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# Dynamic Voltage Stability of an Electric Power Network with Double Fed Induction Wind Power Generators

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**Abstract.** In recent years, the large penetration of wind power poses new challenges for the voltage stability analysis of an electric power network. In this paper is studied the effect of large scale integration of wind power in the dynamic voltage stability of a power network under a fault condition. The automatic voltage regulators of the generating units, the turbine speed governors and the double fed induction generator were modeled. Different load models were used and the under load tap changers were also taken into account. 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.

## Key words

Double fed induction generator, Electric power network, Voltage stability, Wind farm, Wind generator.

## 1. Introduction

In the past, the wind power generation was only of a few kW and mostly connected to the distribution networks. The operational security rule was to disconnect the wind farms as fast as possible when a disturbance occurred, in particular short-circuits.

Currently, wind farms produce a large amount of power and is no longer possible to disconnect them from the grid due to voltage dips caused by short-circuits. Turn off a modern wind farm of hundreds or even thousands of MW might seriously endanger the security and stability of the entire power network and has very important economic and social consequences. Moreover, the new grid codes specify that wind farms should contribute to the power system control as much as the conventional power stations.

Nowadays, Portugal has installed a capacity of 3571 MW of wind power, what means, near 22% of the total installed capacity. Integrating large-scale wind power into an electric power network has a great impact on the voltage stability of the system, in particular, when a large amount of wind power generation is tripped due to a fault [1]. To ensure the electric power system stability it is required that the wind power generators have a great capability to withstand voltage dips. This can be accomplished by the implementation of the Fault Ride Through Capacity (FRTC) function [2], [3].

## 2. Double Fed Induction Generator

The Double Fed Induction Generator (DFIG) is an induction generator where the rotor windings are not short circuited, and are connected through a back to back power electronics converter to the machine terminals or, in other words, to the network [4]. As it is shown in fig.1, the converter controls the rotor speed and the reactive power injected on the network.

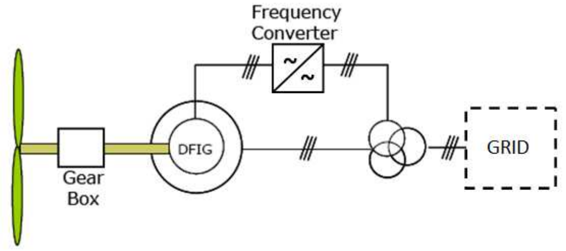


Fig. 1. Wind Turbine with DFIG.

The behavior of the machine in case of voltage dips and system short-circuits depends on its design. The more simple ones are disconnected from the grid and resynchronized later on, at a predetermined speed, for instance the synchronous speed. In this case, the reconnection time is of the order of one minute. More recent implementations allow a faster reconnection, of the order of seconds. This is made possible by the use of more powerful actuators for the pitch-control and the reconnection at the highest possible speed. In this situation, the machine accelerates when voltage dips occur due to the imbalance between motor and load torques. Most advanced implementations use fast disconnection and reconnection for deep voltage dips. In the case of voltage dips with limited amplitude, no disconnection is required. In this last case, crowbar protection is used transiently to decouple the rotor bridge from the rotor circuit [5].

## 3. Model of Wind Turbine Equipped with DFIG

Variable speed induction machines and particularly DFIG are more and more used for wind energy conversion. This allows to operate the turbine at variable speed enhancing the conversion efficiency at low wind speed. One of the main reasons which led to variable speed machine is the synchronizing capability of these machines.

The concurrent option is presently based on/off AC DC AC conversion with possibly a gearless implementation. The size of the power electronic package is reduced to 30-50% when considering DFIG. This is the main reason why such option is often selected [6].

