FAULT ANALYSIS OF AN ISLANDED MICRO-GRID WITH DOUBLY FED INDUCTION GENERATOR BASED WIND TURBINE

Yunqi WANG, B.T. PHUNG, Jayashri RAVISHANKAR
School of Electrical Engineering and Telecommunications
The University of New South Wales, Sydney, Australia

ABSTRACT

The increasing penetration of distributed generations (DGs) in the electrical system is causing severe transient stability problems since most of DGs are characterized by low inertias and poor inherent damping. In this paper, an islanded micro-grid with both synchronous machine and DGs is built to compare the transient stability of the system when a three-phase to ground fault occurs. The simulation result shows that the installation of DG improves the dynamic performance of the micro-grid, and when the DG source is the unit with the energy storage, this improvement is much more significant as this device can absorb power rush caused by the fault and it will supply a reactive compensation to recover the voltage after the fault. But this enhancement is reduced if the DG penetration level is too low or too high. The micro-grid with both storage unit and DFIG based wind turbine shows the best transient performance since both these DGs can reduce the negative effects from the fault.

Key words—Micro-grid, Fault, Wind Turbine, Battery Storage, DFIG

INTRODUCTION

The micro-grid technology is efficient in the sustainable development of the power industry, flexible and efficient in the integrated use of distributed and renewable power generation technology. And its power supply system combines distributed generations (DGs) with integrated system, which can reduce initial outlay, investment risks and energy consumption. Energy efficiency, power system reliability, power system flexibility and energy quality can also be improved with this system. And it will be an important development direction of the electrical industry in the future [1-4].

The drawbacks with DGs is that they are characterized by low inertias, high reactance, short time constant and poor inherent damping [5], which means, the dynamic performance of the whole system may be affected since DGs are unable to regulate system stability. This issue gets aggravated when networks begin to incorporate large numbers of DGs, as the overall dynamics of power system gets significantly impacted [6].

Various researches in the past studied the transient stability of the micro-grid with distributed generations. Reference [7] proves that the usage of inverter-based DG using droop control strategy improves the transient stability of the distribution system for a three-phase-fault. Reference [8] also shows that the micro-grid with a mix of synchronous and inverter based DG has a better transient stability performance.

These previous works have made the following comparisons.

- Comparing fault performance of micro-grid in grid-connected / islanding mode.
- Comparing fault performance of micro-grid with different wind turbine conditions, including different control, crowbar protection or wind turbine type. A performance comparison of the wind turbines with other DG types is not investigated.
- Comparing fault performance of system with / without DGs. The nature of these sources being DC, they are equivalent to an energy source with storage units or even a pure storage system.

The storage units are known to support the transient performance of micro-grids during faults, by exchanging the excess energy available in the system. However, with AC sources like wind turbines employing doubly-fed induction generators (DFIGs), for example, the transient performance of the micro-grid significantly deteriorate, as it does not have any energy storage parts and the constantly change in the rotor speed of the wind turbine also makes an impact on the micro-grid stability.

The main aim of this paper is to compare the fault transients for micro-grids with synchronous machine, DFIG wind turbine and storage device. The simulation is carried out under four different scenarios: (i) the micro-grid with only one synchronous generator, (ii) the micro-grid with a synchronous generator (SG) and a DFIG wind turbine, (iii) the micro-grid including a synchronous generator and a storage unit, and (iv) the micro-grid including a synchronous generator, a DFIG wind turbine and a storage unit. A three-phase-fault is applied to the system at the same bus and the fault clearing time is the same for all simulation scenarios. The characteristics of the SG and the point of common coupling are analyzed to show the difference in transient performance.

FAULT PROTECTION OF DFIG WIND TURBINE

For DFIG based wind turbine, crowbar is the most commonly used protection method against the large short circuit current caused by the suddenly drop of grid voltage [9].

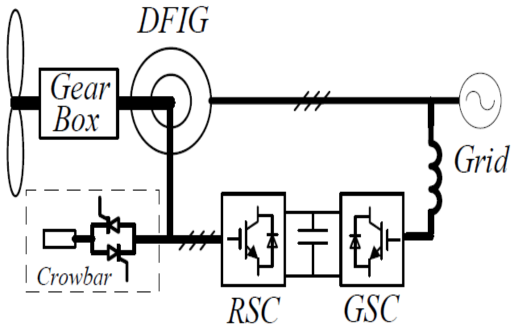

Fig.1 The topology of a typical crowbar protection

Figure 1 shows the topology of a typical crowbar protection. The crowbar will be quickly connected into the rotor side when the fault at grid side is detected. It short circuits the rotor to protect the converter and the system goes to an asynchronous machine operation mode [10]. However, if the fault duration is large and the crowbar is connected for a long time, the problem of reactive power absorption arises which will delay the reconstruction of grid voltage [11].

