THE PERFORMANCE OF SYNCHRONOUS GENERATORS AS AFFECTED BY DIFFERENT TYPES OF AUTOMATIC CONTROLLERS

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SUMMARY

The thesis is a study of the influence of automatic controls of synchronous generating units on the dynamic stability in large power systems in general, and on the machines themselves in particular. These controllers are classified as automatic voltage regulators and speed governors of the synchronous generators.

The research work contains an analytical part as well as an experimental one. A small power system has been chosen for study. This system is composed of a turbo-alternator connected to the bus bars of a large power system through two parallel short transmission lines. The generator is equipped with an automatic voltage regulator, and the prime-mover is fitted with a governer.

In the analytical part of the thesis the equations of the system have been written, then the transfer function of the closed loop system has been derived.

The experimental set-up is composed of a model fly-wheel turbo-alternator driven by a d.c. motor and a model of two parallel short transmission lines. The generator is equipped with an automatic voltage regulator designed and built in laboratory. This is a power-transistor based proportional type regulator. It controls the voltage at the generator terminals as well as the reactive power of the machine.

The driving d.c. motor was made to simulate a steam turbine. The speed governor was designed using an amplidyne. The control winding of the amplidyne is fed through a proportional-plus-integral-plus-derivative controller.

This controller has been designed and built so as to have the flexibility of working. The proportional component either alone or in conjunction with the other two components supplies the control winding of the amplidyne to obtain different cases of controller. The system is equipped with a power angle device designed and built in the laboratory. This gives a signal proportional to the angle between terminal voltage and the internal induced e.m.f. of the machine. This signal may be used for measurements and for control purposes.

The thesis contains also the experiments which were made to determine all the constants of the system by steady-state and transient tests. The whole system was tested under dynamic conditions of switching operations and load changes with machine connected to local load and to infinite bus.

Results are commented upon and discussed. Recommended controller types are suggested.

LIST OF SYMBOLS

A : The coefficient matrix of the state-space model of the synchronous machines.

B : The coefficient matrix to be multiplied of the driving function of state-space equation.

e : the induced e.m.f. of the alternator at no load prefault,

e'_q : the e.m.f. induced in the armature coils of the synchronous machines due to field system flux linkage,

E : A.C. r.m.s. voltage before short circuit, p.u.

E'_q : the e.m.f. behind transient reactance in q-axis of synchronous machine,

H : the inertia constant,

I : alternating current, root mean-square short circuit current, p.u.

I_a : the armature current, root-mean-square,

I_{ao} : the inetial value of the armature current of the d.c. motor,

I_{av} : the average value of the current,

I_d : the armature current, root-mean-square, in d-axis of synchronous machine,

$I_{d\Delta}$: the incremental change in the direct current,

I_q : the armature current, r.m.s., in q-axis of synchronous machine,

$I_{q\Delta}$: the incremental change in the quadrature current,

I_{FA} : the field current of the amplidyne,

I_{qA} : the current of the amplidyne in q-axis winding,

$[i_{abc}]$: the matrix of armature currents in the a, b, c frame,

$[i_{FDQ}]$: the matrix of rotor currents,

$[i_{odq}]$: the matrix of armature currents in the o,d,q frame

J : the moment of inertia of the rotating parts

K_e : the overall gain of the exciter,
K_d : the gain of the derivative component of the controller,
K_g : the governor gain,
K_i : the gain of the integral component of the controller
KM_F, KM_D, KM_Q : factors used for referring rotor values to stator in synchronous machines
K_p : the gain of the proportional component of the controller,
K_{pot} : the attenuation factor of the potentiometer,
$[L]$: the symmetric matrix of constant inductances,
L_d : self inductance in d-axis,
L_D : the inductance of d-axis damper winding
L_f : the field inductance,
L_o : the inductance of zero sequence,
L_n : the inductance connected in the neutral line
L_Q : the inductance of the q-axis damper winding
L_q : the inductance of the armature in the q-axis
M_R : mutual inductance between rotor and stator coils,
$[N]$: the matrix of speed voltage inductance
$[\hat{N}]$: the matrix of speed voltage inductances with transmission lines
$[n_{odq}]$: the voltage matrix of the neutral in o,d,q-frame of axes,
n_r : the reference speed,
n_s : the synchronous speed,
$[P]$: Park's transformation matrix,
P_d : power dissipated as heat due to losses.
P_e : the electrical power
P_i : the input power,
P_m : mechanical power,
R : resistance matrix,

