2})$: Phase of the positive sequence of current at the beginning and end of the feeder;
$phase\ (V_{+1})$ & $phase\ (V_{+2})$: Phase of the positive sequence of voltage at the beginning and end of the feeder.
Voltage and current waveforms at the beginning and end of the feeder have been shown in Figures 4 to 7:

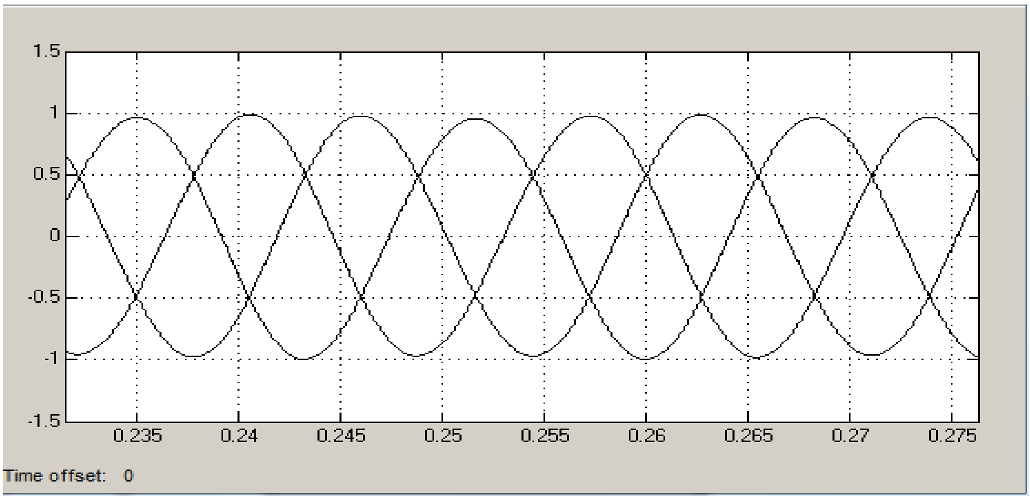

Fig. 4: Sequences of the voltage waveform at the beginning of feeder in no fault condition.

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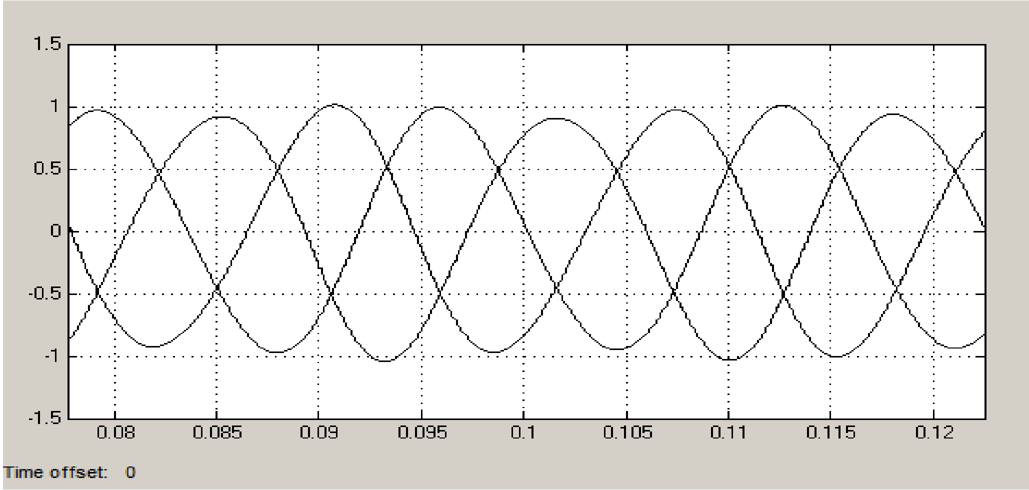

Fig. 5: Sequences of the voltage waveform at the end of feeder in no fault condition.

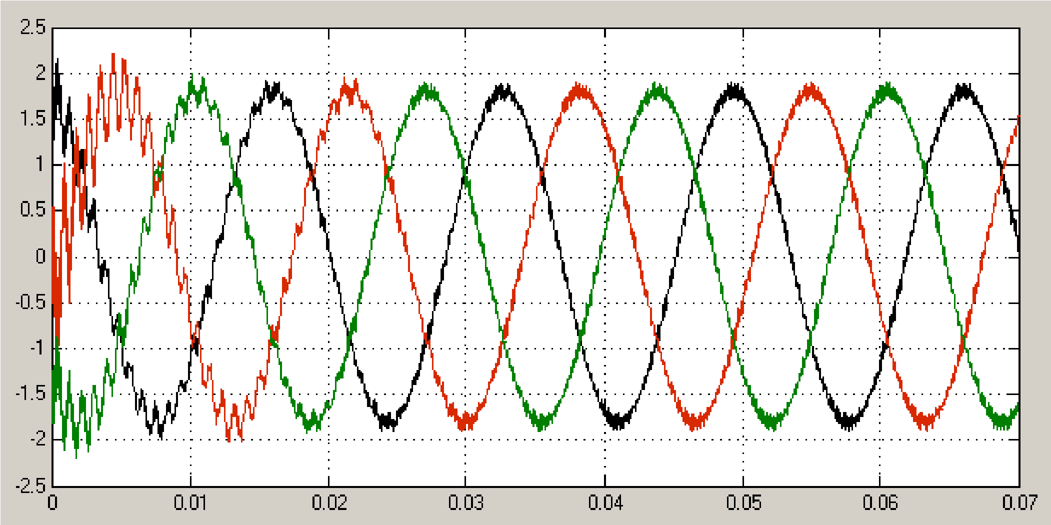

Fig. 6: Sequences of the current waveform at the beginning of feeder in no fault condition.

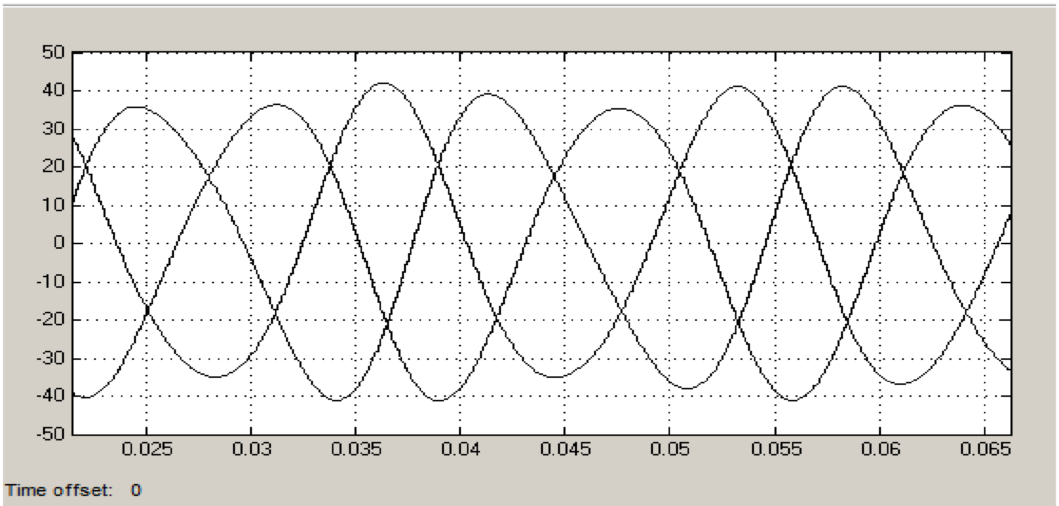

Fig. 7: Sequences of the current waveform at the end of feeder in no fault condition.

