REVIEW OF SYNCHRONIZATION OF TURBO GENERATORS

BY

SUNDAY OKEREKEHE OKPIGHE[1]*; CHARLES MONYE[2]; JAMES EJENIKE OGAGAROJO OVRI[3]

[1] DEPARTMENT OF PROJECT MANAGEMENT TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, NIGERIA.

[2.] MANAGER , BOILER/TURBINE SHOP, THERMAL POWER PLANT AND TURBO BLOWER STATION, AJAOKUTA STEEL COMPANY, AJAOKUTA, NIGERIA.

[3.] DEPARTMENT OT MATERIALS AND METARLLUGICAL ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, NIGERIA.

* CORRESPONDING AUTHOR

ABSTRACT

A Review of Synchronization of Turbo-generators is reported. Factors and criteria for effective and efficient synchronization have been highlighted. Consequences of poor synchronization have been enumerated. The role and benefits of synchronization in the scheme of the power grid system has been emphasized

KEY WORDS: Turbo-Generator, Synchronization, Voltage, Frequency, Phase Angle

INTRODUCTION

Controllable inductive fault current limiters can not only protect against short-circuit faults, but can also enable “gentle” synchronization of turbine generators in isolated power systems and help to maintain synchronization during fault events. These effects are proven by simulations of systems containing two 36 MW, 13.8 kV turbine generators operating in an isolated power system. The use of controllable inductive fault current limiters increases the transient stability, yields smaller oscillations in active power (2.8 versus 6.8 MW) and reactive power (1.6 versus 5.2 MVAr) during a faulty synchronization process (with 5° initial phase difference). Also, during a three-phase-to-ground fault, the current limiter reduces peak currents by 61.2% (from 12.9 to 5.0 kA_{arms}), and helps to maintain generator synchronization during and following serious short-circuit faults.[1]. In a similar vein,

a specific Engineering and Training Simulator is described in detail for the Turbo-generator Model which is a physical model of a Czech Power Plant. This Power Plant consists of six turbo-generators with power 60 MW each. The process model is developed on the basis of mathematical-physical analysis ("first principles" method) of the individual technological subsystems. Dynamic model consists of the common steam collector and of two steam turbines-generators. The process model describes the standard and abnormal operation regimes in the range of 0 % - 100 % of Maximum Continuous Rate, with implementation of individual disturbances by the instructor. The own-built library called "EnergySIM" was developed on the basis of MATLAB-SIMULINK packages.[2]

Because of the awareness in many countries of the objection of pollution, and the lack of available cooling water, modern steam power plants frequently lie far from load centres. Moreover, the rating of turbo generator units is continuously growing, following technology's trends, size economies and the increasing demand on electrical energy. Power transmission lines for large distances are consequently required, thus raising the need for improved safety, reliability, and control of the power plant system as a whole. Reliability especially appears to be a critical factor, affecting the quality of delivery and the economy of production, so that improved reliability is increasingly required. The paper concentrates on the consequences of a typical electrical failure on the reliability of the largest turbo generator unit which is going to be operated in Italy. Owing to the mutually dependent behaviour of the system's different parts, obviously an interdisciplinary problem, it was necessary to construct a general model of a thermal power station which allowed for the simulation of the transient conditions under study, thus providing pertinent solution data and suggestions.[3] In a similar vein, high speed synchronous generators driven directly by gas or steam turbines was investigated. After reviewing problems and interest of variable speed in high power plants, the authors present a brief state of the art about the abilities of classical static inverters to adapt variable frequency to grid ones. Considering the lack of practical solutions, they propose a structure based upon an original use of a matrix converter. Its principle is validated through first experimental results.[4]

