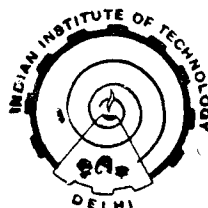


**PERFORMANCE EVALUATION OF A NOVEL VAR CONTROLLER
AND
ITS APPLICATION IN BRUSHLESS STAND-ALONE POWER GENERATION**

K. K. RAY



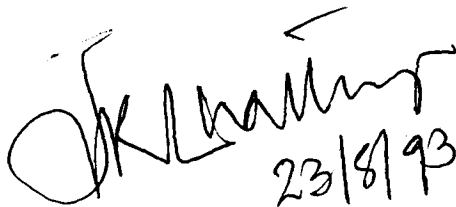
**Department of Electrical Engineering
INDIAN INSTITUTE OF TECHNOLOGY, DELHI**

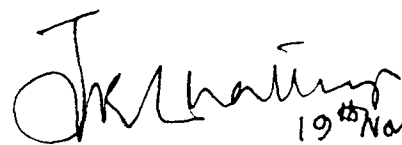
1990

CERTIFICATE

This is to certify that the thesis entitled "PERFORMANCE EVALUATION OF A NOVEL VAR CONTROLLER AND ITS APPLICATION IN BRUSHLESS STAND ALONE POWER GENERATION" being submitted by Kalyan K. Ray to the Indian Institute of Technology, Delhi for the award of the degree of Doctor of Philosophy is a record of the bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of the thesis which, to my knowledge, has reached the requisite standard.

The thesis, or any part thereof, has not been submitted to any other University or Institute for the award of any degree or diploma.


23/8/93


19th Nov 1990

(Dr. J.K. Chatterjee)

Professor

Dept. of Electrical Engineering
Indian Institute of Technology Delhi
New Delhi - 110 016
INDIA

ACKNOWLEDGEMENT

It is a privilege for me to have been associated with Dr. J. K. Chatterjee, my supervisor, during the course of this research work. I have been greatly benefited by his valuable suggestions and guidance.

I am grateful to the authorities of Indian School of Mines, Dhanbad for deputing me to I.I.T , Delhi to pursue the research work.

I am also grateful to my co-research scholars , Sri V.B. Raju, Sri K.L. Puttabuddhi, Sri T.M. George and Sri A.K. Wahi for their help.

I take the opportunity to thank Mr. K.K. Khurana, Mr. R.P. Sharma for their help in different phases of experimentation.

Finally, I wish to thank my wife Mira and my daughter Urmi for their forbearance and understanding.

Date: 19th November 1990.



K.K. RAY

ABSTRACT

With the depletion of conventional sources of energy, another emerging area for application of VAR controllers has been the brushless power generation from non-conventional energy sources such as wind, microhydel etc.

The performance of a novel two-reactor VAR controller, developed at IIT Delhi, has been studied and described in this thesis. Both trigger delay (α) and offset delay (Δ) angle controls have been applied and their effect on inductive VAR control capability of the controller has been observed. The current harmonics injected by the VAR controller into the power source also have been investigated.

It has been observed that two-reactor VAR controller, with only α -control, has a poor VAR- α characteristic. In order to improve the VAR control capability an offset angle (Δ) control has been introduced in the present work. The characteristics of the VAR controller with α and Δ control have been theoretically analysed, and its performance has been experimentally verified. The results indicate, it is possible to achieve better VAR control with α - Δ control.

The possibility of the VAR controller being used as an excitation controller in a capacitor self-excited induction generator has been studied. The performance

of self excited induction generator with two-reactor VAR controller has shown the effectiveness of the VAR controller in maintaining constant terminal voltage.

A mathematical model of the induction generator with the two-reactor VAR controller has been developed. This has been done to evaluate the performance of the system. The effects of the presence of harmonic currents on the system performance also have been evaluated, at different operating conditions depending on α and Δ .

A power balancer, which is a 6-pulse phase controlled bridge convertor, with a resistance load on the dc side, is connected at the generator terminals. This provides real power balance under low frequency external load perturbation to the generator. The effect of the power balancer on the performance of the induction generator, with two-reactor VAR controller, has been studied in presence of low frequency external load perturbation.

