



# The choice of DFIG wind turbine location according to its line fault ride through (LFRT) capability

A. Khattara<sup>#1</sup>, M. Becherif<sup>\*2</sup>, M. Y. Ayad,<sup>\*\*\*</sup>, A. Aboubou

<sup>#</sup>Electrical Engineering Department, Faculty of Sciences and technology, LMSE Laboratory, LMSE Université de biskra BP 145 RP 07000 Biskra Algérie

<sup>\*\*</sup>FCLab FR CNRS 3539 FEMTO-ST UMR CNRS 6174, UTBM Belfort, France

<sup>\*\*\*</sup>Industrial Hybrid Vehicle Application, France

a.khattara87@gmail.com, mohamed.becherif@utbm.fr, ayadmy@gmail.com, a.aboubou@mselab.org

**Abstract**— The penetration of wind power into electrical grids is increased to reduce the use of fossil sources. According to grid codes issued by utilities, tripping of wind turbines following power system faults is not allowed. Besides, to provide voltage support to the grid, reactive current supply is necessary. This paper studies the power flow (PF) of IEEE-14 bus network in the case of line fault ride through.

A doubly fed induction generator (DFIG) wind turbine is installed into different network buses.

A line fault right through (LFRT) is applied on different network buses and the obtained voltages are compared. Here, a new solution proposes to connect the wind turbine to the distribution network to not disconnect the wind turbine during the line fault, the power system analysis toolbox (PSAT) is used to simulate the system production in the presence of fault.

**Keywords**— DFIG; Distribution; LFRT; Power flow; PSAT

## I. INTRODUCTION

With increased penetration of wind power into electrical grids, the mainstream high-power wing-energy conversion systems are based on doubly fed induction generator (DFIG) [1]. This is primarily due to the many advantages that doubly-fed induction generators offer compared to other types of generators in applications where the mechanical power provided by the prime mover driving the generator varies greatly.

One of the important operating requirements of a reliable power system is to maintain the voltage within the permissible ranges to ensure a high quality of customer service. In modern bulk power system, voltage instability would lead to blackout which is of a major concern in planning and operation of power system. Many studies are made in this point, the voltage stability is checked by formulating an index and the corresponding uncertainties input parameters are efficiently modelled using triangular membership function. The proposed technique will be highly useful to ensure voltage security of power system by predicting the nearness of voltage collapse with respect to the existing load condition. This will in turn help in determining the maximum load ability of the given system without causing voltage instability [2].

Aspects of grid stability became more and more important due to the worldwide increase of installed wind power plants. In the past, wind power stations had to be disconnected in the case of grid faults. In several studies, the behaviour of DFIG based wind turbines during grid faults is discussed and elucidated using simulation results. It is shown that with properly designed crowbar and DC-link chopper even zero voltage ride-through is possible [3]. Dr. Sefic presents in [4] an eigenvalue based real time stability evaluation scheme and a real time stability control scheme through voltage and reactive power regulation to keep the stability margin within a pre-specified range. A specific control of the variable speed wind turbine power converters is proposed and described in [5] to support FSWTs during voltage dips. [6] emphasizes on variable speed operation and fault ride-through capability improvement in wind farm network and transmission network respectively. Simulation is performed using PSCAD/EMTDC software to study the behaviour of wind farm, transmission voltage and DC voltage for different changes in wind speed and three-phase short circuit fault. The simulation results validate the connection method performance and the fault ride-through capability improvement. In [7], a hybrid control scheme for energy storage systems (ESS), braking choppers for fault ride-through capability and a suppression of the output power fluctuation is proposed for permanent-magnet synchronous generator (PMSG) wind turbine systems. A methodology based on Z-bus algorithm is proposed in [8] to determine the tripping status of wind farms for a worst case fault, so that it can be used in contingency evaluation procedure. It is demonstrated in [9] that the integration of DFIG wind turbine to the transmission network risks to disconnect this wind turbine from the network during the line fault. To avoid the problem of disconnection from the grids, the DFIG wind turbine should be connected to the distribution network.

