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Transient Stability Enhancement of Induction Generator

Piyush Bahad, Nachiket Korde
Jhulelal Institute of Technology, Nagpur, Maharashtra, India

ABSTRACT

Transient stability enhancement of induction generator is one of the main issues in wind power generator. Fault or any of sudden disturbances on power system may cause rotor speed instability and voltage instability. This paper investigates for transient stability enhancement of induction generator after fault. For transient stability enhancement, the method used in which unique property of reversing the rotating flux of stator field is employed. In this method, after clearing fault for short time rotating field of stator is reversed results in opposition between stator rotating field and mechanical torque. It is nothing but changing operating mode from generating to plugging. This operation avoids rotor from further acceleration. Simulation result shows that proposed method is efficient for enhancing transient stability. Since in this method, no need of any external equipment, proposed method is more attractive than previous methods, from economic point of view.
Keywords : Active Power, Induction Generator, Plugging Mode, Reactive Power, Rotor Resistance, Rotor Speed Stability, Transient Stability, Torque- Slip Characteristics.

I. INTRODUCTION

An induction generator or asynchronous generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotor in generator mode, giving negative slip. Induction generators produce electrical power when their rotor is rotated faster than the synchronous frequency. Induction generator cannot produce reactive power but it consumes reactive power from external source or grid to maintain the stator magnetic field and must control terminal voltage of the generator [1]. Faults that occur on transmission line that lead to over speed and instability of network voltage [2]. After fault clearance and voltage recovery, the speed rotor of induction generator is so high that it does not return to stable value easily. It accelerates to high speed and takes more time to stable [3].

In [4] and [5], using the braking resistor is introduced as a solution for improving transient stability of IGs. The braking resistor decreases the rotor speed and hence improves transient stability. Braking resistors that are connected to the IGs absorb less electrical power in comparison with the braking resistors that connect to synchronous generator and it shows that the braking resistor is less effective in improving the IGs stability than that of the synchronous generators.

In [6] rotor resistance increase after fault so that stable operating region increases and accelerated speed of rotor also reduces to stable value. In [7], the effect of FACTS devices on regulating bus voltage and therefore, on improving transient stability is presented. In [8] and [9], it is shown that SVC and STATCOM considerably improve the system stability during and after disturbances. But solution based on FACTS devices has been recognized as expensive methods.

All the three methods mentioned previously (FACTS devices, rotor circuit control, and braking resistor) need additional equipments such as SVC, STATCOM, UPFC, external resistor.

In this paper, a new and simple method is proposed to enhance transient stability of IGs without using any additional equipment. In this method, the possibility of altering the induction machines operating mode is employed. After fault clearance by just interchanging any two of the stator leads, the operating mode changed from the generating mode into plugging mode for short time so, it does not allow further acceleration of rotor.

II. TRANSIENT STABILITY OF INDUCTION GENERATOR

The equal area criterion was originally developed for synchronous generators and is not a suitable method for evaluation of the IGs transient stability because the operation of an IG is significantly different from that of a synchronous generator due to the nature of its asynchronous operation. IG's stability can be analyzed using the torque–slip curve.

A. Stable Operation

During stable operation electrical generator torque and the mechanical turbine torque are balanced. At this point IG operate at steady state. When system fault occur there is sudden drop in ac voltage as well as electric torque and reactive power. As mechanical torque is greater than electric torque, the IG will begin to accelerate and speed increases. Suppose fault is clear after small time, ac voltage start to recover and IG absorb large reactive power. When electric torque is greater than mechanical torque then it acts as breaking torque and it reduce the speed of rotor and slip also decreases. Deceleration of the IG and decline of rotor slip means a reduction in the reactive power absorbed by the IG. This reduction in the absorbed reactive power, cause to a rise in ac voltage. Stable operation of induction machine in motoring and generating mode is shown by torque-slip curve in Fig.1.