. Furthermore, a review of power-system synchronization, proper sync-check coordination, and fast synchronization methods were considered. When paralleling two sources, it is crucial that the interconnecting circuit breaker be closed only when both sources are in voltage, frequency, and phase coincidence. An operator can synchronize manually or use one of the latest, state-of-the-art automatic synchronizers (ANSI/IEEE device 25A) and sync-check relays (ANSI/IEEE device 25) to automate closing. Generator and bus synchronization share most principles-with some important differences-for each type of synchronization. For generation plants, the method of generator synchronization selected depends greatly on the plant configuration and operating mode. For bus-line applications, the synchronizing method selected depends on the power-system "stiffness", motor loads, and whether a wye-delta transformer is located between the line and bus.[5]

Synchronization is the process of matching a source (generator) with an existing power system, making it possible to operate these systems in parallel. During this process, the voltage, frequency, and phase angle of the generator is synchronized with the voltage, frequency, and phase angle of the power system. The two sources must have (nearly) identical voltage magnitude, frequency, and phase-angle relationships in order to safely parallel the two systems. When paralleled, the synchronized power systems can exchange power and load flows. Proper synchronization provides the following outcomes: i)Minimum disturbance to the two paralleled systems ii)Minimum mechanical and electrical shock to the oncoming generator iii)Monetary benefits from enhanced equipment longevity iv)Rapid loading of the oncoming generator provides power to loads quickly[5].

Also a method for soft-synchronization of generators by controlling an inductive fault current limiter located between the generator and the grid described. Our method limits the peak shaft torque and the frequency oscillations that normally occur following mistimed closure of the bus tie switch. The method improves the success rate of generator close-in, especially during emergencies or when operating with low transient-stability margin, with low inertia and, therefore, it lengthens the life of turbo generators. This method introduces no adverse effects during an ideal (correctly timed) generator-synchronization process. We prove the success of the technique by using transient time-domain analysis and describe the control and an approach to analyze the soft-synchronization process that can be generally applied to either an infinite power system or to a limited-capacity system. After the generator is synchronized to a grid and operates stably, the transient-stability margin between the generator and the grid is not affected by this method. This soft-synchronization method has been validated by simulations with the increased critical margin of the rotor-angle difference and the improved faulty synchronization process with limited power impulse and frequency oscillation.[6] On a similar note, a hardware-in-the-loop simulator which presents itself to the generator synchronizer as a fully functional replacement of the real plant, including the process dynamics and voltage levels at the points of connection is described. The synchronizer interfaces to the simulator in exactly the same way it does to the real plant (i.e., generator and power system). It receives the simulated counterparts of generator and power system voltage waveforms and issues three adjusting signals: increase/decrease generator frequency, increase/decrease generator output voltage, and close circuit breaker (i.e., connect the generator to the power system). An auxiliary input of the synchronizer is used to select the operating mode of the synchronizer.[7] In the same vein, the simulation results of turbo generator faulty synchronization with inverse phase sequence was investigated. Great emphasis is placed on the physical phenomena existing in the rotor because the measurement of rotor damper bar currents is difficult in practice. There are presented the comparisons of maximum magnitudes of stator current and electromagnetic torque determined during faulty synchronization with maximum magnitudes designated during sudden short circuit after both no-load and rated operation condition. In addition, the effect of synchronizing limits on faulty synchronization is presented.[8] Also a detail dynamic model of synchronous turbo-generator capable to take into account for rotor whirl is presented. The model is based on a modified winding function approach that allows exact description of machine windings space distribution. Rotor whirl modeling is based on axial slicing of the machine and summing up on such way obtained winding inductances. On such manner, very complex 3D phenomenon could be reduced to the simpler 2D problem. The effect of rotor whirl on the stator and rotor currents is examined. It is demonstrated that as a result of rotor whirling big circulating currents in parallel paths of stator winding could arise. The numerical model is based on the data of real synchronous turbo-generator TBB-200-2A rated at 247 MVA.[9]