SYSTEM AND MICRO-GRID STRUCTURE

The micro-grid model used in the simulation is shown in Figure 2. The micro-grid works in islanding mode and it connects to grid side via a 15MVA, 1.38/13.8KV transformer and a 2 km transmission line. The system consists of a synchronous machine and a DG which can be either wind turbine or a battery storage device. Two 4MW, 0.9pf lagging load are also connected. Both DGs are controlled by droop control strategy.

The three-phase to ground fault is simulated at grid side at t=5s and it is cleared at t=5.2s. The characteristics of SG and DG, and the voltage at the point of common coupling (PCC) are obtained to show the transients with different DG source and penetration.

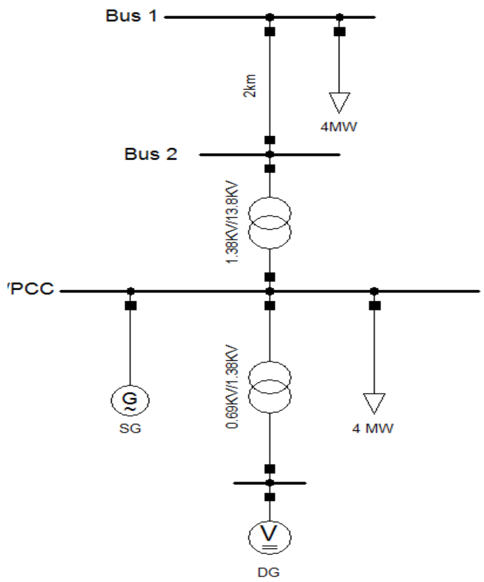

Fig.2 The micro-grid model

IMPACT OF DIFFERENT DG SOURCES

In this section, the system response for a sudden three-phase to ground fault at bus 1 is discussed in four different micro-grid configurations, which include a pure synchronous machine power injection, a mix of synchronous and DFIG-based wind turbine power injection, a mix of synchronous and storage unit power injection and a mix of synchronous, DFIG-based wind turbine and storage unit.

Micro-grid with only synchronous generator

In this configuration, the distributed generators are not used and a synchronous generator is the only source to supply the total load demand. The inertia constant (H) is 3MJ/MVA and Figure 3 shows the characteristics of SG and the PCC voltage and frequency when the fault is cleared in 10 cycles.

From Figure 3 it is observed that when the fault is cleared 0.2s after occurrence, the micro-grid with only SG unit can still maintain stability. But the SG takes a very long time to obtain to its new balance. It is obvious that the SG rotor speed and PCC electrical frequency increases rapidly after the fault, and at about t=10s, the rotor speed gets to the peak value (1.03pu) and it then goes down. However, it does not reach steady state even at t=60s, at which point the simulation is stopped. A similar change can also be found in Figure 3(b) and the peak value of electrical frequency is about 51.6 HZ.

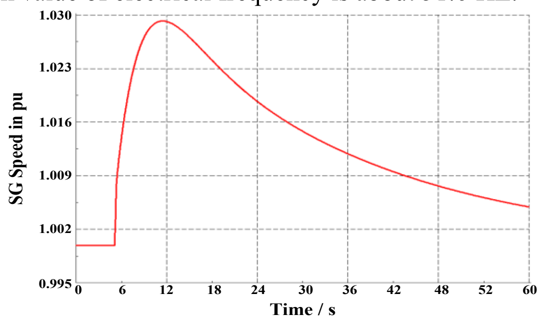

Fig.3 (a) SG rotor speed in pu

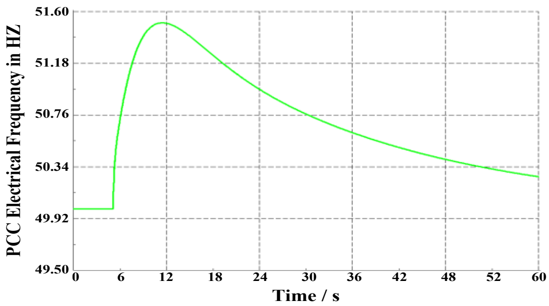

Fig.3 (b) PCC electrical frequency in HZ

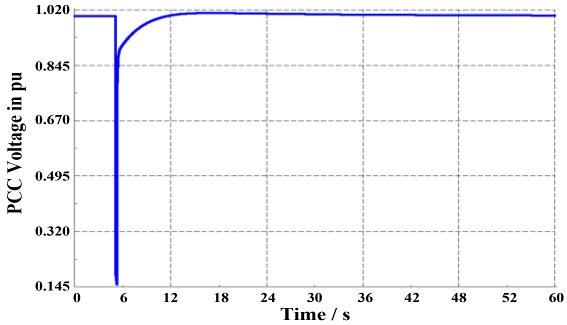

Fig.3 (c) PCC voltage in pu

The PCC voltage shown in figure 3(c) drops during the three-phase fault and when the fault cleared at t=5.2s, the PCC voltage begins to recover but this recovery time is long (more than 60s) because the SG reactive power increases slowly after the fault. And the voltage dip is the largest in this case because there is no component that can compensate for the voltage dip during the fault.