Fig. 2 represents the global scheme. The model of the DFIG is composed of the following different parts:

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

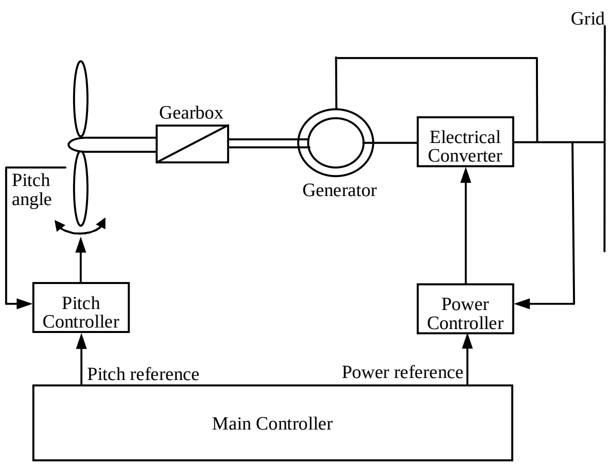


Fig. 2. Model of the DFIG scheme [6].

The control functions are divided into 3 blocks called Main Controller, Pitch Controller and Power Controller. The main controller manages the overall control functions, whereas pitch and power controllers are subordinate units. The objective is to determine the optimal values of the WG speed and of the pitch angle for a given wind speed in order to maximize the electrical power produced [5].

## 4. DFIG Stator Protection

Recently, Transmission System Operators (TSO) have imposed more restrictive grid connection condition to wind farms in Europe. Wind turbines are now required to remain connected to the grid during voltage dips of certain depths and durations. Also active power production has to be restored as soon as the grid voltage is back at normal levels. In some cases a disconnection during the voltage drop is allowed, provided the wind turbine reconnects as soon as the voltage is restored. In the case that’s the voltage drops below the thresholds set by the TSO or the voltage is not restored within the specified time, the wind turbine will disconnect from the grid, reduce its speed (or even initiate a complete stop) and a slower reconnection will occur.

In order to correctly simulate these different modes triggered by a voltage drop, an automaton has been created that disconnects and reconnects the machine stator from the network if certain criteria are met.

This automaton offers the possibility to supervise three machine variables to open the stator and one criterion for the stator closing. An activation signal is transmitted when the terminal voltage falls under one of the three thresholds for more than the specified observation duration or when the output current becomes greater than the specified threshold. A third criterion can be used: an activation signal is sent if the monitored variable of one of the machine macroblocks becomes greater than the specified threshold for the specified duration. In this paper, this last criterion will not be used [5], [7].

In fig. 3, it is shown the default values for the stator disconnection thresholds [8]:

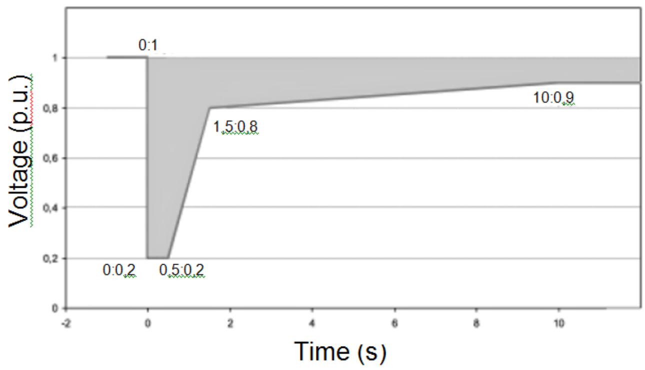


Fig. 3. Requirements of “Fault Ride Through Capability – FRTC” [8].

- Terminal voltage below
  - 0.2 p.u. for at least 0.5 seconds
  - 0.80 p.u. for at least 1.5 seconds
  - 0.90 p.u. for at least 10 seconds

