Effects of Distributed Generations' Integration to the Distribution Networks
Case Study of Solar Power Plant

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Received: 07.02.2017 Accepted:16.03.2017

Abstract- All over the world, the Distributed Generations (DGs) integration to power system has increased in the recent years due to economic, environmental and technical advantages. Turkey which has the huge solar potential has focused on integrating both licensed and unlicensed solar power plants by providing 10 years of purchasing guarantee as an incentive for the electricity producers from solar energy. However, the integration of DGs has several negative effects on the distribution networks (DNs). This work is concerned with investigating the possible challenges that may arise due to integration of PV based DGs on the existing distribution networks. Short circuit current level with respect to variation in MW integration is studied for the case the utility network is weak and strong. When the utility network is strong, the integration effect of inverter based DGs like solar power plants were observed insignificant. However, for the weak utility networks, the integration of inverter based DGs has been observed to have significant influence. Finally, directly integrated DGs (without inverter) are considered to reveal its difference with the non-inverter based DGs. As the case study, the distribution network integration of a solar power project, which is found in the Antalya region of Turkey, is investigated. This is 12 MW solar power plant designed to be connected to the local distribution network in Antalya. It is concluded that the effects of directly integrated DGs are observed more prominent compared to the inverter based DGs. DigSILENT Power Factory simulation tool is used for the study.

Keywords- Distributed Generations, Distribution Networks, DigSILENT, Short Circuit Analysis, Solar Power Plant.

1. Introduction

Even though the intermittency of resource has negative impact on power system reserve, there is increased integration of renewable sources based DGs to the electricity network [1]. Deregulation of electric utilities, environmental concerns, limitations of fossil fuels, decrease in the cost of modules (for the PV based DGs) and etc. are some of the reasons for the increment in the integration of DGs like solar power plants to the distribution networks [2], [3], [4].

As per the report of Turkey's Headquarter of Renewable Energy, Turkey has good solar energy potential with average solar radiation of 1311 $W/m^2.year$ [5]. Especially the southern part of Turkey has a very valuable potential. In recent years, the project development and implementation of solar power plants has boomed in Turkey. The government is also providing supports to the sector by providing incentives, for example, below the capacity of 1 MW, the customers can produce their own energy and sell the surplus energy to the grid without requirement of any license. The government provides also purchasing guarantee for the producers of electricity from solar energy with charming price compared to other resources [6].

Most of the solar power plants are planned to be connected to the distribution networks. In the usual practice, the distribution network operators announce the available capacity of their transformer. Based on the available capacity, the solar power plant owners apply for the connection permission. After the technical requirements are fulfilled, the power plant owners are allowed to be connected their power plant to the nearby distribution network.

Despite the incentives discussed above, the integration of DGs [7], [8], [9] and specifically the solar power plants has dramatic effect on the conventional distribution network [10]. In [11]the method of determining the maximum and minimum capacity of DGs at any point on the radial network is determined. Although the trend and challenges of grid connected PV based DGs with respect to demand and supply balancing is discussed in [12], the challenges with respect to short circuit current and protection are not mentioned. The technical and potential problems in regard to the grid connected DGs are discussed in [13], [14].

The traditional distribution network is radial and passive in structure with unidirectional power flow. In addition, the currently used protection design in MV and LV networks is based on the passive paradigm with no energy flow in the reverse direction [15], [16]. The energy flows in the reverse direction due the integration of DGs, do not suit the conventional protection system. Due to this fact, as far as the physical integration of DGs to the distribution network is concerned, protection is one of the major issues. This study is thus, concerned with investigating the possible challenges that may arise due to integration of PV based DGs to the protection schemes of the existing distribution networks by considering the case study of an ongoing solar energy projects in Antalya, Turkey.

The selection of equipment and the coordination of protection relays are based on short circuit study. Therefore, short circuit study will be conducted at each relaying point in the network. The problems that result with integration of PV DGs will be investigated. In addition, the fault current effects of non-inverter based DGs will be analyzed and compared with inverter based DGs.

This study is based on simulation of interaction of DGs to the DNs by using DIgSILENT Power Factory which is a computer aided engineering tool for the analysis of industrial, utility, and commercial electrical power systems. To achieve the main objectives of planning and operation optimization in power system, it has been used as an advanced integrated and interactive software platform dedicated to electrical power system and control analysis [17].