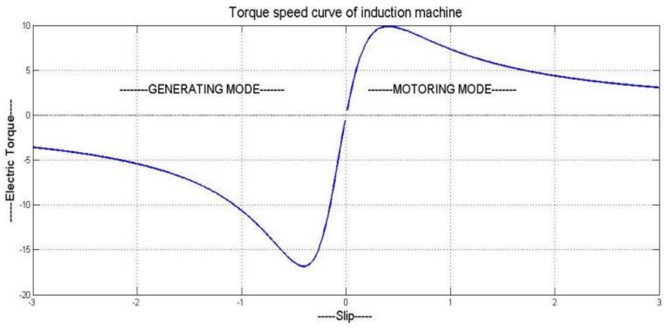

Figure 1. Steady-state torque-slip curve of induction machine

The generalized torque equation for induction machine is given as:

$$T_{em} = \frac{(3*V_{th}^2*\frac{R_r}{S})}{(\frac{N_s*2*pi}{60}*(R_{th}+\frac{R_r}{S})^2+(X_{th}+X_2)^2)} \qquad (1)$$

T_{em}: Electromagnetic Torque
V_{th}: Thevenins equivalent voltage
R_{th}: Thevenins equivalent resistance
N_s: Synchronous Speed
R: Rotor Resistance
S: Slip

B. Unstable Operation

If fault is ON for longer time rotor speed goes on increasing, slip also increases to higher value. Electric torque is less than the mechanical torque therefore rotor slip increases and making the system unstable. If the slip is less than (note that the slip in the generating mode is negative) critical slip or rotor speed is higher than critical speed, the machine will be unstable. Therefore, transient stability can be improved by decreasing the critical slip of the IG. This can be achieved by

- Decreasing the value of stator resistance, stator reactance, mutual inductance, and rotor reactance, and
- Increasing the value of rotor resistance.

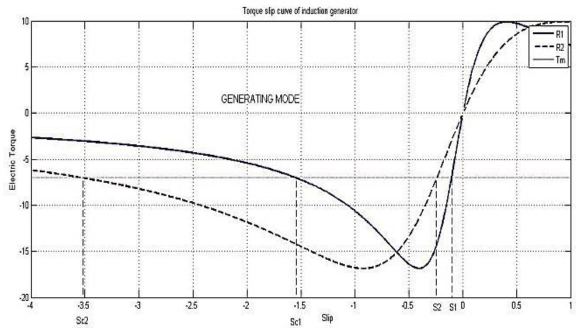

Figure 2. Transient stability improvement by increasing rotor resistance.

The most effective parameter is rotor resistance. Transient stability improvement by increasing the rotor resistance is shown in Fig.2. With the rotor resistance R_1, the stable operating slip varies from its initial value S_1 to the critical slip Sc_1. When the rotor resistance is increased to R_2, the stable operating range is expanded as from S_2 to Sc_2. Therefore, by increasing the rotor resistance there is a significant expansion in the stable operating range.

C. Case Studies Using Plugging Mode

Transient stability simulations were employed to verify the effectiveness of changing operating mode of IGs from generating mode to plugging mode after fault clearance. The test system utilized is shown in Fig.3, which consists of induction generator injecting power of 0.15-MW through the transmission line to the grid.

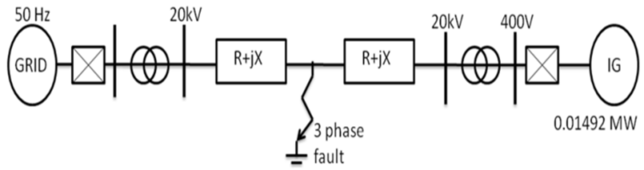

Figure 3. Schematic diagram of simulated system

System studies of induction machine are carried out using MATLAB/Simulink. In this case generator supplying power of 0.15-MW in the transmission network with output voltage of 400 V. Table I show the electrical parameters of induction machine. As shown in fig. 3, the induction machine coupled to the 20-kv network through a 0.2 MVA transformer and connected to infinite bus. A three-phase-to-ground fault is produced at middle of the transmission line from 0.7 to 0.9 s. During fault, rotor gets accelerated, voltage decreases to zero and current increases suddenly to a large value. After fault clearance at 0.9 s. rotor speed still goes on accelerating for long time while voltage and current is settled to the stable value. Fault occurs on the system at the time between 0.7 s. and cleared after 0.2 s.

In the first test, system is same during fault and after fault; operating mode does not change during test. In second test, after clearing fault at 0.9 s., the operating mode of machine is changed from generating mode to plugging mode in the interval between 0.91 s. to 0.95s. At the instant of 0.95 s., the machine gets returned to the generating mode again.