- Output current above
  - 2 p.u. for at least 0.3 seconds

## 5. Electric Power System

In fig. 4, it is shown the modified Cigré Electric Power Network with 32 busbars that was used in this study. The simulations were carried out considering the network data presented in [9], [10].The external system is simulated by means of three infinite 380 kV busbars (N12, N15 and N16). Connected at this voltage level there are two important power stations, N1 and N10 (N1 with a rated power of 2000 MVA and M6 with 5000 MVA) and a wind park with 990 MVA is connected at busbar N17. The total power generated at the 380 kV is 7990 MVA, with a percentage of 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 made of a mix of induction motor, constant impedance loads and compensation capacitors. The other loads are modelled as constant impedance type. The generators are modelled 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 park is connected at busbar N17 by a three-winding transformer. The wind park has 330 wind turbines each with 3 MW and represents an aggregated model. The wind generators are Double Fed Induction Generator (DFIG). A DFIG driving by wind (wind turbine) is represented by an induction machine (WT STAT) with the rotor connected to a converter (WT GSC).

*The following events were simulated*:

- An increase of the wind speed from 7 to 28 m/s, at the time from 20 seconds to 90 seconds;
- A contingency occurs at the time equal to 100 seconds a unit M2 trips;
- A three-phase short-circuit occurs in the busbar N1 at the time equal to 300 seconds;
- At 300.35 seconds the three-phase short-circuit is remove;
- the tripping of the 380 kV overhead transmission line between busbars N3 and N16 at the time equal to 400 seconds.

