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Review of Relevant Studies of Isolated Systems

Lars Henrik Hansen and Per Lundsager

Abstract The report presents the results of a review of studies relating to integration of wind energy in isolated power supply systems, based on a systematic literature survey. The purpose of the study is to develop a methodology consisting of a set of guidelines for wind energy projects in isolated energy systems and a set of tools and models that are operational on an engineering level. The review is based on a literature search in the ETDE Energy Database with a main search covering the period 7/88 to 6/97 and supplemented by partial update periods. A few newer references have been included in the review, most notably the IEC/PAS 62111 specification. The amount of wind energy literature related to the subject is excessively large, and a complete review in which every relevant abstract is identified and examined is not feasible within the framework of this (or probably any other) study. The review results have been organised according to the following keywords: methods & guides, economics, concept of application, system solutions, case studies, financial programmes, dedicated software tools. None of the found references presents methods or tools that contradict the philosophy of Risø's methodology as it is described in the report. It is therefore concluded that Risø's methodology makes a good platform for further development.

Contents

Summary

This report presents the results of a review of studies relating to integration of wind energy in isolated power supply systems, based on a systematic literature survey. The review has been carried out in the framework of a study, *Isolated Systems with Wind Power,* supported by the Energy Research Programme of the Danish Ministry of Energy, file no 1363/97-0007, EFP97.

The study is carried out around a number of actions, one of which is the literature review reported here. The review is based on a literature search in the ETDE Energy Database with a main search covering the period 7/88 to 6/97 and supplemented by partial update periods. A few newer references have been included in the review, most notably the IEC/PAS 62111 specification

The purpose of the present study is to develop a methodology consisting of

1. A set of guidelines (what to do) for wind energy projects in isolated energy systems, and
2. A set of tools and models (how to do it) that are operational on an engineering level, representing today's state of development.

The study intends to base the proposed methodology on the methods and techniques already established by Risø in collaboration and/or interaction with other Danish consultants in the course of a number of Danish wind energy projects (grid connected as well as isolated) carried out world wide during the last two decades.

The review is done by searching library data bases using search profiles with suitable key words and key word combinations, and the resulting references are grouped according to their relevance for a number of main issues in the methodology.

Chapter 2 describes the principles applied in the review, developed in an iterative process where search profiles and main topics were gradually refined to give an operational basis for the review. The chapter includes statistics for a number of searches with various search profiles.

The following chapters present the outcome of the review with respect to the following key issues:

3. Methodologies & guidelines
4. Economic principles
5. Concepts of application & Systems solutions
6. Case studies & Programmes
7. Models & Software tools

For each key issue the statistics of the search for that particular issue is presented and a limited number of key references are listed and reviewed briefly.

Potentially a very large number of references indeed would result from a search unless the search profiles are carefully designed in order to restrict the outcome to operational levels.

Using e.g. "wind" as keyword in a search results in 20,978 hits (for the period 7/88 to 6/97). Using "renewable" as keyword in a search results in 29,015 hits (for the period 7/88 to 6/97). Thus the search profiles were refined in order to get a manageable amount of hits.

In addition to the references found by the structured searching principles described in the previous sections, a number of additional literature references were included, and in the end a few hundred references were selected for review. The bibliography contains 67 entries that were read and evaluated

The general findings of the review are, that the amount of wind energy literature related to the subject is excessively large, and that a complete review in which every relevant abstract is identified and examined is not feasible within the framework of this (or probably any other) study.

A great deal of work has been published conveying useful experiences within each of the topics to be covered by the methodology of the present study. This includes methods and tools for a number of specific issues, but no significant reference presents methods or tools that contradict the philosophy of Risø's methodology.

It is therefore concluded that Risø's methodology is in agreement with all significant references, i.e. it makes a good platform for further development.

Methodology & Guidelines
The most significant development in this respect is the appearance of the IEC/PAS 62111 Specifications for the use of RE in rural decentralised electrification, and the decision that such guidelines in the future should be structured as follows:
- Part A: Project specific guidelines or specifications for project implementation for e.g. rural electrification, large wind diesel grids or other specific applications, to be issued by main actors in the respective fields.
- Part B: Technology specific standards for Photovoltaics, Wind energy and other technologies, to be issued within the IEC standards framework. Only one part B will be issued, to be referenced by all Parts A.

It is concluded that with the exception of the IEC/PAS 62111 no work with the scope of the present study has been carried out before for the design and evaluation of isolated electric power systems with high wind energy penetration, i.e. no comprehensive and consistent methodology, operational on an engineering level, exists for those systems.

It is therefore recommended, that for the type of isolated systems relevant for Denmarks/Risø's field of experience, i.e. medium to large isolated electric power systems with high wind energy penetration, more specific guidelines should be developed in the form of checklists for relevant issues.

For each item on the checklist engineering operational methods & tools should be indicated, and the guidelines should be issued as a Part A guidelines as described above.

Economic principles:
It is concluded that the development of guidelines should continue with the economic principles already applied, i.e. levelised production costs based on life cycle cost analyses.

It is recommended that externalities should be quantified by methods like the Environmental manual, and that other benefits like optional or deferrable loads, uninterrupted power supply etc. be included as well. Furthermore the diversification of economic risks should be introduced.

Models and software:
It is concluded that the WINSYS model and similar models will be the workhorse in the technical-economical analyses of isolated systems with high wind energy penetration.

It is recommended that in addition to WINSYS extensions and similar models the needs for versatile screening models (spreadsheet based) and for system optimisation models should be considered as well as the need for genuine time history models. Furthermore, the models should be prepared for extension to (multiple) RE integration.

List of Acronyms

COE	Cost of energy
DGS	Diesel Generator Set
EDF	Electricité de France
EMS	Energy Management System
ESMAP	WB Energy Sector Management Assistance Programme
ETDE	Energy Technology Data Exchange
EWDS	European Wind Diesel Software Package
GUI	Graphical User Interface
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IRES	Integrated Renewable Energy System
IRR	Internal Rate of Return
LAC	Levelized annual costs
LPC	Levelized production cost
LOLE	Loss of load expectancy
LOLF	Loss of load fraction
LOLP	Loss of load probability
LTMC	Long term marginal cost
NPV	Net present value
PAS	Publicly Available Specification
PV	Photovoltaics
QPW	Quattro Pro for Windows
RAPS	Remote Area Power–supply System
RE	Renewable Energy
SHS	Solar home system(s)
SQI	Service Quality Index
STMC	Short term marginal cost
UNDP	United Nations Development Programme
WB	World Bank
WD	Wind-diesel
WECS	Wind Energy Conversion System
WTG	Wind Turbine Generator

1   Introduction

This report presents the results of a review of studies relating to integration of wind energy in isolated power supply systems, based on a systematic literature survey. The review has been carried out in the framework of a study, *Isolated Systems with Wind Power,* supported by the Energy Research Programme of the Danish Ministry of Energy, file no 1363/97-0007, EFP97.