Synchronizing a generator to the power system must be done carefully to prevent damage to the machine and disturbances to the power system. Traditionally, power plants include a synchronizing panel to indicate what adjustments the operator should make to the governor and exciter and when it is acceptable for the operator to close the breaker. In many cases, the process is automated using an automatic synchronizer with manual control available as a backup. In power plants with more than a single generator or installations with multiple synchronizing breakers, complicated synchronizing circuits with many contacts are required to switch the voltage transformer (VT) and control signals between the operator controls and the high-voltage equipment. Maintaining proper isolation and safety grounding of sensing and control circuits often requires the use of problem-prone auxiliary relays and VTs. Today, protective-relay-grade microprocessor devices can significantly improve manual and automatic synchronizing systems.[10] Poor synchronizing can: i)Damage the generator and the prime mover because of mechanical stresses caused by rapid acceleration or deceleration, bringing the rotating masses into synchronism (exactly matched speed and rotor angle) with the power system. ii) Damage the generator and step-up transformer windings caused by high currents. iii) Cause disturbances to the power system such as power oscillations and voltage deviations from nominal. iv) Prevent the generator from staying online and picking up load when protective relay elements interpret the condition as an abnormal operating condition and trip the generator. [10] Furthermore, IEEE Standards C50.12 and C50.13 provide specifications for the construction of cylindrical-rotor and salient-pole synchronous generators, respectively . The limits for both types of generators are: i)Angle ±10 degrees. ii)Voltage 0 to +5 percent. iii)Slip ±0.067 Hz. Also the synchronizing system must perform the following functions: i) Control the governor to match speed. ii) Control the exciter to match voltage. iii) Close the breaker as close to a zero-degree angle difference as possible. These functions can be provided by the operator using manual means, automated control systems, or some combination of both. To improve visualization of the actual angle between the incoming and running voltages, a synchroscope is used in modern synchronizing panels. The synchroscope indicates the angle difference so that when the two voltages are in phase, the pointer points straight up (12 o'clock position). When the generator is running faster than the bus, the pointer rotates in the clockwise direction; when the generator is running slower than the system, the pointer rotates in the counter clockwise direction.[10]

The synchronization process is described in the Appendix and specific equipment depicted in Figures 1, 1A and 1B.[11]

SUMMARY OF REVIEW

1. Synchronization is the process of matching a source (generator) with an existing power system, making it possible to operate.

2. Controllable inductive fault current limiters protect against short-circuit faults and enable gentle synchronization of turbo generators.

3. Synchronization can be manual or automated (through use of synchronoscope).

4. At point of synchronization, the voltage, frequency and phase angle of generator is synchronized with the voltage, frequency and phase angle of the power system.

5. Poor synchronizing can lead to damage to Turbo-Generator and its prime mover, step-up transformer, disturbance to the power system and the generator falling out of control of the power system.

6. IEEE standard C50.12 and C50.13's specification for the construction of cylindrical rotor and salient pole synchronous generator is : Angle = ±10 degrees, voltage =0 to + 5% and Slip ± 0.067Hz.

DISCUSSIONS

For point 1 above: When bulk power is on demand, this demand is unlikely to be met by a single generator. This may lead to pooling power sources together in order to satisfy this need. The gate way to achieve this need will be the synchronizing of all the generators into a common pool called the power grid system..From this grid system the power is transmitted and distributed to demand points. Hence the role of "Synchronization" in the scheme of power generation, transmission and distribution cannot be over emphasized.

For point 2 above: Short -circuit faults in the grid lead to power wastage and system failure, hence they should be prevented or eliminated at source. Also gentle synchronization enhances smooth and turbulence free power grid system. Hence the adoption of controllable inductive fault current limiters as protection against short circuit fault and enhancer for gentle synchronization is an important and valuable asset.

For point 3 above: The flexibility of choice between manual and automated synchronization will be dictated based on the prevailing circumstances embedded in the power grid systems. In the face of force majeure, the choice of synchronization method will be dictated by the specific nature of the circumstance.

For point 4 above: Meeting the criteria of this point is the underlying principle of synchronization..Effective and efficient synchronization demand that the parameters of the generator agree with that of the power system to which the generator is to be synchronized into in terms of voltage, frequency and phase angle within the tolerable limit. Any deviation in these parameters greater than the prescribed leads to catastrophic consequences.

