

ASYNCHRONOUS OPERATION AND RESYNCHRONISATION

OF LARGE HYDRO-ALTERNATORS

by

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ABSTRACT

In a power system under certain adverse conditions like post fault operation, a synchronous machine or even an entire generating station may fall out of step with the remaining system.

Although asynchronous operation and pulling into step of synchronous motors and condensers are common, large alternators are not generally operated in the asynchronous mode. In the event of an alternator losing transient stability the normal practice is to disconnect the machine from the busbars and later synchronising it by the "exact synchronisation" method. Such a procedure involves the loss of generating capacity and hence interruption of supply to many consumers for a considerable interval of time.

In order to avoid such loss of generating capacity subsequent to a severe disturbance investigations have been carried out in the past to study the feasibility of operating the synchronous machine in the asynchronous mode with its field excitation removed for a short duration and re-energised at a suitable moment, thus allowing the machine to pull into synchronism automatically.

The objective of the present work is to analyse and examine in depth the asynchronous mode of operation of the alternator and means for effective resynchronisation.

The asynchronous mode of operation can be studied using Park's equations, that can predict the performance of an

idealised machine correctly. However, the Park's model is quite involved and thus from practical considerations it is necessary to go for simplified models that can provide results within engineering accuracy.

Many works ^{4,7,9,17,23,27} have reported the asynchronous operation and re-synchronisation aspects for both round rotor and salient pole machines. Simplified models have been suggested^{4,7,27} for the analysis. In the present work it has been highlighted that the simplified models used in the past give poor results for certain modes of field termination, and values of transmission line reactance while obtaining the average torque/slip characteristics upto their first peak. In view of this an attempt has been made to develop a new simplified model which can provide better results than the simplified model suggested in the past. The effect of different modes of field termination and line reactance on average torque/slip characteristics, maximum average torque, torque pulsation and rotor heating have been studied for the asynchronous mode. The nearly best mode of field termination from the point of view of maximum average torque, reduced torque pulsations and reduced rotor heating has been highlighted. A simplified expression for direct evaluation of the maximum average torque has been suggested. Malik and Cory¹⁷ have questioned the validity of the assumptions considered by different authors for developing simplified models to study asynchronous operation. They have simulated the synchronous machine adopting

assumptions no more extreme than those inherent in the two-reaction theory of synchronous machines announced by Park. They have conclusively proved that their model based on exact Park's model with variable slip consideration gives closer results to the ones obtained experimentally on a micromachine as compared to the results obtained from the simple approximate model based on constant slip consideration. Although Malik and Cory have adopted a more exact model without any simplifying assumptions, their model is computationally quite involved. One of the significant contributions of the present work is in developing an approximate model with variable slip consideration which is much simpler and yet gives results quite close to the ones obtained by the exact model of Malik and Cory. Results of the investigations reveal that the best mode of field termination during asynchronous operation is not the field open circuited mode as pointed out by earlier authors, but rather corresponds to the field terminated by a definite magnitude of external resistance. The effect of governor influence on asynchronous operation which has received little attention in the past has also been studied.

In the past hardly any work has been reported to highlight the influence of different excitation control schemes on the process of resynchronisation. In view of this the resynchronisation aspects have been investigated with different types of excitation schemes having different types of feedback signals in order to suggest an effective excitation control scheme for successful resynchronisation.

In chapter 1 a short review of the previous work and a broad outline of the present work is given.

Asynchronous operation and resynchronisation problems have been studied in the past using rigorous Park's model. Chapter 2 pertains to the development of suitable mathematical models for the analysis of asynchronous operation only. Rigorous Park's model has been presented, mention of the existing approximate model has been made and later a much superior approximate model is developed in detail. The more rigorous Park's model and the two approximate models have been compared and discussed qualitatively.

In Chapter 3 distinct superiority of the new approximate model developed in Chapter 2 over the old approximate model has been clearly demonstrated quantitatively. The average torque/slip characteristics upto their first peaks for different operating conditions like different modes of field terminations and values of external reactance are found out for the two approximate models and compared with those obtained by the more rigorous Park's model for justifying the superiority of the new approximate model over the old one. Effect of field external resistance on rotor heating has also been studied and suggestion has been made for its optimum selection. Effect of different modes of field terminations on steady asynchronous operation has also been studied with a view to decide the best mode. Since the knowledge of the maximum average torque developed during asynchronous operation is important, it would be of

practical significance, if T_{av-max} could be evaluated directly without going to the recourse of computing T_{av} for different slips and hence obtaining the maximum which involves much computational time. In view of this, a simplified expression has been developed that can compute directly T_{av-max} from a knowledge of the machine and system parameters. The validity of this simplified expression for T_{av-max} within engineering accuracy has been tested for different modes of field termination and values of external reactance.

In the earlier chapter asynchronous operation has been studied with the assumption of constant slip. Malik and Cory¹⁷ have pointed out that the analog computer results for average torque-slip characteristics obtained by Park's model considering variable slip are close to the test results obtained on a micro-machine than the results based on the Park's model with constant slip consideration. In view of this Chapter 4 develops the exact Park's model with variable slip consideration in the state-space form. The state model developed has shown to be more powerful by selecting the state variables explicitly as the flux linkages, instead of a combination of flux linkages and currents or currents only as used in the past. However, the exact Park's model with variable slip consideration is quite involved. An attempt also therefore, been made to develop a much simple approximate model with variable slip consideration to provide results close to those based on the exact Park's

model with variable slip consideration. The effect of torque input, external reactance and field mode termination on instantaneous quantities like electrical torque, slip, line current, field current and generator terminal voltage during steady asynchronous mode has also been discussed. Attempt has also been made to highlight the best mode of field termination during asynchronous operation.

In Chapter 5 governor action is considered for asynchronous operation. The effect of changes in the governor parameters on asynchronous operation has been examined.

Chapter 6 deals with the resynchronisation aspects. The influence of different types of excitation voltage regulators working on the feedback signals of angle, current and voltage on the pulling into step performance has been critically examined. The performances of the different regulators are compared from the view point of effective resynchronisation. Effects of different gains in the feedback channels of the excitation control schemes, ceiling excitation and mechanical inputs on the resynchronisation performance have also been discussed which have not been attempted in the past.

Finally, Chapter 7 highlights the detailed conclusions of the entire work and the scope for further work.

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