The deferent works above proposed the integration of wind power in the transmission lines where the voltage is higher than the voltage produced by the wind turbine; but the integration of wind energy into distribution networks takes special interesting today, where several studies propose



different solutions for this integration. To evaluate maximum wind energy exploitation in active distribution networks, a method based on a multi-period optimal power flow analysis is proposed [10]; other work proposes a novel methodology for the customer security assessment with high penetration of wind power in modern distribution networks [11]. It is demonstrated in [12] that to avoid the disconnection of DFIG wind turbine from the network during the line fault ride through, one should connect this wind turbine to the distribution network. In this paper, a doubly fed induction generator wind turbine is installed in different part of the IEEE 14-bus network, transmission and distribution, and a line fault is considered at each time by taking the voltage and reactive power generated by this DFIG wind turbine. The results obtained in those injections are compared and a new solution is proposed to not disconnect the wind power during the grids fault. The power system analysis toolbox (PSAT) is used.

## II. PROBLEM FORMULATION

### A. Power flow equations

The power flow problem may be stated with some precisions. The formulation is based on operational consideration of the power industry as well as mathematical considerations [13].

$$P_i = \sum_{k=1}^n |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \quad (1)$$

$$Q_i = \sum_{k=1}^n |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \quad (2)$$

$V_i$ ,  $V_k$ , are the voltages in the  $i$ -th and  $k$ -th bus respectively, the  $G_{ik}$  are called conductances, and  $B_{ik}$  are called susceptances,  $\theta_{ik}$  is the argument.

### B. Voltage Stability Index Estimation

Voltage Stability is defined as the ability of power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition [14]. Voltage stability is a problem in power networks, which are heavily load, faulted, or with insufficient reactive power supply. Although voltage instability is essentially a local phenomenon, the problem of voltage stability concerns whole power system, and is essential for its operation and control. The main reason for voltage instability is the increased of load, for that reason, voltage stability is also called load stability problem. Voltage collapse is the process by which the sequence of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system [15].

The technique uses measurements of voltage phasors and no-load voltage at the bus to calculate the voltage stability L-

index. The index gives the distance of the bus to the voltage stability limit. The voltage stability L-index is given by the equation:

$$L = \frac{4[V_0V_L\cos(\theta_0-\theta_L) - V_L^2\cos^2(\theta_0 - \theta_L)]}{V_0^2} \quad (3)$$

Where,  $V_0$  is the no load voltage at the node and  $V_L$  is load voltage. When the value of L at every load bus in the system is less than 1.0, the system is voltage stable. As the value of L approaches 1.0 at any bus, the system approaches its stability limit, and becomes unstable when L exceeds 1.0 at the referred bus [16].

### C. Voltage dip and reactive power flow

The magnitude of the voltage dip across a transmission line will depend predominately on the amount of reactive power (Q) that flows through the reactance of the line. This means that to minimize a voltage dip, reactive power sources should be located as close as possible to the load. This relationship is summarized in the following formula[17]:

$$(V_1 - V_2) = X_L \frac{Q}{V_2} \quad (4)$$

Where  $V_1$  is the source voltage,  $V_2$  line voltage and  $X_L$  is the line reactance.

## III. CHARACTERISTICS

To show a solution for the problem studied in this paper, the simulation was performed using Matlab Simulink™ PSAT.

IEEE 14-bus network is modelled in the PSAT, a DFIG wind turbine of 5MW is integrated to the transmission part then to the distribution part of IEEE network, and at each time a line fault is applied near to the wind turbine to show its line fault ride through in that case, the line fault considered is during 500 ms and its resistance is 0  $\Omega$ . Figure. 2 presents the IEEE 14-Bus, where the lines between buses 1, 2, 3, 4, 5, 6, 7, and 8 are the transmission lines and the lines between buses 9, 10, 11, 12, 13 and 14 are the distribution lines.

