SHORT-CIRCUIT CURRENTS SUPPLIED FOR INDUCTION GENERATORS

Juan Carlos GOMEZ
Rio Cuarto National University- Argentina
jcgomez@ing.unrc.edu.ar

Sebastián M. NESCI
Rio Cuarto National University- Argentina
snesci@ing.unrc.edu.ar

Franco A. BARBERO
Rio Cuarto National University- Argentina
fbarbero@ing.unrc.edu.ar

ABSTRACT

Short circuit current supplied by induction generators is becoming a matter of concern due to the increasing power share. Besides, in spite of that the induction generator operation principle is analogous to the traditional synchronic generator, its excitation and thus short-circuit supply is widely dissimilar: Induction generators are mainly applied to produce electric energy through wind turbines. Several papers showing analytical studies have been published, but just a few experimental results have come out. The present work is carried out mainly experimentally, extending the results by applying simulation software. Experiments using laboratory scale induction generator are presented. Four induction generator excitation types where investigated: remnant magnetism excitation, capacitor excitation, dc rotor excitation, and double feed induction generator. As rarely just one type of excitation is available, combined excitations were also studied. The research shows that induction machine short circuit contribution is closely related to excitation type and that the currently used initial and successive damped values represent an overestimation.

INTRODUCTION

Induction generators are mainly applied to produce electric energy through wind turbines, being directly connected to distribution lines. Wind power generators usually belong to utilities or companies which main activity are electric energy generation, and associated businesses. Calculation of short-circuit current supplied by synchronic generators is a very well known procedure, with strong analytical roots and easy to carry out by using any of several today available specific software [1]. Conversely, magnitude and duration of short-circuit current supplied by induction generators is not easy to calculate due to the many dissimilar involved technologies and machine schemes. Presently, several power systems have or are in the way to reach the wind-power share limit of penetration, due to operation constrains and stability limits, which as several researchers expressed is of 20 % [2].

Must be also considered that each generator type has dissimilar short circuit current contribution, being very high for synchronous generators, lower for asynchronous or induction generators and very low for generators using inverters [3]. The mentioned penetration limit and the relative size of induction generators indicate that short-circuit current contribution is now a matter of concern. Several papers showing analytical studies – based on classical theory and applying specific simulation software – related to this short circuit current have been published [4], [5], [6]. Besides, just few experimental results have come out [7], [8].

The induction and synchronous machines operation under transient conditions, and specifically under short-circuit situation, can be theoretically analyzed by using the theorem of constant flux linkage [1], [5]. The mentioned theorem indicates that the total flux linkage with any closed circuit cannot change when a disturbance occurs but must remain constant at the initial value. Thus, all the machine circuits will react to any intent of change of flux linkage; currents will necessarily appear in the involved closed circuits. As there are no sources to maintain these currents flowing, they will decay in time following an exponential law, ruled by the corresponding time constants [1]. Depending on the number and type of closed circuits, dissimilar phenomena (different current magnitude, duration and wave shape) may exist, producing the well known direct-current (dc), subtransient, transient an steady-state current components or time periods [9], [10]. The four mentioned phenomena have durations that depend on the machine characteristics and external circuit for the three former ones and on the protection system for the last duration phenomena. It has been considered that the equipment size and phenomena durations are such as to not introduce speed change that is true for real world machines and reasonably accurate for laboratory machines [11], [12].

RESULTS

Four induction generator operating principles ranging from 5 to 10 kW where experimentally investigated: remnant magnetism excitation, capacitor excitation, dc rotor excitation of wounded rotor induction generator working as synchronic machine, and multiple feed induction generator, without power electronic interphase. Each machine was operated at as many operation schemes as possible. The test procedure consisted in the application of a sudden short-circuit on to the machine terminals, while connected to the main supply by a non-rigid connection, being the machine adjusted for rated voltage and synchronic speed, recording short-circuit magnitudes by using a digital oscilloscope. The non-rigid connection (through a suitable current limiting resistance/inductance) is used in order to limit the main supply collaboration to short-circuit current.

A. Induction machine excited by remnant magnetism

A 5.5 kW induction machine was connected to the laboratory supply, being transferred to non-rigid connection after the start. Afterwards, the machine was short-circuited...
during suitable time, which allows the record of the phenomena. Figure 1, shows short circuit currents supplied by this machine excited by remnant magnetism, showing also the subsequent restart current after the short-circuit cleaning. The current first peak magnitude depends on the short-circuit connection angle and is mainly ruled by the armature winding time constant, but the following current decaying part depends on the electromagnetic and mechanical time constants. These three time constants can be estimated through some simple tests. Also, the restart phenomena showing the classical oscillations can be easily seen.

**Figure 1, Behavior of squirrel-cage induction generator excited by remnant magnetism.**

Other tests on an induction machine, but of wounded rotor type were carried out, that show a faster current reduction, due to its shorter time constants. It can also be seen the restart process after short-circuit has been cleared, that have similar form to that shown in Figure 1. Oscillogram, clearly illustrates that short-circuit current supplied by induction machines only excited from the main supply has short duration, and magnitude similar to motor direct-start current, being followed of the restart-current.

**B. Squirrel-cage rotor induction generator excited by capacitor.**

The test procedure was similar to the previous one, having now capacitors which fully compensate motor magnetizing current, in other words providing the necessary excitation.