The study is carried out in collaboration between Risø National Laboratory and Darup Associates Ltd., Denmark, and National Renewable Energy Authority NREA, Egypt, with the main purpose to establish a methodology, operational on an engineering level, for the design and evaluation of isolated electric power supply systems with high wind energy penetration.

The study is carried out around a number of actions, one of which is the literature review reported here. The review is based on a literature search in the ETDE Energy Database with a main search covering the period 7/88 to 6/97 and supplemented by partial update periods.

A few newer references have been included in the review, most notably the IEC/PAS 62111 specification dealt with in section 3.2.

1.1   Background and Purpose

During the last two decades there has been considerable efforts on both national and international levels to implement wind energy in connection with local and regional electric power supply by integrating wind energy into small and medium sized isolated distribution systems world wide. These systems are often, but not necessarily always, powered by diesel power plants, and a fairly recent review made for the Danish International Development Agency DANIDA ((Lundsager & Madsen, 1995)) identified about 100 reported and documented wind-diesel installations world wide.

In addition to these and other actually implemented systems a great deal of preparatory and investigative studies have been made in the framework of national and international R&D institutions and programmes, development agencies and financing bodies. Thus, even though internationally approved methods for layout, design and evaluation of such systems have so far not been established, a considerable body of experience exists based on the tools and approaches developed for and applied in each specific case. Much of this work has been reported in the open literature

The purpose of the present study is to develop a methodology consisting of 1) A set of guidelines (what to do) for wind energy projects in isolated energy systems, and 2) A set of tools and models (how to do it) that are operational on an engineering level, representing today's state of development.

1.2 Outline of Risø's Methodology

The study intends to base the proposed methodology on the methods and techniques already established by Risø in collaboration and/or interaction with other Danish consultants in the course of a number of Danish wind energy projects (grid connected as well as isolated) carried out world wide during the last two decades.

This experience may at the present stage be summarised in a philosophy combining technical assessments based on logistic modelling with economic evaluations based on life cycle costing principles. The WINSYS model as described in (Hansen & Tande, 1994) represents this philosophy in a form where the development of both technical and economical performance throughout the project life time is accounted for.

The WINSYS model and the associated methodology has been verified for the type of cases it is designed for.

1.3 Outline of the Report

The purpose of this review is to identify areas where the already established philosophy needs to be changed or supplemented. By screening the literature the intention is to get an overview of the previous experience to be utilised in the methodology to be established by the present study.

The review is done by searching library data bases using search profiles with suitable key words and key word combinations, and the resulting references are grouped according to their relevance for a number of main issues in the methodology.

Chapter 2 describes the principles applied in the review, developed in an iterative process where search profiles and main topics were gradually refined to give an operational basis for the review. Potentially a very large number of references indeed would result from a search unless the search profiles are carefully designed in order to restrict the outcome to operational levels. The chapter includes statistics for a number of searches with various search profiles.

Chapters 3 to 9 present the outcome of the review with respect to the following key issues:
- Methodologies and guidelines
- Economic principles
- Concepts of application
- Systems solutions
- Case studies
- Programmes
- Software tools

For each key issue the statistics of the search for that particular issue is presented and a limited number of key references are listed and reviewed briefly by their abstract, authors remarks and key issues. Conclusions and recommendations for the key issue in question are outlined based on the result of the search.

2 Principles Applied in this Review

This chapter describes the principles applied in this review. With emphasis on experience, the review – of Danish as well as international studies – is made concerning integration of hybrid power sources in isolated or remote systems. Special importance is attached to descriptions of regional conditions with respect to economy, methodology, power quality and sustainability.

The Energy Technology Data Exchange (ETDE) Energy Database is selected to serve as the main Literature source, due to its comprehensive coverage of energy research and technology (more than 3.5 million bibliographic citations). Refer to http://www.etde.org/ for further information.

2.1 Preconditions for the Review

This review is mainly concerned with isolated or remote electricity supply systems with wind power. The size of the installed power in the considered energy producing system is expected within the range of 10 kW to 500 kW, which covers both small and large remote systems. Characterisation and demands to small versus large remote systems are expected to be quite different a fact which of course influences the studies, which are considered relevant for this review of isolated or remote electricity supply system. Meanwhile, the review is not limited to consider systems with wind power as add-on, i.e. the review is also concerned with studies of new planned systems for sites with no power supply at all or studies of other hybrid system solutions, such as solar cells, biogas etc.

The following list of keywords is presented to characterise and limit, what is relevant for this review. The keywords are: "autonomous", "battery", "diesel", "economic", "economy", "energy", "hybrid", "hydraulic", "hydro", "guidelines", "isolated", "methodology", "model", "modeling/modelling", "power", "renewable", "review", "rural", "simulation", "software", "storage", "study", "system" or "wind". These keywords should cover the studies of interest and hopefully not exclude any studies of relevance.

2.2 Searching Principles and Results

This section gives a short description of the performed Literature search in the ETDE Energy Database. Using e.g. "wind" as keyword in a search results in 20,978 hits (for the period 7/88 to 6/97). Thus, the search has to be refined in order to get a manageable amount of hits. To do so, the searching is divided in two search directions, one related to "wind" and one related to "renewable".

2.2.1 Wind as main Keyword

"Wind" as keyword is quite general and as described above it results in almost 21,000 hits. The profile of the search has to be further refined to eliminate the irrelevant hits, e.g. literature on wind tunnel tests, wind stress etc. The result of combining "wind" with one or several of the keywords listed in Section 2.1 is presented in Appendix B. As described the keyword combination: *wind and (energy or power) and (system or systems)*, forms a suitable base for a wind related search.

Some of the keywords characterising what is relevant are synonyms for others. To improve the overview, they can be gathered into groups as shown below:
1.   Autonomous, isolated or rural.
2.   Battery, hydraulic, hydro or storage.
3.   Diesel, hybrid or renewable.
4.   Domestic.
5.   Economic or economy.
6.   Guidelines or methodology.
7.   Model, modeling/modelling or simulation.
8.   Review or study.
9.   Software.

Using these groups, the search result for the "wind" related search can be presented as in Table 3, where the search results are listed for three periods. The first period is the present available time period in the ETDE Energy Database, while the second and third period are partial update periods.

Table 1. Base: wind and (energy or power) and (system or systems).

