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Optimal location of fault current limiters to improve fault current and voltage sag in AC and DC microgrids

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Abstract: One of the most important issues about implementing superconducting fault current limiters in the future intelligent networks is studying its possible effects on fault current and power quality parameters. Hence, SFCL locating in power systems has been taken into consideration. Due to the microgrid connection to the power grid, abnormal fault current is a serious issue that should be eliminated. The side effects of fault occurrence on power quality can cause electrical equipment failure which increases the need for controlling power quality parameters including voltage sags. This paper uses resistive SFCL to overcome the mentioned problems in microgrids. Different SFCL arrangements are studied in Matlab Simulink environment to decrease the fault current and voltage sag improvement, and the optimal arrangement will be selected. The simulation results introduce the optimal SFCl for fault current and voltage sag control while indicating that SFCL is effective for AC and DC microgrid protection.

Keywords: Supeconductive fault current limiter, microgrid, power quality, voltage sag, fault current.

I. INTRODUCTION

Electrical microgrid or a more common term, the microgrid is assigned to a structure of a distribution network in which simultaneous generation and transfer of heat and electrical energy are possible. A microgrid is a part of an active distribution network that can be described as a combination of heat and electrical loads and distributed energy resource (DER) units [1, 2].

The study of the power quality in the distribution networks has been drawing attention of the researchers for so many years in many research areas such as distributed generations, protection, and power electronics [3, 4]. Researches have been done about using fault current limiters to decrease the fault currents in distribution networks and microgrids [5, 6]. AC SFCL locating and efficiency in AC microgrids [7, 8] and DC SFCl in DC microgrids have been studied. Also, SFCL locating and its effects on intelligent networks including AC and DC microgrids simultaneously are studied in order to decrease fault current [9-12]. In [9] the validation of locating fault current limiter in a grid including adjacent AC and DC microgrids has been studied. In this paper, some arrangements are proposed for locating SFCL, and the optimal SFCL arrangement for fault current reduction has been introduced via simulation. In another work [10] implementation and location of resistive SFCL in power systems including low voltage AC and DC is analysed and it is shown that fault current in microgrid affects the adjacent grids. Also, the best position of SFCL is determined for limiting all the fault currents without any effects on distributed generation's performance. In [11] the feasibility of using SFCL in microgrids with distributed generation of grid connected wind turbine is studied, and considering different positions of SFCL, the best position was the connecting point of wind turbine and grid. In [12] the optimal locating of the SFCL in the intelligent network was studied for reducing the faults. In these articles different arrangements of SFCL are studied for current reduction and the optimal arrangement is introduced. But the effect of this arrangement for improving the power quality parameters including voltage sag is ignored. In some papers, SFCL is used to improve voltage sag in distribution systems [13, 14]. In [13] the voltage sag is studied considering the effect of SFCL impedance and fault conditions in distribution systems. In [14] the voltage sag in the annular distribution network is analysed and the analysis results in an annular network with voltage sag in the radial distribution system is investigated. But no study has been done on microgrids for improving voltage sags. There were also proposed several protection schemes [15-25] for microgrids based on current or voltage relays, symmetric components, current differential protection, harmonic components, traveling waves and adaptive protection. However, none of which was a perfect method. That is to say that all of them have advantages and disadvantageous. For instance, some of them perform well only in connected mode of operation or islanded mode of operation. Some of them perform well for only synchronous distributed generations (DGs) and some others for inverter-based DGs [26].

In this paper, SFCL positioning is done considering the effect of voltage sag in microgrids including AC and DC microgrids. This power grid includes a microgrid with wind farm and a DC low voltage grid connected to the

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photovoltaic farm. With different SFCL conditions for worst cases, the transient state is studied. With simulation, it became possible to determine the strategic position of SFCLs in power systems for voltage sag improvement without a negative effect on distributed generation sources. Next are the studied network, simulation results, and conclusion.

II. THE STUDIED NETWORK

The studied power grid is a part of South Korea power grid which includes a traditional grid and two AC and DC microgrids as shown in figure (1).

A. Traditional grid

In Traditional grid, power is supplied via a 100MVA three-phase synchronous machine and is transmitted by a 14kV line with a length of 200km. For distribution network a step-down transformer 154 kV: 22.9kV is placed in front of the main branch. This distribution network is divided into three branches of traditional, AC and DC microgrids.

