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Enrichment of transient stability for smart grid by pluging mode functioning in wind energy plant

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ABSTRACT

This paper gives the solution for enrichment of transient stability for smart grid connected squirrel cage induction generators used in wind energy system. In most of the wind power plant induction generator is popular because it can recover energy with relatively simple control, it generates useful power at the variable speed of the rotor, it has low cost and low maintenance. Fault occurs in power system leads to over speed of rotor, consequently the over speed of rotor introduced transients in power system after clearing fault. If the transients are withstanding for more time in the system, the system will have difficult to stable the transients. So, for this paper deals with the transient's stability enrichment of smart grid connected squirrel cage induction generator by using plugging mode operation and stable the transients after clearing the fault. Simulation results show that the proposed method can be effective in enhancing the transient stability. Since in this method, there is no need for accessory equipment, the proposed method is more attractive from the economic point of view.

Keywords— *induction generators (IGs), Plugging mode, squirrel-cage, transient stability, wind turbine.*

1. INTRODUCTION

A Smart grid is an electricity network that can intelligently integrate the action of all users connected to it –generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies. The Smart grid is intelligent as it is capable of sensing system overloads and rerouting power to prevent or minimize a potential outage; of working autonomously when conditions require resolution faster than humans can respond and comparatively in aligning the goal of utilities, consumers and regulators. It is capable of meeting increased consumer demand without adding infrastructure which shows efficiency. Accepting energy from virtually any fuel source including solar and wind as easily and transparently as coal and natural gas; capable of integrating any and all better ideas and technologies energy storage technologies. This grid enables real time communication between the consumer and utility so consumer can tailor their energy consumption based on individual preferences, like price and /or environmental concerns

The key challenges of Smart Grid are:

a) Strengthening the Grid
b) Enhanced intelligence
c) Communications
d) Integrating intermittent generation
e) Moving offshore
f) Capturing the benefits of DG and storage and preparing of plug in hybrid vehicles

In recent years, wind energy has become one of the most economical renewable energy technologies. Today, electricity generating wind turbine proved and tested technology, and provide a secure and sustainable energy supply. At good windy sites wind energy can already successfully compete with conventional energy production. Many wind power generators are induction machines, either squirrel cage or wound rotor if under the condition of high power induction generator connected to weak networks, there is possibility of transient instability of smart grid connected induction generator.

At staring induction machine operates as motor till the rotor speed is greater than synchronous speed therefore the slip of induction motor is negative and induction machine acts as generator and delivers a power supply to smart grid. When faults occur on system it leads to rotor instability as well as voltage instability. But when fault is cleared rotor speed is too high that takes more time to become steady state.

Previous researches have revealed that flexible ac transmission system (FACTS) devices, rotor circuit control and braking resistors are there methods that can improve the IGs stability. In [4] FACTS devices provide and absorb the reactive power in regulating manner of transmission line hence stability has maintained. In [5] and [6] SVC and STATCOM are the facts devices which considerably improves system stability during and after disturbances. Also, in [7] the effect of unified power flow controller (UPFC) on improving the rotor speed stability and voltage is stable solution based on FACTS devices have been a recognized as expensive method.

In [8] and [9] rotor circuit have been investigate one possibility is to employ and a electronically controlled external resistance connected with rotor winding and another one is to control the voltage applied to rotor through converter in doubly fed IG , however this method is only applicable to the slip ring rotor or wound rotor type IG and cannot be applied to squirrel cage type IG.

In [10] and [11], using braking resistor technique is introduced as a solution for improving transient stability enrichment of IG. Application of this method for transient stability enrichment of synchronous generator has been investigated for many years [12].The braking resistor decreases rotor speed hence improves transient stability by absorbing electrical power during fault however the operation of IG is significantly different form synchronous generator and therefore the braking resistor is less effective for improving IG transient stability than synchronous generator stability. The absorbed electrical power by braking resistor is proportional to square of voltage. For a synchronous generator, during the fault, terminal voltage of generator can be increased by increasing the amount of exciting current. Also, existence of braking resistor improves the power factor of synchronous generator and therefore the decreases the effect of armature reaction. Reduction of armature reaction increases terminal voltage of synchronous generator, but for IGs increasing the terminal voltage is not possible therefore the braking resistor are connected to IG absorbs less electrical power in comparison with braking resistor that are connected to synchronous generator. Hence braking resistor is less effective in case of IGs. Furthermore, all three mention previously have some disadvantages like economic concern and less effective.