Group combinations		Number of hits		
Group	Period	7/88 - 6/97	1/95 - 9/96	10/96 - 6/97
--	base	6810	1511	701
1	autonomous, isolated or rural	488	99	53
2	battery, hydraulic, hydro or storage	1547	289	205
3	diesel, hybrid or renewable	2943	692	403
4	domestic	1540	309	216
5	economic or economy	101	12	14
6	guidelines or methodology	219	54	29
7	model, model(l)ing or simulation	1789	420	204
8	review and study	1910	404	179
9	software	170	43	27

It should be noted that the use of these search profiles does not guarantee all the hits to be relevant for this review. Since the assessment criterion on what is relevant, is difficult to put in a unique search profile, titles and abstracts have to be evaluated by hand. Therefore, the groups: 1, 5, 6 and 8, are selected for the period 10/96 - 6/97 in order to minimise the number of hits, but simultaneously to be representative for the scope of this review. The concatenation of these four groups contains 242 hits. From these 242 literature references 19 are selected (i.e. found relevant) and described in the following chapters.

2.2.2 Renewable as main Keyword

Using "renewable" as keyword in a search results in 29,015 hits (for the period 7/88 to 6/97). Thus for this case, the search profile has to be further refined. Since the review is focussed on isolated systems, it is reasonable to let the base of the search profile consist of *renewable and (rural or remote)*. This will limit the number of hits to 148, which is a manageable number. As described above, these literature references have to be evaluated by hand. From these literature references 25 are selected (i.e. found relevant) and described in the following chapters.

Comparing the selected literature references with those selected in the previous section, it turns out that they have only one reference in common. Thus, the suggested search profiles provide this review with a wide range of relevant studies.

3   Additional Literature References

In addition to the references found by the structured searching principles described in the previous sections, a number of additional literature references are included. These additional references are of course relevant for this review, but not all of them are covered by the ETDE Energy Database.

Furthermore "special tool profiles" are used to identify more literature references on the software tool encountered during the reviewing process. The main outputs from these specialised profiles are gathered in Chapter 9.

3.1.1 Limitations

Several books have been written on the subject of power system stability and on the dynamic behaviour of power systems. This is not the issue of the this review as described in Section 1.2. However, readers interested in this subject are referred to e.g. (Anderson & Fouad, 1994) or (Kundur, 1994).

3.1.2 Methodology and Guidelines

The Chapter contains selected references on methodology and guidelines. In addition to the Section on renewable energy the Chapter also includes a Section on the IEC/PAS 62111 guidelines for RE in rural decentralised electrification.

3.2   Renewable Energy

3.1 *Wind Energy Systems - A Buyer's Guide*. (Atlantic Wind Test Site & MSC Enterprice, 1997).

Abstract (rev.): Wind Energy Systems - A Buyer's Guide is a booklet intended to provide a brief introduction to wind energy and it offers helpful information to further such understanding. The information in the booklet combined with additional resources identified at the end of the booklet, will provide a realistic preliminary assessment of the practicality of pur-

chasing, operating and maintaining a wind turbine. Economics and the cost of energy are illustrated by case studies.

> Remarks: A mix of a wind energy tutorial and a bid on a complete methodology on a general level for Canadian conditions (with emphasis on remote conditions). Good survey on a basic level of the issues in wind energy implementation. Few specifications of concrete methods in the guide itself, but many literary references at the end.

Methodology: A checklist of questions and issues to be discussed with suppliers of wind energy equipment. A good and comprehensive layman's guide.

Economics: Costing and economy covered quite detailed using economic principles similar to IEA recommendations.

Case studies: Presents 3 case studies providing typical examples of application, described in detail.

3.2 *Best Practices for PV Household Electrification Program*. (Cabraal et al., 1996).

Abstract (rev.): PV solar home systems (SHS) are increasingly employed as an energy supply option for rural populations. The past 20 years' experience with small-scale SHS programs in developing countries has had mixed results. However, efforts in recent years have been more successful. In support of World Bank lending operations, the Banks Asia Alternative Energy Unit (ASTAE) has undertaken a series of case studies of currently operating SHS programs in Indonesia, Sri Lanka, the Philippines, and the Dominican Republic. These programs have varying degrees of government, NGO, and private sector involvement. This report summarises ASTAE's draft Solar Photovoltaics: Best Practices for Household Electrification report which identifies the institutional, financial, and technical factors fundamental to the success of a PV solar home system project.

> Remarks: Dealing with PV technology, this WB technical paper describes best practices seen from WB perspective to improve prospects for successful project design and implementations. Based on experiences in selected countries the paper gives an insight in the concepts and issues regarded by the WB as essential for the technical and economical success of RE programmes.

Methodology: The paper describes issues - in particular economical issues - that should be addressed in any methodology aiming at WB (and probably most other international) funding.

Economics: Assumes - but does not describe - technical-economical performance assessed by accepted methods. Emphasis on the issue of first cost barrier and financial issues.

Project design: Institutional models, financial sustainability & technical requirements.

3.3 *PV Applications in Rural Areas of the Developing World*. (Foley, 1995).

Abstract (rev.): Within the framework of a research programme supported by the Federal Ministry for Science and Technology on a surface of one square kilometre six local, self-sufficient photovoltaic plants for various agricultural applications have been installed. In the field of live-

stock all consumers of the pig-breeding shelter are supplied by a photo-voltaic plant. Moreover, the following plants have a photovoltaic supply: mobile animal food station with computerised control systems, green-house in combination with solar collectors, ventilation of a pond and an electrolysis plant for the household.

> Remarks: A WB technical paper "making the case" for applying PV in rural areas of the developing world. Argues the PV case in terms that are acceptable to WB
>
> A similar paper for Wind Energy might be appropriate.

Methodology: The paper describes issues that should be addressed in any methodology aiming at WB (and probably most other international) funding
Economics: Assumes - but does not describe - technical-economical perform-ance assessed by accepted methods.
Project design: Institutional models, role of governments and funding agencies

3.4 *Wind-Diesel Systems for Remote Communities*. (Island Technologies In-corporated & Passmore Associates, 1995).

Abstract (rev.): Differences between wind energy for remote electrical grids and for large city interconnected grids are reviewed. Benefits of wind/diesel technology as supplement to conventional diesel generation of electricity are described. Further, influences of the size of the wind energy penetration ratio on the control system is briefly discussed, to-gether with wind turbine design and wind/diesel control considerations. A set of guidelines and recommendations for development is presented.

> Remarks: A mix of a wind-diesel tutorial and a bid on a complete meth-odology on a general level for Canadian conditions (with emphasis on remote conditions). Good survey on a basic level of the issues in wind-diesel implementation. Few specifications of concrete methods in the guide.

Methodology: A hands-on guideline for project design.
Project design: A checklist of questions and issues to be discussed with suppli-ers and in particular users of wind-diesel equipment. A good and comprehensive layman's guide.

3.5 *Wind-Diesel Systems*. (Hunter & Elliot, 1994).

Abstract: The broad topics covered in this book are: wind-diesel system options; matching the wind-diesel system to the community; assessing wind resource; designing a system; case studies of wind-diesel systems - a demonstration plant, an island electricity scheme and a research fa-cility: modelling techniques and validation; system installation and moni-toring; economic assessment.