Micro-grid including a synchronous and a DFIG-based wind turbine

The micro-grid in this configuration consists of a 4MW synchronous generator together with a 4MW DFIG-based wind turbine, the inertia constant of SG being maintained at 3 MJ/MVA.

The three-phase fault is simulated at same bus and the fault clearing time is still in 10 cycles after the fault.

As shown in Figure 4, following the fault at t=5s, the voltage sag appeared in the micro-grid and crowbar protection of wind turbine short circuited the rotor side converter (RSC) after a 3ms short delay and the wind turbine goes to an asynchronous machine operation mode. The reactive power output of wind turbine is below 0, which means the wind turbine absorbs power from the grid. After 63ms the crowbar is disconnected and the RSC is re-synchronized and the wind turbine starts to supply active and reactive power; the crowbar operation is minimized to start injecting reactive power to the grid although the fault is still not cleared. But because the PCC voltage is low at this time, the active power output doesn't increase until the fault is cleared. The active power output increases at t=5.2s and the wind turbine works as DFIG again.

The micro-grid shows a better dynamic response when the DFIG-based wind turbine is installed. The PCC voltage has a smaller drop because wind turbine absorbs power from the grid to compensate the voltage dip when it operates in asynchronous generator mode. The wind turbine power drop is the main reason for the frequency overshooting during the fault, but the SG rotor speed and system frequency increase are less after the fault since the SG active power variation is smaller. And it still takes about 40sec for the voltage to recover (stable at t=45s) because the wind turbine with crowbar protection can't produce enough power to support the voltage recovery after the fault.

