Influence of the Reactive Power Management for Wind Power Plants in the Dynamic Voltage Stability

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***Abstract*- Nowadays, the large penetration of wind power generation poses new challenges for the dynamic voltage stability analysis of an electric power system. In this paper is studied the influence of the reactive power management for wind power plants in the dynamic voltage stability of an electric power network under a fault condition, considering two different Doubly-Fed Induction Generators (DFIG) models. The automatic voltage regulators of the generating units, the turbine speed governors and the wind turbine were modeled in detail. Different load models were used and the under load tap changers were taken into account too. The simulation results were obtained using the EUROSTAG software package. Finally, some conclusions that provide a better understanding of the dynamic voltage stability in a system with a large amount of wind power generation are pointed out.**

I. INTRODUCTION

In recent years, with the increased presence of wind power generation in the electric power network, many countries have established or are creating a set of specific requirements, grid codes [1] for operation and grid connection of wind power plants. Disconnection of wind power generators in case of voltage dips cannot be accepted any longer, since voltage and transient stability support during and after disturbance are required [2].

The grid codes concerning wind power production are specific of each country. The aim of these grid codes is to ensure that the continued expansion of wind power production does not compromise the power quality, as well as the security and reliability of the electric power system. Consequently, the risk of losing a significant portion of wind generation during fault events decreases and the transmission system operators can maintain a reliable and secure system operation even with high wind power penetration levels [3].

Currently, the wind power plants are required to be able to satisfy the voltage control and reactive power demands. The wind power plants should provide the reactive power exchange with the grid, due to the present penetration level of wind power in the system. The exchange rate and level are specified by the transmission system operator.

In the disturbance period wind power plants are requested to restore the voltage level to the nominal value at the connection point, by injecting required amount of reactive current. Modern wind power plants are not allowed to disconnect during a network fault as long as voltage at the connection bus is not lower than the voltage level specified in the grid codes [4].

Nowadays, Portugal has installed a capacity of 3571 MW of wind power, what means, near 22% of the total installed capacity. In Fig. 1 it is shown the fault ride-through requirement for wind turbines and in fig. 2 it is presented the grid support during faults by reactive current injection as stated in the Portuguese grid codes [1], [5].

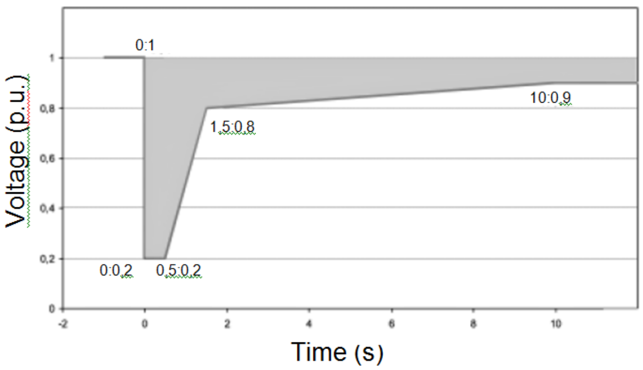

Fig. 1. Fault ride-through requirement for wind turbines in the Portuguese transmission grid.

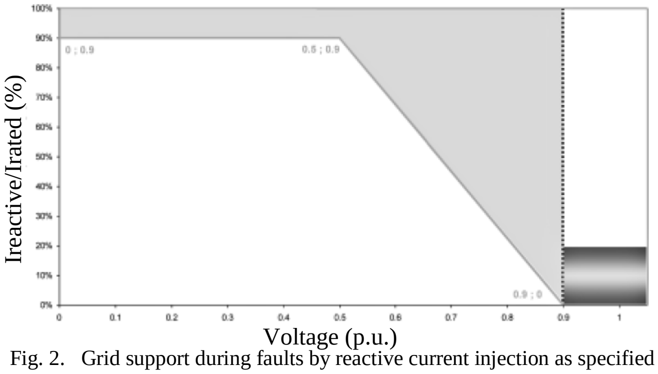

Fig. 2. Grid support during faults by reactive current injection as specified in the Portuguese grid codes.