2. The Challenges of PV Based DGs on the Distribution Networks

In distribution networks the fault current may rise to 10-15 time the nominal current depending on the type of source. This high fault current can trigger protection relay easily. However, if distribution network with large PV installations experiences a fault, the fault current may not rise sufficiently due to interfaced inverter which limits the fault current. Due to this fact, there are several shortcomings on the conventional protection schemes when PV based DGs are involved in distribution networks. For instance, false tripping might occur due to the integration of DGs into the distribution network on the same substation with a load. If we consider Fig.1 the current supplied from DG may exceed the pickup settings of relay R2, leading to tripping due to occurrence of fault at F. The influence is more for the long feeders protected by the instantaneous overcurrent and supplied from the weak grids [18].

If we consider again the fault at F in Fig.1**Hata! Başvuru kaynağı bulunamadı.**, the relay R1 may not be able to trip due to fault current contribution from PV based DG. This event, which is known as protection blinding, occurs when the feeders are long or the concentration of DGs is high. Protection blinding may result in the rise of dangerous touch voltage and spread of the fault current to more equipment. Its severity depends on the local short-circuit current level, location of fault, DG's capacity and the grid impedance.

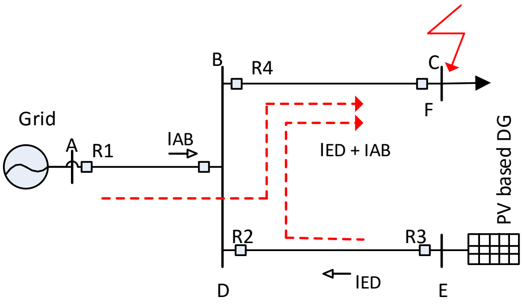


Fig. 1. The negative effect of PV based DG integration on the conventional protection

Additionally, parallel operation may result in reduced fault impedance which may cause unexpected high fault current which is above the fault currents for which the equipment is designed. The fault current that flows on line BC of Fig. 1. will be the sum of the fault current from lines AB and ED which designated as IAB and IED on Fig. 1 respectively (PV DG), increasing the fault current on the equipment on the line BC. Furthermore, the fault impedance seen by the relay R1 increases since the in feed is available from the PV DG.

In the overhead networks, transient faults are cleared by opening circuit breakers (CBs) temporarily and reclosing it again. If the fault is transient it will be cleared, but if it is permanent CB will keep opening and closing continually till the number of reclosing operation is reached. On the other hand, when DGs are available, they will continue to supply the fault and the recloser activity will not be successful [18], [19], [20]. This situation damages the equipment and affects the reliability of supply.

3. Description of the Solar Power Plant Site

The site of solar power plant project in Antalya with total 12 MW capacity is located at 36.25° latitude and 29.92° longitude. It is one of the preeminent land for solar energy generation in Turkey. Fig. 2 shows the overview of the site.