In such a case, fault detection system shows 1 for no fault condition (Figure 8).

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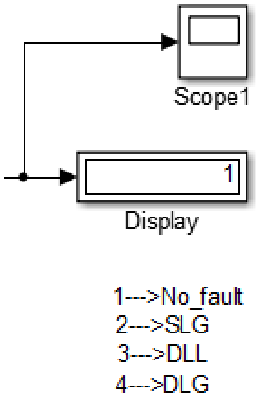

Fig. 8: Declaring no fault condition by error detection system.

Fault conditions:

When a fault occurs in one of the feeders of micro-grid, fault current flows from the power source to the fault location. The amount of fault current depends on the type and power of production of any of energy sources of the micro-grid. Log of the fault to the fault location from different directions causes a change in the sequence of voltage and current, and especially the phase of sequence of current. In case of faults, all of fault detection systems feel the change in values of voltage and current, or fault-induced phase shifts, but the final decision is made by the central protection system. When the central protection system identifies a moment difference in the recorded values of the beginning and end of the feeder, will announce the fault in that feeder. The important thing is that during the time of fault, values of sequences and phase of sequences of voltage and current will change in all the fault detection systems. However, the values recorded at the beginning and end of the feeder are equal.

Single line to ground fault conditions:

To determine if there was a single line to ground fault (SLG) in the micro-grid, a 2 ohm fault was created at time t = 0.4sin one of the feeders. The values of positive, negative, and zero sequences of voltage and current and differences of phase of these sequences at the beginning and end of feeder are shown in figure 9.

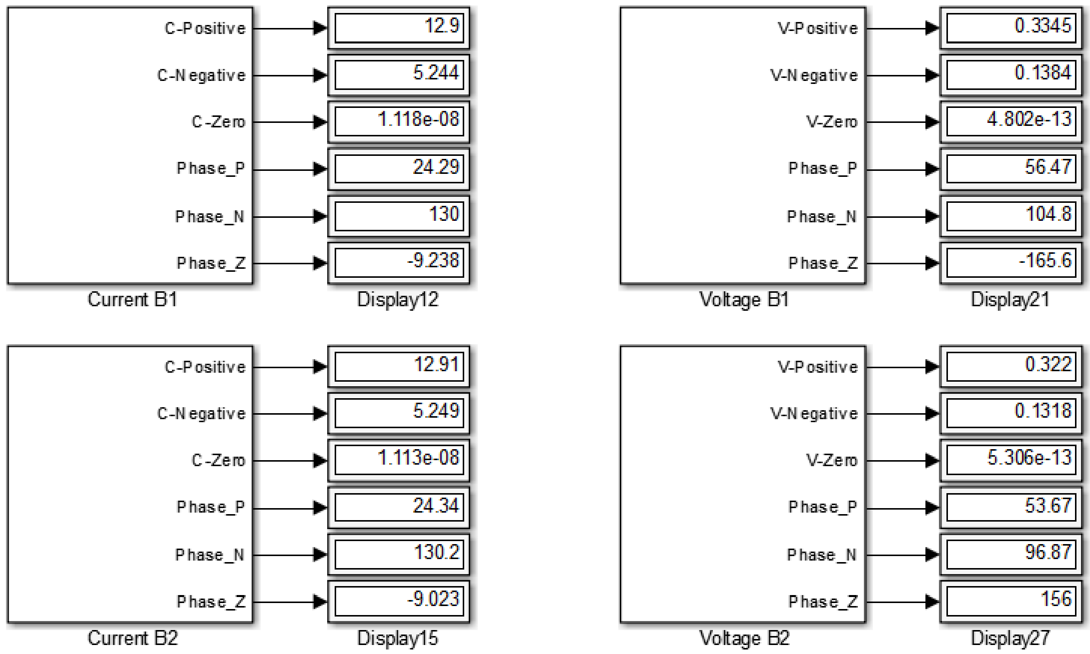

Fig. 9: The values of positive, negative, and zero sequences of voltage and current at the beginning and end of feeder in SLG faults.

Then, it can be concluded that in case of SLG fault:

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Equation 3:

$$V_{+1} \cong V_{+2} \text{ و } I_{+1} \cong I_{+2}$$
$$V_{-1} \cong V_{-2} \text{ و } I_{-1} \cong I_{-2}$$
$$V_{01} \cong V_{02} \text{ و } I_{01} \cong I_{02}$$
$$\text{phase}(I_{+1}) \cong \text{phase}(I_{+2})$$
$$\text{phase}(I_{-1}) \cong \text{phase}(I_{-2})$$
$$\text{phase}(V_{+1}) \cong \text{phase}(V_{+2})$$
$$\text{phase}(V_{-1}) \cong \text{phase}(V_{-2})$$

In which:
V_{01} & V_{-1} & V_{-2}: The positive, negative and zero sequences of voltage at the beginning of feeder;
V_{02} & V_{-1} & V_{+2}: The positive, negative and zero sequences of voltage at the end of feeder;
I_{01} & I_{-1} & I_{+2}: The positive, negative and zero sequences of current at the beginning of feeder;
I_{02} & I_{-2} & I_{+2}: The positive, negative and zero sequences of current at the end of feeder;

Voltage and current waveforms at the beginning and end of the feeder, are shown in figures 10 to 13.