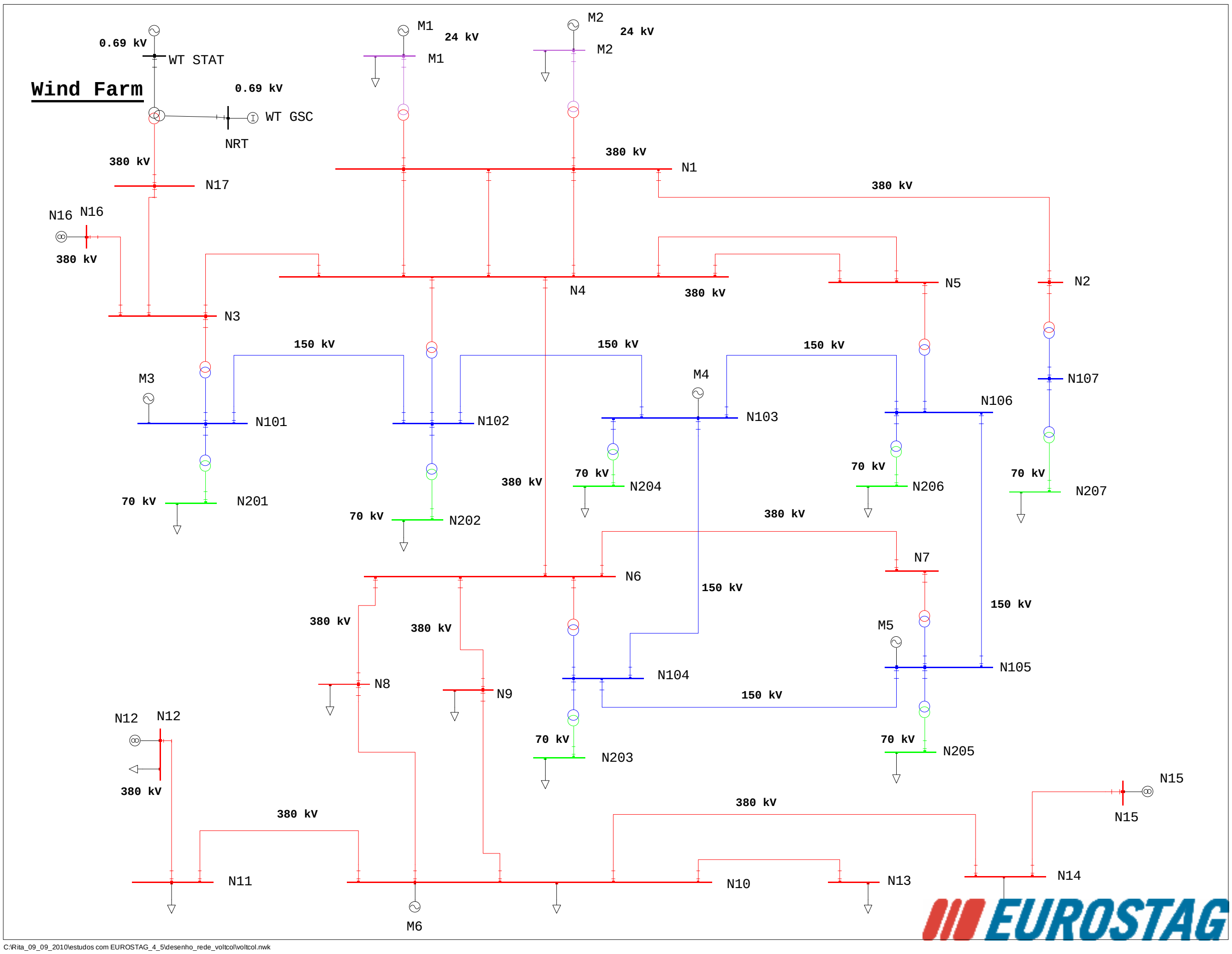


Fig. 4. Cigré test power network single line diagram [9], [10].

Three scenarios were analyzed. In the first one (case I) the wind farm is disconnected from busbar N17. In another one (case II) the wind farm is connected to busbar N17 but after a three-phase short-circuit the DFIG stator protection is activated and the WT STAT machine stator opening. In the last one (case III) in order to respect the transmission system operators rules the DFIG stator protection was regulated for the values shown in fig. 3. Wind turbines are now required to remain connected to the grid during voltage dips of certain depths and durations.

## 6. Results

In fig. 5 it is shown an increase of the wind speed from 7 m/s at 20 seconds to 28 m/s at 90 seconds. The main controller manages the overall control functions, whereas pitch and power controller are subordinate units. The objective is to determine the optimal values of the turbine speed and the pitch angle for a given wind speed in order to maximize the electrical power produced.

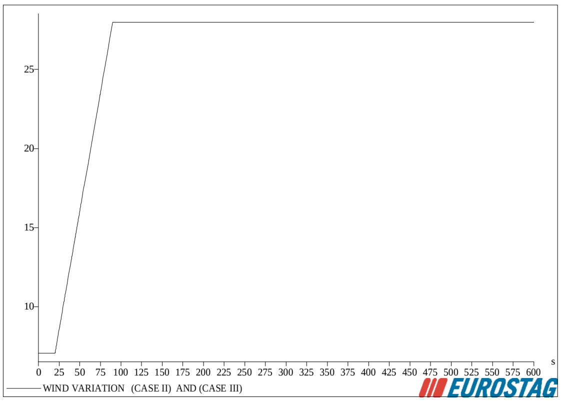


Fig. 5. Wind Variation for case II and Case III.

When the wind speed is above the rated value (11.5 m/s), the full load controller is activated. It controls the pitch angle limiting the produced power to the rated value. The main objective of the full load controller is to limit the mechanical torque of the turbine and to keep the generator speed constant at its nominal value. The speed is controlled directly by the pitch controller, as the electrical power output is set to it's the nominal generator power. Fig. 6 presents the variation of the pitch angle for case II and case III.

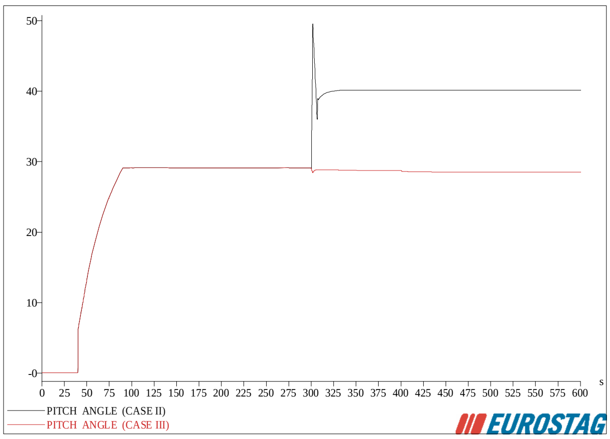


Fig. 6. Pitch angle.