> Remarks: The book is the output of the IEA Annex VIII working group, representing a large body of international experience representing state of affairs at the termination of the Annex in 1989. The book is a mix of a wind-diesel tutorial and a bid on a complete methodology on a mostly technical level, "making the case" for winds-diesel systems almost en-

tirely on technical grounds and to a large extent based on experience with more or less experimental systems implemented in "university type" or donor financed environments. Aimed mostly at researchers and system designers/developers (manufacturers).

Methodology: Although not a guidebook, the book presents a number of (technical) tools and techniques for design and evaluation of prospective sites and systems.

Economics: Presents a useful methodology for economic appraisal based on internationally accepted economic assessment methods, although formulated differently from the IEA recommendations.

Concepts of applications and system solutions: An introduction to the basic principles and a number of concrete system architectures.

Case studies: Two R&D systems and one island demonstration plant.

Software: Survey of 14 technical simulation models from the international R&D community, 8 transient models for power quality prediction, 6 performance models for prediction of power performance and fuel savings.

Project design: Matching community loads, installation and monitoring of WD systems

3.6a *Rethinking Development Assistance for Renewable Electricity.* (Kozloff & Shobowale, 1994).

Abstract (rev.): Development options for renewable resources was the subject of this speech recorded at the Renewable Energy Commercial Trade Show and Markets Conference. A cross-section of specific project from several countries is reviewed with an eye towards development assistance. It was concluded that thorough commercialization was the best way to ensure the success of renewable energy projects, although few agencies are considered to have the time and resources to bring a plan through from R&D, demonstration, and market diffusion stages with a follow-up. Choices, which affect sustainability and lessons learned through the research, are examined. Moreover, the selection of mainstream cost effective applications of renewable energy technologies, the fostering of multilateral leadership for international co-operation in commercialization, the favouring of long-term strategies to build markets by stimulating demand for renewables in developing countries, and the targeting of programs towards countries whose policies allow fair competition among energy technologies are recommended. The need for a balance among the competing objectives of environmental protection, export market growth and partner country development are underlined.

> Remarks: Guidelines mostly aimed at donor agencies and financing bodies. The report reviews recent experience with RE technologies in development programmes. Lessons learnt and recommendations fit well with our experience. Emphasis on soft issues (commercialization, institutional framework etc) in addition to economics. Recommendations make sense and will hopefully be implemented, and our methodology should assume that they will be implemented. Most of the conclusions address issues that, although they are critical to sustainable RE utilisation, must be solved by governments and financing institutions (and not by analysts, advisors or consultants). Example: Even a well designed project may fail in case of heavy power sector distortions such as heavy and/or hidden subsidies.

Concepts of application and system solutions: Outlines a number of concepts and systems solutions for various RE technologies of relevance/interest to financing institutions. Our methodology should be able to address these.

Case studies: Brief description of distributed utility (distributed generation) applications. Reviews of various RE technology programmes (Danidas wind energy programme in India used as success story)

3.6b *Rethinking Development Assistance for Wind Power*. (Kozloff, 1995).

Abstract: Electricity generation from wind turbines is now cost competitive for grid and off-grid applications in many developing regions, and close to competitive in others. Wind resources could generate thousands of megawatts of badly-needed power in Asia, North Africa, and Latin America. Barriers to penetrating power generation markets remain, however, including unequal access to investment capital, energy price and other market distortions, and often weak institutions for commercialising new technologies. Recognising the potential economic and environmental benefits of wind power, bilateral and multilateral assistance organizations have for several years offered financial and technical assistance to promote its diffusion. Based on this experience and assistance for other renewable electric technologies, lessons and recommendations can be drawn regarding how assistance could more effectively overcome persistent market and policy barriers, especially in light of the ongoing restructuring of developing countries' power sectors.

> Remarks: The paper makes no secret of being based on 3.6a. Therefore, the notes above apply, seen in the light of wind power which is the main focus of the paper.

Concepts of application and system solutions: Outlines a number of concepts and systems solutions for various RE technologies of relevance/interest to financing institutions. Our methodology should be able to address these.

Case studies: Brief description of distributed utility (distributed generation) applications. Reviews of various RE technology programmes (Danidas wind energy programme in India used as success story)

3.3   IEC/PAS 62111

3.7 *Specifications for the use of renewable energies in rural decentralised electrification.* (Research and Development Division, 1999).

Abstract: The General Directives for the use of Renewable Energies in Decentralised Rural Electrification take the form of 24 documents describing the functional specifications on which the design, implementation and exploitation of the constituent parts of these electrification systems should be based.

A PAS is a technical specification not fulfilling the requirements for a standard, but made available to the public and established in an organisation operating under given procedures. IEC/PAS 62111 was submitted by Electricité de France and has been processed by IEC technical committee 82: Solar photovoltaic energy systems. This PAS is also relevant

to the activities of TC 21, Secondary cells and batteries, and TC 88, Wind turbine systems.

Remarks: Guidelines conceived primarily for small to medium size systems for rural electrification. 1st edition contains a mix of guideline issues and purely standards related issues. 2nd edition will be cast in two parts, a Part A dealing with guidelines for RE in rural electrification, and a part B dealing strictly with standards for the RE technologies.
Part A will be developed for this particular use by EDF. Other parties may develop a part A for other particular uses such as our own applications.

> Part B will be developed in the framework of IEC in only one version, to be referenced by individual parts A developed by various parties.

Methodology: Presents the "EDF methodology for RE in rural decentralised electrification"
Project design: Guidelines for system design & operation, technical specification of components, and specification of a system for a specific site.

4 Economic Principles

A standard method for estimating the cost of energy (COE) from wind energy conversion systems is recommended in (Tande & Hunter, 1994). The IEA recommendation are developed for grid connected WTG's, but the principles should be generalised to hybrid systems, as it is done in WINSYS (Hansen & Tande, 1994) and other models.

The references in this Chapter deal with various aspects of assessing the costs and values of energy on this basis in terms which are acceptable to national and international donors and financiers

4.1 Cost Analysis of Electrification

4.1 *The Value of Marginal Analysis in Electric Power System Operations.* (Katzman & Shelton, 1989).

Abstract (rev.): Electric utilities have traditionally based their calculation of costs and derived prices on the basis of averages. Marginal analysis provides an alternative method of costing and price setting. Not only does marginal analysis yield different computations, it can lead to different and more efficient decisions. This point is illustrated by an example concerning the evaluation of biomass cogeneration to a utility and the costing of rural extensions.

> Remarks: Emphasis is on distinguishing between short term marginal cost (STMC) and long term ditto (LTMC). STMC is the marginal cost normally used and implemented in our models (e.g. avoided fuel cost). LTMC is the marginal cost asociated with e.g. grid extension (to remote sites), expansion of existing generating capacity (at least partly covered by LOLE considerations) etc. LTMC should be addressed in our methodology.