Table I: **Specification Of Induction Machine**

Nominal Power	0.1492 MW
Nominal Frequency	50 Hz
Voltage (line-line)	400 V(rms)
Stator resistance	0.01965
Rotor resistance	0.01909
Stator inductance	0.0397
Rotor inductance	0.0397
Mutual inductance	0.1

III. Simulation Results

Speed

As we are working with induction generator, speed of rotor is more than synchronous speed. In case of p.u. system, it is more than 1 p.u. shown in Fig. 4 in generating mode operation. As fault occurs on transmission system at 0.7 s, speed of rotor increases to sudden high value up-to fault cleared at to 0.9s. After clearance of fault time taken by system conventionally is shown in Fig.4. While in case of plugging mode after fault clearance for short time operating mode changes from generating to plugging mode than again operate in generating mode shown in Fig. 5. Comparison of speed recovery in both cases is shown in Fig. 6. Comparison shows that speed stabilized rapidly in case of plugging mode.

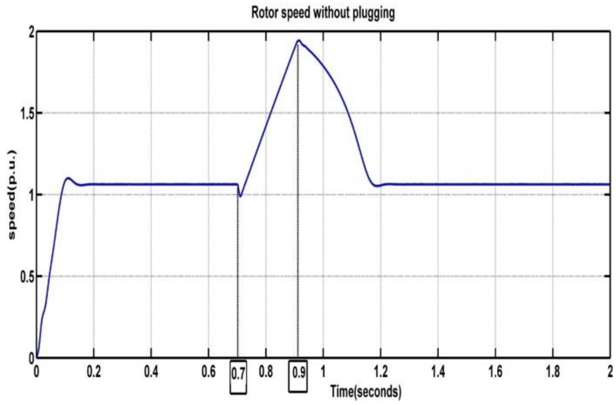

Figure 4. Rotor speed without plugging mode.

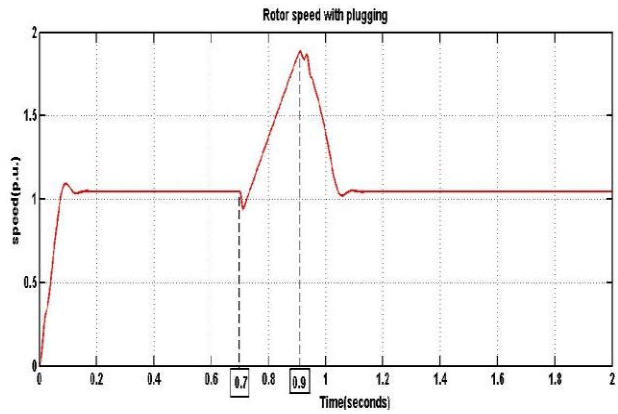

Figure 5. Rotor speed with plugging mode.

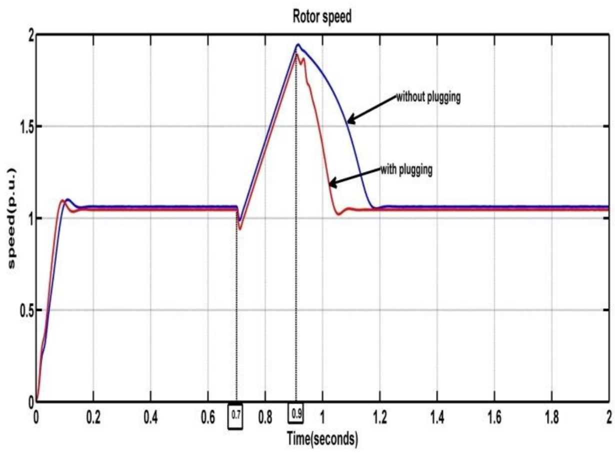

Figure 6. Comparison with and without plugging mode

Stator current and Rotor current

During starting stator and rotor current both are high after some time it comes to stable value. Frequency of stator current is same as the grid frequency, while rotor current frequency is less. When fault occurs, stator and rotor current both increases suddenly to the high value and becomes zero during fault time. After fault clearance for short time, operation changes from generating mode to plugging mode. As shown in Fig. 7, the stator has high current after fault clearance in plugging mode, called as plugging current and it comes to the stable value earlier as compared to conventionally time consumed by system. Rotor current also comes to the stable value earlier as compared to the conventional system shown in Fig. 8.