In fig. 7 it is shown the speed of the induction machine for case II and Case III. In case II after the three-phase short-circuit at 300 seconds the DFIG stator protection is activated and the WT STAT machine stator opening (speed 1 p.u.).

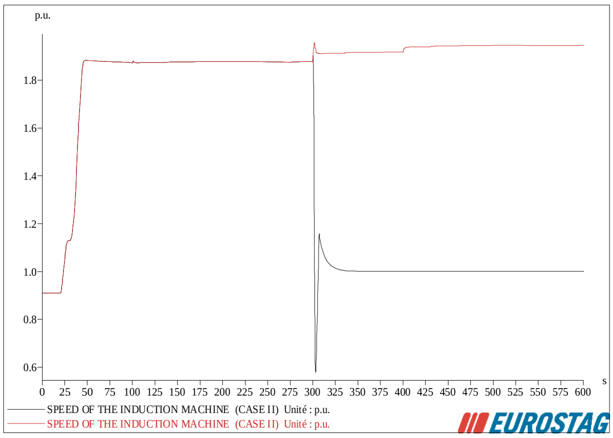


Fig. 7. Speed of the induction machine.

Fig. 8 presents the Active power injected by stator (WT STAT) and rotor (WT GSC) of DFIG for case II and case III.

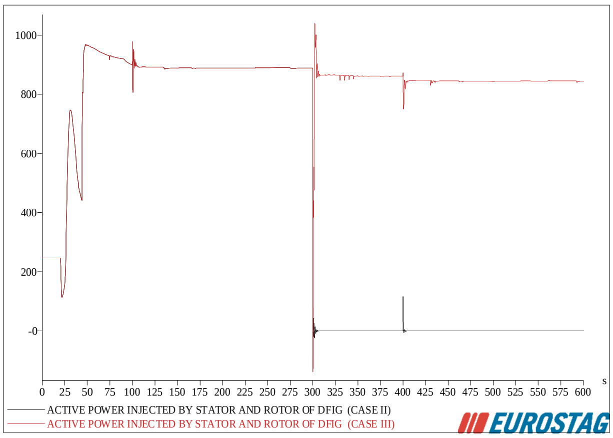


Fig. 8. Active power injected by stator and rotor of DFIG.

In fig. 9 it is shown the field currents of M1 for the three scenarios analysed.

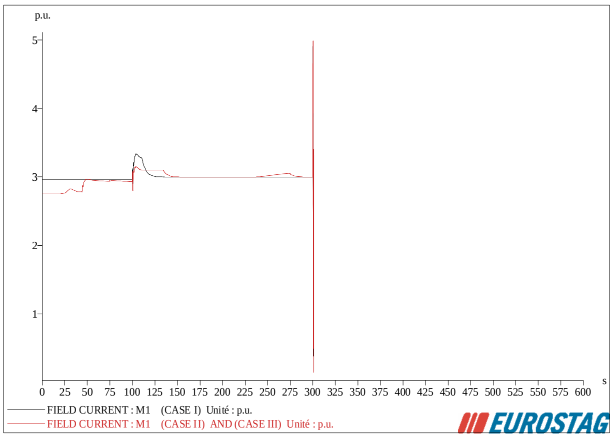


Fig. 9. Field currents of M1.

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 case I, and at time 150 seconds for cases II and III, the OvereXcitation Limiter (OXL) of M1 operates (fig. 9) and the field current changes to its maximum value of 3 per unit.

The three-phase short-circuit in busbar N1 at 300 seconds produce the loss of synchronism of the unit M1 (fig. 9) for the three scenarios analysed.

For the voltage stability studies the voltage variation in busbars N107 and N207 were chosen to exemplify the system trajectory, since the voltages at the other busbars have a similar behaviour. Fig. 10 and fig. 11 present the voltage variation at busbar 107 and 207 respectively for case I, Case II and Case III.