Economics: Two important economic concepts for our methodology. Results are based on accepted economic concepts including these two (but no equations).

Concepts of application: Two different typefied applications.

Case studies: Several consumer load patterns

4.2 *Decentralized versus Grid Electricity for Rural India: The Economic Factors*. (Sinha & Kandpal, 1993).

Abstract (rev.): The provision of rural energy in India has been regarded as synonymous with rural electrification. However, low load factors, long distribution lines with low load densities, and the associated high transmission and distribution losses in most rural areas of India make many of the rural electrification programs economically unattractive. Decentralized energy technologies based on local resource availability can be a viable alternative to rural electrification through the extension of the grid. The cost of grid electricity to the end user is quantified in this paper and compared with the cost of electricity from decentralized energy systems to obtain the specific distances from the grid, the level of demand, and the load factor conditions, under which using decentralized energy systems for rural India makes economic sense. It is found that for small and isolated villages with low load factors, decentralized energy technologies make sense.

> Remarks: In reality this paper is an example on the application of the LTMC concept (ref 4.1) to decide on the viabilities of two options for rural electricity. Examples on concrete calculations including equations and graphs.

Economics: Equations for application of the LTMC concept

Case studies: Several cases for isolated villages and clusters.

4.3 *Cost of Electricity generated and Fuel Saving of an Optimized Wind-Diesel Electricity Supply for Village in Tangier (Morocco)*. (Nfaoui et al., 1996).

Abstract (rev.): In several of the remote areas of Morocco, diesel generators are used to provide electrical power. Such systems are often characterized by poor efficiency and high maintenance costs. The integration of wind turbine with a diesel/battery hybrid system is becoming cost-effective in wind locations. A wind/diesel energy system with battery storage is modelled using the Tangiers wind regime over a one year period (1989), and synthesized consumer load data based on the characteristics of typical usage of domestic appliances, along with the estimated working patterns of a local isolated community. In this work, a more realistic hourly consumer load is used, which is the result of an experiment realized in a Maroccan village using a diesel engine to provide electricity for lighting and audio-visual. The optimum wind turbine size and the benefits of a storage system on fuel saving are also reviewed. This paper is concerned with diesel fuel consumption: an optimum design of the considered system is to be found which minimises the cost energy generation over the equipments' lifetime. The wind/diesel energy system is shown to be competitive with diesel-only generation in the wind regime of the Tangier location.

Remarks: An example of a straightforward technical-economical assessment of the wind diesel option for local electricity supply in Tangier. Technical performance prediction reported in usual terms, but model(s) used are not properly referred to. Economic performance prediction based on simplified life cycle cost principles (in accordance with the IEA recommendations).

Economics: Based on simplified life cycle cost principles

4.4 *Techno-Economics of Electric Power Generation through Renewable Sources of Energy: a Comparative Study*. (Kishore & Thukral, 1993).

Abstract (rev.): As presented in this paper, significant attempts have been made in promoting devices for irrigation-water pumping like solar systems, gasifier diesel engines and wind mills, which have not been commercially successful in general. Major research, development and demonstration projects are executed mainly in the developed countries, to study the technical and economic feasibility of electric power generation both in stand-alone and grid-coupled modes of renewable energy sources. Many technologies are now either available or strongly feasible for electric power generation through renewable energy sources. Several economic indices can be used for comparison of widely different systems such as cost per kW installed and cost per kWh generated. In order to decide the economic viability of a given system, it is desirable to evolve a single index that incorporates parameters like total initial costs, overall power conversion efficiency, operating and maintenance costs, fuel costs, system life, etc. In this paper the levelised annual cost is used as the single index to assess various renewable energy sources.

Remarks: The paper is really an excercise to rate a variety of RE technology systems against each other based on (what we call) levellized production cost LPC, in the paper termed LAC, annual production costs. LAC is defined on basis of net present value (NPV) in a simplified life cycle cost analysis (in accordance with IEA recommendations). Technical performance is predicted by estimating the capacity utilization factor (our capacity factor).

Methodology: May give useful input to our methodology as a checklist on "what to remember".

Economics: Simplified economic indicators that comply with IEA recommendations

System solutions and case studies: Several (16) cases with combinations of RE technology and system layouts are analysed as examples on "how to do".

4.2 Rural Electrification and Economic Perspectives

4.5 *Decentralized Rural Electrification: State of the Art and Technical and Economic Perspectives*. (Chabot, 1996).

Abstract (rev.): This paper reviews the approach currently underlying decentralized rural electrification, which is based on analysing requirements, arranging them by priority and choosing appropriate solutions combining the criteria of energy efficiency with the use of local renewable energy resources. The main decentralized rural electrification techniques in use are described briefly, along with the corresponding energy services each of them can cover. The current costs of the systems, projects, and services are discussed along with the short - and medium - term technical and economic changes in decentralized electrical production and consumption, with a view toward expanding to Larger-scale dissemination. As presented, the development of decentralized rural electrification by renewable energies has a potential impact in terms of environmental benefits and costs cuts, and a few pointer are given as to how these costs and benefits can be better defined in the future.

> Remarks: The paper is quite strategic/political in that it deals with the various perspectives and conditions that must be dealt with and fulfilled in order to obtain large scale application of RE in rural areas in developing countries. The paper postulates costs of energy (COE) for RE components and shows total (global) COE's for several systems in the form of nomograms, but calculations are not shown.

Methodology: Checklist.
Economics: Postulates costs of energy (COE) for RE components and shows total (global) COE's for several systems solutions. Calculations are not shown.

4.6 *Profitability and Economic Prospects for the Solar Electrification of Rural Regions in Senegal*. (Schaefer, 1994).

Abstract (rev.): The paper reports on a comparison of cost between a centralised village photovoltaic plant and, firstly, the two conventional solutions of rural electrification (diesel plant, expansion of the medium voltage network); and secondly, family-based photovoltaic plants (SHS, solar home systems). First a scenario is developed permitting a comparison of these four alternatives of rural electrification. This is used as a basis for determining the cost and profitability (in the sense of relative advantageousness) of each of the four alternatives. This is followed by a sensitivity analysis in which the response of the calculations to certain changes in key parameters is studied. Finally the paper presents the most important conclusions from the study.

> Remarks: A summary paper presenting a methodology similar to our present methodology for calculation of COE for a number of alternative technical-economical scenarios. Results are presented, but calculations are in references in the paper.

Methodology: Similar to ours.
Economics: COE used for comparisons, but calculations not shown.
Case studies: Results - but no calculations - shown for four different possible technical scenarios.
Project design: Elements for a checklist.