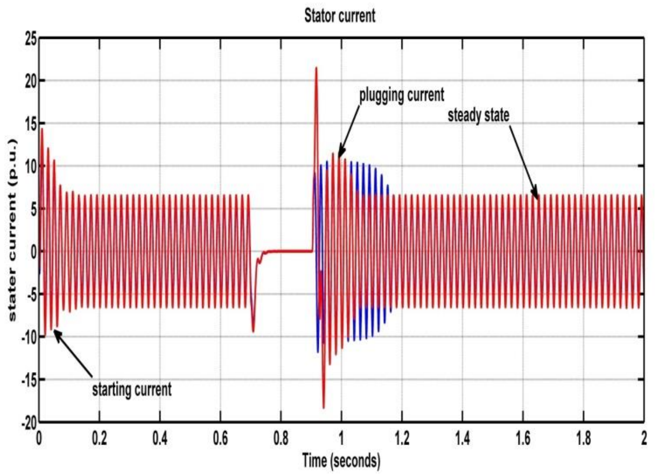

Figure 7. Comparison of stator current with and without plugging mode.

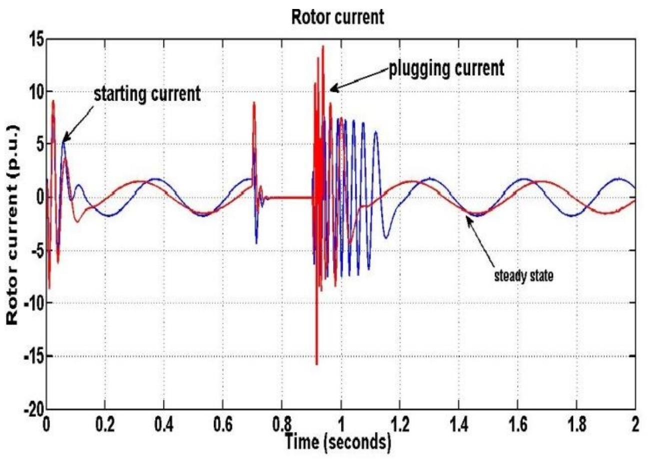

Figure 8. Comparison of rotor current with and without plugging mode

Electrical Torque

The electromagnetic torque in generating mode and plugging mode are negative. Equation 2 confirms that it would lead to decrease in the rotor speed after fault clearance.

$$T_m - T_e = J\frac{d\omega}{dt} \tag{2}$$

In any of system, there is balance between mechanical torque and electromagnetic torque. When any of the loads increases or decreases suddenly or any of faults occurs on system causes unbalance between mechanical and electrical torque, which causes increases in rotor speed. Speed is unstable still balance not occurred. In case of conventional system more time taken to balance between mechanical and electrical torque, but by applying plugging condition early balance is possible shown by Fig 9.

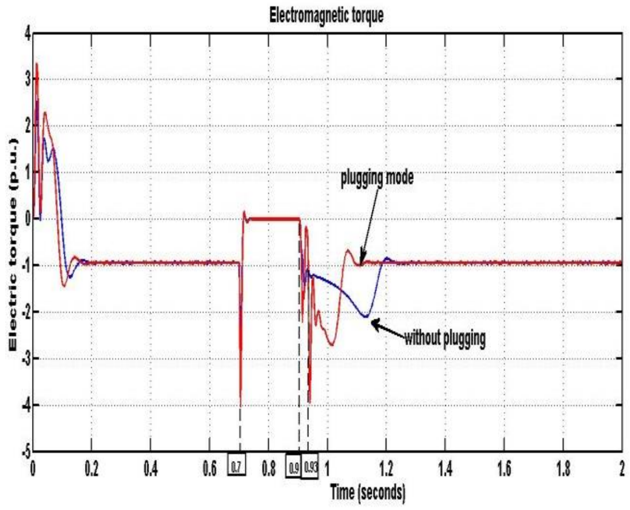

Figure 9. Comparison of electromagnetic torque with and without plugging

IV. CONCLUSION

Transient stability can be improved more effectively by changing operating mode from generating mode to plugging mode. This method is more effective than others such as, using FACTS devices, rotor circuit control, increasing rotor resistance, using braking resistor, SMES (Superconducting Magnetic Energy Storage device) or pitch control because all these methods require additional equipments which made more complicated and economically high in value. Simulation results confirm the effectiveness of the proposed method shown by the table II, which seems to be more economical alternative in comparison with other methods.

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