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Manual on Induction Motors Used as Generators

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0. PREFACE

This handbook sets out to indicate how an induction motor could be used as generator, in the following abbreviated to IMAG. In addition to providing a practical selection method for IMAGs, the handbook covers all aspects related to the operation and control of the machine, safety and protection of the electrical installation and its economic advantage in comparison with synchronous generators generators.

The contents of this handbook should be helpful to engineers and technicians engaged in micro-hydropower projects. It is not only intended for the hydropower engineer specialized in electrical engineering but rather for all those faced with the problem of electricity generation at a reasonable cost. The formal theory of electrical engineering used in the book has been simplified in order that the non-specialized mechanical, civil, rural or agricultural engineer should be able to follow all aspects covered by the book and to undertake the necessary computations without difficulty.

Moreover, Appendix A provides a short introduction into the basics of electrical engineering. It should be studied previously to the main text by those not being familiar with electricity generation and distribution.

S.I. units have been used throughout the book and standard symbols for physical properties employed.

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HOW TO USE THE MANUAL

Chapter 2 introduces the basic principles of synchronous and induction generators (or IMAGs), their advantages and drawbacks. The handbook does not cover the generator as an isolated part of a micro-hydropower plant (MHP) but stresses the interdependence of the hydraulic, generating and consumer system. Various combinations in which an IMAG might be installed are examined: operation in parallel to a large grid, in parallel to other MHPs (minigrid) or as a stand-alone electricity generating unit.

To help the reader understand the working principle of an induction machine, a simplified theory including the differences between the (normal) motor operation and the generating mode is presented in Chapter 3.

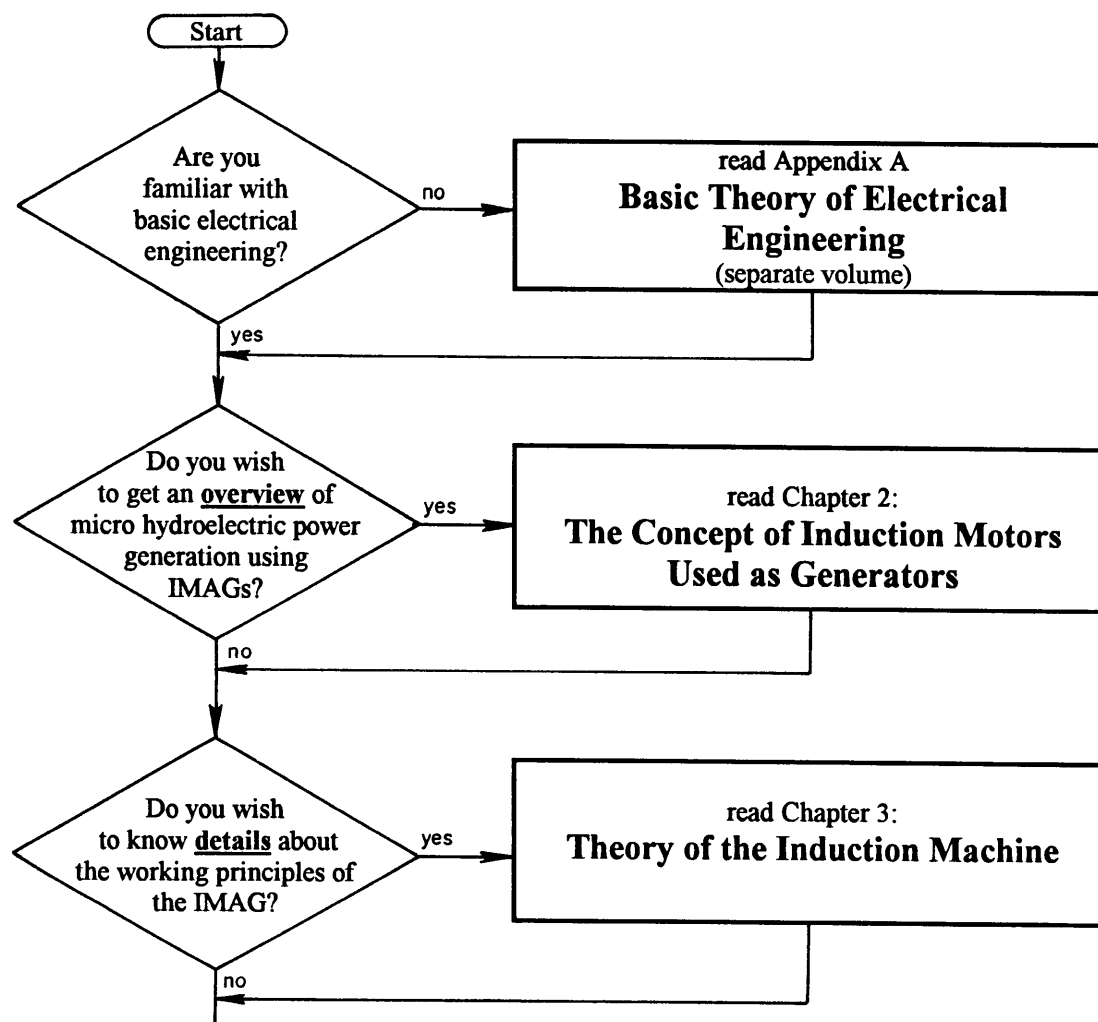
Chapter 4 proposes a practical selection procedure with diagrams based on test results of standard induction motors.