4.3. Socio-economic Objectives and Externalities

4.7 *Income Impacts of Alternative Rural Energy Systems: Case Study of a Village in Punjab, India*. (Pangotra, 1988).

Abstract (rev.): This study assesses the potential impacts of four alternatives energy systems for stationary power applications on the household income of different population groups in a village in Punjab, India. It is shown that for all categories of potential users (farmers and owners of industry) the electricity option is most cost-effective. The next best option is diesel, followed by biogas and producer gas,in that order. In contrast, most of the non-user households (artisans, laborers, etc.) realize significant income gains under the biogas and producer gas options. With electricity as the benchmark, the aggregate losses of the users exceed the aggregate gains of the non-users under all options. It is argued that neither the potential Pareto improvement criterion of economic efficiency nor the Rawlsian theory of distributive justice lend support to energy-supply options other than electricity.

> Remarks: This Ph.D. study contains a concept study of four energy systems in typical rural communities in India. Assessing scenarios by established techniques. Indicators e.g. annual net household income calculated by simulation of household budgets. Presents models for energy requirements of typical consumers, models for technical performance of biogass plants and for power system / consumer interaction.

Methodology: Flow-chart type models for local biomass resource balance.
Economics: Applied project criteria are Potential Pareto income improvement, and Rawls' concept of distributive justice (pp261ff).
Concepts of application: Four concepts, interaction with local biomass resources, electrification used as benchmark.

4.8 *Options for Rural Electrification in Mexico*. (Vera, 1992).

Abstract (rev): This paper summarizes a study which examined 19 commercially available options for electrifying remote communities in Mexico. Characteristics of a typical community are defined and, using 7 of the technologies, power systems are designed capable of supporting this community. The performance of these systems is evaluated with respect to their ability to satisfy 11 technical design objectives, 5 socio-economic objectives, and their impact on the environment. A photo-voltaic-diesel generator hybrid system with wind generator option is recommended for the typical community.

> Remarks: The whole paper is a case study, where 7 system configurations out of 19 possible ones are assessed for a generic technical-economical scenario and rated relatively to each other.

Methodology: Includes useful listing of technical criteria and issues for application of a given system configuration in a remote location.
Economics: Uses our principle, i.e. the NPV as economic measure, based on a simplified life cycle cost analysis.
Case studies: The whole paper is a case study.

4.9 *The Environmental Manual for Power Development - Status and Results from Case Studies in the Philippines, Poland and Morocco.* (Herberg & Fritsche, 1996).

Abstract (rev.): The Environmental Manual for Power Development (EM) is a multiyear and multidonor project sponsored by a group of bilateral and multilateral development agencies and is co-ordinated by the World Band. The EM is a Windows based computerized tool for the analysis of the environmental impacts of energy (mainly electricity) systems and of the cost trade-offs associated with project alternatives (e.g. low sulphur fuel, flue-gas desulphurization, demand side management (DSM), co-generation, renewables). The EM uses the comprehensive life cycle approach to determine environmental impacts (from 'cradle to grave'). The EM database offers a broad variety of generic (prototypical) information on energy systems, including costs, efficiency and environmental impacts. It covers conventional fossil fuel power plants, boilers and their supporting infrastructure (e.g. mining, refinery, transport) transmission and distribution systems, renewable energies (hydropower, photovoltaic power, biomass, wind, etc.), and cogeneration and DSM technologies. Furthermore, emission control technologies are included. The EM can be used for a wide range of applications - from 'early screening' of energy projects under consideration, and energy/environmental planning of utilities and countries, to cost impact analysis of setting different environmental standards. During its development, the EM was tested in real-world applications to demonstrate its usability; these case studies included both database adaptations to the countries and application of the model to support the decision making process on energy systems. Results from the Philippines, Poland and Morocco are presented, and future activities are addressed.

> Remarks: This is a methodology to assess the "life cycle environmental cost" of a given power supply system in terms accepted by WB (who contributed to the development of the EM tool). In other words: It is a methodology to assess the external cost or value in terms which should be acceptable to national and international donors and financiers.

Methodology: Should be assessed for possible application in "our" methodology

Economics: The levelized cost principle applied to external costs

Case studies: Three national cases

Software: EM is supposedly available as a Windows program, and it should be acquired and tested. May be downloaded from
http://www.worldbank.org/html/fpd/em/.

5 Concepts of Applications

The references in this Chapter pay special attention to the concepts of application, i.e. the overall principles for the application of RE systems and components in various modes and contexts. This includes principles for interaction between various RE sources and types of energy consumption.

5.1 Concepts

Concepts include both technical and non-technical issues.

5.1 *Conceptual Systems Model for the Assessment of Electric Energy Technologies*. (Rakel et al., 1990).

Abstract (rev.): A conceptual systems model is presented in this paper in order to provide a framework for the assessment and comparison of the impacts of various technologies for electricity generation and distribution. The model also shows the influence of social factors and political institutions on technology implementation. A case study is presented in which the model is used to assess a rural electrification project in the Dominican Republic using photovoltaic technology. It is shown that the technology is appropriate for most desired end-uses, and has many positive social, environmental, and economic characteristics.

> Remarks: Flow chart model for including socio-economical impacts in the technical-economical assessment of an RE system. Good intentions and common sense arguments, but no calculations.

Methodology: Flow chart model.
Case studies: Results of assessment of ongoing rural electrification project presented.

5.2 *Experimental Rural Photovoltaic Electrification Programs: Technical Specifications for overcoming the Economic and Space Constraints Characteristic of Rural Areas in Developing Countries*. (Gouvello, 1999).

Abstract (rev.): Above and beyond the economic and financial constraints that are inhibiting the general spread of electrical service to rural populations in developing countries by means of interconnection to the network, it is shown in the article that this conventional approach is becoming less and less competitive in rural areas. Meanwhile, its built-in spatial progression mechanism also lends structural support to the existing social and geographic disparities, rather than reducing them. Individual (SHS) or community photovoltaic systems can avoid this bias, which is so hard to accept in a public service, and they are also becoming more and more competitive. It appears that the organization cost of installing, managing, and maintaining a large number of individual systems dispersed throughout the countryside, where no prior adequate logistics exist, may become prohibitive. The article identifies several approaches, leading to a new definition of the roles of public and private players, and users. On the basis of these "technical specifications", three major cur-

rent programs in Mexico, Zimbabwe, and Morocco are examined from the viewpoint of coordinating the operators at different territorial levels, namely that of the user, the region, the national, and the international levels.

> Remarks: An "infrastructural" approach, based on a Ph.D study. Mainly a policy paper advocating that decentralized application of (in this case) PV may be more profitable in the long run than centralized application in spite of high initial costs (in infrastructure etc).

Concepts of application: Decentralized applications, argued on political-economical grounds.
Case studies: Three national programmes are reviewed.

