SOME STUDIES ON COMPENSATED EHV TRANSMISSION LINES

A THESIS

Submitted by

B. VISWANATHAN

In partial fulfilment of the requirements for the award of the Degree of DOCTOR OF PHILOSOPHY

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
NEW DELHI 110 016

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DEDICATED TO MY BELOVED FATHER AND GURU

CERTIFICATE

Certified that the thesis entitled 'SOME STUDIES ON COMPENSATED EHV TRANSMISSION LINES' being submitted by Shri B. VISWANATHAN, is a record of work carried out by him under our joint supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree.

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October, 1984. B. VISWANATHAN.

ABSTRACT

The planning, operation and control of a power system are to a significant extent governed by stability considerations. Whereas transient and steady - state angular stability have been dealt with quite frequently in the literature, voltage stability on the other hand has evoked considerable interest only in the recent past. Published literature concerning the analysis of voltage stability phenomenon have not considered the effects of series compensation and the uncertainties of the load parameters which relate the complex load power with the load voltage. As an objective of the present work, the voltage stability of EHV lines with series compensation is investigated with both the deterministic and probabilistic modelling of voltage-sensitive loads. The analysis of voltage stability of transmission systems with series compensation is based on a newly defined dV_R/dK_s criterion. Furthermore, the effects of fixed and switched series compensation on the time to collapse of voltage at the load-end of long transmission systems during a period of rapid increase in load demand in a short duration are also investigated. The above investigation of voltage collapse also takes into consideration the voltage characteristics of the distributed parameter line, the load characteristics and the on-load transformer tap control.

In this thesis, an attempt has also been made to extend the conceptual planning tool for assessing the loadability limits of EHV transmission lines that are consistent with the available var reserves in the system, presented by Kay et al., to the case of compensated transmission lines by taking into

consideration the effects of transformer taps and load modelling 31 . An algorithm parallel to that given by Kay et al., 31 but which also considers the effects of series compensation, the voltage - dependent load characteristics, the status of the receiving-end transformer tap and the distributed nature of the line parameters has been developed and used to determine the loadability limits of series compensated lines that are consistent with the available var reserves in the system. A simple method is also presented in this thesis to determine the necessary shunt compensation at the load-end of a transmission system to maintain the load-end voltage at a fixed percentage of the sending-end voltage under all loading and power factor conditions.

A new index of compensation effectiveness is defined and used to study the effectiveness of various series and shunt compensation schemes 3 for EHV transmission system in the present work. The expression for the new index of compensation effectiveness is derived in a form suitable to incorporate the influence of various factors such as line length, line loss factor and the degree of series and shunt compensation in a straight-forward manner.

In the present work, the analysis of steady-state subsynchronous resonance in series-compensated transmission system is considered with both deterministic and probabilistic modelling of system parameters. The deterministic analysis is carried out in the R-X_c plane (i) by using an algorithm that is the modification of that given by Sreedharan and

Ghodgaonkar in Ref. 57 and (ii) by using a new analytical technique which does not require the application of any of the stability criteria as in Refs. 41, 57, 60 . A novel probabilistic approach which takes into consideration the system uncertainties for demarcating the stability zones in the R-X_C parametric plane is also presented.

All the studies on compensated transmission system reported in this thesis are supported by numerical results and discussions.

NOMENCLATURE

A_o, B_o C_o, D_o	:	generalised circuit constants of a compensated transmission line
C	:	line shunt capacitance/unit length
Im ( )	:	imaginary part of
$\dot{I}_R$	:	receiving-end current
K_d	:	degree of shunt compensation
K_s	:	degree of series compensation
L	:	line inductance/unit length
$P^{vs}_{C\alpha}$,	:	voltage stability limit of a lossy compensated line in terms of the SIL of a lossy line
P_R	:	receiving-end active power
$P_{R\ crit}$	:	line loadability limit
Q_R	:	receiving-end reactive power
R	:	resistance of the transmission system
R_{fd}	:	d-axis field winding resistance
R_{kd}, R_{kq}	:	d and q axis damper winding resistance respectively
Re ( )	:	real part of
$\dot{S}_R$	:	receiving-end complex power
T_a	:	amplifier time constant
T_e	:	exciter time constant
T_s	:	feedback stabilising loop time constant
U_a	:	amplifier gain
U_c	:	measuring device gain
U_s	:	feedback stabilizing gain

$\dot{V}_R$	:	receiving-end voltage
$\dot{V}_S$	:	sending-end voltage
V_d, V_q	:	direct and quadrature axis components of infinite bus voltage
V_{td}, V_{tq}	:	direct and quadrature axis components of machine terminal voltage respectively
X_{ad}, X_{aq}	:	d and q axis magnetizing reactances respectively
X_c	:	reactance of series-capacitor
X_d	:	d-axis synchronous reactance
X_e	:	transmission system reactance which includes the line, sending-end and receiving-end transformer reactances
X_{ffd}	:	d-axis field winding self reactance
X_{kkd}, X_{kkq}	:	d-axis and q-axis damper winding self reactances respectively.
X_l	:	line inductive reactance
X_q	:	q-axis synchronous reactance
X_t	:	transformer reactance
Y	:	shunt admittance of the line
Z	:	series impedance of the line
Z_o	:	surge impedance of a lossless line
Z_o'	:	surge impedance of a lossy line
f	:	frequency
$\dot{I}_d$, $\dot{I}_q$	:	d-axis and q-axis component of bus currents respectively
$\dot{I}_{td}$, $\dot{I}_{tq}$	:	d- and q-axis armature current respectiv-

l	: line length
m, n	: load characteristic parameters
p	: differential operator $\frac{d}{dt}$
r	: line resistance/unit length
y	: shunt admittance/unit length of the li...
z	: series impedance/unit length of the line
α'	: line loss factor
β	: propagation constant of a lossless line
	: propagation constant of a lossy line
δ	: transmission angle
θ	: line angle of a lossless line
θ'	: line angle of a lossy line
Δ	: prefix to denote small changes in the quantities about an operating point
	: standard deviation
	: mean value
w	: angular frequency

Symbols not included here are defined at appropriate places.

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