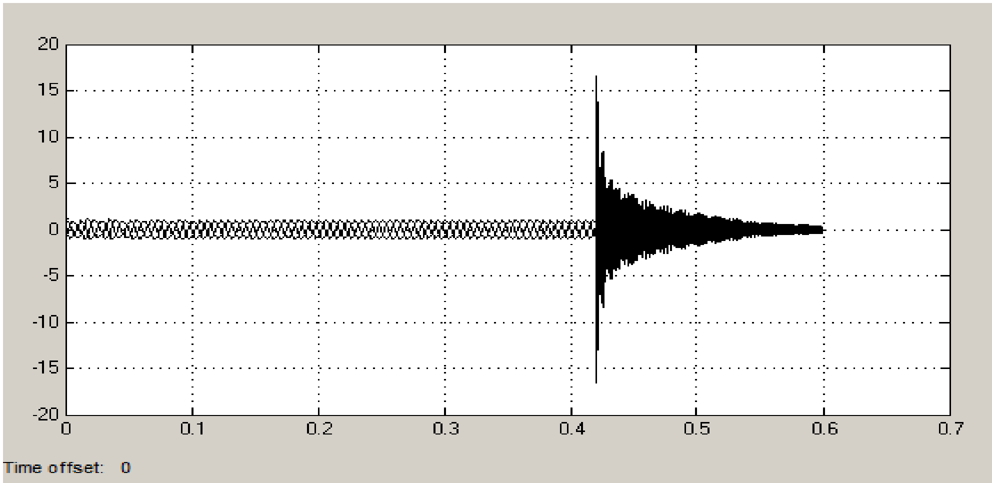

Fig. 10: Voltage sequence waveform at the beginning of feeder in SLG fault.

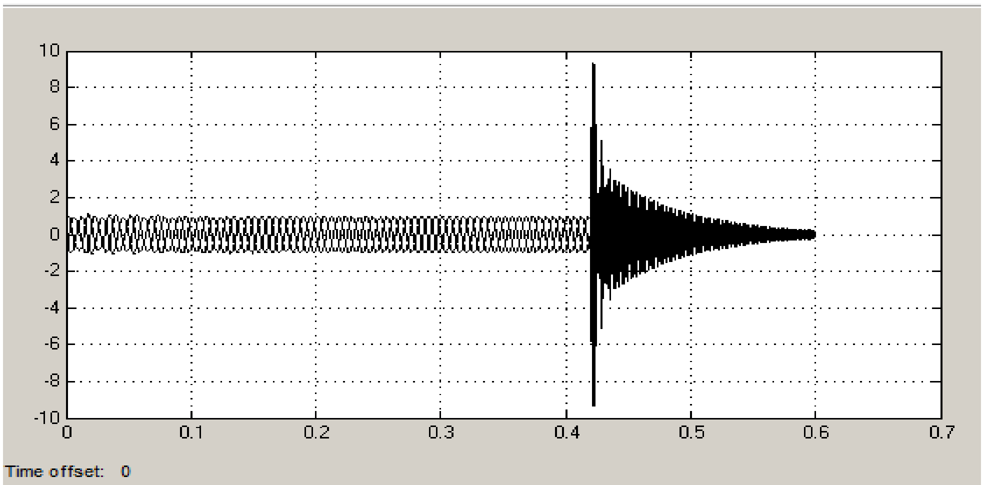

Fig. 11: Voltage sequence waveform at the end of feeder in SLG fault.

Double line to line fault condition:

To investigate the micro-grid when double line to line (DLL) fault occurs, a 2 ohm fault was created at time t = 0.4s in one of the feeders. The values of positive, negative, and zero sequences of voltage and current and differences of phase of these sequences at the beginning and end of feeder are shown in figure 15.

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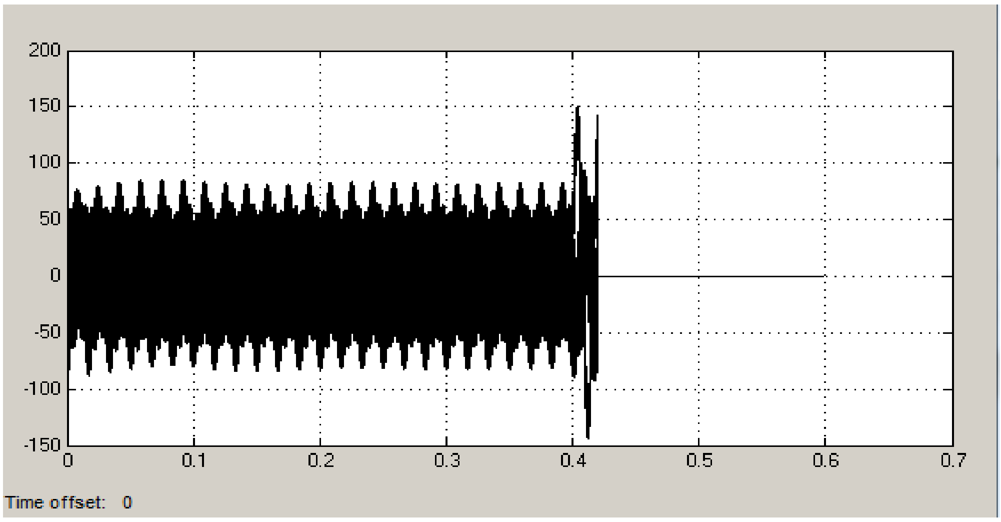

Fig. 12: Current sequence waveform at the beginning of feeder in SLG fault.

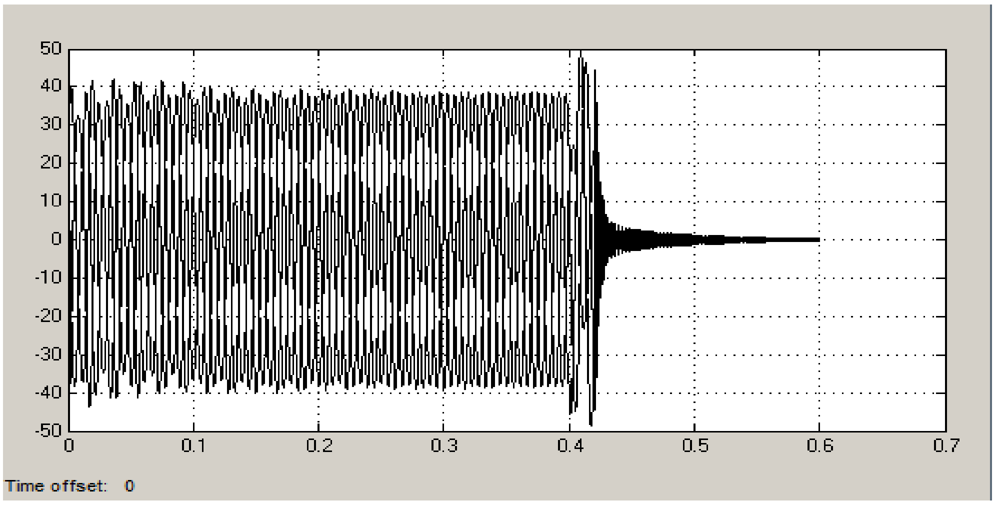

Fig. 13: Current sequence waveform at the end of feeder in SLG fault.