Fig. 2. The site of solar plants in Antalya

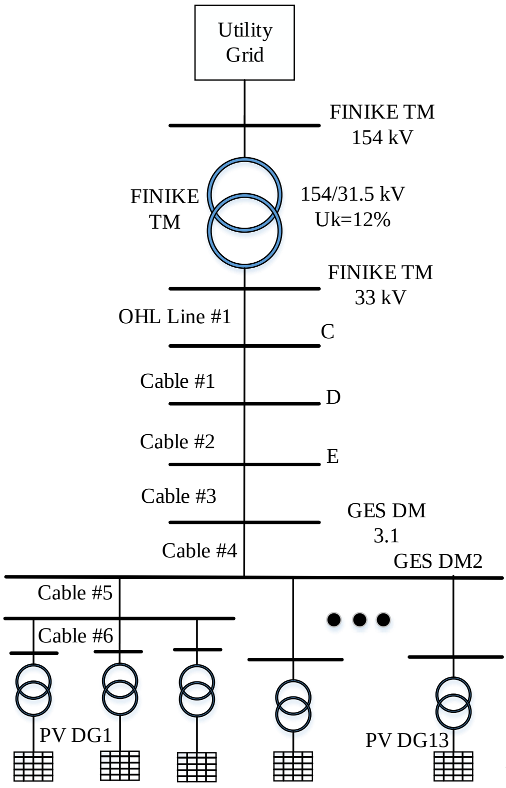


Fig. 3. Single line diagram of the solar plants in Antalya

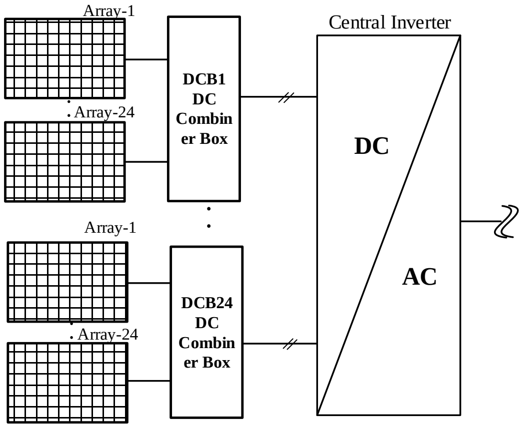


Fig. 4. The main components of solar plants

Figure 3 shows the single line diagram of the solar power plants in Antalya with the data of overhead power plant, lines and cables are given in Table **1** and Table **2**. Figure 4 illustrates the main components of solar plants. The 120 Wp PV panels are used for converting solar energy to electricity. The panels are grouped to make strings and the strings are grouped to form arrays. The DC combiner boxes are used to combine arrays. Central inverter is used to convert the DC power to AC. Unit transformers are used to step-up the output voltage of the inverter which is 0.4 kV to 33 kV. In this study, the analysis is mainly conducted by calculating fault currents that occurs at different location and direction. During occurrence of the fault, the inverter, which is used in this project, limits the fault current to 150% of the rated current. The unit transformer further limits the fault current which is supplied from the PV based DGs.

Table 1: Types of overhead lines and cables used in solar plants

Pos. No.	**Type**	**Length (m)**
OHL Line #1	2x3x477 MCM	30080
Cable #1	3x1x400/25 mm2 YAXC7V-R	75
Cable #2	3x1x150/25 mm2 YAXC7V-R	440
Cable #3	3x1x95/16 mm2 YAXC7V-R	515
Cable #4	3x1x95/16 mm2 YAXC7V-R	760
Cable #6	4x(3x1x240) mm2 N2XH	15

4. The Effect of Total Short Circuit Current

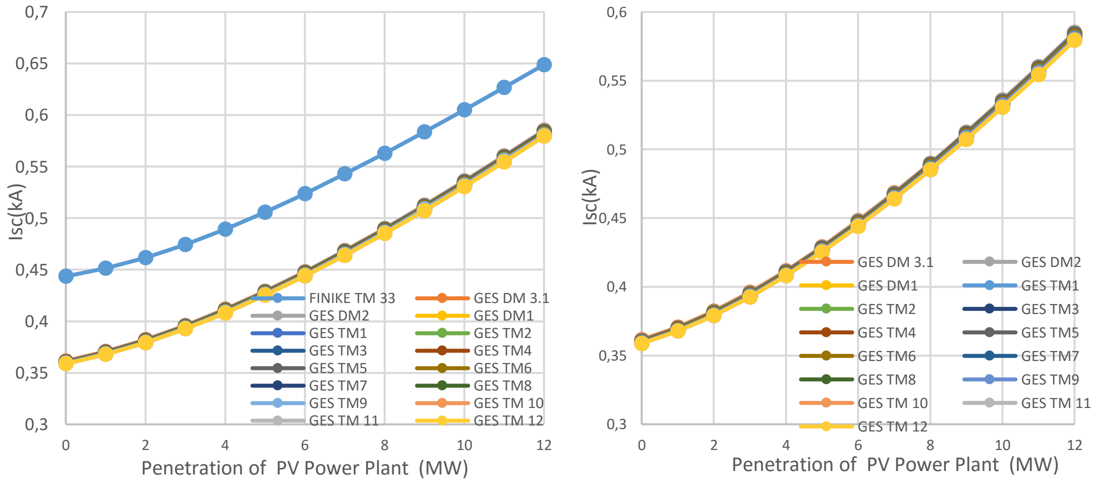
The total short circuit is to mean that the fault current is flowing from the two directions towards the bus. In order to demonstrate the integration effects of PV based DGs to the distribution network with respect to the fault currents, the following scenarios are considered.

Firstly, a relatively weak source network with short circuit power of 27 MVA is considered. Each PV based DG is connected step by step Fig. 5(a) shows an increasing penetration of PV based DGs and its effect on the three-phase steady state fault current on each bus. For example, on FINIKE TM bus, the short circuit current increases from 444 A (with no DG connected) to 645A (with 12 MW DG connected). Consequently, the total increase in the fault current is 201 A.

On the other hand, by considering the situation when the network is strong (with short circuit power of 1040 MWA), the fault current variation is shown in Fig. 5(a), the increase in the fault current is 110 A for the same bus and same condition of DGs increase. The trend observed above is the same for the other buses also. By excluding the FINIKE TM bus, the variation of the fault current for the rest of the buses can be observed as shown in Fig. 5(b) and Fig. 6(b).