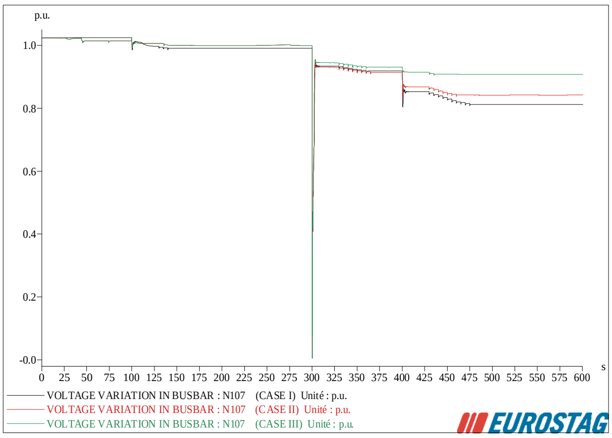


Fig. 10. Voltage variation in busbar 107.

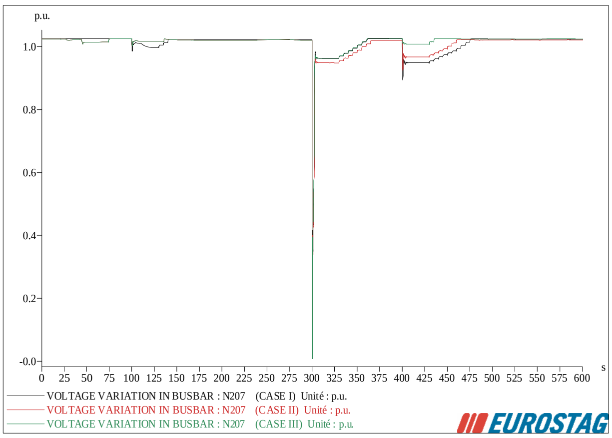


Fig. 11. Voltage variation in busbar 207.

Fig. 12 presents the changes in the transformer taps, corresponding to the power device connected between busbars N107 and N207.

After these contingencies and the tripping of the 380 kV overhead transmission line between busbars N3 and N16 at the time equal to 400 seconds, the under load tap changer are activated in order to restore the voltages at 70 kV busbars as it can be seen in fig.11 (for busbar N207).

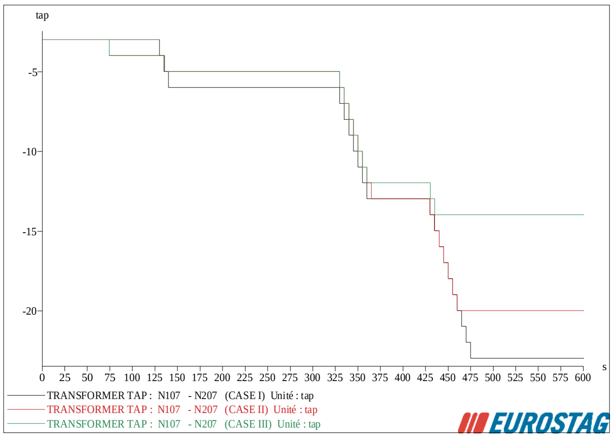


Fig. 12. Under Load Tap Changers position.

The voltage rise at busbar N207 implies an increase of the active and reactive power consumption in this busbar. 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 busbar N107 decrease (fig. 10).

## 7. Conclusion

This paper presents a study of the influence of large scale integration of wind power in the dynamic voltage stability of a power network, using the double fed induction generator model. The impact of the voltage ride through requirements of the grid codes was 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 demonstrated that wind turbines must be connected to the grid during voltage dips of certain depths and durations. In case III, where the Fault Ride Through Capability was used, the system voltages after the contingencies remain near the nominal value. Also active power production has to be restored as soon as the grid voltage is back at normal levels. In some cases a disconnection during the voltage drop is allowed, provided the wind turbine reconnects as soon as the voltage is restored.

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