Chapter 5 deals with the operation and control of an MHP equipped with an IMAG while Chapter 6 provides a general overview of safety and protection measures required in small-scale electricity generation and distribution schemes.

A simple method of dealing with economics in conjunction with energy production is proposed in Chapter 7. Chapter 8 includes a number of worked examples which show step by step the procedure of selecting an IMAG and comparing it with conventional generators.

The flowchart of Figure 0.1 below provides an overview of the contents of the manual; it should be seen as a guide to readers of different levels and interests on how to use the handbook in its most effective way.

FIGURE 0.1 :
Guide through the handbook



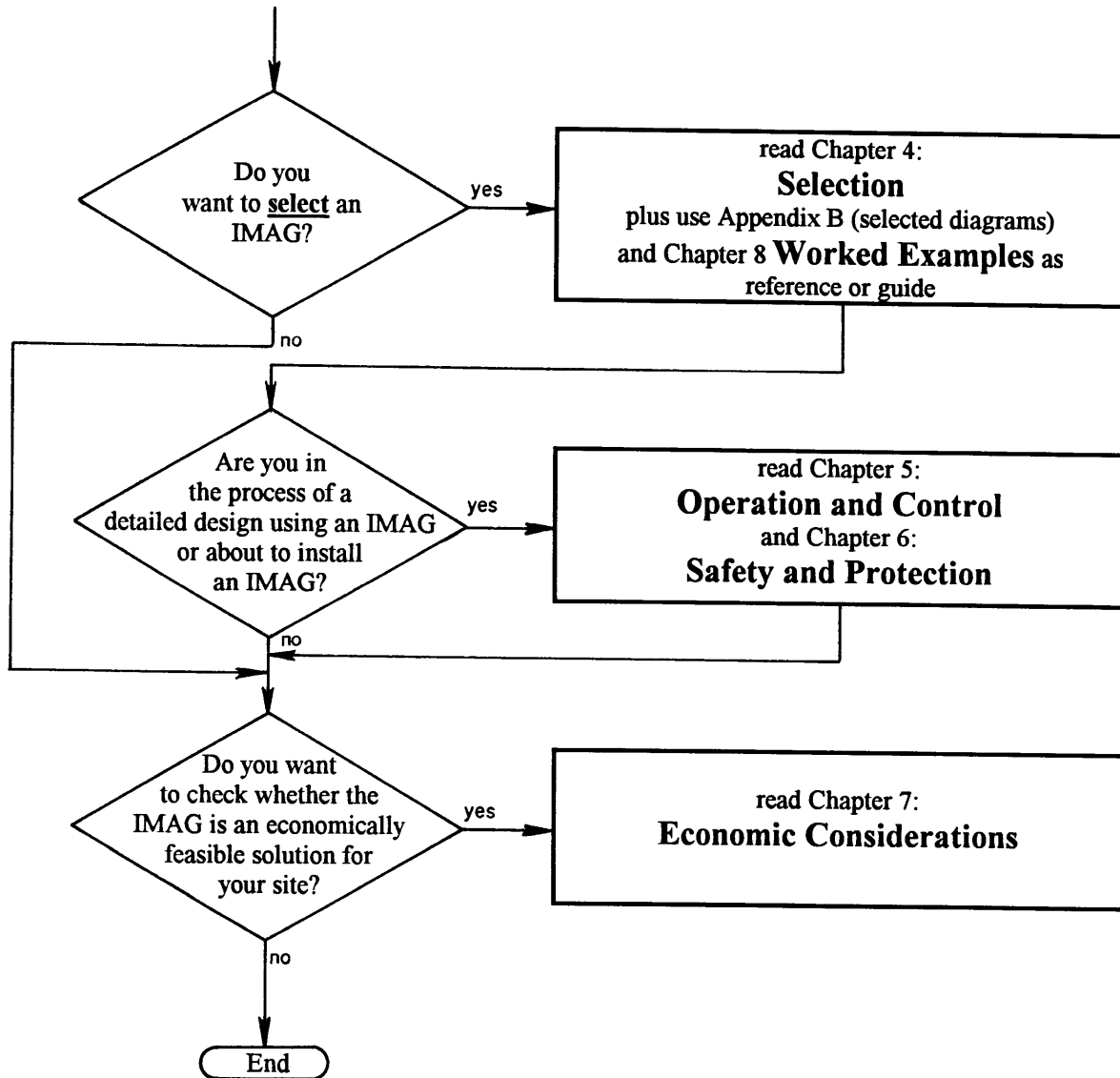


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<i>Symbol</i>	<i>SI-Unit</i>	<i>Quantity</i>
α	$^{\circ}$	Angle
Φ	Wb = V s	Magnetic flux
ϕ	$^{\circ}$	Phase angle
η	-	Efficiency
μ	Vs/Am	Permeability of a magnetic circuit
ρ	$\Omega\text{mm}^2/\text{m}$	Resistivity of conductor material
ρ	kg/m^3	Density
Ω	rad/s	Angular speed
τ	s	Time constant
Δ	-	Delta connection
Y	-	Star (Wye) connection

<i>Subscripts</i>	<i>Meaning</i>
0	No load
1	Phase 1 / Primary winding (transformer)
2	Phase 2 / Secondary winding (transformer)
3	Phase 3
C	Capacitive
Cu	Copper
eff	Effective values
el	Electric
Fe	Iron
i	Instantaneous value
L	Inductive
n	Nominal value
g	Generator mode
m	Motor operation
m	Magnetizing
mec	Mechanical