5.3 *Eastern Islands Pilot Project: Assessment of the Potential for Large-Scale Renewable Energy-based Electrification of Off-Grid Communities in the Eastern Islands of Indonesia. (Community Power Systems Division, 1994)*.

Abstract (rev.): The objective of the study is to assess the feasibility of supplying sustainable utility-grade AC electric power to 50 or more villages in the Eastern Islands of Indonesia. Currently, power is available only in rural communities that the Government of Indonesia (GOI) has electrified using small diesel generators. This project would provide 24-hour power without the high incremental economic and operational costs that would be incurred by extending the use of standalone diesel generators. The report is divided into the following sections: (1) Summary, (2) CPS 2000 Series-AC Hybrid Power Systems for Rural Electrification, (3) Background, (4) Design of the Eastern Islands Pilot Project, (5) Economic and Technical Considerations, (6) Selection and Characterization of the Pilot Regions, (7) Mapping and Surveying of Candidate Communities, (8) Project Implemenatation, and (9) Large-Scale Commercialization.

> Remarks: Almost a small manual on project design for off grid community RE power systems. Comprehensive and qualified, much in line with our methodology.

Methodology: Presents the "Westinghouse/IPC Methodology for Project Design and Development".
Economics: Uses the life cycle cost principle
Concepts of application and system solutions: Makes the case for their own PV-wind-diesel community power system, installed in Indonesia.
Case studies: Full technical-economical analysis of systems for Indonesia
Software: SOLCAD spreadsheet for technical-economical analyses, detailed printouts in appendices.

5.4 *Significance of Renewables for the Power Supply in Remote Regions of Developing Countries*. (Dienhart & Hille, 1994).

Abstract (rev.): The article deals with the role of a decentralised power supply based on interconnected systems of diesel generators and renewables on the order of 10 to 100 kW. Such "hybrid systems" can be realised either by incorporating renewables technologies in already existing diesel-fueled plants or for the initial electrification of rural areas in developing countries. The energy-economic value of a decentralised

power supply is first assessed by estimating the installed diesel plant capacity and possible expansion rates. After a short technical description the article discusses the economic efficiency of hybrid systems based on renewables and, firstly, batteries as the present-day storage technique; and secondly, hydrogen as the storage medium of the future. For this purpose a comparison of electricity production costs is made between hybrid plants and conventional diesel systems by means of model calculations. The results presented are based on system studies performed as part of the German-Saudi Arabian project HYSOLAR.

> Remarks: Makes the case for decentralized power supply based on a review of 55 developing countries. Discussion of hybrid RE system architectures based on the SMA concept, assuming batteries eventually to be replaced by hydrogen storage. Technical-economical analyses of a number of scenarios.

Economics: NPV based on life cycle cost principles.
Concepts of application and system solutions: Hybrid RE system architectures based on the SMA concept, assuming batteries eventually to be replaced by hydrogen storage
Case studies: System studies for specified scenarios.

5.5 *Micro and Mini Hydroelectric Power Assessment in Uruguay*. (Nunes & Genta, 1996).

Abstract (rev.): The School of Engineering in Montevideo has carried out an assessment of the potential and studies of the feasibility of the use of renewable energy for the generation of electrical power, both at the industrial level and the autonomous level for rural electrification. Original assessment methodologies were developed (SIMENERG?), including calculation tools which allow, for example, to analyze historical meteorological data, to calculate the available energy in different kinds of energy generators and also to stimulate the operation and design of autonomous systems with established load requirements and service quality. At the micro and mini hydropower assessment, the main role was placed on the census of potential users and the preliminary analysis of the representative places for the different technical solutions adequate to the variety of topographic conditions and load requirements. For power above 1 MW and up to 5 MW, the generating potential was assessed all over the country. If power lower than 1 MW or lower than 100kW (mini and micro) is considered, the information available in maps with contour lines, including in those of a 1:50,000 scale, is not enough to identify the most adequate places. Instead, knowledge of the place is indispensable in these cases. A preliminary plan of several installations was worked out.

> Remarks: A screening of the potential for small hydro in Uruguay using a methodology completely analogous to screening of wind energy in a country.

Methodology: Same as our methodology for wind energy
Case studies: Two small hydro plants

5.2 IRES

Integrated Renewable Energy Systems (IRES) utilise various RE technologies for power supply.

5.6 *Energizing Rural Areas of Developing Countries using IRES.* (Ramakumar, 1996).

Abstract (rev.): Renewable energy resources can play a significant role in supplying the energy needed in the rural areas of developing countries for improving the living environment and for economic development. The concept of energization in which all the available renewable resources are used in an integrated fashion with proper resource-need matching is preferable to straight-forward electrification. This paper discusses the application and design of Integrated Renewable Energy Systems (IRES) for energizing the rural areas of developing countries. The design tool IRES-KB that has been developed has the potential for on-site interaction with local populace and can serve both as a design tool and as a planning tool.

> Remarks: A review of issues in rural energy based on results of a Ph.D. thesis. Makes the case for integrated renewable energy systems (IRES) for rural energy.

Methodology: Presents a framework for listing RE resources and energy needs, and for need-ressource matching.
Economy: Uses total life cycle cost as economic measure.
Software: Knowledge-based IRES-KB design tool, developed for the study, is described. (refer to Section 9.1.2 for further details).

6 System Solutions

This Chapter is different in scope from Chapter 5 in that it aims at specific system solutions rather than generic principles of application. It contains three references on specific system solutions.

6.1 *Design of a Hybrid Power Storage and Generation System for a Remote Community.* (Devgan & Walker, 1995).

Abstract (rev.): There are thousands of small communities in various parts of the world, even in developed countries, that are too far away to be economically connected to an electric supply system. This paper describes the design of a "hybrid" Wind/Diesel power generation and storage system and the electric power distribution system for a small rural community of 50 persons. The most cost effective and reliable system designed to satisfy reasonable growth over the next twenty-five years consists of three 10 kW wind turbines, a 30 kWh storage battery and a 17.5 kW backup diesel generator. Moreover, this paper describes efforts to train a neural network to predict wind power over the next time interval

and few more time intervals. This is very essential for significant penetration of wind power systems.

> Remarks: University undergraduate village power systems design study. Applies a fairly rigorous design methodology including mapping of water and power demands for a range of consumer groups and types. Appears to use the Hybrid 1 code to assess technical-economical performance of a range of system alternatives. A neural network approach for predicting wind speeds is looked into.

Case study: Obviously based on a concrete (but unidentified) location
Systems solutions: Treats a range of possible system configuration in a fairly systematic way, implementing consumer "building blocks" to establish assumed load patterns.
Economics: Uses conventional levelized COE to rate the performance of each system alternative

6.2 *An Innovative Autonomous 2 kW Hybrid Photovoltaic-Wind Power System for Rural Electrification (AREP).* (Pierik et al., 1996).

