The Effect of Fault Current Limiters on Distribution Systems with Wind Turbine Generators[1]

Gökhan Cakal*, Fatma Gül Bagriyanik*, Mustafa Bagriyanik*‡

* Istanbul Technical University, Faculty of Electrical and Electronics, Electrical Engineering Department, Istanbul, Turkey

gokhancakal@hotmail.com, bagriyanikf@itu.edu.tr, bagriy@itu.edu.tr

‡ Corresponding Author; Mustafa Bagriyanik, Istanbul Technical University, Faculty of Electrical and Electronics, Electrical Engineering Department, Istanbul, Turkey, Tel: +90 212 285 6958, Fax: +90 212 285 6700, e-mail: bagriy@itu.edu.tr

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Abstract- When renewable resources are connected to the existing network, the level of fault current can increase, and the protection devices cannot be capable to interrupt fault current. In this paper the effect of fault current limiters on distribution systems with wind turbine generators is studied. Fault current limiter (FCL) is a device that is used to limit over current and destructive current occurring in the power systems. The choice of where in a distribution system to place FCLs to obtain best operating conditions is an important issue, because the placement of these devices must be carefully considered in order to keep them cost effective and to prevent the limiters themselves from disrupting existing protective measures. An example test system based on a distribution system in Fethiye where is a district in western Anatolia was considered to study the effects of FCLs. Solid state fault current limiter is considered to dispose the negative influences of grid integration of wind turbine generators. The effectiveness of FCL is verified with the several case studies by time-domain simulation. Simulations are performed by using PSCAD®/EMTDC™.

Keywords- Fault current limiter, distribution system, wind turbine generator.

1. Introduction

The researches show that renewable energy systems are becoming increasingly important and they are included in the network. Today, wind power has become one of the fastest growing renewable energy solutions, and it is widely used to produce electricity in many countries such as China, Germany, Spain, United States, India, and Denmark.

Total capacity of wind power in the world is growing fast. In Fig. 1, cumulative wind power capacity between years of 1997 and 2011 is shown. According to half-year report of The World Wind Power Association [2], cumulative capacity of global wind power is 254,000 MW. The predictors expect 273,000 MW wind power will supply electricity to the world network system within the end of 2012. The graphic that is designed for this development is shown in Fig.2.

Turkey has important wind energy potential especially in the Marmara region, coasts of western and southern Anatolia. Wind power capacity of Turkey is growing year by year as seen in Fig.3.

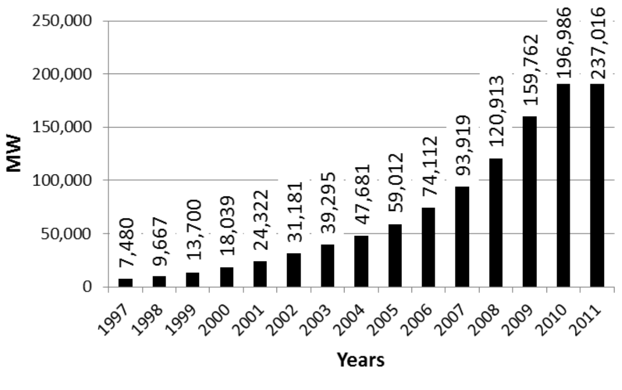

Fig. 1. Global Cumulative Installed Wind Capacity (MW) between 1997 and 2011 [1].

[1] The short form of this paper was presented in The European Workshop on Renewable Energy Systems (EWRES 2012), which took place on 17-28 Sep. 2012, Antalya, Turkey

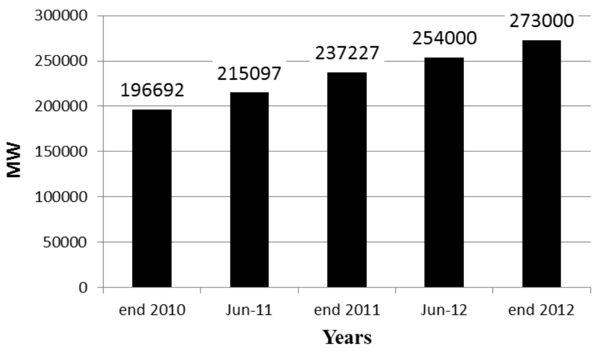

Fig. 2. Global Cumulative Installed Wind Capacity between 2010 and June 2012 [2].