Table 2. Total strings current calculation

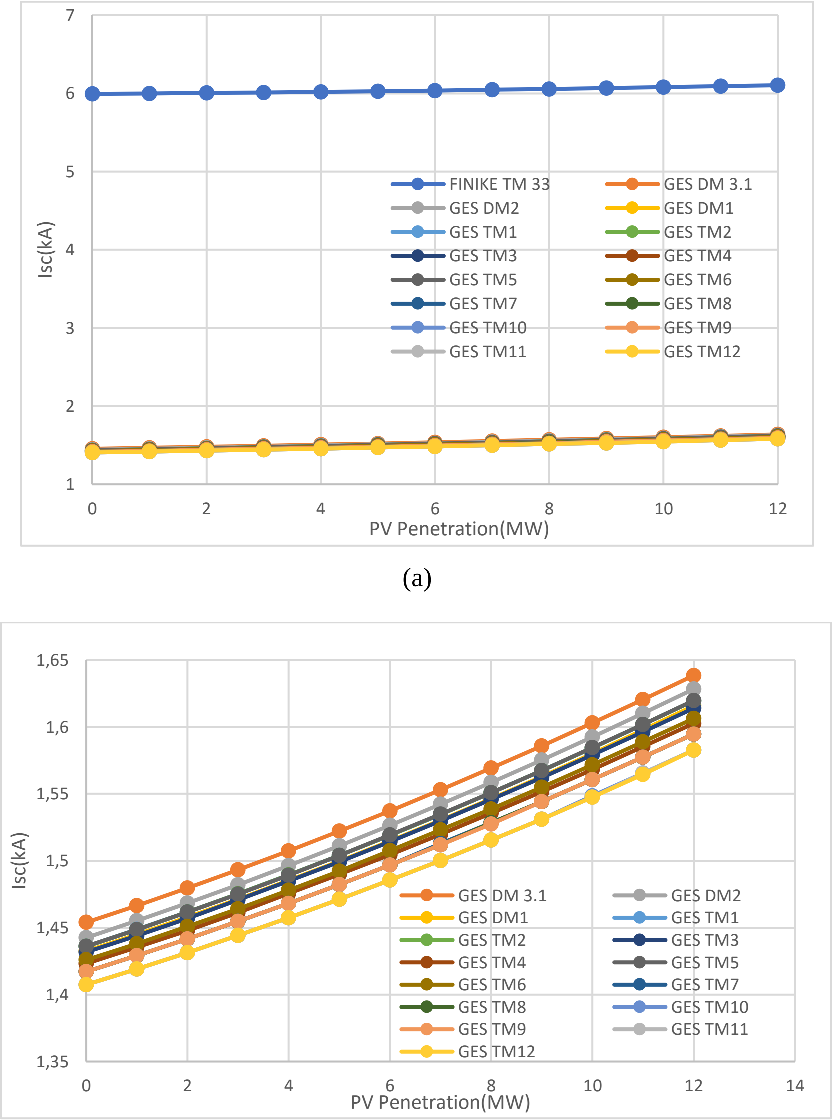
Power Plant Names	6X5 Array (No.)	6X10 Array (No.)	ISC (STC) (A)	NO of Panels	PDC (kWp)	NO. of Strings	Total String Current at 70 °C
ABS_GÜRSES 102/37-40	10	151	1.84	9360	1123.2	936	1753
SALT_1 GÜRSES 102/39-40	2	154	1.84	9300	1116	930	1742
SALT_GURSES_2 102/37-38	6	155	1.84	9480	1137.6	948	1776
AKSOLAR_GURSES_2 102/37-38	0	82	1.84	4920	590.4	492	922
BUSOLAR_GÜRSES 102/25	6	163	1.84	9960	1195.2	996	1866
SATÜRN_GÜRSES 102/25	0	166	1.84	9960	1195.2	996	1866
BERRAK_1_GÜRSES 102/25	0	83	1.84	4980	597.6	498	933
AKSOLAR 101/36	0	166	1.84	9960	1195.2	996	1866
ANSOLAR 101/36	0	166	1.84	9960	1195.2	996	1866
SİMETRİ_1_GÜRSES 101/37-38	0	166	1.84	9960	1195.2	996	1866
AKGÜNEŞ_GÜRSES 101/36-37	0	166	1.84	9960	1195.2	996	1866
SALT1_GÜRSES_3 101/36-37	0	166	1.84	9960	1195.2	996	1866
SATÜRN 101/42	6	135	1.84	8280	993.6	828	1551



(a) (b)

Fig. 2. The effect of PV based DG integration on weak distribution network and the fault current variation

For the weak system, the short circuit current at the FINIKE TM is 1.2 times the fault current at the furthest bus from it, while it is 4 times for the strong network. The latter case is better with regard to the protection relays grading. In this case, even though the fault current difference between each bus for both weak and strong network is small, the difference is more visible for strong network (Fig. 6 (b)).