In such a case, fault detector system shows number 2 to show that SLG fault has occurred (Figure 14).

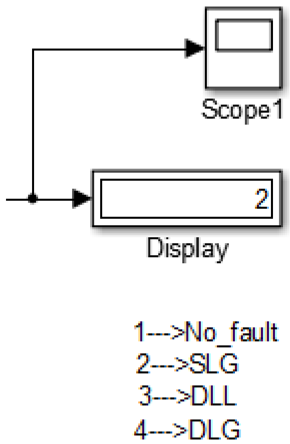

Fig. 14: Showing SLG fault condition by fault detector system.

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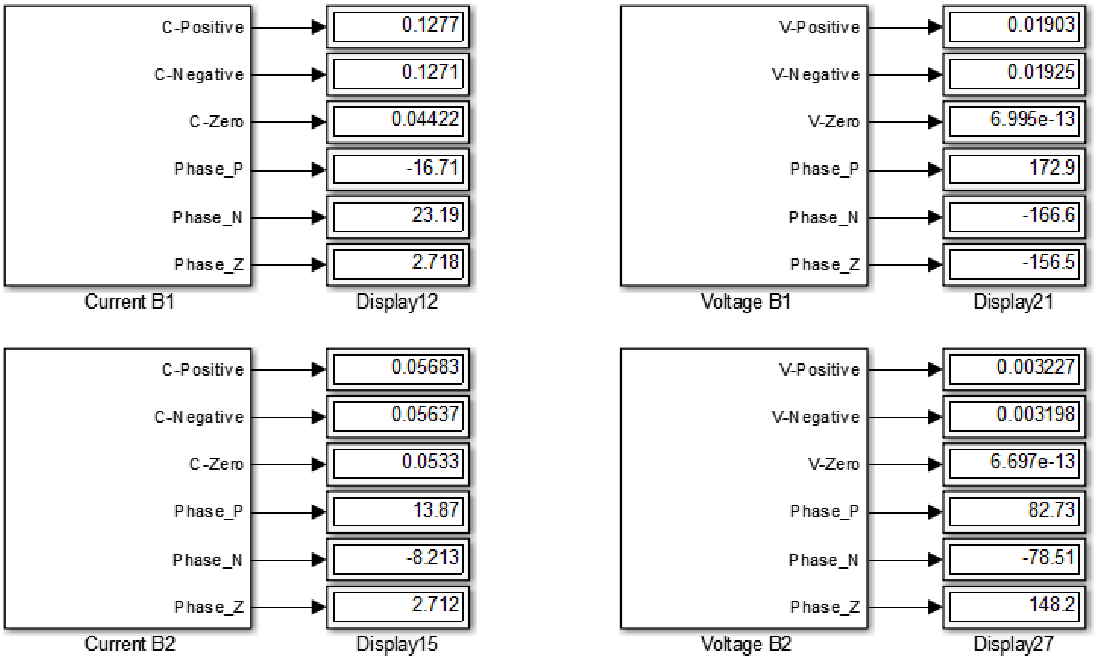

Fig. 15: The values of positive, negative, and zero sequences of voltage and current at the beginning and end of feeder in DLL fault.

The examining and comparing of the values shown in figure 15, it can be concluded that in case of DLL fault the equations in the network are as follows:
Equation 4:

$$I_{+1} \cong I_{-1} \text{ و } I_{+2} \cong I_{-2}$$
$$I_{01} \cong 0 \text{ و } I_{02} \cong 0$$
$$V_{+1} \cong V_{-1} \text{ و } V_{+2} \cong V_{-2}$$
$$V_{01} \cong 0 \text{ و } V_{02} \cong 0$$
$$\text{phase}(I_{01}) \cong \text{phase}(I_{02})$$

Voltage and current waveforms at the beginning and end of feeder are shown in figures 16 to 19.

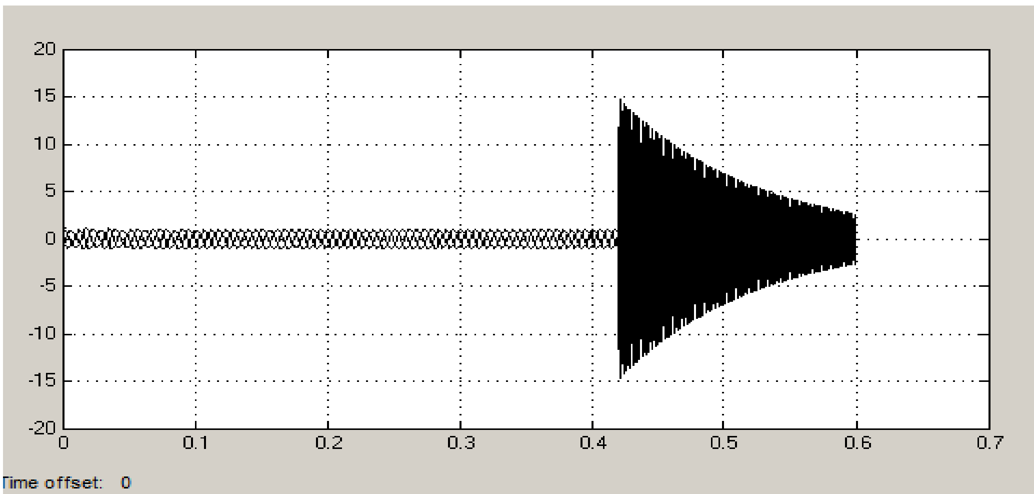

Fig. 16: **V**oltage sequence waveform at the beginning of feeder in DLL fault.

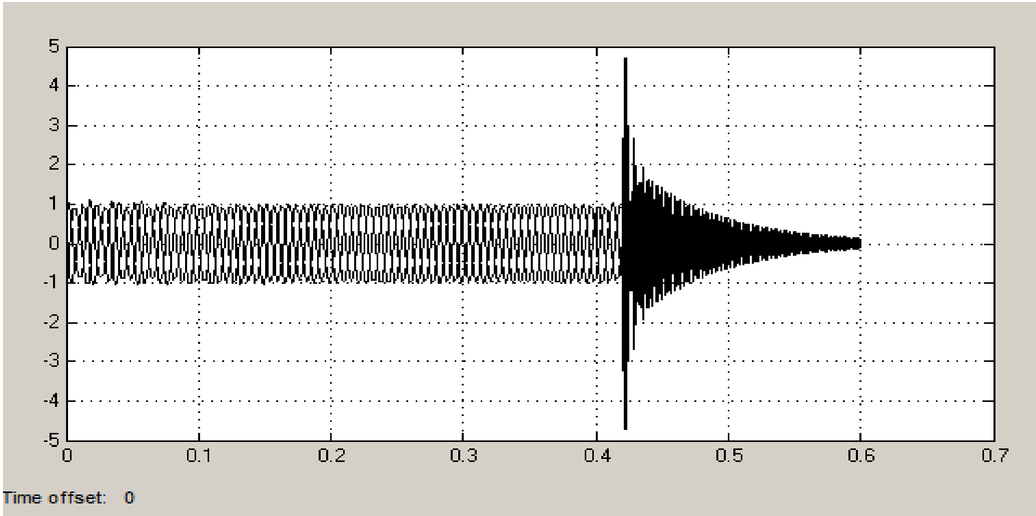

Fig. 17: Voltage sequence waveform at the end of feeder in DLL fault.