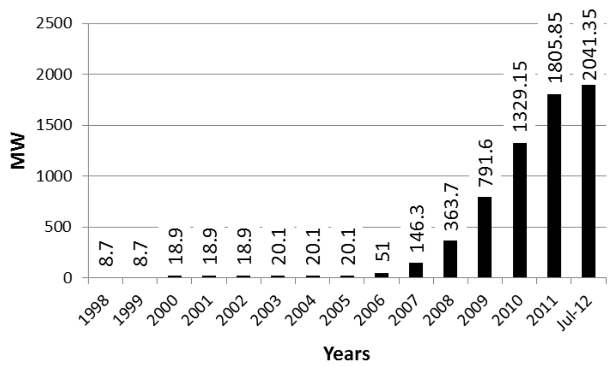

Fig. 3. Global Cumulative Installed Wind Capacity between 1998 and 2012 in Turkey [3].

In next few years, there will be more and more wind power plants connected to the electrical grid, and the utilities will have problems. The integration of wind turbine generators increases fault current level beyond the capacity of existing protection devices. The system stability and voltage quality may be corrupted. So the power system switchgear and power system protection should be carefully designed to obtain a secure operation of the system.

Higher fault currents can create major problems because the overcurrent protection relays trip the circuit breakers and the flow of power between electric utilities and customers is interrupted. They can damage or degrade transmission and distribution equipment, requiring expensive and time-consuming repairs. Fault Current Limiters (FCLs) regulate the amount of current moving through the transmission and distribution systems under abnormal conditions. In [4-10], it is shown that Fault Current Limiters (FCLs) suppress this negative influence of DG on distribution systems. The use of superconducting fault current limiter (SFCL) reduces fault current level at the stator side and improve the fault ride-through capability of the system [11].

FCL is a device that is used to limit over current and destructive current occurring in the power systems. FCL that normally shows low impedance values, produces high impedance values when short-circuit current occurs. The need of FCL is increased mostly because of the increase in usage of clean energy resources like wind or sun. Today, fault current limiter has started to gain importance in order to limit fault current. The task of the FCL is to limit the level of the destructive current without affecting the distribution system [12-13]. In [14-15], different types of Superconducting FLCs were modelled, and the operation of superconducting FCLs was discussed. In [16], the authors tested inductive and resistive superconducting fault current limiter built with the same length of high temperature superconducting (HTS) tape, and presented a comparison. According to their results, the limiters are very fast and the first peak is almost equally limited by both types of limiters.

Although FCLs can offer many advantages, their advantages such as reducing the voltage sag caused by the fault, improving the system security and reliability, etc. greatly depend on the number and locations of FCL placement. The location of FCL is simple as it’s suitable to locate between source and load. However, it gets more complicated in ring systems. The choice of where in a distribution system to place FCLs to obtain best operating conditions is an important issue, because the placement of these devices must be carefully considered in order to keep them cost effective and to prevent the limiters themselves from disrupting existing protective measures. Some studies show that the most effective way to decrease the fault current level is to locate FCL before each transformer in a ring distribution system [17-19]. But this solution is very expensive. In literature, there are also several methods to determine the optimum number and locations for FCL placement in terms of installing smallest FCLs circuit parameters to restrain short-circuit currents under circuit breakers’ interrupting ratings [20].

The main purpose of this study is to investigate the impacts of wind turbine generators in distribution system, and to give the benefits of using FCLs in an example open loop distribution system. The system data are based on a distribution system in Fethiye where is a district in western Anatolia. In the paper, three different system operating cases are considered to study effects of solid-state fault current limiters (SSFCLs), and each case is simulated by using PSCAD®/EMTDC™ [21]. The rest of the paper is as follows: Section II introduces the fault current limiters. We provide the test system and results in Section III and finally conclusions are given in Section IV.

2. Fault current limiters

A simple power system model with FCL is given in Fig. 4, where VS is source voltage, Z_S is internal impedance, Z_L is load impedance, Z_F is fault impedance, and Z_{FCL} is impedance of FCL [14].

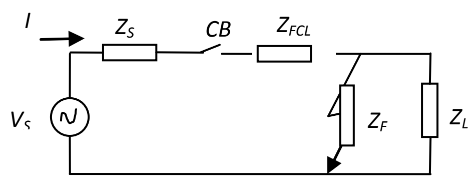

Fig. 4. A Simple Electric Circuit with FCL.