II. APPLICATION EXAMPLE

In fig. 3, it is shown the modified Cigré Electric Power Network with 32 buses that was used in this study [6], [7]. The external system is simulated by means of three infinite 380 kV bus (N12, N15 and N16). Connected at this voltage level there are two important power stations, N1 and N10 (M1 and M2 with a rated power of 2000 MVA and M6 with 5000 MVA). A wind park with 990 MVA is connected at bus

N17. The total power generated at the 380 kV is 7990 MVA, with 12.4% of wind power.

The total generation at 150 kV level is 500 MW (M3, M4 and M5). The total load of the system is 5000 MW and is mainly located at the sub transmission level (70 kV). The 70 kV loads are a mix of induction motor loads, constant impedance loads and compensation capacitors. The other loads were modeled as constant impedance type. The generators were modeled in detail. The automatic voltage regulators (AVR) of the generating units and the turbine speed governors (SG) were taken into account in the study. The 380/150 kV transformers have remote controlled taps. The 150/70 kV distribution transformers are fitted with automatic tap-changers regulating on the low voltage side. In this study the out-of-step and under voltage relays protecting the generating units were modelled.

The wind farm is connected at bus N17 by a three winding transformer. The wind farm has 330 wind turbines each with 3 MW and is represented as an aggregated equivalent model.