In this paper new and simple method is proposed to easily stable the transient instability of squirrel cage of induction generator without using additional equipments. In this plugging mode is used to improve transient stability .Plugging mode is nothing but the interchanging the any two phase connection .when fault is occur rotor is accelerates more and more than the plugging mode is applied for some instant after clearing the fault then rotating magnetic field is rotates in opposite to rotor consequently electrical braking is done and rotor slows down and improves transient stability.

2. TRANSIENT STABILITY OF INDUCTION GENERATOR

Basically, equal area criterion is use to analyze the transient stability of synchronous generator but in case of induction machine it is analyze by using torque slip characteristics due to its asynchronous nature. Steady state torque-slip characteristic is shown in Fig. 1.

During unstable operation of machine, electrical torque is less than that of mechanical torque which leads to rotor instability which is given by equation (1)

$$T_m - T_e = J\frac{d\omega}{dt} \quad (1)$$

Where,
T_m: Mechanical Torque
T_e: Electrical Torque
J: Moment of Inertia
ω: Rotor Speed

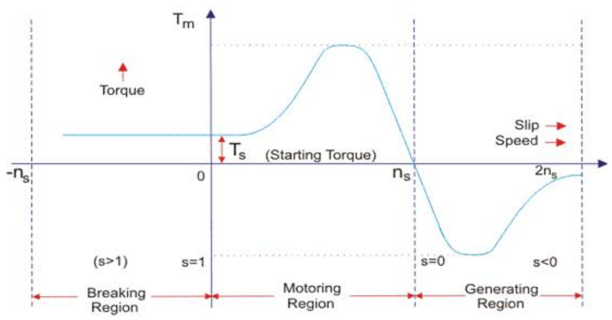

Fig. 1: Steady state torque-slip characteristics of induction generator

2.1 Electrical Torque in plugging mode

For this stability improvement , successful solution are those that can amplify electrical torque over mechanical torque therefore by using plugging operation mode of machine changes from generating to plugging which prevent the generator from further acceleration and gives electrical braking to slow down rotor speed . In plugging two phases are interchange which opposes the rotating magnetic flux and mechanical torque , which support to decrease the rotor speed.

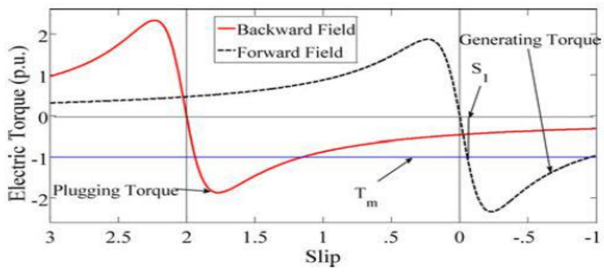

Fig. 2: Electromagnetic torque of induction machine in plugging and generating modes[14]

2.2 Limitation of plugging mode in case of Squirrel cage Induction generator and solution on that

In fig.3 generating mode (slip < 0) and plugging mode (slip > 1), the machine power is negative. Negative *Pe* in the plugging mode implies that kinetic energy of the rotor is dissipated in the form of heat in the rotor winding.

$$P_e = 3R' \cdot I_2'^2 \cdot 1\text{-}s/s$$

But it should be noted that based on the torque–slip characteristic depicted in Fig. 4, at the operating slip of s1 , the machine generates less electrical torque in the plugging mode than in the generating mode. Therefore, changing operating mode from generating mode to plugging mode makes the system more probable to instability. Because, in the plugging mode, the difference between the mechanical and electrical torques gets larger than that in the generating mode and according to (1), the machine in plugging mode accelerates much faster than in generating mode.

The aforesaid problem can be solved by using of another unique property of induction machines. The slip at which the maximum torque occurs is proportional to the rotor resistance. According to Fig. 4, for a sample induction machine, increasing the rotor resistance from *R*0 to 5*R*0 shifts the maximum torque to the starting zone (slip≈ 1). Also, by increasing the rotor resistance up to 9*R*0, the maximum torque will shift to the plugging zone (slip ≈ 2). Therefore, it is obvious that by increasing the rotor resistance, the electrical torque in the plugging mode will be greater than the electrical torque in generating mode and can result in system deceleration after fault clearance, leading to stable operation of the machine.