SYMBOLS

VAR	-	Volt Ampere Reactive
E	-	Generated Voltage
V	-	System Line Voltage
α	-	Trigger Delay Angle
β	-	Trigger Advance Angle
Δ	-	Offset Angle
Xv	-	Inductive Reactance of VAR Controller
dc	-	Direct Current
ac	-	Alternating Current
Vm	-	Voltage Amplitude
V _r	-	Reactor Voltage
i _r	-	Reactor Current
f _i	-	Input Frequency
K	-	Phase of Ripple Voltage
p	-	Ripple Voltage Pulse Number
θ_l	-	Lower Current Zero of Current Lobe
θ_h	-	Upper Current Zero of Current Lobe
θ	-	Angle of Current Lobe
λ	-	Current Conduction Angle
di/dt-		Current Derivative
dv/dt-		Voltage Derivative
rms	-	Root Mean Square
i _{rm}	-	Index of Input Current Lobe
a _n , b _n ,		Harmonic Components

ν	-	Speed
I_{ll}	-	Reactive Load equivalent Current
P	-	Number of poles
n	-	Revolutions per Second
F	-	Frequency
Z	-	Impedance
P_l	-	Load power
μF	-	Micro Farad
δ	-	Current Conduction Angle
VA	-	Volt - Ampere
Z_{sn}	-	Harmonic Stator Impedance
Z_{rn}	-	Harmonic Rotor Impedance
Z_{ln}	-	Harmonic Load Impedance
P_{rn}	-	Harmonic Rotor Loss
P_{sn}	-	Harmonic Stator Loss
I_{sn}	-	Harmonic Stator Current
I_{rn}	-	Harmonic Rotor Current
I_{ln}	-	Harmonic Load Current
pf	-	Power Factor
pu	-	Per Unit.
Ω	-	Ohm
I_{cn}	-	Harmonic capacitor current
V_{tn}	-	Harmonic terminal voltage

I_1	-	Fundamental Component of Current
I_a	-	Active Component of Current
I_r	-	Reactive Component of Current
α_n	-	New Trigger Delay Angle
β_n	-	New Trigger Advance Angle
C	-	Capacitance
L_s	-	Stator Inductance
L_r	-	Rotor Inductance
L_m	-	Magnetising Inductance
R_s	-	Stator Resistance
R_r	-	Rotor Resistance
s	-	Slip
V_t	-	Terminal Voltage
V_g	-	Airgap Voltage
I_c	-	Capacitor Current
I_m	-	Magnetising Current.
I_s	-	Stator Current
I_r	-	Rotor Current
I_{RL}	-	Resistive Component of Load Current.
I_{XL}	-	Inductive Component of Load current.
X_c	-	Capacitive Reactance
X_m	-	Magnetising Reactance
X_r	-	Rotor leakage reactance
X_s	-	Stator leakage reactance

CONTENTS

	Page No.
CERTIFICATE	(i)
ACKNOWLEDGEMENT	(ii)
ABSTRACT	(iii)
LIST OF SYMBOLS	(v)
CONTENTS	(viii)
CHAPTER 1: INTRODUCTION	1
1.1 Need for VAR Controller	1
1.2 Power Generation from Non-conventional Sources of Energy.	2
1.2.1 Solar Energy System	2
1.2.2 Biofuel Energy System	3
1.2.3 Tidal Energy System	4
1.2.4 Wind Energy System	5
1.2.5 Micro-Hydro-Electric Energy System	7
1.2.6 Interim Conclusion	8
1.3 Induction Generator	9
1.3.1 Double Output Induction Generator (DOIG)	9
1.3.2 Squirrel Cage Induction Generator (SCIG)	11
1.4 VAR Controllers State-of-the-art	13
1.4.1 VAR Control by Varying Capacitive Current	14
1.4.2 Synchronous Condenser	14
1.4.3 VAR Control by Varying Inductive Current	15
1.4.3.1 Fixed Capacitor Thyristor Controlled Inductor	15
1.4.3.2 Inductively Loaded AC/DC Converter	17
1.4.3.3 Twelve Pulse Back-to-Back AC/DC Converter	18
1.5 A New Concept in VAR Controller	19
1.6 Scope of the Present Work and Chapterwise Breakup	21