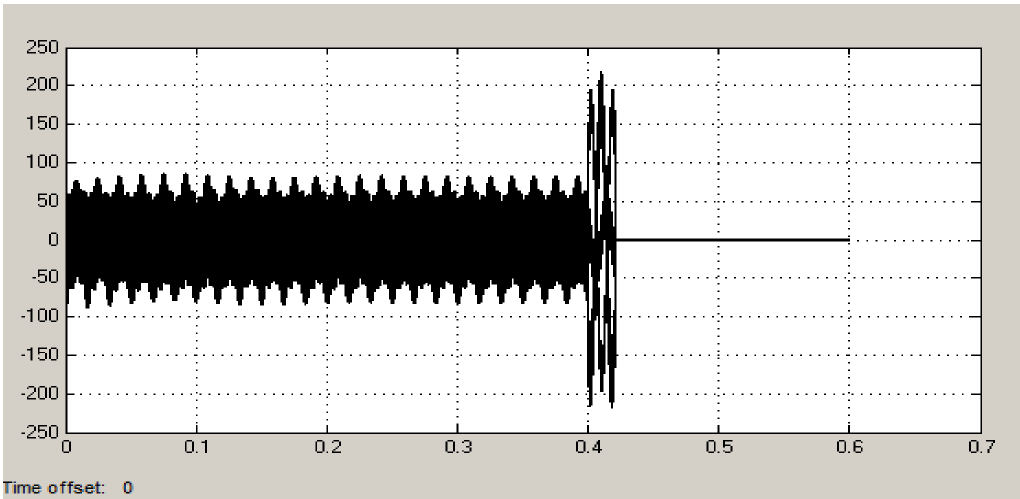

Fig. 18: Current sequence waveform at the beginning of feeder in DLL fault.

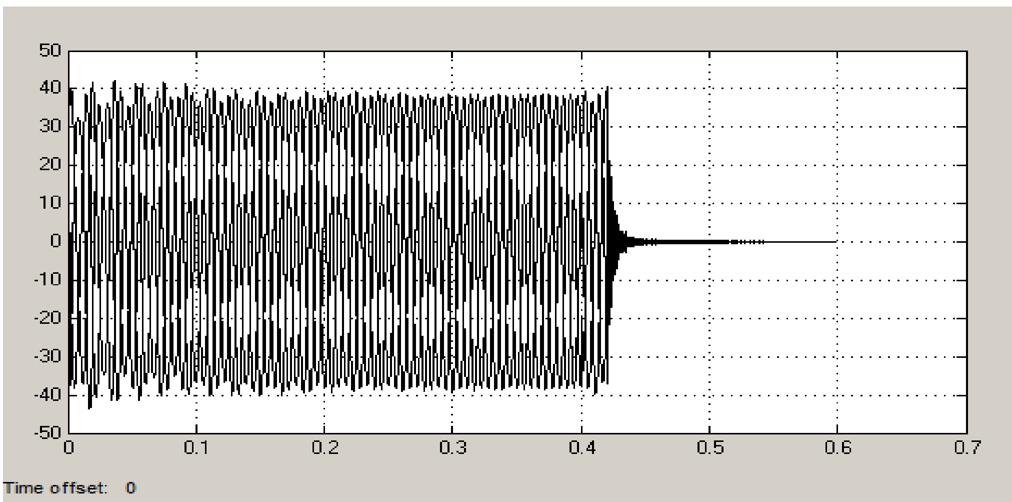

Fig. 19: Current sequence waveform at the end of feeder in DLL fault.

In this condition, fault detector system shows number 3 to indicate that DLL fault has occurred (figure 20).

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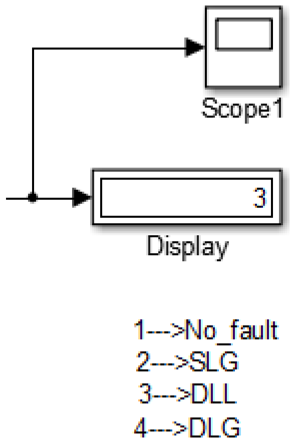

Fig. 20: Showing DLL fault condition by fault detector system.

Double Line to Ground fault condition:

To investigate the micro-grid when Double Line to Ground (DLL) fault occurs, a 2 ohm fault was created at time t = 0.4s in one of the feeders. The values of positive, negative, and zero sequences of voltage and current and differences of phase of these sequences at the beginning and end of feeder are shown in figure 21.

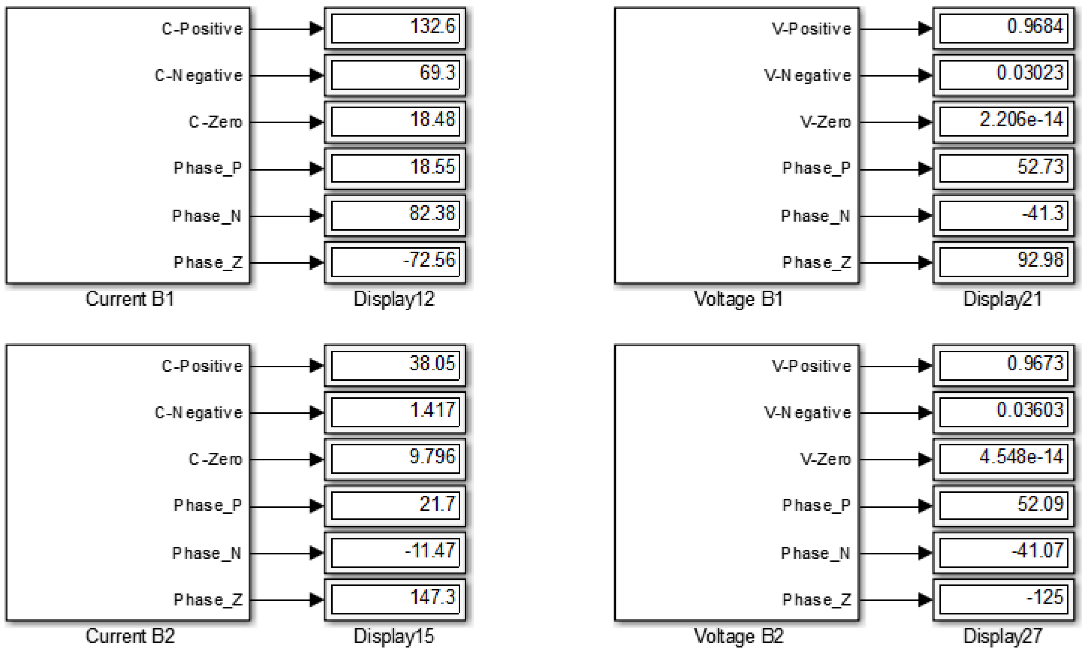

Fig. 21: The values of positive, negative, and zero sequences of voltage and current at the beginning and end of feeder in DLG fault.