B. Microgrid

Microgrid includes both AC and DC microgrids and each of them has DG sources. AC Microgrid includes a wind farm that has 5 fixed speed induction turbine. Each turbine has 2MVA apparent power. The normal voltage of the microgrid is 22.9kV which is the normal voltage of Korea distribution network. In the case of DC microgrid, PV farm consists of 500 panels, and each module has a nominal power of 3kW. Normal voltage of the DC microgrid is 1.kV. The main difference of these two microgrids is in voltage source converter (VSC), Pole Mounted Transformer (PMT) and Domestic Power Converter (DPC). Since the studied power grid includes both AC and DC microgrids, two models of SFCL (AC and DC SFDL) are used. The SFCLs used in this paper, has a block diagram as shown in figure (2) and their specification is as follows:AC SFDL model is designed based on 6 basic parameters of RSFCL while DC SFCL is designed by removing RMS blocks and harmonic filters. Three main step in designing both SFDLs

- RMS current flow in SFCL specification table is compared with a pre-determined value.
- If this current is more than the trigger current, the SFCL resistance reaches to its maximum point in a certain period of time.
- When it iss less than the trigger current, again after the recovery time, the minimum resistance will be the SFCL resistance.

III. THE PROPOSED METHOD

The proposed method for SFCL locating in grids will be discussed in this section. Since SFCL installation is expensive, it should be installed where the system has the best performance and highest efficiency. For this reason, in this paper, the best place for SFCL installation in the grid is chosen considering different arrangements of SFCL. These arrangements are as follows: According to Fig.1, the first arrangement includes an AC SFCL on the TR2 transformer output. The second arrangement consists of 2 AC and DC SFCL. The third one includes one AC and one DC SFCL in DC microgrid. The forth have AC and DC SFCL in the output of DGs.

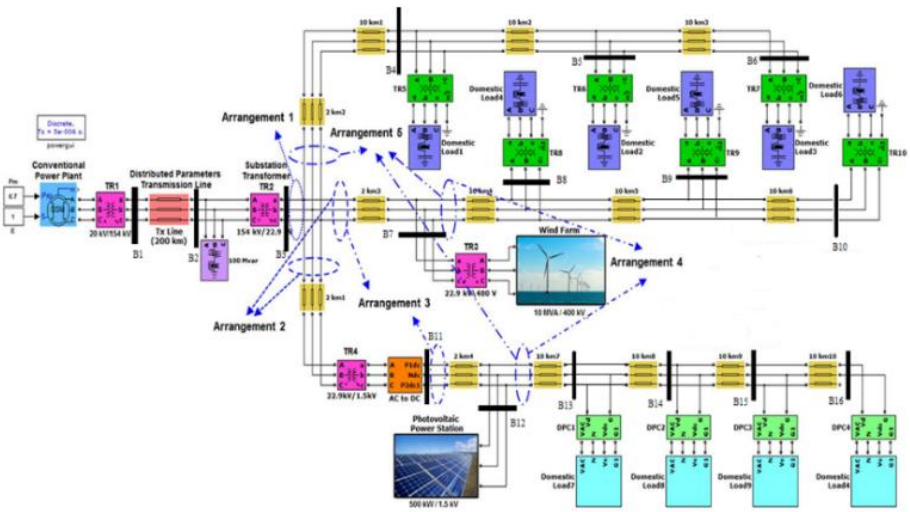

Fig. 1 The studied power grid

The fifth one is the same as the forth plus an AC SFCL at the input of traditional power grid.