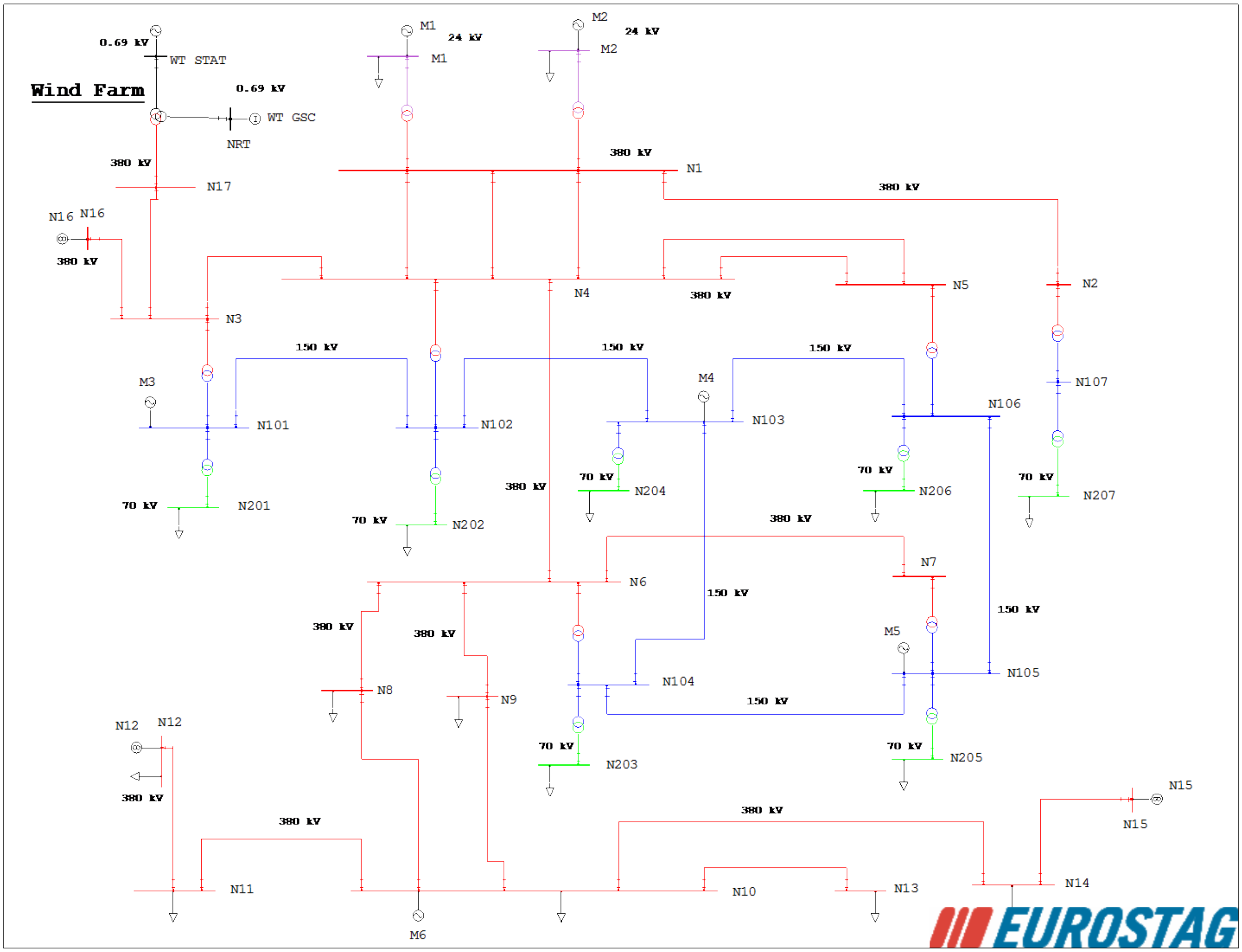

Fig. 3. Grid Cigré test power network single line diagram

III. CASE STUDIES

In this paper two different DFIG models were analyzed. Fig. 4 presents the global scheme of the first model (case I). The model of the DFIG is composed by the following different parts [8], [9]:

- Model of the doubly-fed machine and the converters;
- Aerodynamic model of the wind blades;
- Model of the wind turbine control (Pitch controller, Power controller and Main controller).

In case I the reactive power control scheme is disconnected. In order to protect the stator DFIG, an automaton has been created that disconnects and reconnects the machine stator from the network if certain criteria are met.

In fig. 1, it is shown the default values for the stator disconnection thresholds [5]:

- Terminal voltage below
  - 0.2 p.u. for at least 0.5 seconds;
  - 0.8 p.u. for at least 1.5 seconds;
  - 0.9 p.u. for at least 10 seconds.
- Output current above
  - 2 p.u. for at least 0.3 seconds.

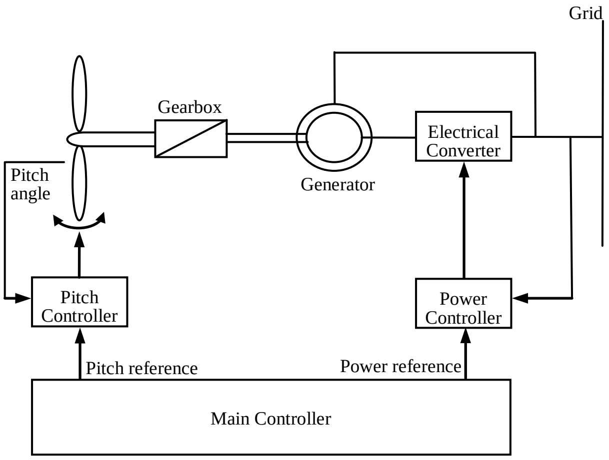

Fig. 4. Model of the DFIG scheme (case I) [8].

In case II a model with DFIG, crowbar and chopper was used. This model is different from the previous one (case I) in the modeling of internal protections of the machine (crowbar and chopper). The DC-link was modeled in detail. It is considered as ideal and instantaneous in the model of case I. This part only describes the differences between this model and the model of case I. Fig.5 represents the global control scheme of the model of case II.

The model of the DFIG is composed by the following different parts [8]:

- Model of the doubly-fed machine and the converters;
- Model of calculation rotation speed and torque;
- Model of wind turbine control (power controller and main controller).

The most efficient wind parks now use technologies that allow them to stay connected during a fault and to produce again right after this fault. The model used take into account these new technologies.