In steady-state condition, before FCL installation, the current flowing through the line is

$$I = \frac{V_S}{Z_L + Z_S} \quad (1)$$

When a fault occurs, the current becomes as

$$I = \frac{V_S}{Z_F + Z_S} \quad (2)$$

Because the value of the fault impedance is too small, the fault current becomes so high. When a FCL is installed into the line, the fault current is limited by the impedance of the FCL, and the current value can be reduced,

$$I = \frac{V_S}{Z_F + Z_{FCL} + Z_S} \quad (3)$$

FCLs can be divided into three main categories: Passive fault current limiters, Solid-state current limiters, and Hybrid limiters. Passive fault current limiters do not need to be controlled by external signals. In the simplest implementation of this type FCL can be done by using a limiting inductance. In the solid state FCL, the fault current limitation is performed by utilizing power electronics equipment, their required controlling systems, and associated sensors. When a fault occurs, the current flows through the limiter element thanks to power electronics circuit. Under normal circumstances, as the limiter is deactivated, there is no voltage drop or loss of energy. Hybrid Limiters known as Solid-State Switch /Mechanic Switch Hybrid Limiters are the combined types of passive and solid-state limiters. These limiters use a combination of mechanical switches, solid state FCL(s), superconducting and other technologies to create current mitigation [4].

In Solid-State Fault Current Limiter model in Fig.5 fault current limiter is applied by using thyristor-based power electronics components/elements when a fault occurs. Normally, limiter is not activated.

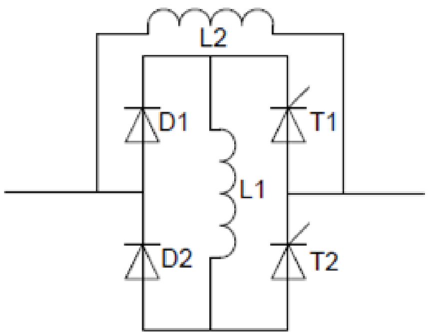

Fig. 5. Solid-State Fault Current Limiter Model [15].

IGCT-based Half-controlled Bridge Type FCL was presented in [15]. This model comprises the main components: DC reactor (L2), two diodes (D1,D2), two IGCTs(T1,T2) and current limiter reactor (L1). Under normal operating conditions, IGCT T1 and T2, the diodes D1 and D2 remain in conduction. All current flows through the diode and IGCT Bridge. Positive and negative cycles pass by one cycle. The current flowing from L1 is constant and voltage drop is zero. When there is a fault, T1 and T2 are OFF. After a matter of milliseconds, all current flows through limiting reactors L2. Here, L1 DC reactors are used to reduce voltage drop that arises from use of power electronics components. A ZnO arrestor that is parallel to L2 can also be employed to eliminate the operating over-voltage [15]. This model is considered to obtain the benefits of using FCLs in our study.

3. Simulation Results

3.1. Test System

Figure 6 shows a single-line diagram of the test system. The system data are based on a distribution system in Fethiye where is a district in western Anatolia. The system is open loop distribution system. The Turkish power grid is represented by Thévenin equivalent, and connected to the distribution system through a line (954 MCM Cardinal conductor). The voltage level of distribution systems is 34.5 kV. In the substation, there are three parallel transformers that feed the loop system. The open loop system supplies 8 secondary distribution transformers (T4-T11). Each wind turbine generator is connected to the system through a transformer. PSCAD®/EMTDC™ software package is used to simulate the test system [21]. The parameters which are used in the simulations are shown in Table 1 and 2.

Table 1. Transformers Parameters.

Transformer	Rated MVA	Voltage Level (kV) Primer/Secondary
T1	10	154 / 34.5
T2	10	154 / 34.5
T3	10	154 / 34.5
T4	5	34.5 / 0.4
T5	1	34.5 /0.4
T6	0.63	34.5 /0.4
T7	1	34.5 /0.4
T8	5	34.5 / 0.4
T9	0.63	34.5 /0.4
T10	0.4	34.5 /0.4
T11	1	34.5 /0.4

Table 2. Wind Turbine Generator Parameters.

Parameter	Value
Rated Active Power / MW	9.9
Rated Reactive Power / MVAr	1.41
Rated Voltage / kV	10
Armature Resistance [Ra] / pu	0.002
Unsaturated Reactance [Xd] / pu	0.920
Unsat. Transient Reactance [Xd'] /pu	0.300
Unsat. Sub-Transient Reactance [Xd''] /pu	0.220