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IV. SIMULATION RESULTS

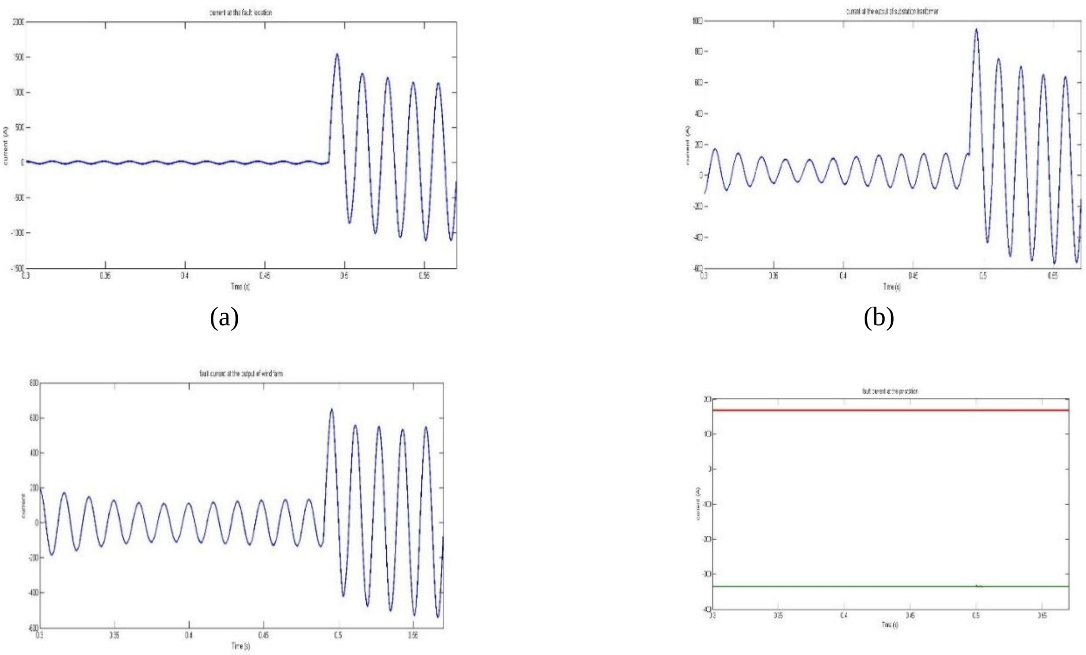
In this section, the simulation results of different SFCL arrangements is discussed for fault current improvement and voltage sag reduction. The simulation results for three case of fault occurrence in AC microgrid, a fault in DC microgrid and fault occurrence in the traditional branch without DG are provided.

1- Simulation Results for fault current

The faults in AC and DC microgrids and the traditional branch occurs in 0.49 seconds and the study period is from 0.47s to 0.57s. Three cases of fault occurrence in AC grid with DG, fault occurrence in DC microgrid and fault occurrence in AC microgrid without DG will be discussed.

A. First case, fault occurrence in AC microgrid

In this case, the fault between B9 and B10 buses of power grid of Fig.1 occurs in 0.49 seconds. First, the results for different parts are studied to distinguish each generator's contribution in fault current. Fig.2a shows the fault current in fault position. Fig.2b shows the fault current in the output of interior station transformer (TR2), Fig.2c shows the fault current in the output of wind farm and Fig.2d shows the fault current in the output of PV farm.



(c) (d)

Fig.2. fault current in different parts of the network (a) in the fault position, (b) in the output of interior station transformer, (c) in the output of wind farm, (d) in the output of PV farm

It can be understood from the above figures that the fault currents are fed with wind farm and traditional power supply and based on this simulations, PV has no contribution in fault current.
Now, the fault current results in fault place in different arrangements will be discussed. Fig.3a shows the fault current in fault place for different SFCL arrangements and also for no SFCL case. As expected, best results are achieved for arrangements 4 and 5 in which the SFCL is placed in the direct path of fault current because SFCL shows impedance for all fault currents and in arrangements 1, 2 and 3 the results are nearly the same and this refers to not flowing fault current from PV farm. Next has discussed the fault current in the wind turbine output in different arrangements. Fig.3b shows the fault current in the wind farm output for different SFCL arrangements and for no SFCL case. Also, in this case, the best results are achieved for arrangements 4 and 5.

Next, the fault current at the output of interior station of Transformer (TR2) in different arrangements will be discussed. Fig.3c shows the fault current at the output of interior station transformer (TR2) for 5 different SFCL arrangement and for no SFCL case.