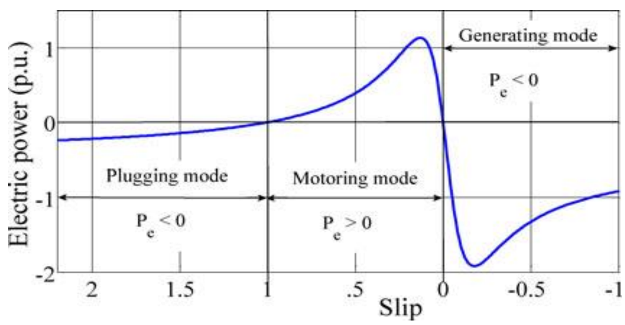

Fig. 3 Electric power–slip curve shows that in both generating and plugging modes, the power of the machine is negative.

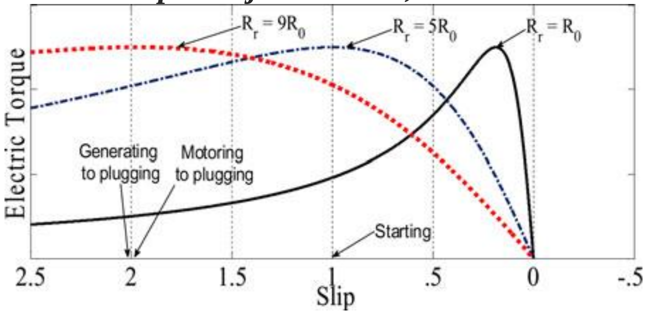

Fig.4.Shifting maximum torque to the desired slip by increasing the rotor resistance

A. Using Deep Rotor Bar or Double-Cage Rotor to Increase Electrical Torque in the Plugging Mode

Skin effect is the tendency of an alternating electric current (ac) to distribute itself within a conductor with the current density being largest near the surface of the conductor, decreasing at greater depths. The skin effect causes the effective resistance of the conductor to increase at higher frequencies. Rotor current frequency is obtained from (5). At the plugging mode, the slip is near to 2, and therefore, the current frequency of the rotor bars is almost 120 Hz. At the generating mode, the slip is near 0.03 and so current frequency of the rotor bars is almost 2 Hz. Therefore, the rotor resistance in the plugging mode is much higher than in the generating mode and at the moment of changing operation mode from generating to plugging, there will be a sudden increase in the rotor bars resistance. This is more severe in the machines with deep bars or double-cage rotor. This phenomenon is illustrated in Fig. 6:

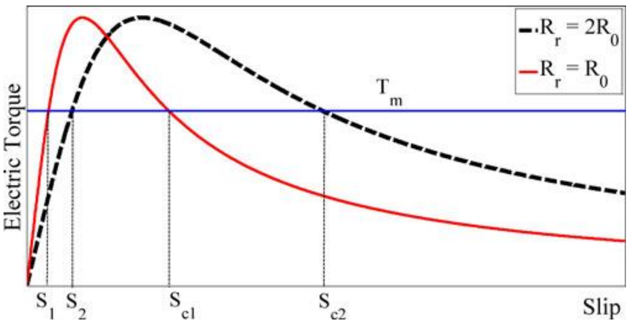

Fig. 5. Transient stability improvement by increasing the rotor resistance and, therefore, increasing the critical slip.

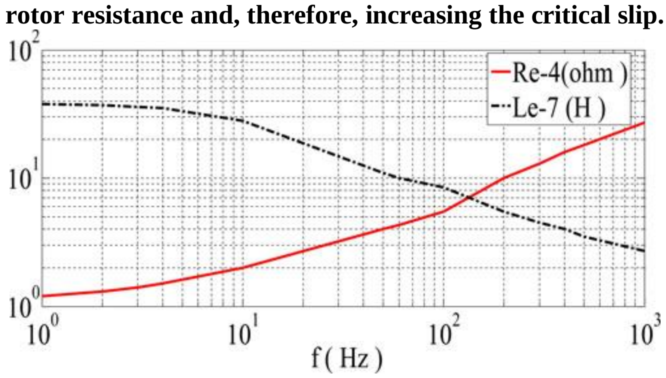

Fig. 6. Rotor resistance and inductance as a function of frequency, for a typical double-cage induction machine [16].

$$f_{rotor} = Slip \cdot f_{stator}. \quad (3)$$

The problem of electric torque is less than mechanical torque, to overcome this, property of induction generator is use in which the slip at which maximum torque occurs is proportional to resistance. But in case of squirrel cage induction generator having less value of resistance therefore it cannot enhance electrical torque in plugging and becomes more unstable. In case of double cage rotor having more outer cage resistance which enhance the electrical torque in plugging and makes the system stable.