r	Rotor
s	Stator
st	Starting

LIST OF SYMBOLS

<i>Symbol</i>	<i>S.I. Unit</i>	<i>Quantity</i>
A	m ²	Area
a	-	Inflation rate
B	T = Wb/m ²	Magnetic induction or magnetic flux density
C	F = A s / V	Capacitance
g	m/s ²	Gravitational acceleration
E	Ws (or kWh)	Electric energy
F	N	Force
f	Hz	Frequency
H	A/m	Magnetic field strength
H	m	Turbine pressure head (liquid column)
I	A	Current
I _μ	A	Magnetizing current
i	-	Interest rate
l	m	Length
L	H = Vs/A	Inductance
N	-	Number of turns of a coil / North pole / Neutral
n	1/min, rpm	Rotational speed
n _s	1/min, rpm	Synchronous speed
P	W	(Active) power
p	-	Number of pole pairs
R	Ω	Ohmic resistance
S	VA	Apparent power / South pole
s		Slip
t	s	Time
T	° C	Temperature
T	Nm	Torque
Q	Var	Reactive power
Q	m ³ / s	Flow, discharge
U	V	Voltage
v	m / s	Velocity
X	Ω	Reactance
X _m	Ω	Magnetizing reactance
X _σ	Ω	Leakage reactance
Z	Ω	Impedance

LIST OF ABBREVIATIONS

AC	Alternating current
DC	Direct current
AVR	Automatic voltage regulator (of synchronous generators)
IMAG	Induction motor as generator
IGC	Induction generator controller
ELC	Electronic load controller
IP	International protection
LV	Low voltage
MV	Medium voltage
HV	High voltage
MHP	Micro hydropower / micro-hydropower plant
O&M	Operation and maintenance
PAT	Pump as turbine
PE	Protective earthing
RMS	Root mean square values (effective values)
RF	Recovery factor (economics)
rpm	Revolutions per minute
C-2C	System of connecting capacitors on a three-phase IMAG serving a single phase load