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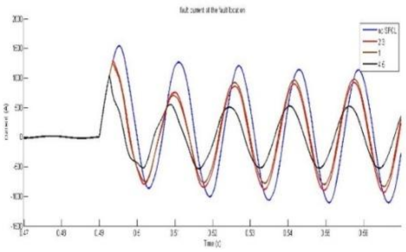
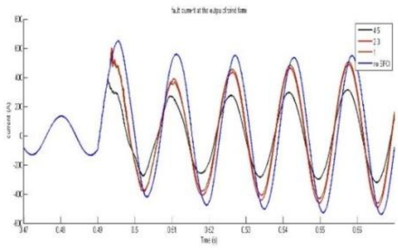
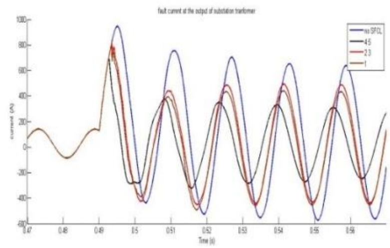


(a)



(b)



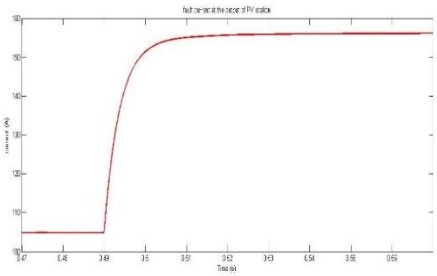
(c)

Fig.3. fault current in different parts for fault occurrence in AC microgrid, (a) in fault position, (b) in the output of wind farm, (c) in the output of interior station transformer

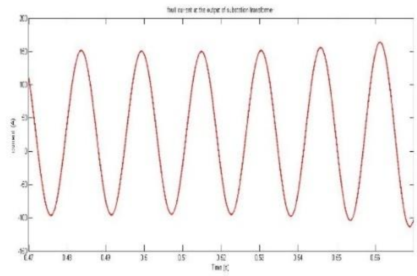
In this section, the best results achieved for arrangement 4 and 5. Now one may ask that why arrangement 4 and 5 show better results while all the arrangements are placed on the feeding line fault current flow and arrangements1, 2 and 3 are nearly the same. The reason is that the current level differs in the location of SFCL in arrangements when the SFCL specifications for the arrangement are the same.

B. Second case, fault occurrence at DC microgrids

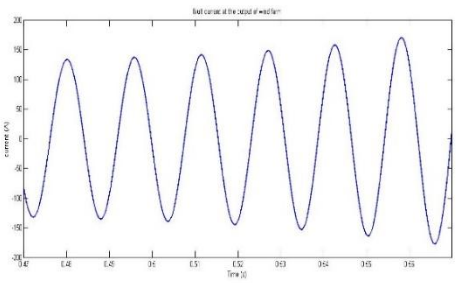
In this case, the fault between B13 and B14 buses in power grid occurs at time 0.49s. First, the results for different parts were studied to determine each generators contribution in fault current. Fig.4a shows the fault current at the output of PV farm. Fig.4b shows the fault current at the output of interior station transformer (TR2) and Fig.4c shows the fault current at the output of wind farm. The above figures show that the fault current is mainly fed by the PV farm and based on this simulation the wind farm and traditional feeding grid and wind farm have no role in providing fault current. Now the results of a fault current in fault place in different arrangements are studied. Fig.4d shows the fault current in the fault place for 5 different SFCL arrangement and without SFCL.



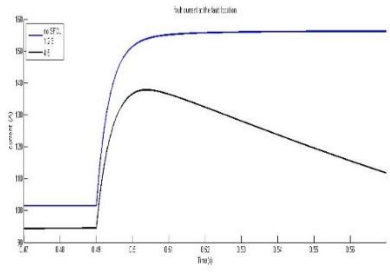
(a)



(b)



(c)



(d)

Fig.4. fault current in different parts for fault occurrence in DC microgrid, (a) in the output of PV farm, (b) in the output of interior station transformer, (c) in the output of wind farm, (d) in fault position

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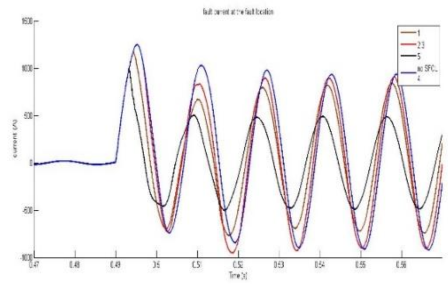
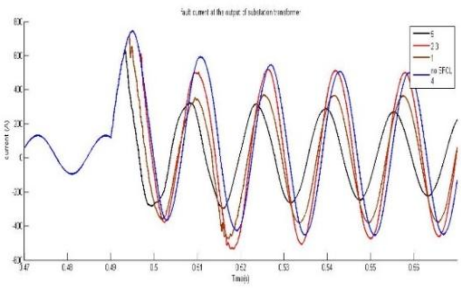
In this case arrangement, 4 and 5 achieved the best results and other arrangements are not activated because wind farm and traditional feeding line have no role in providing the SFCL fault currents. This can be attributed to the rectifier.