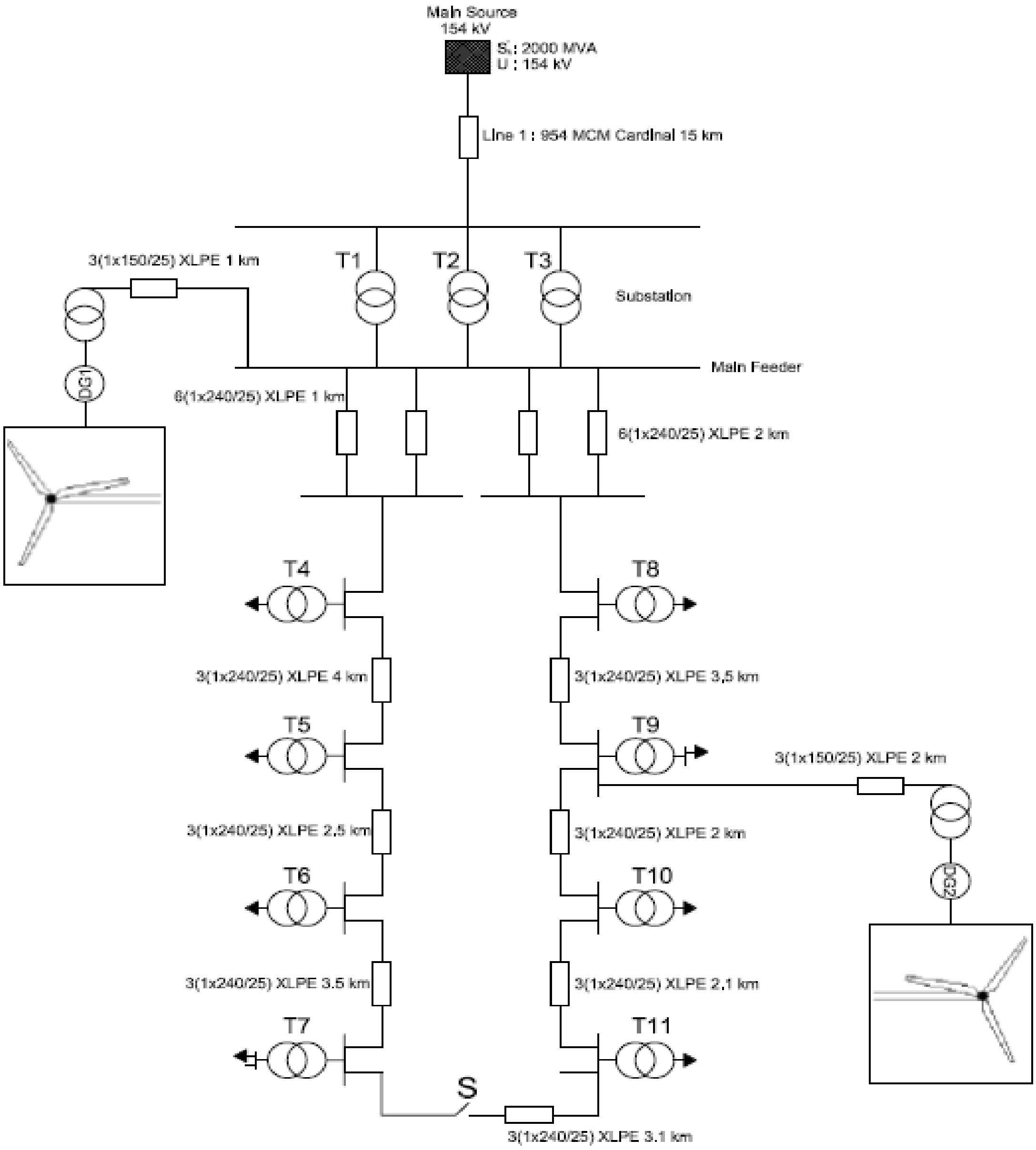

Fig. 6. Single line diagram of the open loop distribution system with wind turbine generator.

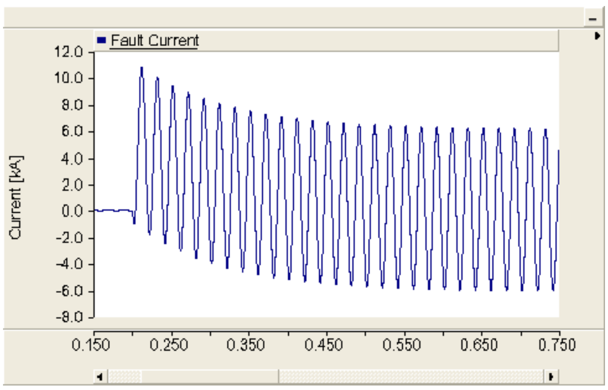

Fig. 7. Fault Current in Case 1.

3.2. Case 1 : The system without wind turbine generator

In this system case, only the power grid supplies energy to the distribution system. When a symmetrical 3-phase fault occurs at the high voltage terminals of transformer T5, the current flowing through the left part of the open loop is shown in Fig. 7. In normal condition, the line current is 100 A. The peak value of the fault current that flows through the line reached 10 kA in the first cycle. After a few cycle, this value reduces to 6 kA.