CHAPTER 2: TWO-REACTOR VAR CONTROLLER	30
2.1 Introduction	30
2.2 New Technique for VAR Control	31
2.2.1 The Configuration	32
2.2.2 Current Waveforms	34
2.2.3 Experimental Observations	39
2.3 Harmonic Analysis	40
2.4 Computer Programme and Results	47
2.4.1 Fundamental Components	48
2.4.2 Harmonic Distribution	48
2.5 Analysis of Two-Reactors VAR Controller	49
2.5.1 Harmonic Analysis	51
2.6 Results	56
2.6.1 Fundamental Component	56
2.6.2 Harmonic Distribution	57
2.7 Variation of X_v with α	58
2.8 Conclusion	59
CHAPTER 3: TWO-REACTOR VAR CONTROLLER WITH OFFSET ANGLE CONTROL	76
3.1 Introduction	76
3.2 The Offset Angle Control	76
3.3 Current Waveforms with Offset Angle Control	80
3.4 Analysis	84
3.5 Computer Results	89
3.6 Relationship between X_v - Δ	92
3.7 Conclusion	94
CHAPTER 4: PERFORMANCE ANALYSIS OF A SELF-EXCITED INDUCTION GENERATOR USING TWO-REACTOR VAR CONTROLLER	104
4.1 Introduction	104
4.2 Self-Excitation in an Induction Generator	105
4.2.1 Operation at no Load	107
4.2.2 Operation on Load	110
4.2.2.1 Effect of Variation in Active Power on VAR Demand	110
4.2.2.2 Effect of Active Power Load on Generation Frequency	112
4.2.3 The Effect of Stator Impedance	113
4.2.4 Interim Conclusion	115
4.3 The Equivalent Circuit of Generating System	116

	Page.No
4.4 Analysis	117
4.4.1 Determination of Machine Parameters	121
4.4.2 Analysis with VAR Controller	123
4.5 Results and Discussion	125
4.5.1 Computed Results without VAR Controller	125
4.5.2 Experimental Results	131
4.6 Application of VAR Controller	132
4.7 Results and Discussions	134
4.7.1 Experimental Results with VAR Controller	134
4.7.2 Effect of α Control on Voltage Regulation	134
4.7.3 Effect of (α, Δ) Control on Voltage Regulation	135
4.7.4 Variation of Δ for Constant V_t	138
4.8 Conclusion	139
CHAPTER 5: EFFECTS OF HARMONIC CURRENTS ON INDUCTION GENERATOR	162
5.1 Introduction	162
5.2 Effects of Presence of Harmonics in the Generating System	163
5.3 Analysis of the Harmonic Equivalent Circuit	165
5.4 Results and Discussion	170
5.4.1 Operating with Varying Terminal Voltage	172
5.4.1.1 Harmonic Terminal Voltage V_{tn} and Capacitor Current I_{cn}	173
5.4.1.2 Harmonic Load Current I_{ln}	174
5.4.1.3 Harmonic Stator and Rotor Current I_{sn} , I_{rn}	176
5.4.1.4 Harmonic Generated Voltage V_{gn}	177
5.4.1.5 Harmonic Power Losses in Stator and Rotor Circuits P_{sn} , P_{rn}	179
5.5 Conclusion	180
CHAPTER 6: PERFORMANCE OF SELF-EXCITED INDUCTION GENERATOR WITH LOAD POWER BALANCER	191
6.1 Introduction	191
6.2 Principle of Load Power Balancer	194
6.3 Analysis of a Load Power Balancer	196

6.3.1	Input Current Waveform	197
6.3.1.1	The Analysis	198
6.4	Computed Results	207
6.5	Effect of Current Harmonics	209
6.6	Dynamic Control Strategy	212
6.7	Conclusion	218
CHAPTER 7:	CONCLUSION	226
7.1	Summary of the Principal Results	226
7.2	Scope for Future Work.	228
REFERENCES		230
APPENDIX		235