C. Third case, fault occurrence in AC microgrid without DG source

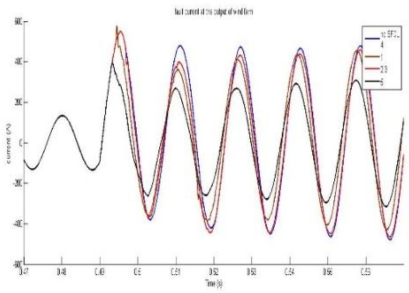
In this section, the results of a short circuit in the traditional grid without DG source for 5 different SFCL arrangement and the case without SFCL will be explained. Fig.5a shows the fault current in the fault place. Fig.5b shows the fault current at the output of interior station transformer (TR2) and Fig.5c shows the fault current at the output of wind farm. It can be seen that in this case the best limitation corresponds to arrangement5 and the difference between the arrangement 4 and 5 is apparent.



(a)



(b)



(c)

Fig.5. fault current in different parts for fault occurrence in AC microgrid without DG source, (a) in the fault position, (b) in the interior station transformer, (c) in the output of wind farm

1- Simulation Results for Voltage Sage

A. First case, fault occurrence in AC microgrid

It is assumed that the fault occurred in AC microgrid and in the middle of the line between buses 9 and 10. Fig.6a shows the voltage of busses 7 to 10. It is concluded from the Fig.6a that the voltage sag at the output of wind farm (bus7) is less than busses 8 and 9 due to the distributed generation. The farther away from the distributed generator and closer to the fault bus (bus9), the more is voltage sag. Fig.6b shows the voltage at the output of PV farm (bus12). It can be seen from the Fig.6b that the fault at the AC microgrid has no effect on the voltage of PV wind farm. Now the voltage at the interior station transformer (bus3) in different SFCL arrangements will be studied. Fig.6c shows the voltage at the output of interior station transformer (bus3) for 5 different SFCL arrangement and the case without SFCL. In this case, the best results correspond to arrangement 4 and 5. Again one may ask that why arrangement 4 and 5 show better results while all the arrangements are placed on the feeding line fault current flow and arrangements1, 2 and 3 are nearly the same.

Now the voltage at the output of wind turbine (bus7) in different arrangements is studied. Fig.6d shows the voltage at the output of wind turbine (bus7) for different 5 SFCL arrangements and the case without SFCL.

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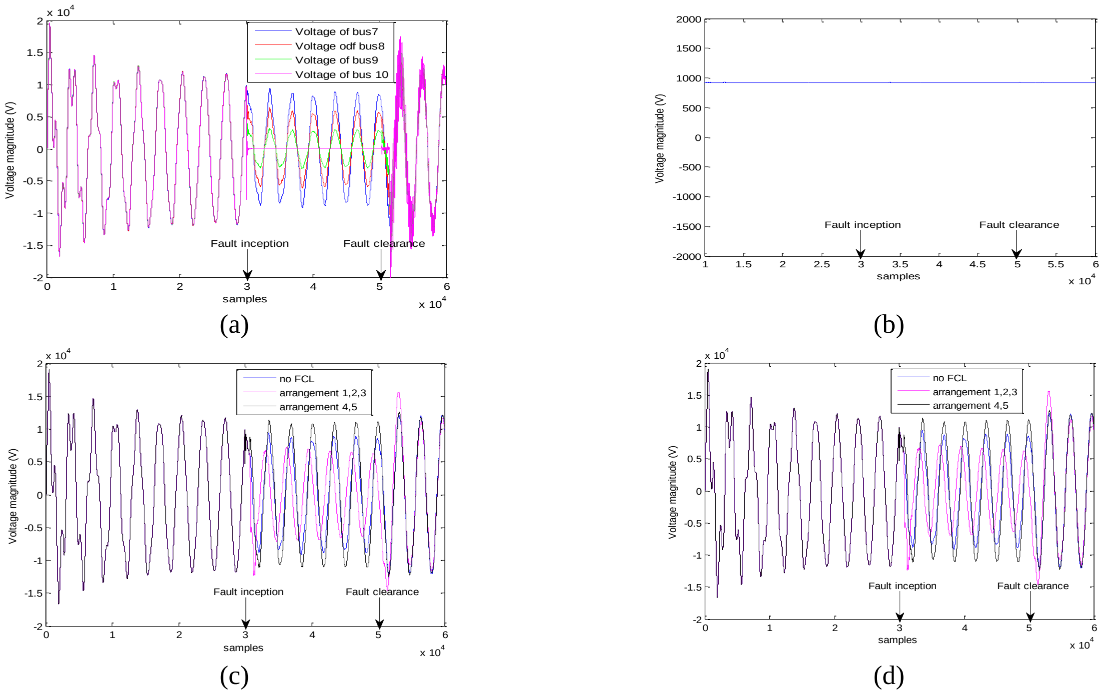