3.3. Case 2 : The system with wind turbine generator

In this case, there is a wind turbine generator that is integrated to existing loop system. When a symmetrical 3-phase fault occurs at the high voltage terminals of transformer T5, the current reaches the peak value of 27 kA and becomes steady state at 23 kA as seen in Fig.8. Presence of wind turbine generator increases the fault current level.

3.4. Case 3 : The system with wind turbine generator and FCL

In this scenario, there are wind turbine generators that are integrated to existing grid with FCL. The SSFCL is installed to the test system. As shown in Fig.9, the SSFCL decreases the fault current to 4 kA.

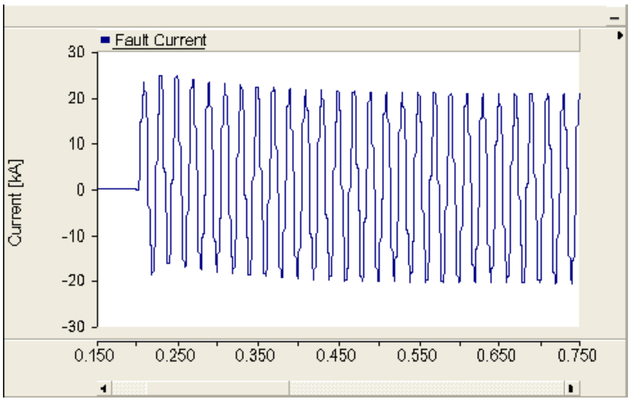

Fig. 8. Fault Current in Case 2.

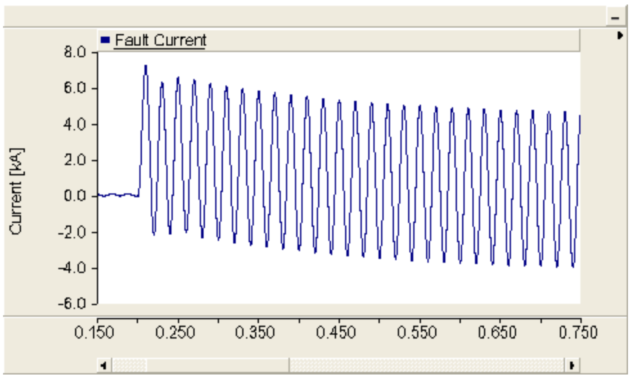

Fig. 9. Fault Current in Case 3.

In this study, four possible locations are considered for placement of FCL. The cases are as follows;

- FCL on faulted bus (T5-end of the line between T5 and T4),
- FCL on DG Bus (series in the line between wind turbine generator and substation)
- FCL on Main Source (series in line 1 between substation and main grid),
- FCL on Main Feeder (series in tie line between substation and the loop)

Figure 10 shows the obtained fault current values for these cases. If the location of FCL is close to the faulted bus, it's more effective to suppress negative influences of wind turbine generator. But it is a very expensive solution to locate FCLs to each line between distribution transformers.

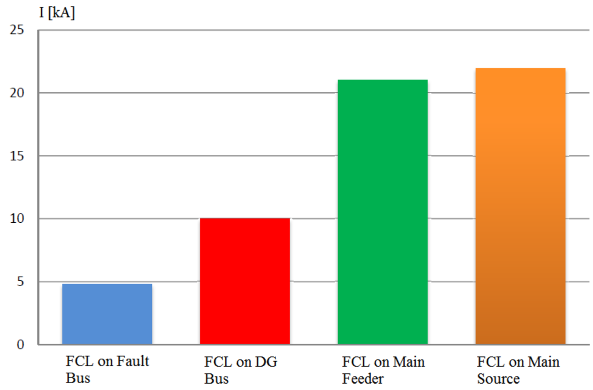

Fig. 10. Currents of conditions for different locations of FCL.

4. Conclusion

Presence of wind turbine generator may cause higher fault currents that are over the breaking capacity of circuit breakers. Therefore, existing protection devices are exposed to more electrical and mechanical stress than normal. Capacities of these devices begin to become inadequate. That requires the need of increase of capacity and of costs.

In this paper SSFCL is considered to dispose all these negative influences of grid integration of wind turbine generators. In normal system operation, considered SSFCL has no effect on voltage and current, since they are based on power electronics devices. An example test system based on a distribution system in Fethiye where is a district in western Anatolia was considered to study the impacts of wind farms, and the results show the benefits of using SSFCLs. According to the simulation results, if a wind turbine generator is installed into the system, the fault current increases to the value beyond the breaking capacity of circuit breaker (CB). The protection devices remain incapable due to CB' breaking limits. The short circuit current decreases, after the SSFCL is installed into system.

Acknowledgements

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