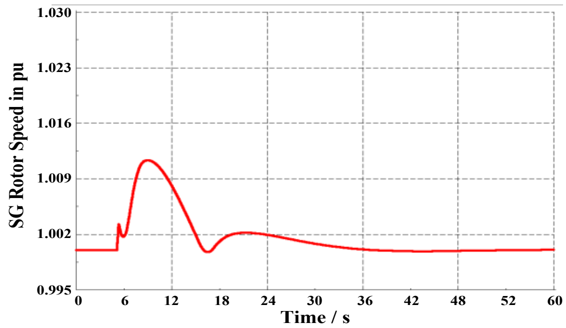

Fig.4 (a) SG rotor speed in pu

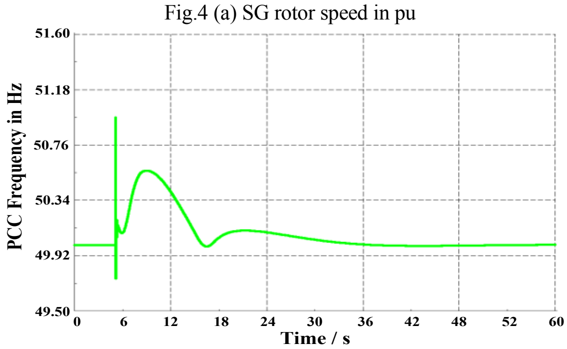

Fig.4 (b) PCC electrical frequency in HZ

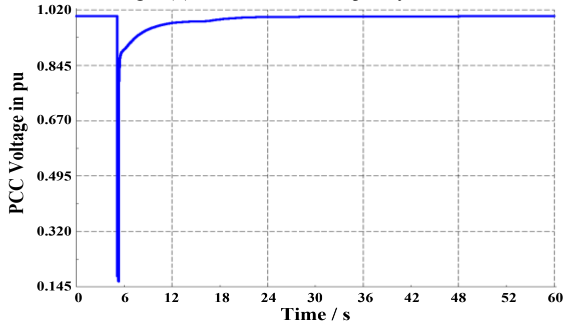

Fig.4 (c) PCC voltage in pu

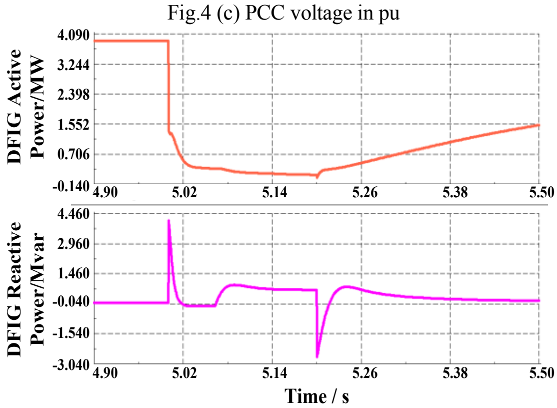

Fig.4 (d) Wind turbine power output during the fault

Micro-grid including a synchronous and a storage unit

The storage unit is used as the DG source in this configuration. It can be considered equivalent to either a renewable energy source with a storage unit or a pure storage device. The dynamic performance of the micro-grid is highly enhanced because the storage unit can absorb power rush caused by the fault without any impact on the system frequency, as shown in Figure 5.

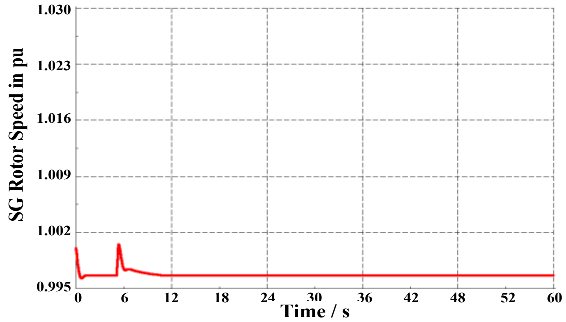

Fig.5 (a) SG rotor speed in pu

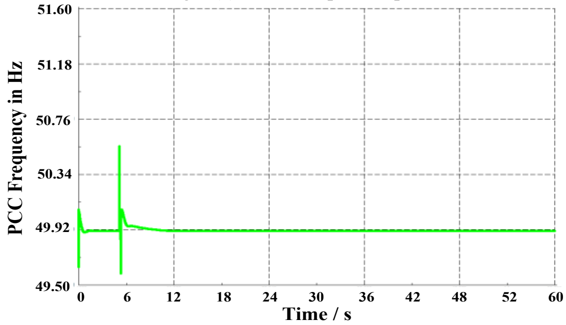

Fig.5 (b) PCC electrical frequency in HZ

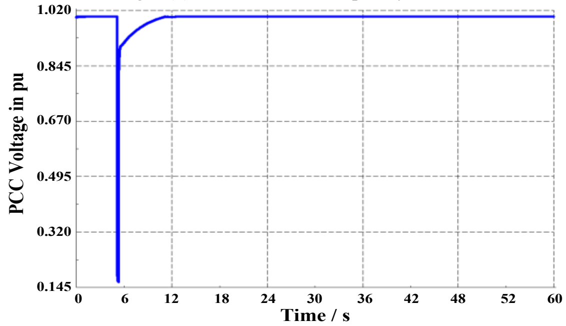

Fig.5 (c) PCC voltage in pu

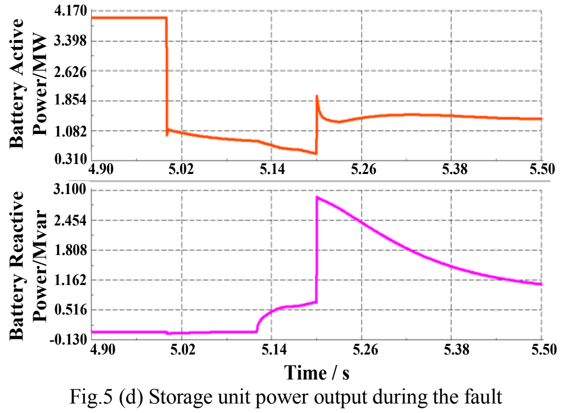

Fig.5 (d) Storage unit power output during the fault

The PCC voltage has a smaller drop since the battery delivers reactive power to PCC bus during the fault. The active power output of battery increases rapidly after the fault, and hence the SG rotor speed variations and PCC frequency oscillations remain smaller. The micro-grid recovers at t=15s because the storage unit delivers the reactive power after the fault to help the fast recovery of the PCC voltage.

Micro-grid including a synchronous, a DFIG based wind turbine and a storage unit

Both the DFIG based wind turbine and storage unit are connected at PCC bus in this configuration. The load demand is shared by SG and wind turbine initially. The system transient performance for the fault is shown in Figure 6.