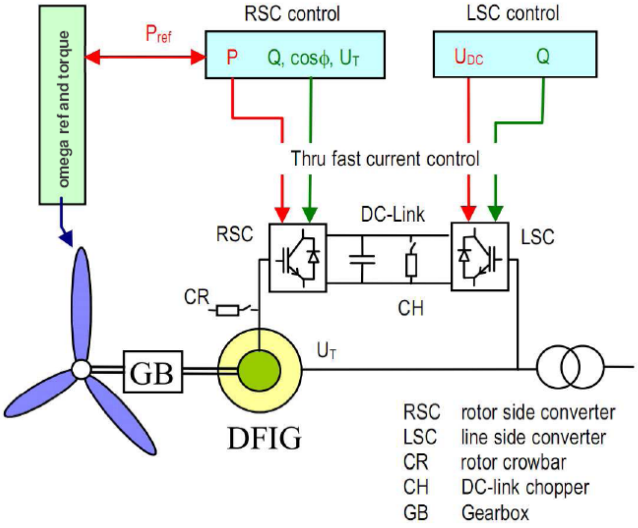

Fig. 5. Model of the DFIG scheme (case II) [9].

IV. RESULTS

In both cases the following events were simulated:

- An increase of the wind speed from 7 to 25 m/s, ~~at the time~~ from 20 seconds to 90 seconds;
- A contingency occurs at the 100 seconds and ~~a~~ the unit, M2 trips;
- A three-phase short-circuit occurs in the bus N1 at ~~the time equal to~~ 300 seconds;
- At 300.25 seconds the three-phase short-circuit is remove;
- the tripping of the 380 kV overhead transmission line between buses N3 and N16 at 400 seconds.

In fig. 6 it is shown the voltage variation in bus N17 for the case I and case II. The wind farm is connected at this bus.

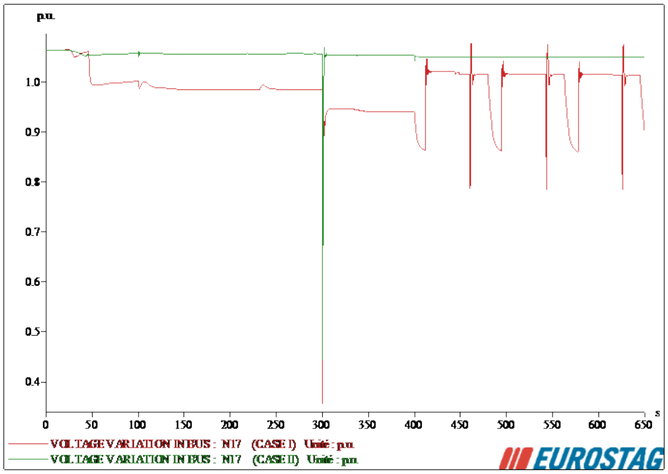

Fig. 6. Voltage variation in bus N17 (case I and II).

Fig. 7 and fig. 8 present, respectively, the active and reactive power injected by the stator and the rotor of DFIG for case I. In this case after the three-phase short-circuit at 300 seconds, the DFIG stator protection is not activated. Nevertheless, after the tripping of the 380 kV overhead transmission line between buses N3 and N16, at the time equal to 400 seconds, the DFIG stator protection is activated, since the voltage at bus N17 was below 0.9 p.u. for at least 10 seconds (fig. 6).

When the protection stays open there is no longer active power generation by the stator and by the rotor of the DFIG. In this model there is no reactive power generation during the DIG operation, although when the protection is activated the rotor will inject reactive power through the DC bridge into the network. This injection of reactive power will increase the voltage on bus N17 and the DFIG will be reconnected to the network. At this moment there is no longer reactive power generation and voltage decrease again, though the protective devices operate once more (Fig. 6 and 8).

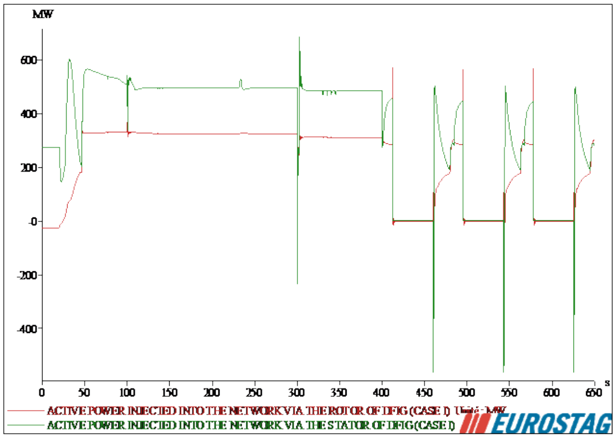

Fig. 7. Active power injected by stator and rotor of DFIG. (case I).