Fig.6. Voltage at different parts for fault occurrence in AC microgrid, (a) at the busses 7, 8, 9,10, (b) at the output of PV wind farm (bus 12), (c) at the output of the interior station transformer (bus3), (d) at the output of wind farm (bus7)

B. Second case, fault occurrence in DC microgrid

Here it is assumed that the fault occurred in DC microgrid in the middle of the line between bus 14 and 15. Fig.7a shows the voltage at the output of PV wind farm (bus 12). Fig.7b shows the voltage at the interior station transformer (bus3). Fig.7c shows the voltage at the output of wind farm (bus7) and Fig.7d shows the voltage at bus 5 in the traditional grid (without DG).

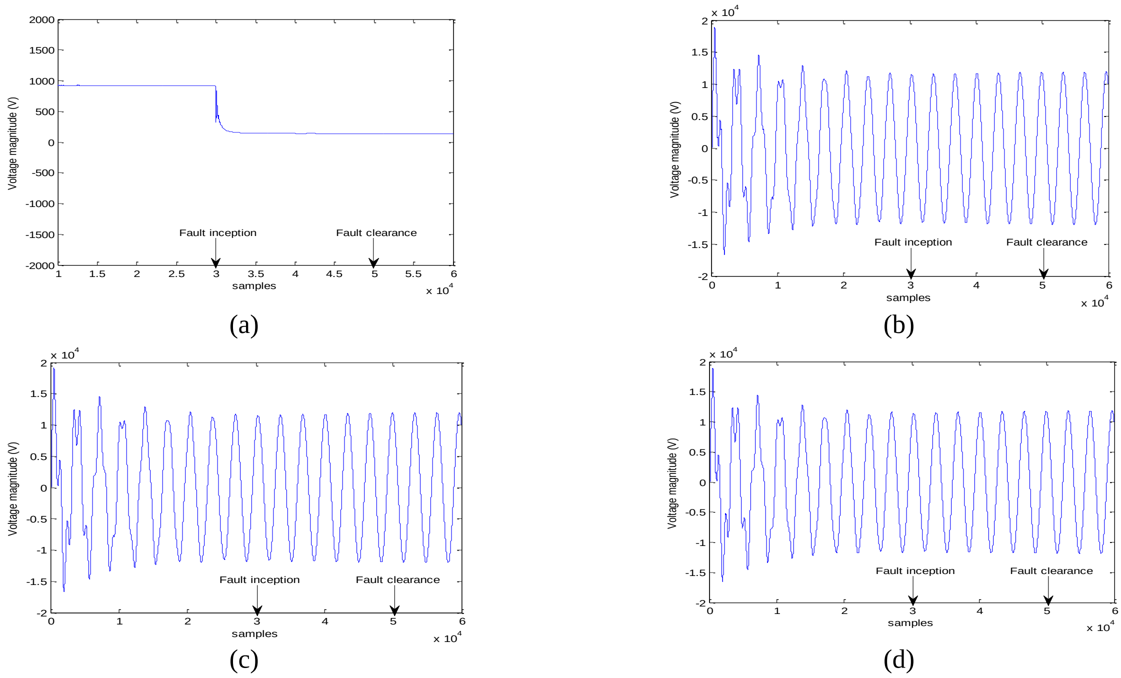

Fig.7. Voltage at different parts for fault occurrence in DC microgrid, (a) at the output of PV farm (bus12), at the output of interior station transformer (bus3), (c) at the output of wind farm (bus7), (d) at bus 5 in traditional grid

Above figures show that the fault at DC grid has no effect on the voltage of AC microgrid and traditional grid (without DG).