**Figure 2, Short-circuit current of capacitor excited induction generator.**

Figure 2 shows three components; high frequency short duration capacitor discharge current, induction generator fast damped contribution and constant main supply contribution current. Analytical results obtained by using MATLAB SIMULINK, applying the corresponding machine and circuit characteristic values show close resemblance to Fig. 2. Short-circuit currents of this type of generation shows lower magnitude and longer duration than the previous scheme.

**C. Wounded rotor induction generator with dc rotor excitation.**

A wounded rotor induction machine was run at rated speed and excited with dc current through two of the rotor terminals up to reach 50 % of the armature rated voltage. This particular excitation circuit is composed of two phase windings which magnetic directions have an angle of 120°, thus the resultant flux is the geometric addition. This 50 % percentage was not overcome due to dc supply limitations, which added to the explained angle difference inhibit rated stator voltage completion. Reached the mentioned conditions, a sudden three-phase short-circuit was established at its terminals, recording armature currents.

**Figure 3, Short-circuit current of induction generator operating as synchronous machine.**

Figure 3 shows the dc, transient and steady-state components. Subtransient component does not exist due the rotor is not provided of dumping winding and to the lack of any other possible circuit of low inductance/resistance ratio where currents can be generated by applying the theorem. In other words, the behavior is similar to a normal synchronous machine but with lower magnitudes and shorter non permanent phenomena duration [13]. Machine rated values were not reached due to equipment limitations.

**D. Double feed (ac rotor excitation) induction generator.**

The same wounded rotor machine used for the previous experiment was tested as double feed induction generator. The machine was driven by an induction motor supplied by an adjustable speed drive that allows a wide speed control, being the generator excitation feed through the rotor winding, getting the generation from the stator winding, which eventually will be connected to the main supply. A speed adjustable synchronous machine was used for the adjustable frequency excitation. Several tests were carried out, being some of them described below. The under test generator speed was adjusted to 9 Hz, that is 270 rpm, and the variable frequency excitation supply was set on 41 Hz, which together results in generation at 50 Hz. Once the necessary conditions were reached, the induction generator was paralleled with the main supply, in semi-rigid way. Under this situation, a sudden short-circuit is applied.
Figure 4 shows the short-circuit current supplied by the generator and main supply. As expected, Figure 4 illustrate that the behavior of this generation scheme is very similar to a synchronous machine. Stator flux related to the stator rotates at the synchronous speed, 50 Hz and 1,500 rpm in this case.

Rotor flux rotate respect to rotor at 41 Hz, in other words at approximately 80% of the synchronous speed, that is 1,230 rpm. As rotor speed was 270 rpm, the rotor flux to rotor relative speed results also 1230 + 270 rpm, then both fluxes are rotating at the same speed thus the fluxes relative speed is zero, both are synchronized. Similarly to any synchronous machine, after that the terminal short-circuit has been started, the current is kept by the existing excitation. The non-permanent phenomena are caused by the dc component and the transient component circulating through the rotor winding. Subtransient phenomenon is not present due to the lack of squirrel cage. Presence of oscillations on the current magnitude is clearly visible, which is due to the influence of the mechanical system and its interactions, which were previously mentioned but not considered [12].

Figure 5 shows the MATALB SIMULINK scheme used for the modeling of short-circuit phenomena on this type of excitation.

Figure 6 shows analytical results, which is very similar to the experimentally determined oscillogram, shown as fig. 4.

Figure 6, analytical short-circuit current for double-feed induction generator.

E. Triple feed (ac rotor excitation) induction generator

Similarly to the previously explained case, but now with parallel connected capacitors, providing an additional excitation source. Thus excitation is triple: rotor, stator main supply, and stator connected capacitor. This situation is normally presented in the real world due to connected capacitors or through the distributed capacity of interconnection cables, which is today starting to be usual due to the world wide dissemination of offshore wind farms. Figure 7 shows the experimentally obtained short-circuit current supplied by the induction generator, where capacitor discharge current, dc and transient components can be easily seen.

Figure 7, short-circuit current supplied by a triple fed induction generator.
The oscillogram shown in figure 8 is rather complex, where can be seen initially the load current supplied by the mains, followed by the short-circuit value, until the fault is cleared. Afterwards an overcurrent is presented, which corresponds to the induction generator re-excitation and capacitor charge that are quickly damped out, followed by a mechanical oscillation until the normal load current is recovered. Figure 9 shows the simulated results obtained by applying the mentioned software, using the scheme of fig. 5 including now capacitors. The general form is similar to fig. 8, but slight amplitude differences due to the impossibility of considering all the involved mechanical characteristics.

CONCLUSIONS

Short-circuit current supplied by an induction generator just excited from the mains can reach the start current value, depending on the making angle and the damping speed. The restart current is lower than the start one. The short-circuit phenomena in case of machine excited by capacitor is similar to the case of excitation by network, but the presence of the capacitor discharge current. This component can reach high values depending on the short-circuit angle, in spite of that its duration is short. When the induction machine is connected as synchronous, short-circuit current would be similar to start current of the machine as induction motor. Once the non-permanent period has elapsed, the permanent value will be kept by the dc excitation, similarly to a synchronous machine. Maximum current was reached when excitation was through a frequency converter feeding the rotor, plus the stator excitation from main supply and capacitors. Short-circuit permanent current was of the same order that induction motor, also a speed change was noticeable. Research shows that the induction machine short circuit contribution is closely related to the excitation type. Maximum electrodynamic solicitation is reached for double and triple-fed machine. The currently used initial and successive damped values represent an overestimation. Induction generator behavior modeling by MATLAB SIMULINK represents a useful tool provided that results are verified by experiments.

REFERENCES