For point 5 above: The above point clearly specify the outcome and fallout from poor synchronization. Therefore utmost attention must be given to the synchronization process. In this regard regular maintenance and servicing of the synchronizing equipment and instrumentation is of paramount importance. Use of qualified and certified personnel for maintenance and operations is essential.

For point 6 above: Standards so specified by the IEEE should be so maintained in theory and practice in order to have a safe and reliable operation regime for the turbo generator synchronization process. This is the gateway and the bridge that links generated power to consumers of power.

CONCLUSION

In this review, the findings of the various authors so cited have been blended. The criteria of voltage, frequency and phase angle convergence at point of synchronization has been highlighted..Synchronization that constitute a bridge between power generation on one hand

and transmission/distribution on the other hand is of vital importance and hence instrumental to the overall success of the power grid system. All efforts must therefore be made to put a sustainable, effective and efficient synchronization system in place in order to get the product (the generated power) to the market place (power consumers). All the authors whose works have been cited are hereby acknowledged.

REFERENCES

1.YUCHENG ZHANG, ROGER A. DOUGAL, STEPHEN B. KUZNETSOV (2010), ***Influence of Inductive Fault Current Limiter on Generator Synchronization in Wiley online library. March 2010. DOI:*** *10.1111/j.1559-3584.2010.00236.x*

2. P.Neuman (2012),Power Plant and Turbogenerator Models for Engineering and Training Simulators In IFAC Proceedings Volumes. Volume 45, Issue 21, 2012, Pages 313-318 doi. 10.3182/20120902-4-FR-2032.00056

3. E.Chiricozzi A.Spena(2003)Effects of electrical faults on reliability of turbogenerator unitsin large steam power plants in Electric Power Systems Research. Volume 1, Issue2, April1978, Pages 153-166 doi. 10.1016/0378-7796(78)90009-3

4. *S. Turri ; A. Lacaze ; J.M. Kauffmann(2003).* ***De-synchronized generator using a synchronous turbo-generator and a matrix converter in*** *Electric Machines and Drives Conference, 2003. IEMDC'03. IEEE International****. Date of Conference:*** *1-4 June 2003****. INSPEC Accession Number:*** *7678572****. DOI:*** *10.1109/IEMDC.2003.1211243* ***Publisher:*** *IEEE****. Conference Location:*** *Madison, WI, USA, USA*

5. ***Richard C Schaefer (2016), The art of generator synchronizing* in** *Pulp, Paper & Forest Industries Conference (PPFIC), 2016 IEEE Austin, TX, USA,19-23 June 2016* ***Date Added to IEEE Xplore:*** *28 July 2016* ***INSPEC Accession Number:*** *16192828* ***DOI:*** *10.1109/PPIC.2016.7523471* ***Publisher:*** *IEEE IEEE Transactions on Power De... > Volume: 26 Issue: 4*

6. *Yucheng Zhang ; Roger A. Dougal(2011)* ***Soft-Synchronization of Generators Using Controllable Inductive Fault Current Limiters***

Published in: *IEEE Transactions on Power Delivery (Volume: 26, Issue: 4, Oct. 2011)*

Page(s): *2428 - 2435* ***Date of Publication:*** *23 June 2011* ***ISSN Information:***

INSPEC Accession Number: *12288198*

7. *A.J. Grono (2001)* ***Synchronizing generators with HITL simulation***

Published in: *IEEE Computer Applications in Power (Volume: 14, Issue: 4, Oct 2001)*

Page(s): *43 - 46* ***Date of Publication:*** *Oct 2001* ***Print ISSN:*** *0895-0156*

INSPEC Accession Number: *7079510* ***DOI:*** *10.1109/67.954527*

Publisher: *IEEE* ***Sponsored by:*** *IEEE Power & Energy Society*

8. ***Adam Gozdowiak/ Piotr Kisielewski Ludwik Antal (2017)*** *Physical Phenomena Existing in the Turbogenerator During Faulty Synchronization with Inverse Phase Sequence* ***Published Online:*** *2017-10-27 |* ***DOI:*** *https://doi.org/10.5277/ped160112* ***Citation Information:*** *Power Electronics and Drives, Volume 1, Issue 1, Pages 149–157, ISSN (Online) 2543-4292, ISSN (Print) 2451-0262, DOI: https://doi.org/10.5277/ped160112*