The examining and comparing of the values shown in figure 21, it can be concluded that in case of DLG fault the equations in the network are as follows:

Equation 5:

$$V_{+1} \cong V_{+2}$$
$$V_{-1} \cong V_{-2}$$
$$V_{01} \cong V_{02} \cong 0$$
$$\text{phase}(V_{+1}) \cong \text{phase}(V_{+2})$$
$$\text{phase}(V_{-1}) \cong \text{phase}(V_{-2})$$
$$I_{+1} \neq I_{-1} \neq I_{01} \neq 0$$
$$\text{phase}(I_{+1}) \neq \text{phase}(I_{-1}) \neq \text{phase}(I_{01})$$

Voltage and current waveforms at the beginning and end of feeder are shown in figures 22 to 25.

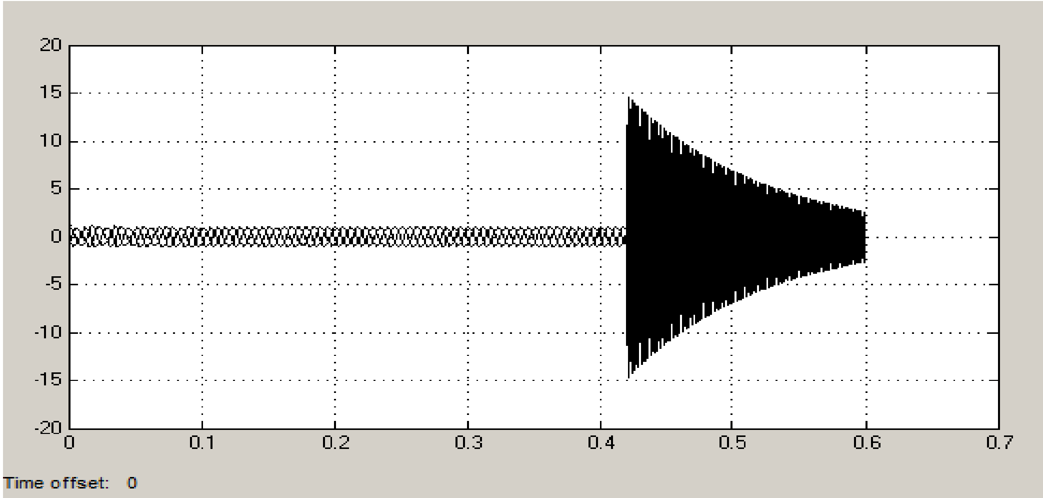

Fig. 22: Voltage sequence waveform at the beginning of feeder in DLG fault.

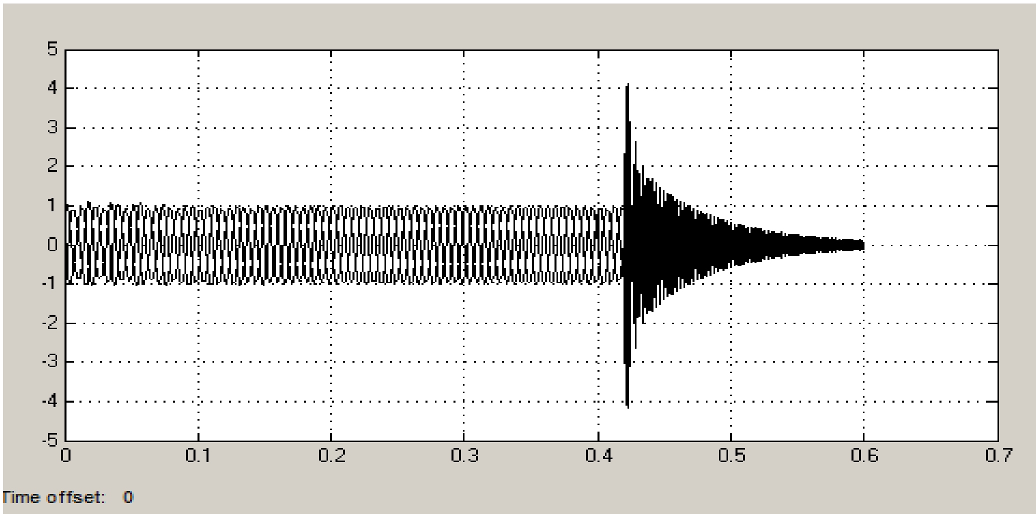

Fig. 23: Voltage sequence waveform at the end of feeder in DLG fault.

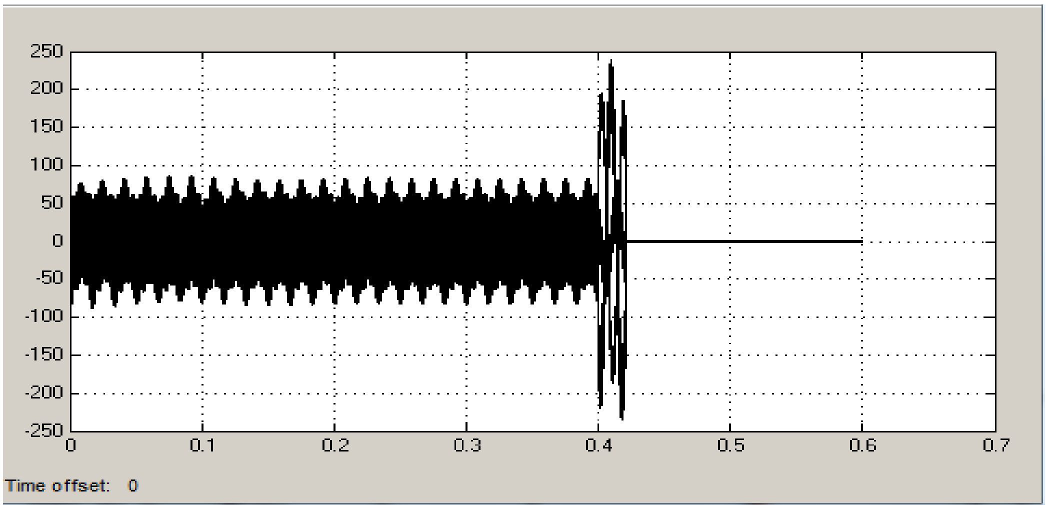

Fig. 24: Current sequence waveform at the beginning of feeder in DLG fault.

