Jean-Marc Chapallaz, Jacques Dos Ghali,
Peter Eichenberger, Gerhard Fischer

Manual on Induction Motors Used as Generators

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The authors:

Jean-Marc Chapallaz is a Swiss electro-mechanical engineer specialized in the design of hydraulic machinery and equipment. He worked in industry both at home and abroad for over ten years. In 1981, he established his own company of consulting engineers, mainly engaged in energy and water supply projects. He has designed and implemented around 20 micro-hydropower plants ranging from 0,5 to 450 kW power output.

His engagement in development cooperation includes short term consultancy missions for hydropower projects in Asia and the Caribbean, the organization of training courses for hydropower engineers and other contributions to programmes of technology transfer.

Jacques Dos Ghali, is a senior lecturer at the Swiss Federal Institute of Technology in Lausanne. After ten years in industry (electrical power stations and networks) he was appointed to the electricity department of the Federal Institute of Technology in 1970. His activities in the field of micro-hydropower include the development of an electronic load controller and lectures on electrical engineering for hydropower training courses. His involvement in development cooperation is mainly in the field of energy planning, the establishment of master plans and education programmes, and the implementation of electric laboratories in universities and technical colleges in various countries in Africa.

Peter Eichenberger has been working with J.-M. Chapallaz, Consulting Engineers since 1990. He has a background in civil engineering and hydraulics, and spent a number of years with other Swiss civil engineering consultants mainly on rural development projects. Prior to joining J.-M. Chapallaz, he worked as a senior development adviser in a pump lift irrigation project in Sumatra, Indonesia.

Gerhard Fischer is a German mechanical engineer specialized in hydraulic machinery and governing systems. After graduating from the Institute of Hydraulic Machinery in Stuttgart, he spent six years as a researcher there, working on improved turbine and governor designs for both industrialized and developing countries. In 1988, he joined J.-M. Chapallaz, Consulting Engineers where he cooperated in the design of micro-hydropower plants and turbines. He carried out various short-term consultancy missions for development aid projects in Africa, the Caribbean and Columbia.