3. DETAILS SYSTEM DEVELOPMENT

3.1 Case Study

System studies of induction generator are carried out by using MATLAB/Simulink. The power system model used for system development Fig.7.

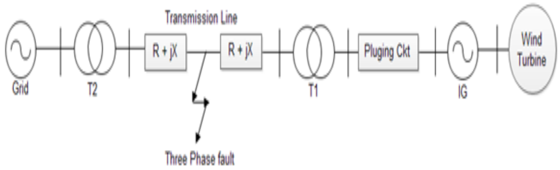

Fig. 7. Schematic diagram of simulated system

In this; three 0.015 MW induction machines with an output voltage of 400V are presented. The induction machine is coupled to the 20 KV transmission line with the help of 0.2 MVA step-up step-down transformer. A three phase to ground fault is produce at the center of line at 0.7 and it is cleared at 0.9s.

Table 1: Summary of test report

Description	Machine A	Machine B	Machine C
Rotor Winding	Squirrel cage	Squirrel cage	Double cage
Operating mode 0<t<0.9	Generating Mode	Generating Mode	Generating Mode
Operating Mode 0.91<t<0.93	Generating Mode	Plugging Mode	Plugging Mode
Operating Mode 0.93<t<2	Generating Mode	Generating Mode	Generating Mode

The mechanical input Torque to the induction generator is set at 1 p.u. throughout study for transient stability analysis of the system three tests are performed which are shown in below Table 1.

In the first test, machine A remains in generating mode in this test plugging mode is not use. Machine A is equipped with ordinary squirrel cage. In second test, in machine B plugging mode is use for the interval of 0.91 to 0.93 s, the operating mode of machine changes from generating to plugging mode and again after plugging mode machine returned to the generating mode. In third test, squirrel cage induction machine with double cage rotor is use with plugging mode operation for interval 0.91s to 0.93 s and return to generating mode again.

4. RESULT AND DISCUSSION

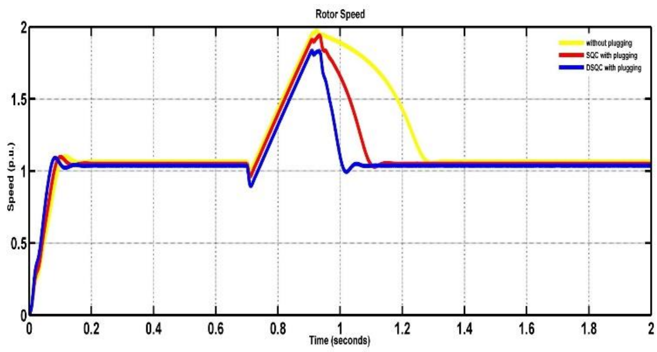

Fig.8 Rotor speed of machine A , B and C

Fig. 8 shows, rotor speed of machine A denoted by yellow line, machine B denoted by red line and machine C denoted by blue line is shown. In this fault is occur at 0.7 sec after that rotor speed increasing but when fault clears at 0.9 machine A and machine B takes more time to stable than machine C. From this result it is seen that plugging to double squirrel cage induction generator becomes earlier stable than both A and B machine by using plugging mode operation after fault clearance.

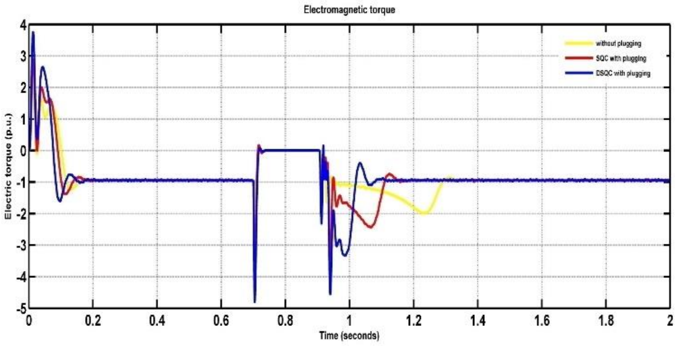

Fig. 9. Electromagnetic torque of machine A, B and C

In Fig. 9, Torque of machine A, B and C is shown. From this we can say that again machine C becomes stable after plugging mode operation and it enhance its electrical torque over mechanical torque and becomes steady state.