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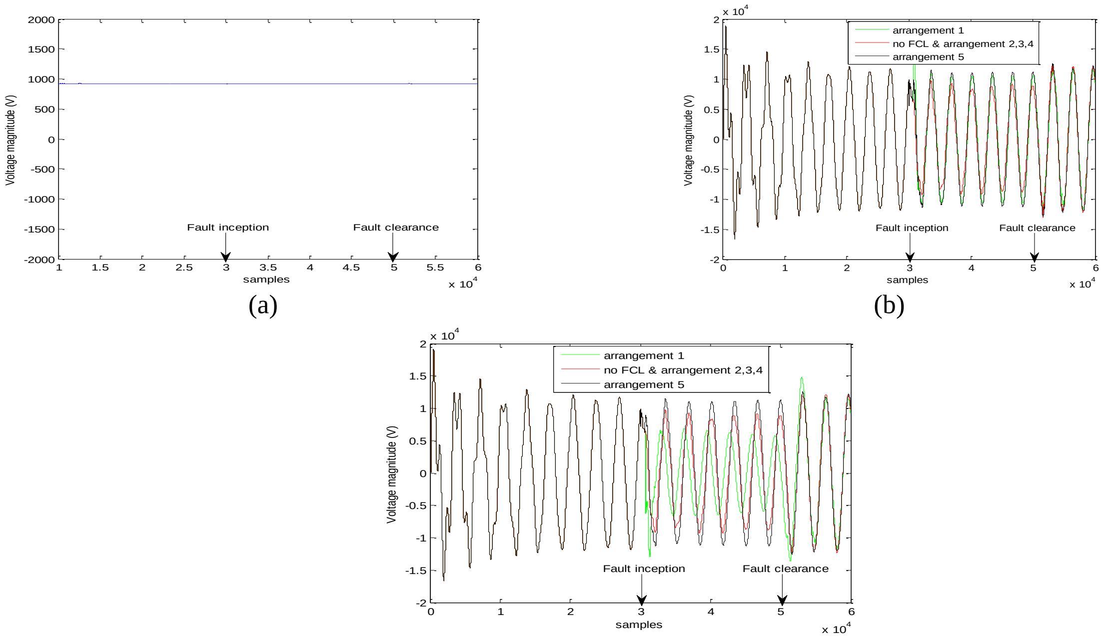
C. Third case, fault occurrence in AC microgrid without DG

It is assumed here that the fault occurred at the traditional grid (without DG) and in the middle of the line between bus 5 and 6. Fig.8a shows the voltage at the output of PV (bus12). It can be seen that the fault at the traditional grid (without DG) has no effect on the output of PV source. Fig.8b shows the voltage at the output of interior station transformer (bus3). It can be seen that in this case, the best result corresponds to the arrangement 5. Fig.8c shows the voltage at the output of wind farm (bus7). It is evident that in this case also the best results corresponds to arrangement 5.



(a) (b) (c)

Fig.8. Voltage at different parts for fault occurrence in AC microgrid without DG, (a) at the output of PV source (bus12), (b) at the output of interior station transformer (bus3), (c) at the output of wind farm (bus7)

V. CONCLUSIONS

This paper presents an analysis of SFCL location in a grid including AC and DC microgrids and its effect on controlling fault current and voltage sag. Various simulations were done assuming fault occurrence in different points of the grid including AC microgrid with DG, DC microgrid, and microgrid without DG and best arrangement for improving fault current and voltage sag reduction was determined considering different SFCL arrangements (5 arrangements). The results show that the arrangement 5 which consists of three SFCL (at the output of DG and inputs of the microgrid without DG) had the best results.

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