(a)

(b)

Fig. 3. The effect of PV based integration on strong network and the fault current variation

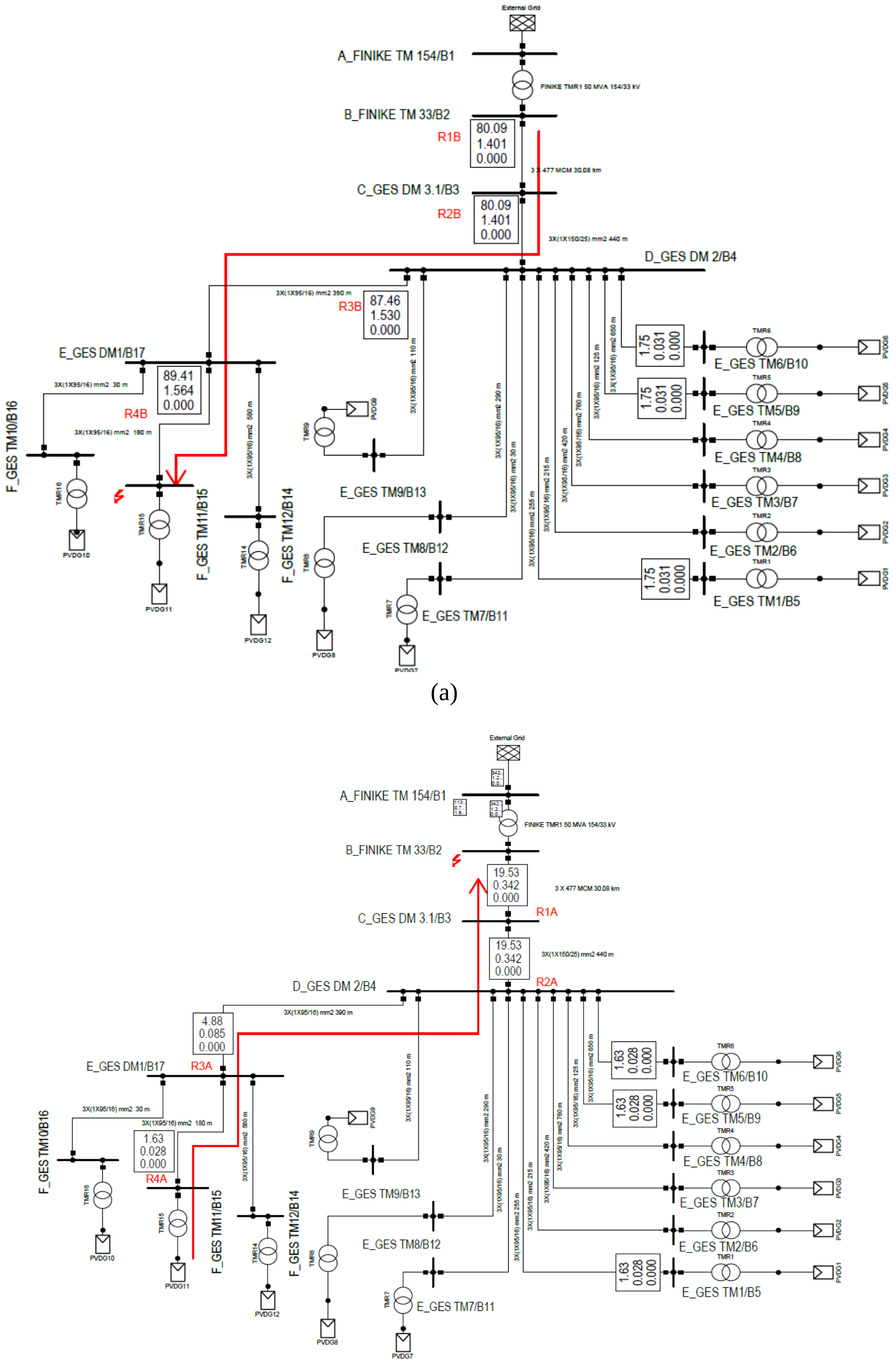
For instance, when the network is strong the difference in fault current is more than 10 A between GES DM 3.1 and DM2 buses. When the network is weak the difference in the fault current for the same buses is less than 1 A. Availability of significant difference for the fault current between buses is important with regard to the protection coordination of relays.