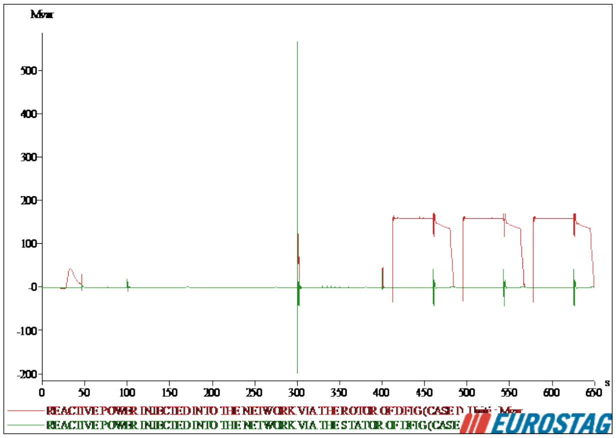

Fig. 8. Reactive power injected by stator and rotor of DFIG. (case I).

Fig. 9 and fig. 10 present, respectively the active and reactive power injected by stator and rotor of DFIG for case II. In this model of the DFIG the internal protections of the machine is made by the crowbar and chopper.

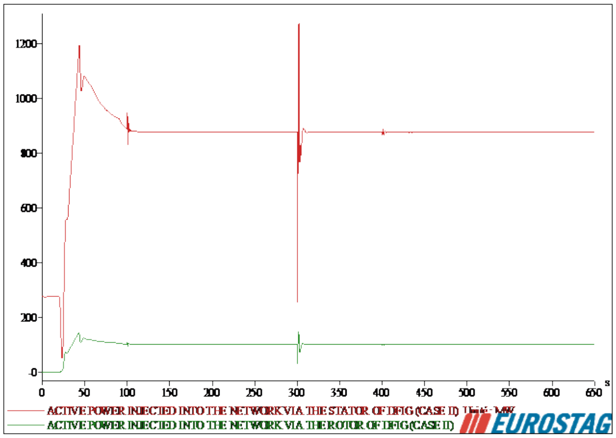

Fig. 9. Active power injected by stator and rotor of DFIG. (case II).

Fig. 11 shows the field currents of M1 for case I and case II. After unit M2 tripping at 100 seconds, since M1 is closer to M2, it produces more reactive power. ~~This phenomena leads, at time equal to 125 seconds in both cases, ~~T~~t~~he OvereXcitation Limiter (OXL) of M1 operates and the field current changes to its maximum value of 3 ~~per unit~~p.u.,,at 125ms, in both cases..

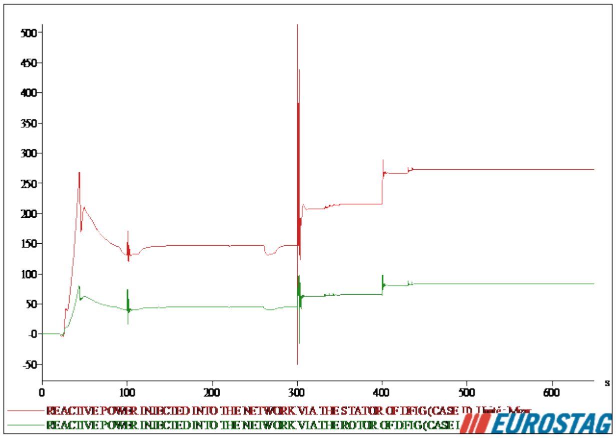

Fig. 10. Reactive power injected by stator and rotor of DFIG. (case II).

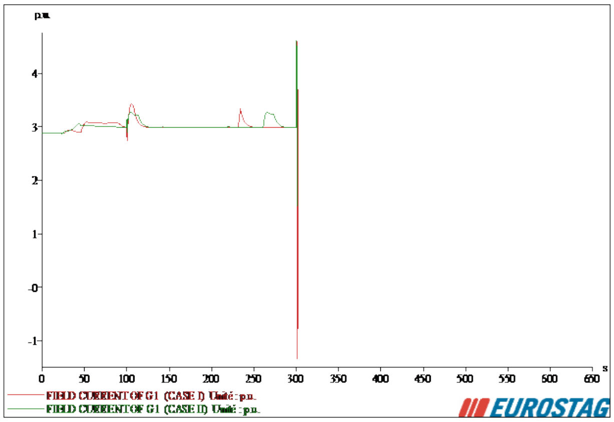

Fig. 11. Field currents of M1 (case I and II).