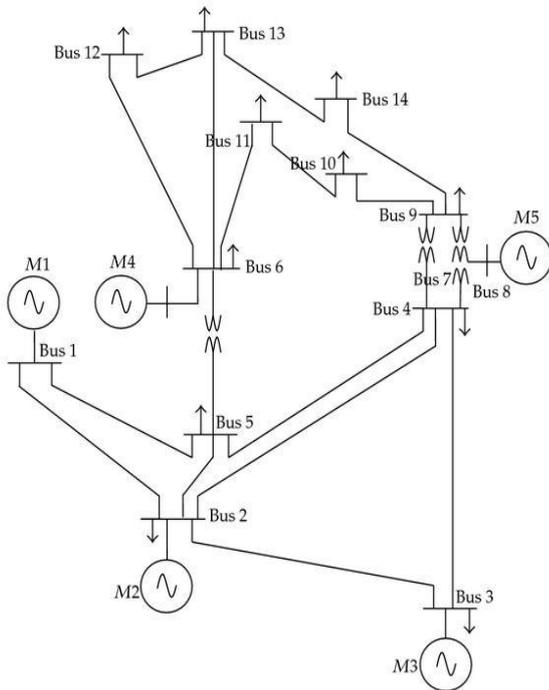


Fig. 1 IEEE 14-Bus network

#### IV. SIMULATION RESULTS

##### A. The version of this template is V2. DFIG wind turbine connected to the transmission part of network

To perform simulation, a DFIG of 5MW 0,96 kV equipped with a transformer 0,96/69 kV is connected to the bus 5. At time 3s, a three phases fault of zero resistance and 0.5s of fault during clearance is considered in the same bus.

Figure. 2 gives the voltage in bus 5 before, during and after the line fault.

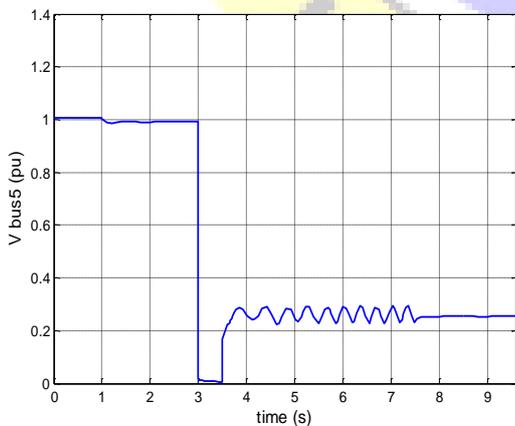


Fig. 2 Voltage before, during and after the line fault in the case of transmission network.

According to the figure above the voltage in bus 5 before the line fault is in standard, but during the line fault a voltage dips appears and it remains after that the fault line disappeared; so the DFIG wind turbine have not a line-fault ride-through capability when it is connected to the transmission line.

Figure 3 shows the reactive power synchronization of DFIG wind turbine before, during and after the fault.

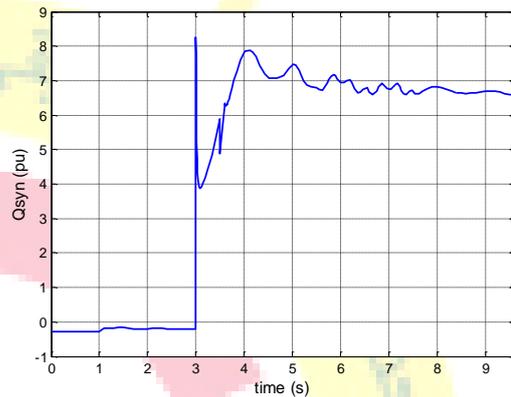


Fig. 3. Reactive power synchronization when DFIG wind turbine connected to the transmission network before, during and after the line fault.

The DFIG reactive power increases during the line fault to contribute in maintaining the voltage, but the line fault has defeated.