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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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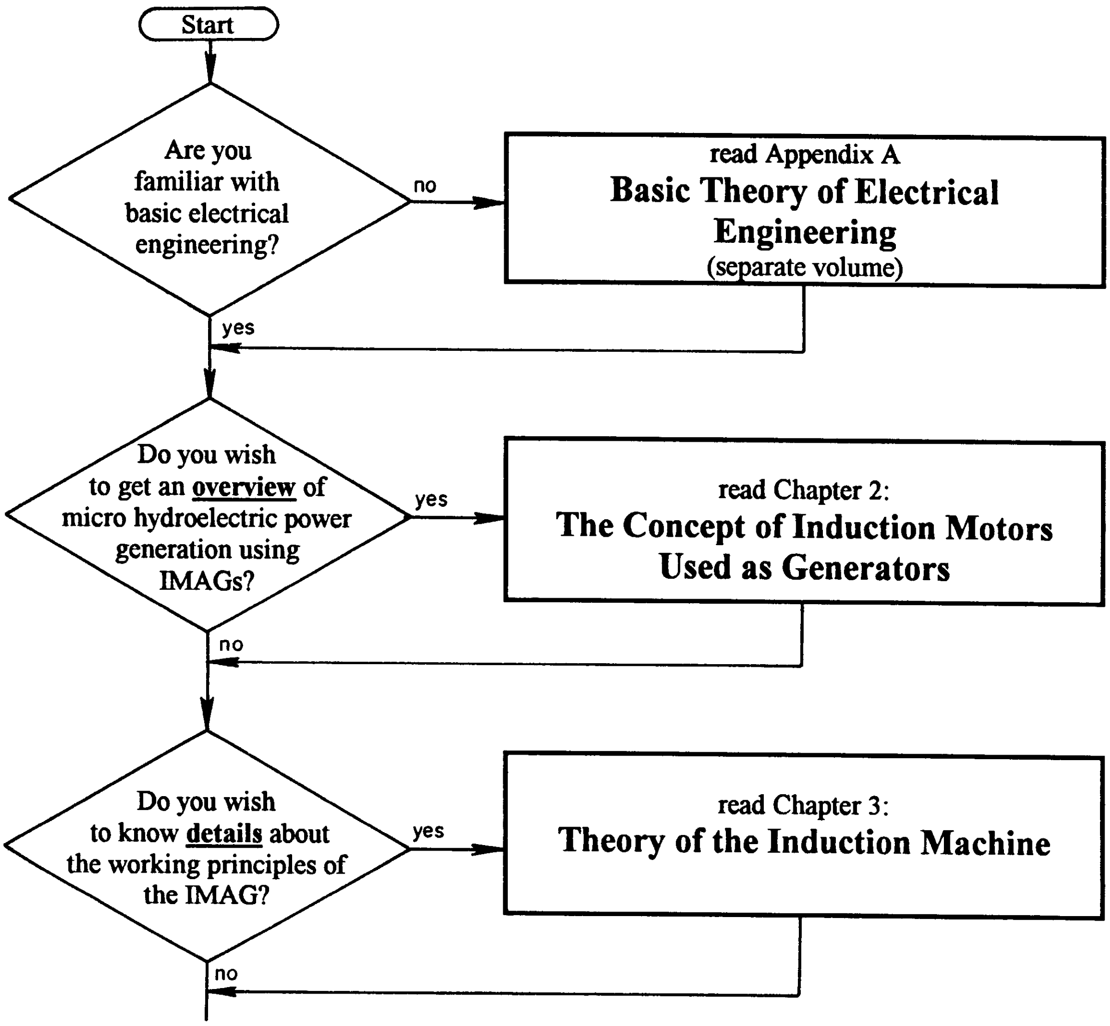
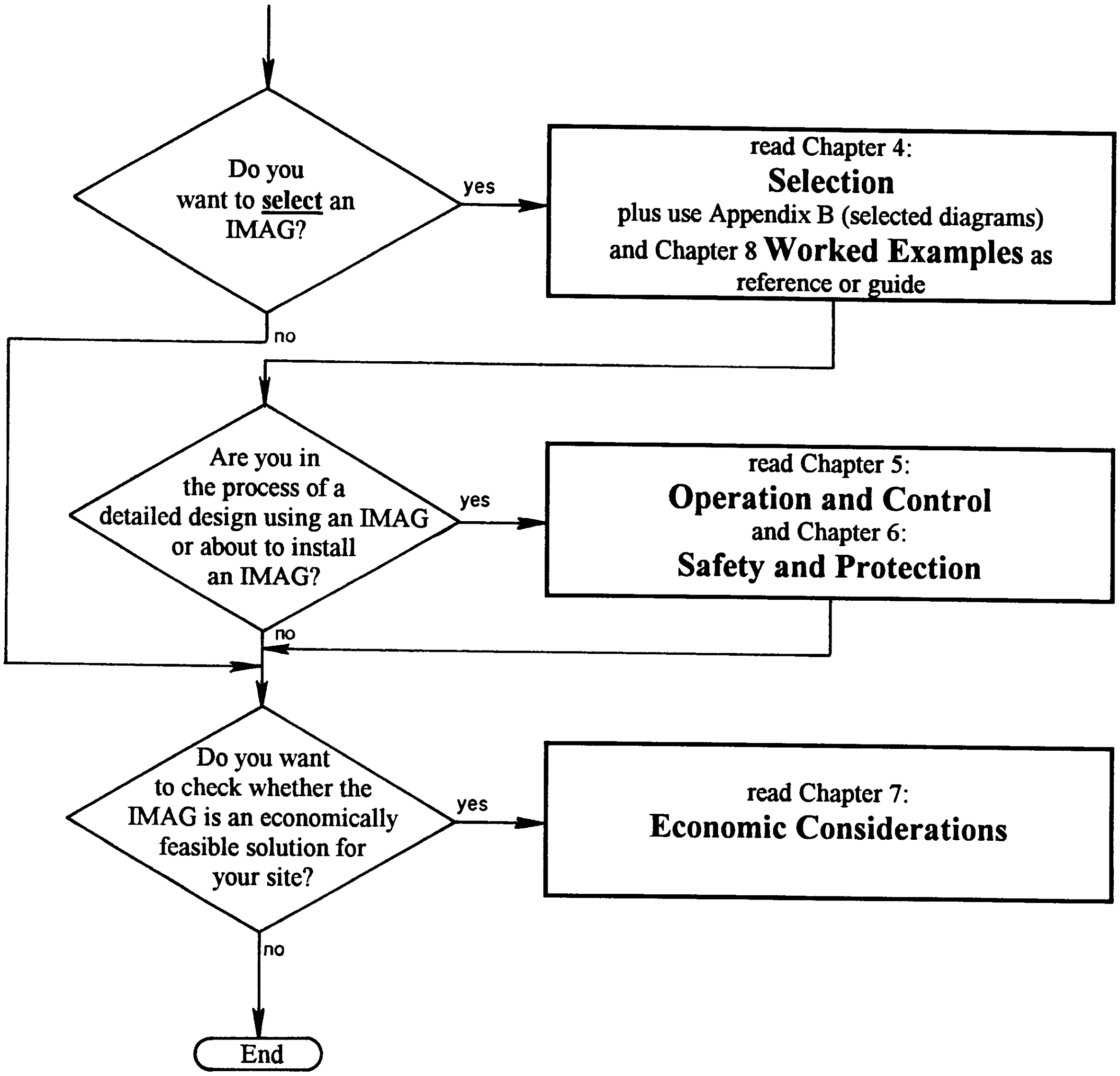
HOW TO USE THE MANUAL

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 an 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




Do you want to select an IMAG?
yes
read Chapter 4:
Selection
plus use Appendix B (selected diagrams)
and Chapter 8 Worked Examples as reference or guide
no
Are you in the process of a detailed design using an IMAG or about to install an IMAG?
yes
read Chapter 5:
Operation and Control
and Chapter 6:
Safety and Protection
no
Do you want to check whether the IMAG is an economically feasible solution for your site?
yes
read Chapter 7:
Economic Considerations
no
End

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Symbol	*SI-Unit*	*Quantity*
α	°	Angle
Φ	Wb = V s	Magnetic flux
ϕ	°	Phase angle
η	-	Efficiency
μ	Vs/Am	Permeability of a magnetic circuit
ρ	$\Omega mm^2/m$	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

Subscripts	*Meaning*
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

Symbol	*S.I. Unit*	*Quantity*
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