The three-phase short-circuit in bus N1 at 300 seconds produce the loss of synchronism of the unit M1 (fig. 11) for the two cases analysed.

Fig. 12 and fig. 13 present the active and reactive power flow in transmission line between buses N16 and N3 for case II, respectively.

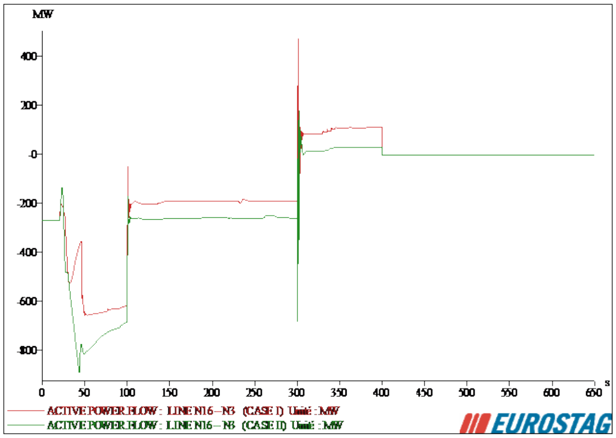

Fig. 12. Active power flow in transmission line between buses N16 and N3 (case I and II).

Fig. 13. Reactive power flow in transmission line between buses N16 and N3 (case I and II).

For the voltage stability studies the voltage variation in bus N107 and N207 were chosen to exemplify the system trajectory, since the voltages at the other bus have a similar behavior. Fig. 14 and fig. 15 present the voltage variation at bus 107 and 207 respectively for case I and Case II.

Fig. 14. Voltage variation in bus 107 (case I and II).

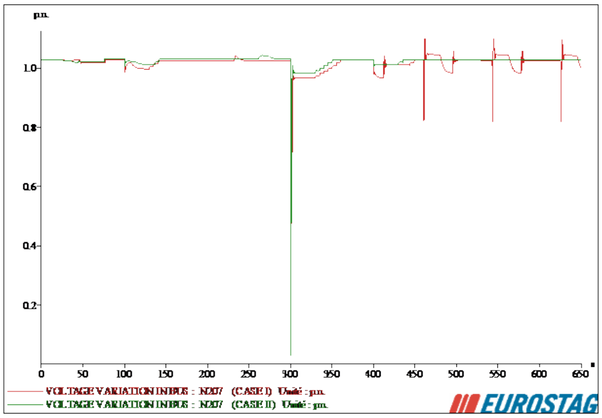

Fig. 15. Voltage variation in bus 207 (case I and II).

The voltage rise at bus N207 implies an increase of the active and reactive power consumption in this bus. The 70 kV loads were modelled as a mix of induction motor and constant impedance. For this type of loads it was confirmed that the under load tap changer action will influence the transmission lines power transfer capability putting at risk the system voltage stability and as a result the voltage at bus N107 decrease.

V. CONCLUSIONS

This paper presents a study of the influence of the reactive power management for wind power plants in the dynamic voltage stability of a power network, considering two different schemes of double fed induction generator models. The impact of the voltage ride through requirements of the grid codes and the grid support during faults by reactive current injection as stated in the Portuguese grid codes were considered and analyzed. In order to assess the power network voltage stability it was simulated severe contingencies in different locations.

From the results obtained it was shown that wind turbines can be a source of reactive power to help the grid during contingencies. The bus voltage values are much more stable when the wind farm generates reactive power.

From the transmission system operator point of view this is an advantageous behavior for the DFIG equipped with crowbar and chopper. It would be better if during the fault, more reactive power was produced and after the fault, have a quick return of the bus voltage to its nominal values. The DFIG model with crowbar and chopper allows the transmission system operator to ask for ancillary services like reactive power generation, during or after the fault.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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