9. ***Gojko Joksimovic****(2016) Synchronous Turbo-Generator Model Accounting for Rotor Whirl*

Conference Paper · *April 2016 DOI: 10.1109/MELCON.2016.7495346*

Conference: Conference: MELECON 2016, At Limassol, Cyprus

10. Michael J. Thompson (2012). Fundamentals and Advancements in Generator Synchronizing Systems Schweitzer Engineering Laboratories, Inc. © 2012 IEEE This paper was presented at the 65th Annual Conference for Protective Relay Engineers and can be accessed at: http://dx.doi.org/10.1109/CPRE.2012.6201234.

11.TIAJPROMEXPORT (TPE) (1983) Operating Manual for the Synchronization of Turbo-generators 1 and 2 at the Thermal Power Plant and Turbo Blower Station TPP/TBS at Ajaokuta Steel Company, Ajaokuta, Nigeria.

APPENDIX (SOURCE: [11])

To synchronize Q_1 through KG-1 to Q_2 with Q_2 = 132KV open;

a. Q_1 =11.5KV from Generator 1 (See Figures 1 and 1A)

I) first switch synchronizing key of Q_1 on. The switch is on the vertical part of the Control Desk.

Ii) switch on manual synchronization switch to ‘’precise’’ position on Panel Board.

Iii) watch the Voltage, Frequency and Phase display on the corresponding meters . a set for Q_2 and a set for Q_1.

Iv) if corresponding values of Voltage and Frequency in(ii) are equal and the phase difference as displayed by the common meter for Q_2 and Q_1 is $\leq 19^0$, then we switch on Q_1. THE SYSTEM IS SAID TO BE SYNCHRONIZED. The ‘’manual synchronization switch’’ is then turned to synchronize position.

b. $Q_1 = 0$ (ie. Before Q_1 from Generator side = 0). (See Figures 1 and 1B)

I) switch on the’’ synchronize switch of Q_1’’ on the vertical part of the Control Desk.

Ii) with another key switch the ‘’Blocking against non-synchronous closing’’ to its off position. Switch is on panel marked ‘’COMMON STATION APPARATUS’’.

III) Switch on Q_1

IV) Switch on the switch ‘’Blocking against non-synchronous closing on. This switch is on the main display Panel Board section marked ‘’COMMON STATION APPARATUS’’.

NOTE THAT IF PHASE DIFFERENCE = 180^0, THE GENERATOR WILL BE DESTROYED.