$[R_{abc}]$: resistance matrix of the stator coils,
R_e : the transmission line resistance,
R_f : the field winding resistance,
$[R_{FDQ}]$: resistance matrix of the rotor coils,
R_q : the resistance of armature winding per phase,
S_{base}, S_B : the base KVA.
T_e : the electrical torque,
T_g : governor response time,
T_m : mechanical torque,
$[U]$: the system driving functions,
U_3 : unit matrix 3 x 3
V : the generator armature voltage,
$[V_{abc}]$: R.M.S. voltage of phase a, b and c in matrix
V_g : terminal voltage of the exciter,
$[V_{o,d,q}]$: voltage matrix of the armature coils in the odq frame
V_q : voltage in q-axis
V_{qA} : voltage in q-axis of the amplidyne
V_r : reference voltage
W_{ke} : the kinetic energy stored in the rotating parts,
$[x]$: a vector of the state variables,
$[x]^t$: transposed matrix,
X_d : the direct-axis reactance of synchronous machine
X'_d : the direct-axis transient reactance of synchronous machine,
X''_d : the direct-axis subtransient reactance of synchronous machine,

α : relative angular displacement between the machine shaft and the standard vector,
δ : the power angle,
$[\lambda_{abc}]$: the flux linkage matrix of the armature coils in the abc frame
$[\lambda_{odq}]$: the flux linkage matrix of the armature coils in the odq frame,

λ : the flux linkage,

ω : angular speed of the rotating parts rad/sec

ω_R : the reference angular speed

θ : the angular displacement of the rotor in radians

τ_j : a constant depending on the inertia constant

τ_{do} : the d-axis open circuit transient time constant

τ_d' : the d-axis short circuit transient time constant

τ_d'' : the d-axis short circuit subtransient time constant

τ_e : the exciter time constant

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 TYPES OF CONTROLS APPLIED TO A SYNCHRONOUS GENERATOR

There are three types of controls usually applied to synchronous generator units. These are the mega watt frequency control, Mega VAR voltage control and supervisory control.

1.1.1 Mega watt/frequency

The objective of this process is to exert control of frequency and simultaneously of the real power exchange via outgoing lines. The frequency or speed is sensed and compared with a reference value. The difference signals are amplified, mixed, and transferred into a real-power command signal which is sent to the prime-mover to call for an increment in the torque [1].

1.1.2 Mega VAR, Voltage

The objective of this process is to exert control of the voltage state $|V_t|$. An important characteristic of an exciter control system is its ability to respond rapidly to voltage conditions during both normal and emergency system operation. The voltage error $\Delta |V_t|$ is sensed, and transferred into a reactive power command signal ΔQ, which is fed to the excitation source. The result is a change in the rotor field current, and thus in the generator electromotive force (e.m.f.), which finally adds up to an incremental change in the reactive power of the generator [1].

1.1.3 Load Dispatching Control

The objective of this process is to control the output of each unit within a plant and each plant within a large power system. This is achieved by continually monitering all plant outputs and interchanges of power with other system components. This control gives the system the ability to face changes in load and keeps the system stable [1].

1.2 THE IMPORTANCE OF A SPEED-GOVERNOR

The prime movers of a modern electrical power system may be steam, hydraulic or gas turbines, reciprocating steam or internal combustion engines, or wind turbines. Only the first two types are considered in the present research since they are normally used for driving generators in large power systems.

An engineer who designs or operates a power system, often needs to know the general characteristics of a turboalternator or hydro-generator under different operating conditions, and in many cases the hydraulic and steam turbines can be considered to have similar properties. The main characteristics, that we are interested in, are the speed-load curves. These curves usually have a drop in speed as load is increased. This drop in speed or change in frequency must not exceed a certain value. Speed governors are needed to obtain this specification. For a generator which supplies power to a local load, the main requirement from the speed governor is to keep the speed constant at all load values. On the other hand, when a generator is connected to the bus bars of a large system, the effect of the speed governor decreases because the large-system forces the speed of the small