Cost and Design Study of Modular Small Hydro Plants Volume 1: Cost and Design Study

> EM-3534, Volume 1 Research Project 1745-6

Final Report, June 1984

Prepared by

ACRES AMERICAN INCORPORATED 1000 Liberty Building 424 Main Street Buffalo, New York 14202

> Principal Investigator L. Pereira

> > Prepared for

Electric Power Research Institute 3412 Hillview Avenue Palo Alto, California 94304

> EPRI Project Manager C. W. Sullivan

Energy Storage and Hydroelectric Generation Program Energy Management and Utilization Division

CONTENTS

Section		Page
1	INTRODUCTION	1-1
	Background	1-1
	Objectives of the Study	1-1
	Pump-as-Turbine Concept	1-2
	Organization of the Report	1-4
	Volume 1 - Report	1-4
	Volume 2 - Appendixes	1-6
	Volume 3 - Application Manual	1-7
	Volume 4 - Siphon Penstock Model Test Report	1-7
2	MAJOR EQUIPMENT	2-1
	Pumps-as-Turbines	2-1
	Selection Considerations	2-1
	Design Considerations	2-8
	Summary of Comparison between PATs and Conventional Turbines	2-9
	Induction Generators and Speed Increasers	2-12
	Selection Considerations	2-12
	Design Considerations	2-12
	Summary of Comparison between Induction and Synchronous Generators	2-17
3	ALIYTI TADY FOULDMENT	2.1
5	Floctrical Equipment	3-1
	Control and Protoction Systems	2 1
	Transformer Switchesen and Ausilianu	3-1
	Electrical Equipment	3-6
	Mechanical Equipment	3-6
4	EQUIPMENT COSTS	4-1

EQUIPMENT COSTS

4-1

Section

	5 SI	PHON PENSTOCK	5-1
		General	5-1
		Typical Arrangement	5-1
		Siphon Penstock Material	5-2
		Filling Systems	5-2
		Cost Estimates	5-6
		Operating Experience	5-6
e	5 PR	EFABRICATED POWERHOUSE	6-1
		General	6-1
		Prefabricated Powerhouse Substructure	6-1
		Prefabricated Electrical Switchgear House	6-5
		Construction Schedule	6-5
		Conclusions	6-5
	7 EF	FICIENCY AND RELIABILITY OF PAT FACILITY	7-1
		Efficiency	7-1
		Reliability	7-1
		Operation and Maintenance	7-3
	8 S [.]	TUDY OF REPRESENTATIVE SITES	8-1
		Introduction	8-1
		Site Selection	8-1
		Analysis of Selected Sites	8-3
		Conclusions	8-11
		Selection of Sites for Case Studies	8-13
		PATs Only	8-13
		PATs with Siphon	8-13
	9 C/	ASE STUDIES OF SITES	9-1
		Introduction	9-1
		Bend Feed Canal - PAT Installation	9-1
		Location and Hydraulic Characteristics	9-1
		Conventional Development	9-1
		PAT Development	9-3
		Economic Analysis	9-3
		Conclusions	9-10

Page

S	ect	ion	
_			

10

11

Abbeville - PAT Installation	9-10
Project Description	9-10
Conventional Development	9-11
PAT Development	9-11
Economic Analysis	9-11
Conclusions	9-14
Marmot Dam - PAT and Siphon Penstock Installation	9-14
Project Description	9-14
Conventional Development	9-19
PAT/Siphon Penstock Development	9-19
Economic Analysis	9-22
Conclusions	9-22
Holloway Dam - PAT and Siphon Penstock Installation	9-22
Project Description	9-22
Conventional Development	9-28
PAT/Siphon Penstock Development	9-28
Economic Analysis	9-31
Conclusions	9-31
Conclusions of Case Studies	9-37
PROPOSED FIELD TEST OF TWO PROJECTS	10-1
Purpose of Field Tests	10-1
Proposed Program of Work	10-1
Phase 1: Preliminary Engineering	10-2
Phase 2: Licensing	10-2
Phase 3: Detailed Design and Procurement	10-2
Phase 4: Construction	10-2
Phase 5: Testing and Commissioning	10-4
Phase 6: Plant Operation and	
Maintenance Evaluation	10-4
Project Data	10-4
APPLICATION SURVEY	11-1
Site Survey	11-1
Purpose of Survey	11-1
Data Sources	11-1
Selection (riteria	11-3

Section

Survey Results						11-4
Potential	for	ΡΑΤ	Applica	ations		11-4
Potential	for	PAT	Siphon	Penstock	Applications	11-4

12 REFERENCES

12-1

Page

ILLUSTRATIONS

Figure		Page
1-1	Application Ranges of Pumps-as-Turbines and Standard Hydro Turbine Generator Sets	1-3
2-1	Comparison of Typical Conventional and PAT Unit Selection	2-2
2-2	Typical Section Vertical Column Circulating Pump	2-4
2-3	Performance Characteristics of Ingersoll-Rand Vertical Pump in Pump and Turbine Operating Modes - Model 30B	2-5
2-4	Runaway Characteristics of Pumps	2-10
2-5	Conical Draft Tube Dimensions and Clearances for Typical Vertical PAT Unit	2-11
2-6	Manufacturers' Range of Standard Induction Generators	2-14
2-7	Speed Increaser Application Range	2-16
3-1	Typical Two-Unit PAT Plant Single-Line Diagram	3-3
4-1	PAT Unit with Conical Draft Tube Cost Estimate	4-2
4-2	Induction Motor (Generator) Vertical Type Cost Estimate	4-3
4-3	Induction Motor (Generator) Horizontal Type Cost Estimate	4-4
4-4	Speed Increasers Cost Estimate	4-5
4-5	Electrical Auxiliary Systems Cost Estimates	4-6
4-6	Turbine Inlet Valve Cost Estimates	4-7
5-1	Typical Siphon Penstock Arrangement for Multiple Units	5-3
5-2	Siphon Penstock with Inverted Bell-Mouth Intake	5-4
5-3	Siphon Penstock with Horizontal Intake	5-5
6-1	Prefabricated Powerhouse Structural Steel Substructure	6-2
6-2	Cost for Cast-in-Place and Prefabricated Steel Powerhouse	6-3