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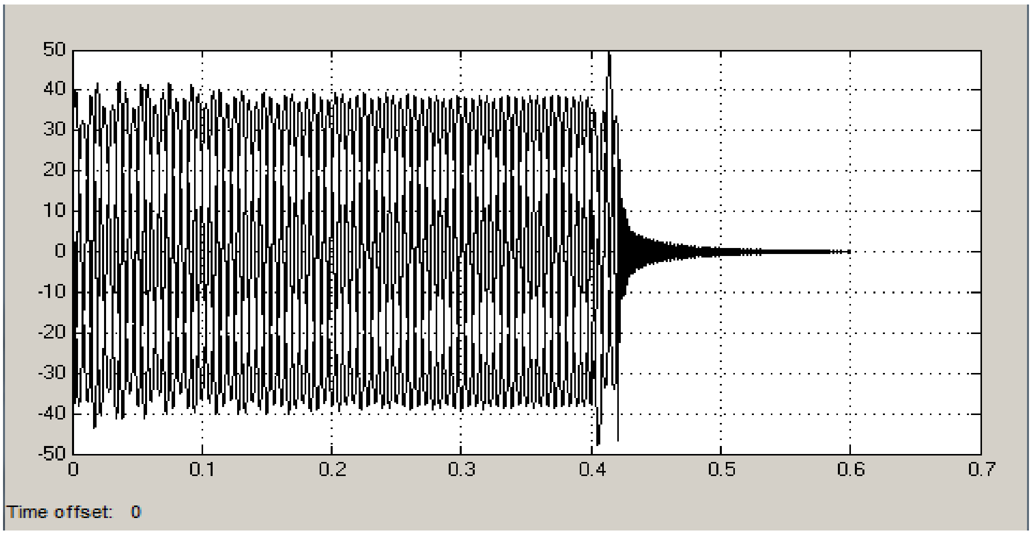

Fig. 25: Current sequence waveform at the end of feeder in DLG fault.

In this condition, fault detector system shows number 3 to indicate that DLG fault has occurred (figure 26).

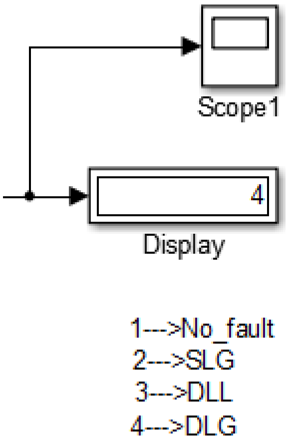

Fig. 26: Showing DLG fault condition by fault detector system.

Examining of the fault detection method in case of island function of the micro-grid:

The proposed method was induced to the micro-grid in the island function mode and it was perceived that this method can easily identify all kinds of SLG, DLL, and DLG faults in island mode like in connected to the network mode.

Fault location algorithm:

Basically, the faults that occur in a network feeder are single line to ground fault with resistanceR_f, double line to line and line to ground faults with arc resistanceR_{arc} and ground resistance $R_f$in different phases; that before presenting the fault detection algorithm, these two types of short circuit faults are modeled on the basis of figure 27.

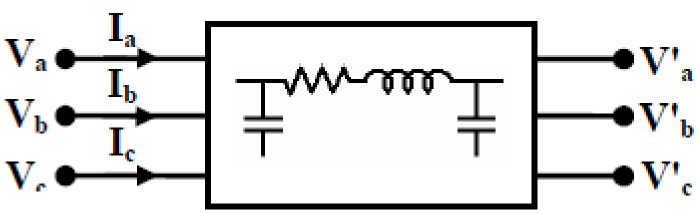

Fig. 27: Circuit model of part of the distribution feeder.

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SLG fault modeling:

A short circuit single line to ground fault with ground resistance R_f at distance d per unit from the beginning of the feeder is shown in figure 28.

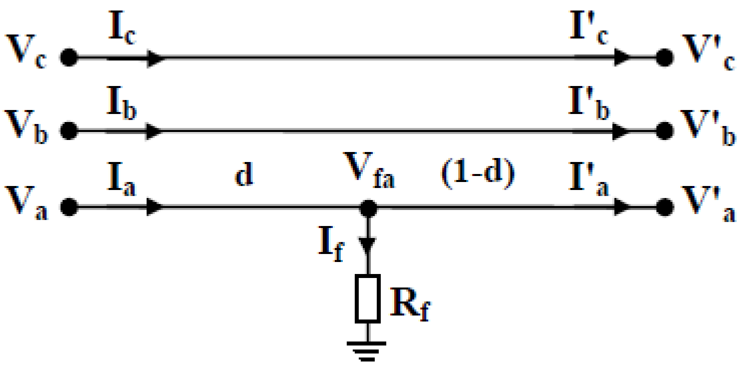

Fig. 28: Circuit model of SLG.

According to figure 28, the equation between the beginning of the meant place and the place of fault can be written as follows:
Equation 6:

$$V_a = d(Z_{11}I_a + Z_{12}I_b + Z_{13}I_c) + V_{fa}$$

On the other hand, according to figure 28-4 it can be written:
Equation 7:

$$V_a = R_f(I_a - I'_a)$$

In which I'_a is the value of phase and V_{fa} is voltage phasor. However, since the location of the fault, i.e. the distance d, is unknown, regardless of the fault, using the voltage phasor V_a the feeder can be load distributed with a good approximation [5] and the calculated current I_a can be used instead of the vakue of the current I'_a. Substituting equation 7 in 6 and parsing the resulting equation in both the real and imaginary parts with values d and R_f can be obtained.
Equation 8:

$$d = [Re(V_a)Im(I_a - I'_a) - Im(V_a)Re(I_a - I'_a)]/ \\ [Re(z_{11}I_a + z_{12}I_b + z_{13}I_c)Im(I_a - I'_a) \\ - Im(z_{11}I_a + z_{12}I_b + z_{13}I_c)Re(I_a - I'_a)]$$

DLL and SLG faults modeling:

In this condition also, a DLL and a DLG faults occur in distance d from the beginning of feeder with arc resistance R_{arc} and ground resistance R_f that is shown in figure 29. Like the previous condition, according to [23] the voltage of faulty phases of the beginning of feeder and the location of fault can be written as:
Equation 9: $V_a = d(z_{11}I_a + z_{12}I_b + z_{13}I_c) + V_{fa}$
Equation 10: $V_b = d(z_{21}I_a + z_{22}I_b + z_{23}I_c) + V_{fb}$
Given the above equations, these equations are resulted:
Equation 11:

$$V_a - V_b = d[(z_{11} - z_{21})I_a + (z_{12} - z_{22})I_b + (z_{13} - z_{23})I_c) \\ +(V_{fa} - V_{fb})]$$