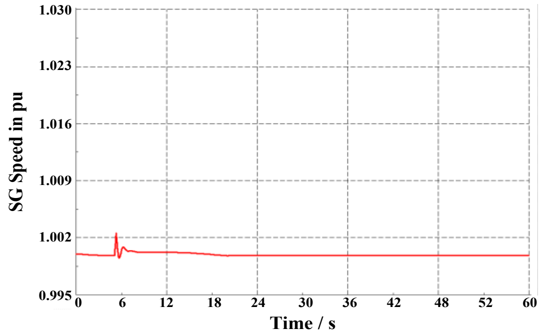

Fig.6 (a) SG rotor speed in pu

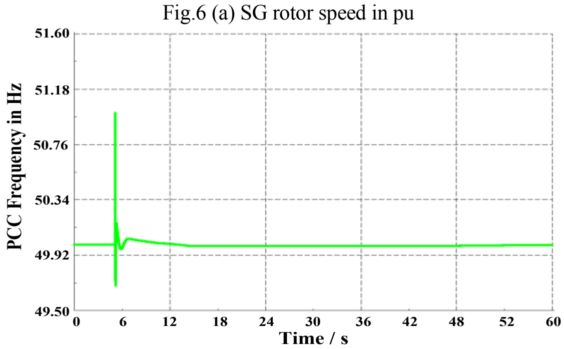

Fig.6 (b) PCC electrical frequency in HZ

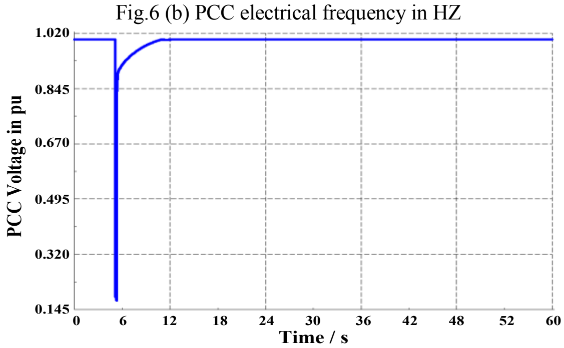

Fig.6 (c) PCC voltage in pu

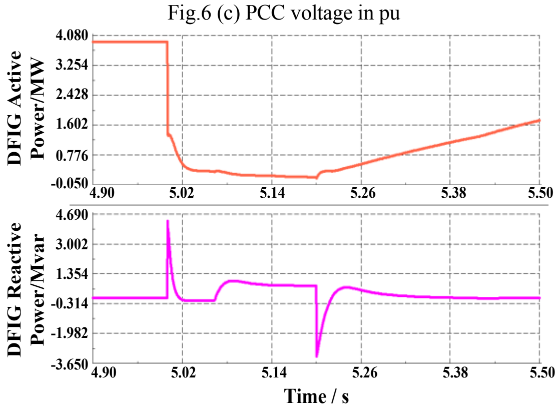

Fig.6 (d) Wind turbine power output during the fault

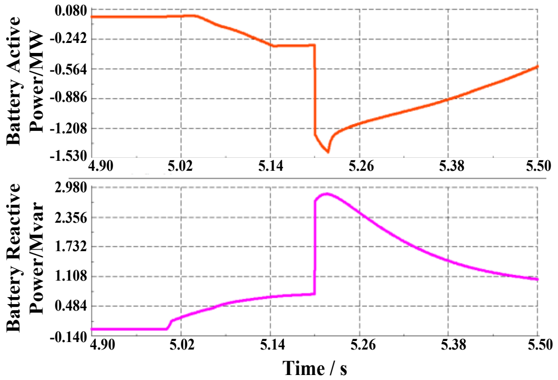

Fig.6 (e) Storage unit power output during the fault

The battery begins to deliver reactive power and absorb active power at t=5s to balance the system during the disturbance. The DFIG wind turbine also absorbs reactive power from the grid side when crowbar protection is operated, so the PCC voltage reduction is the smallest and SG rotor speed also has the least increase with the smallest power variation.

The electrical frequency in this case shows the least oscillation after the fault. But the initial overshoot following the fault is higher than in scenario 3 as the wind turbine rotor speed change also affects the system frequency. The PCC voltage is stable at t=10s, which is the shortest among the four scenarios.

CONCLUSION

This paper investigates the dynamic response of an islanded micro-grid when a sudden three-phase fault is applied. The simulation results show that the integration of DG in the micro-grid can help improve the transient performance of both the synchronous generator (SG) and micro-grid. With the wind turbine connected, the voltage dip is smaller, and the transients on the SG rotor speed and electrical frequency are reduced. The recovery time needed for the system to go back to the initial state is also decreased by connecting a DG. And this improvement is much more significant when the storage unit is used as the DG source. The best dynamic performance is found in the micro-grid with both DFIG-based wind turbine and battery storage connected.

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