##### B. DFIG wind turbine connected to the distribution part of network

The DFIG wind turbine is equipped now with a transformer of 0,96/13,8 kV and is connected to the bus 13. At time 3s, a three phases fault of zero resistance and 0.5s of fault during clearance is considered in the same bus of the distribution line.

The Figure. 4 gives the voltage in bus 13 before, during and after the line fault.



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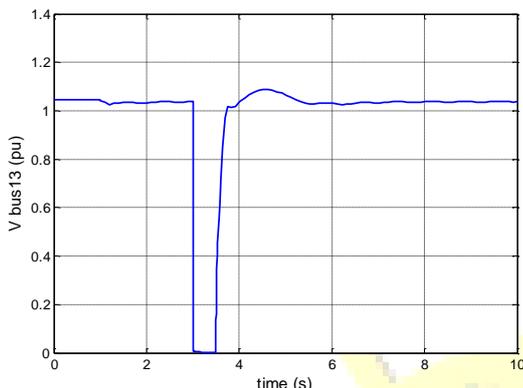


Fig 4. Voltage before, during and after the line fault in the case of distribution network.

According to the figure above the voltage in bus 13 before the line fault is in standard, and during the line fault a voltage dips appears, but the voltage returns to its value after the line fault; so the DFIG wind turbine has a line-fault ride-through capability when it is connected to the distribution line.

According to the equation (4), when a line fault is applied, a voltage dip appears and the DFIG wind turbine generates more of reactive power to compensate the voltage loss. When the DFIG wind turbine was connected to the transmission part the voltage dip was huge and the reactive power generated was not enough to compensate the voltage loss. The reactive power generated was not enough because the reactive power necessary to compensate the voltage loss is up of maximum reactive power can be generated by the DFIG wind turbine. Wherever when the DFIG was connected to the distribution part, the reactive power generated was enough to compensate the voltage dip.

Figure. 5 shows the reactive power synchronization of DFIG wind turbine before, during and after the line fault.

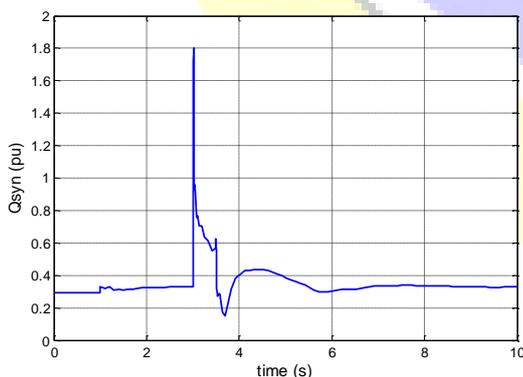


Fig 5. Reactive power synchronization before, during and after the line fault when the DFIG wind turbine is connected to the distribution part.

The DFIG reactive power increases during the line fault to contribute in maintaining the voltage, then it decreases to its value after that the line fault disappears.

The DFIG wind turbine has the capability to contribute to maintain the voltage during a line fault when it is connected to the distribution network, however it can't inject enough reactive power to maintain the voltage during the line fault when it is connected to the transmission network. As a solution now, the DFIG wind turbine should be connected directly to the distribution network to avoid the problem of disconnection from the network during a line fault.

### V. CONCLUSION

The line fault ride through capabilities of DFIG wind turbine is presented in this paper; the DFIG is integrated in two different parts of IEEE 14-bus network. The first is the transmission, while the second is the distribution, and it is equipped with transformer, a three phases fault is applied in those parts of network and at each time the voltage and the reactive power synchronization of DFIG wind turbine results are given before, during and after the line fault. The results are given using the PSAT; it is demonstrated that the line fault ride through capability of DFIG wind turbine is obtained while DFIG wind turbine is integrated in the distribution network. Because the reactive power generated in the case of line fault was in the limit reactive power can be generated by the DFIG wind turbine and was enough to compensate the voltage dip.

Finally, it is demonstrated that to avoid the problem of disconnection the DFIG wind turbine from the network during a line fault; DFIG should be connected directly to the distribution network.

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