According to figure 29, it can be written:
Equation 12: $(V_{fa} - V_{fb}) = R_{arc}(I_a - I'_a)$

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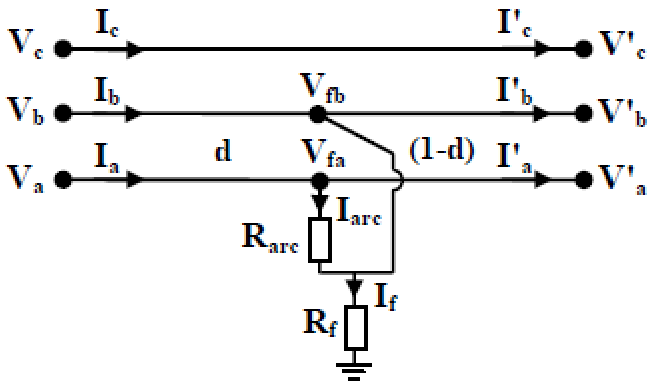

Fig. 29: Circuit model of DLL and DLG.

Substituting equation 12 in 11, like in SLG condition, d and R_f can be obtained, that distance d is as follows:
Equation 13:

$$d = [\mathrm{Re}(V_a - V_b)\mathrm{Im}(I_a - I'_a) - \mathrm{Im}(V_a - V_b)\mathrm{Re}(I_a - I'_a)] / [\mathrm{Re}((z_{11} - z_{21})I_a + (z_{12} - z_{22})I_b + (z_{13} - z_{23})I_c)\mathrm{Im}(I_a - I'_a) - \mathrm{Im}((z_{11} - z_{21})I_a + (z_{12} - z_{22})I_b + (z_{13} - z_{23})I_c)\mathrm{Re}(I_a - I'_a)$$

Structure of fault location algorithm:

Fault detection algorithm is such that that first, the mean values of LF (Load Factor) and PF (Power Factor) are estimated based on the voltage and current data before the fault of the beginning of the feeder [6] and [4]. Then after fault phasors are calculated using samples of voltage and current. Finally, fault location algorithm investigates different parts of feeder calculating distance d from the beginning of any part to find fault, so that if d is less than 1, the part is considered as a site of fault candidate, and otherwise the part is estimated free of fault.

After testing all the parts of the feeder for faults, to reduce the number of first fault candidate parts, the fault candidate parts whose upstream indicator, fuse or separator is not activated should be omitted from the faulty parts to attain a minimum number of faulty parts.

Examining Fault location by proposed algorithm:

The results of inducing the fault location algorithm to the micro-grid are shown in tables 2 to 4. As seen in the results, this algorithm has high accuracy in locating fault. The error ate in calculating the fault distance from feeder is expressed as percent.

Table 2: Examining 2 ohm fault location in 1 kilometer from the beginning of the feeder.

Real distance of fault location (km)	Fault resistance R_f	Fault kind	Distance calculated by algorithm	Error rate in calculating (percentage)
1	2	SLG	0.987	1.3
1	2	DLL	0.987	1.3
1	2	DLG	0.987	1.3

Table 3: Examining 3 ohm fault location in 2.5 kilometers from the beginning of the feeder.

Real distance of fault location (km)	Fault resistance R_f	Fault kind	Distance calculated by algorithm	Error rate in calculating (percentage)
2.5	3	SLG	2.467	1.32
2.5	3	DLL	2.467	1.32
2.5	3	DLG	2.467	1.32

Table 4: Examining 20 ohm fault location in 3 kilometers from the beginning of the feeder.

Real distance of fault location (km)	Fault resistance R_f	Fault kind	Distance calculated by algorithm	Error rate in calculating (percentage)
3	20	SLG	2.961	1.3
3	20	DLL	2.961	1.3
3	20	DLG	2.961	1.3

With the results obtained from the tables above, we can say that the error rate of 1.3% indicates that this method is able to accurately calculate the location of the error. Of the most important advantages of this method is that it can be independent of the fault resistance noted. In other words, this method is able to easily calculate, with the accuracy 98.6%, the fault location in case of high or low fault tolerance.

Discussion and Conclusion:

The main objective of this paper is to provide a simple and accurate method for detecting and locating faults in micro-grids that not only has a high speed but also has high location accuracy. Besides, its dependence to the differences of function situation is so low. The traditional protection methods that are used to protect distribution networks, factors such as the harmonic, fault location impedance, and even instability of network highly impact the network. But the protection algorithm proposed in this paper is able to detect the kind and location of the fault with the least rate of error, using the values of network voltage and current sequences and phase of these sequences.

After inducing the proposed method to detect the fault in the micro-grid, it was perceived that:

- This method has the ability of detecting the Single Line to Ground faults in both connected to the network and island modes.
- This method has the ability of detecting the Double Line to Line faults in both connected to the network and island modes.
- This method has the ability of detecting the Double Line to Ground faults in both connected to the network and island modes.
- This method has the ability of detecting various kinds of high impedance-faults in both connected to the network and island modes.

With the implementation of the proposed algorithm for fault location it was found that:

- This method is able to locate the fault when SLG fault occurs with accuracy 98.6% in both connected to the network and island function modes.
- This method is able to locate the fault when DLL fault occurs with accuracy 98.6% in both connected to the network and island function modes.
- This method is able to locate the fault when DLG fault occurs with accuracy 98.6% in both connected to the network and island function modes.
- This method is able to locate the fault in case of occurrence of all kinds of high impedance-faults and low impedance-faults with accuracy 98.6% in both connected to the network and island function modes.

The characteristics above are the main advantages of this method. Moreover, the impedance of the fault location and load changes do not affect the performance of this protection network. Besides, protection algorithm proposed in this paper doesn't have any dependence on the differences of current value and also is able to easily detect the fault. This algorithm has the ability of detecting faulty feeder and can separate the faulty part from the network. In the simulation done in this study Photovoltaic panel is used as DG source that has advantages such as lack of noise pollution, no need for connection to national power network, no need for water to generate electricity, saving energy costs, a long life and low need for repair and maintenance, no need for fossil fuels, no emissions, and return on investment in the shortest time than other renewable energies. Photovoltaic panels in cases such as uninterruptible power supplies, power production for agriculture, construction of solar powerhouses, electricity supply in remote areas of the national power network, electricity supply for the plants, hotels, hospitals and residential areas.

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