5. Effects of the Fault Current From one Side

In this case study one DG terminal is selected as reference (PV DG11) and three phase fault is applied on this terminal as shown in Fig. 7(a). The selection is arbitrary and makes no significant difference even if other DG terminals are selected. For this case, the strong network condition is considered. Then, the short circuit current is measured at the FINIKE TM bus with respect to the increase in the penetration of the PV DGs. FINIKE TM bus is the nearest bus to the utility network (Electricity Transmission Corporation of Turkey).

The results in boxes in the Fig. 7 indicates the steady state short circuit power, steady state short circuit current and peak short circuit current respectively, based on the IEC 60909 short circuit calculation method. When the fault current from the PV DG increases, the short circuit current coming from the source network is decreasing as shown on Fig. 8(a). For increase of 12 MW with step of 1 MW, the decrease in the short circuit current is 6 A. This shows that the fault contribution from PV based DG do not have much influence on reducing the short circuit current of the strong network. But if the penetration is very large and the network is weak, the increased in penetration level has significant influence and can result protection blinding.

For the same fault location (on the bus of PV DG11), the trend in the short circuit is observed on the PV DG11 terminal bus and shown on the Fig. 8(b). On the PV based DG terminal, with increase of the penetration, the short circuit fault current increases.

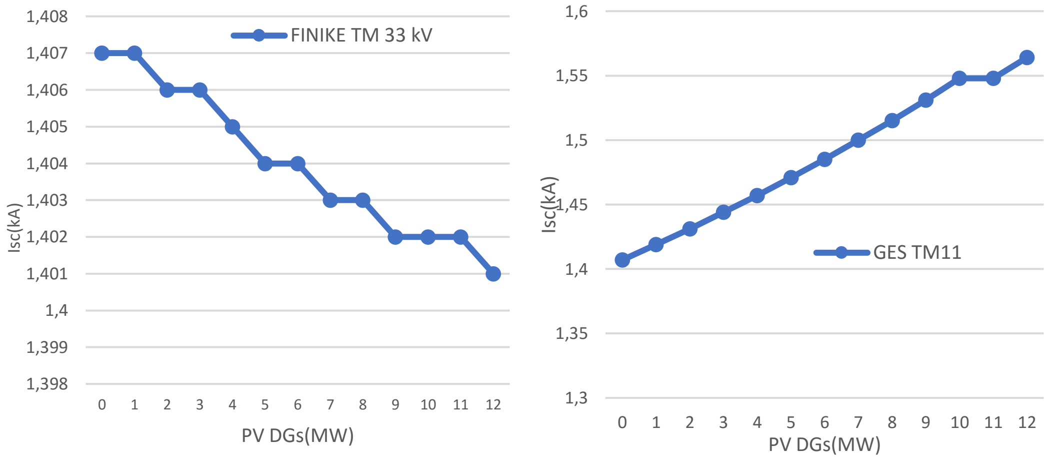


(a)

(b)

Fig. 4. (a) When fault is applied on the GES TM11 (b) When fault is applied on FINIKE TM bus

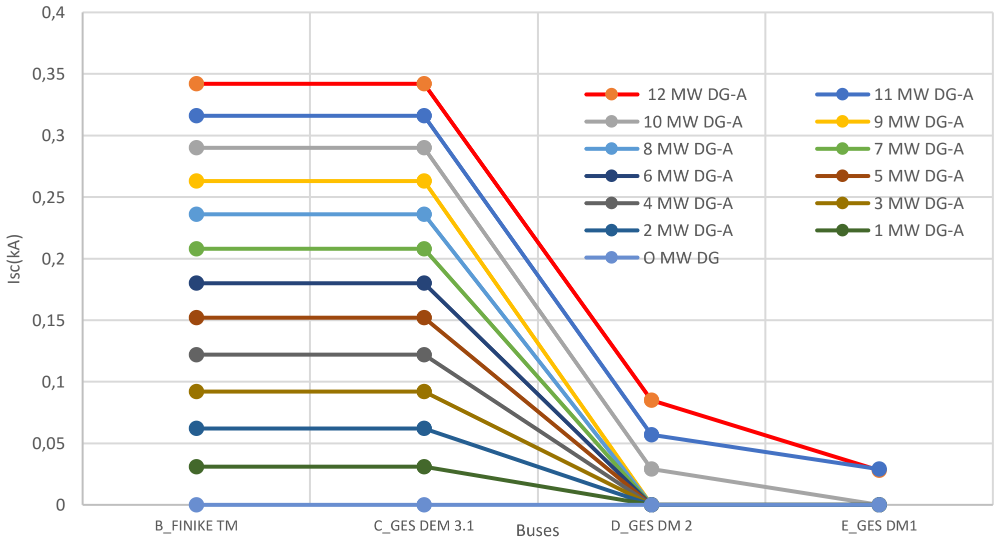
Thus, if overcurrent based protections are used, it is necessary to adapt the setting values for each increase or decrease of the DGs penetration.