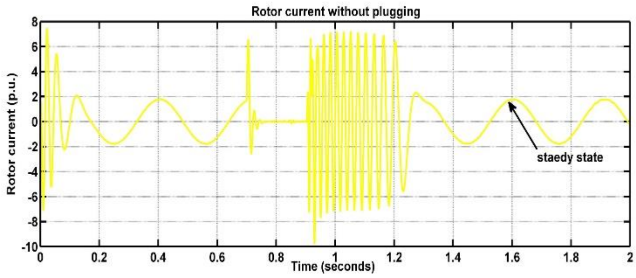

Fig.10. Rotor current of machine A

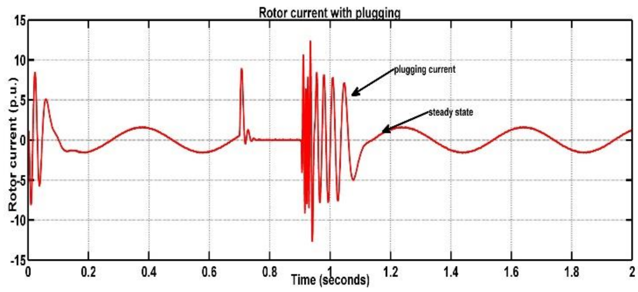

Fig.11. Rotor current of machine B

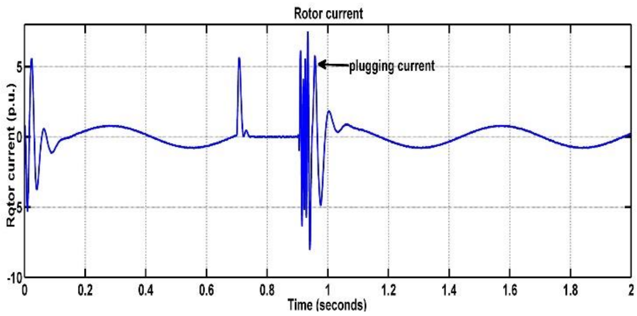

Fig. 12. Rotor current of machine C

From Fig.10, Fig. 11 and Fig 12 shows that the machine A is takes more time to steady state than machine B and C. Machine B and machine C takes time 0.28 sec. and 0.195 sec. respectively to steady state as shown in fig.

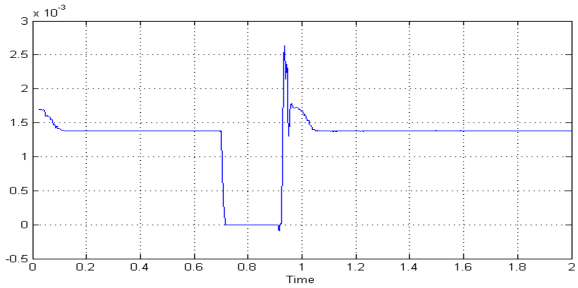

Fig.13. Reactive power of machine C.

In Fig. 13, reactive power of machine C is shown, after plugging mode operation reactive power absorb by induction generator becomes decrease and become stable as that of before.

Therefore, it can say that plugging is efficient only at one condition that during plugging frequency, resistance should be high enough. Due to which plugging at lower value of rotor resistance in plugging frequency become more unstable than that of machine A which is in generating mode.

5. CONCLUSION

(a) In this paper we have shown that plugging mode operation can substantially improve the transient stability of Smart Grid.
(b) Using the plugging mode can be useful just in a condition that the resistance of the rotor bars in the plugging frequency is big enough. Thus, for a machine with small resistance of rotor bars, staying in the generating mode results in better performance.
(c) Using plugging mode operation along with rotor speed of IG, rotor current and electromagnetic torque also stabilized to steady state condition from transient state.

6. ACKNOWLEDGEMENT (optional)

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