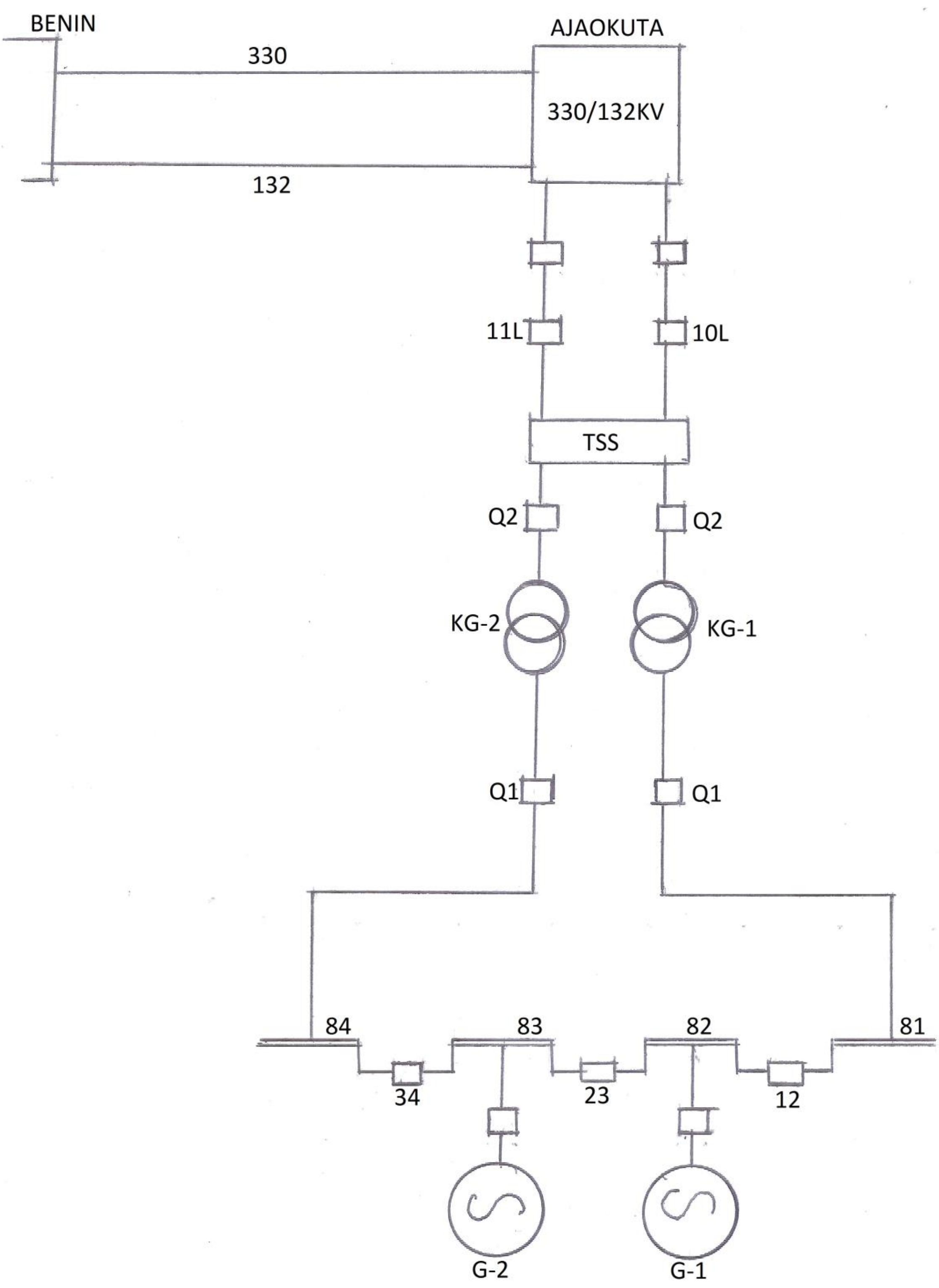
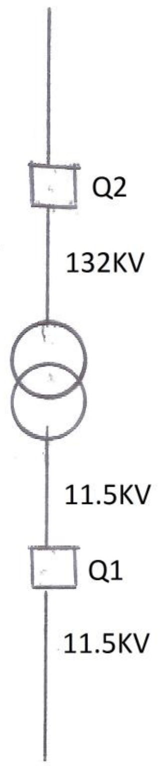


FIG. 1 SYNCHRONIZATION BUSBAR AT TPP/TBS AJAOJUTA, NIGERIA

G-1 GIVES 110MW AND G-2 GIVES 90MW. SOURCE: [11]



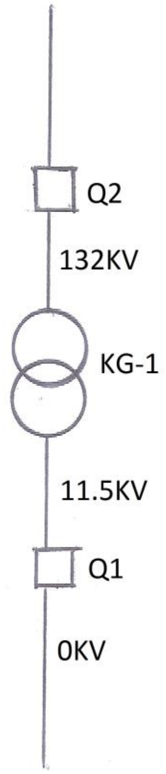


FIG. 1A FIG. 1B

Q_1 = 11.5KV FROM GENERATOR 1	**Q1 =0 KV**

SOURCE :[11].