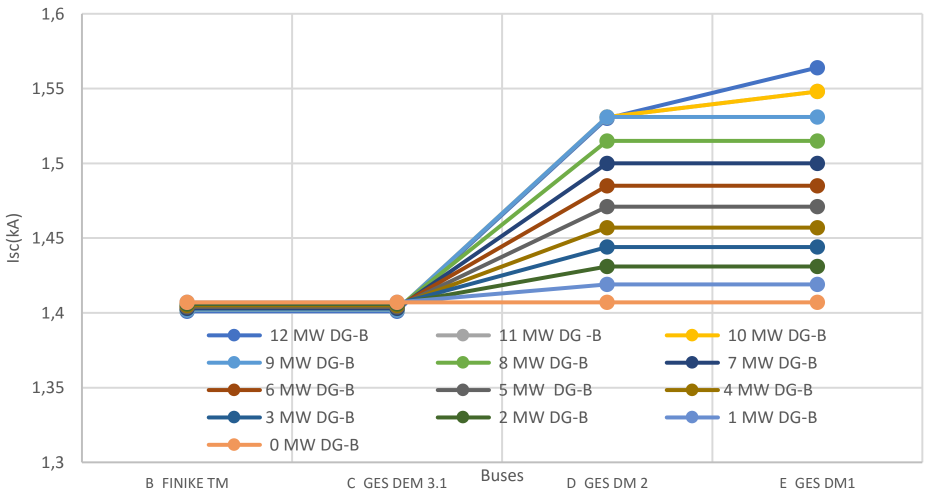
(a) (b)

Fig. 5. The variation fault current for the fault at GES TM11

Furthermore, by applying fault on the FINIKE TM as shown in Fig. 7(b), the variation of fault current from PV DG11 to the FINIKE TM substation is observed. When all the DGs are offline (not connected to the grid), the fault current is zero along all of the buses, but when DGs are integrated, the fault current is increasing from the PV DG11 to the FINIKE TM, Fig. 9(a). The increment occurs on GES DM1, GES DM2 and GES DM 3.1 as the power from DGs are collected on these buses. After GES DM 3.1, we do not observe any increase in the fault since there are no DGs connected. In similar way, for the case when the fault is applied on PV DG 11 terminal, the fault current varies as shown on Fig. 9(b). In this case fault current increase is observed on GES DM2 and GES DM1 buses. This is due to the collection of the fault current from PV DGs of neighboring feeders.



(a)



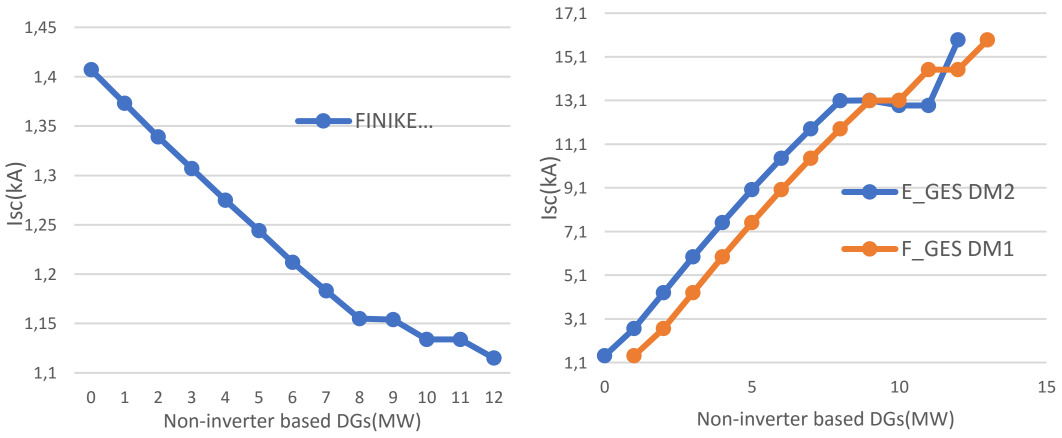
(b)

Fig. 6. The variation of fault current for the upstream and downstream faults

6. The Effect of Non-Inverter Based DGs

The non-inverter based DGs like directly interfaced wind turbines, are connected to the DNs without the interface of inverter. Consequently, the DGs can inject significant amount of current during fault. It is assumed that the non-inverter based DGs are connected to same network as in Fig. 7 in the place of previously simulated PV based DGs. Thus, the short circuit current, which is injected to the network from each DG, is 1.539 kA.

To observe the fault current pattern, three-phase fault current is applied first as in Fig. 10 (a) in the direction of the red arrow on all buses. As shown in Fig. 10(a) at FINIKE TM the fault current injected from the grid decreases from 1.407 kA to 1.115 kA (a total decrease of 292 A) for the integration of 12 MW. This may result in protection blinding at R1B. Consequently, the short circuit variation due to the injection of DGs has significant effect significant on the network. The worst effect due to DGs variation can be observed from Fig. 10 (b). The fault current at the R3B and R4B position varies from 1.407 kA to the 15.87 kA (the total variation is 14.463 kA). In such situations, the protection relay setting is depends highly on the DG penetration level. For example, the relay setting, which is set by considering when the all the DGs are connected to the DNs, will definitely result in protection blinding when only few DGs are on. On the other hand the settings, which are used when only few DGs are online, may not able to detect the fault current when more DGs are integrated. Moreover, enormous change in fault current level should be considered when the switchgears are selected.



(a) (b)

Fig. 7. (a) Fault variation at the R1B position (b) Fault variation at the R3B and R4B positions

Finally, the effect of integration of inverter based and non-inverter based DGs on weak system is shown on Fig.11. When non-inverter based DGs integration is increased (0-12 MW) on weak system, the fault current at the FINIKE TM bus is observed to decrease by 77 A. Additionally, for the weak system with inverter based DGs for the 0-12 MW integration increase, the decrease in current of FINIKE TM bus is insignificant as shown in Fig. 11.

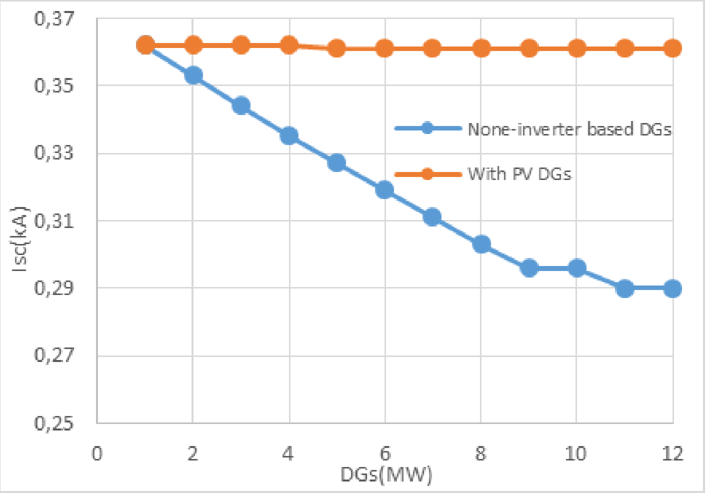


Fig. 11. Comparison of inverter and non-inverter based DGs integration effect for weak system

7. Conclusion

With increased integration of DGs to the distribution network, the fault current generally increases. For the non-inverter based DGs the increase is significant and can cause damage of equipment and mis-operation of protection devices. If the integration is in large quantity, the inverter based DG can also result in the wrong operation of protection devices. Due to the increased DGs integration, the fault current injected from the source to the fault point is observed to decrease for both weak and strong networks. But the possibility of protection blinding is more for non-inverter based DGs. Furthermore, increase in short circuit has more effect in the weak network than in strong network. Usually, there is a great variation of the fault current variation along the network due to DGs integration. This calls for the new protection philosophy, which adapts to the fault condition on the network.

Normally the fault current variation due to DG integration affects the determination of switchgear ratings. Considering the solar power plant in Antalya, even though the short circuit current level increases with increasing of the DGs, with current design, there is no significant problem with respect to withstand capacity of the materials. This is due to the fact that the materials selected for the project can with stand a fault current up to 16 kA.

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