Abstract: A mobile power supply system of 2 kW with a wind turbine, photovoltaics, batteries and a back-up generator set has been developed, constructed and is now tested. The system is a reduced size prototype for the development of new hardware (a bi-directional converter) as well as new control concepts (energy management and battery management). The lay-out of the system, its innovative features and the first test results are presented.

> Remarks: An "intelligent" and highly integrated system solution for small village power, almost down to individual house supply. Applies an energy management system (EMS) that dispatches energy to/from each module according to a pricing concept very similar to that applied in the SIMENERG model (refer to Section 9.2.4).

System solutions: At present on R&D/pre-demonstration stage, it seems a good bid on the future integrated concept (class 4 in the old days). Very interesting EMS concept.

6.3 *Remote Power Supply by Wind/Diesel/Battery Systems - Operational Experience and Economy.* (Kniehl et al., 1995).

Abstract: To continuously supply remote villages and settlements not connected to the public grid with electric power is an ambitious technical task considering ecological and economical points of view. The German company SMA has developed a modular supply system as a solution for this task in the range of 30 kW to 5 MW. Meanwhile more than 20 applications of these 'Intelligent Power Systems (IPS)' have proved their technical reliability and economical competitiveness worldwide under different, and also extreme environmental conditions. Actually it is the first commercially available advanced Wind/Diesel/Battery System for remote area electrification. The modular autonomous electric supply systems realized by SMA basically consist of two or more diesel power sets, battery storage with converter, a rotating phaseshifter, and an optional number of wind turbines. All modules are coupled on the 3-phase AC system grid and run in various parallel configurations depending on the

wind speed and the consumer power demand. The control system operates fully automatical and offers a very user-friendly graphical interface. This advanced system control also contains a remote control and operating data output via modem and telephone line. SMA and CES have considerable experience with Wind/Diesel/Battery Systems for more than eight years. In many cases wind energy converters in the power range of 30 to 40 kW were used, but it is also possible to use larger wind turbines (e.g. 250 kW). In the following the system technology is described in detail, experience of different system sizes in several countries of application is presented, and economical analyses for power supply by IPS are given in comparison to a conventional fully diesel power supply.

> Remarks: Makes the case for the fully integrated WD system. Quotes calculated and monitored results for technical and economical performance in internationally agreed terminology, but does not show the calculations.

System solutions: The SMA system is a bid on the future integrated system, marketed semi-commercially (EU / development projects) in today's marketplace.

Case studies: Two cases from EU / development projects in Ireland and PRC are reported.

7 Case Studies

The references presented in this Chapter are divided into site specific (i.e. local) and national case studies.

7.1 At Sites

7.1 *An Analysis of the Performance Benefits of Short-Term Energy Storage in Wind-Diesel Hybrid Power Systems*. (Shirazi & Drouilhet, 1997).

Abstract (rev.): A variety of prototypes of high penetration wind-diesel hybrid power systems have been implemented with different amounts of energy storage. They range from systems with no energy storage to those with many hours worth of energy storage. Prior studies indicate that for high penetration wind-diesel systems, short-term energy storage provides the largest operational and economic benefit. This study uses data collected in Deering, Alaska, a small diesel-powered village, and the hybrid systems modeling software Hybrid2 to determine the optimum amount of short-term storage for a particular high penetration wind-diesel system. These findings were then generalized by determining how wind penetration, turbulence intensity, and load variability affect the value of short term energy storage as measured in terms of fuel savings, total diesel run time, and the number of diesel starts.

> Remarks: Almost a classroom example on the use of Hybrid2, in this case with emphasis on the influence of battery storage size on technical system performance. A detailed and carefully worded study.

System solution: The Northern Power system (medium size village power system) incl. rotary converter used as basis for the study.
Case studies: Deering, Alaska, used as basis for the analyses.
Software: Demonstration of the capabilities of Hybrid2 (refer to Section 9.2.3).

7.2 *Electrification of Land Areas in South Sulawesi.* (Cambari et al., 1990).

Abstract (rev.): In order to get background information about the needs and resources of the farmers, a field study was carried out in South Sulawesi (Indonesia). In this survey the power requirements of each household are determined and the level of subsidy for electricity is calculated. Depending on the location of the village various supply strategies such as the following may be recommended: Grid connection; photovoltaic systems; minihydropower; diesel generator sets. Based on the fieldwork carried out in some regions in South Sulawesi, the common indicators for rural electrification is presented.

> Remarks: The paper does not fulfil the promises of the abstract (which may do justice to the study that is the background for the paper).

System solutions: Various specific system architectures are considered
Case studies: The specific sites are not identified
Project design: Contains useful input regarding the prediction of consumption patterns for specific types of consumers.

7.3 *Experience with Village Level Electrification.* (Brown, 1995).

Abstract (rev.): The electrification of villages and small industries in developing countries using renewable energy is an attractive concept, bringing to mind images of participation, self determination, and sustainability. Such projects are complex, however, and involve an ambitious level of intervention into the lives of the remote rural villages which are often involved. This paper looks at such projects, from the last 15 years, in China, Nepal, Peru, Sri Lanka, Columbia, India and Zimbabwe, taking one example from each country. All of these schemes use hydro power and most are in the range of 40kW to 100kW. Most projects discussed have been established for 5 years or more. The technical and socio-economic strengths and weaknesses of these schemes are drawn out, with a view to offering guidance to future schemes.

> Remarks: The publication is based on concrete and well documented experiences, and it offers some guidance on project implementation with emphasis on non technical issues.

Methodology: Experiences, checklist, recommendations
System solution: Various RE, village power, hydro
Case studies: 7 site related cases from 7 countries
Project design: Soft issues

7.2   In Countries

7.4 *Hybrid Wind/PV/Diesel Hybrid Power Systems Modeling and South American Applications*. (McGowan et al., 1996).

Abstract (rev.): This paper presents an application case study and comparison of performance results between two computational models for simulating the performance of hybrid power systems. The first model, HYBRID2, is developed at the University of Massachusetts. The second model, SOMES, is developed at Utrecht University. Both models are designed to predict the technical and economical (life cycle cost) performance of hybrid power plants that typically might be comprised of renewable energy sources, a battery bank, and a diesel generator. A South American (Brazil) based hybrid power system (used to power a remote telecommunications system) is used for the applications case study. A final system configuration is used as a basis for model prediction comparison, which is established as a result of HYBRID2 parametric evaluation. Both codes yield similar performance results, and the paper points out that the predicted performance discrepancies are basically due to different subcomponent models and differences in control strategy. The generalized nature of this work is intended to be of interest to engineers involved with the design and analysis of hybrid power systems.

> Remarks: Example of small hybrid village power system used to evaluate two state of the art simulation models. Result regarding model performance and accuracy of the models are of particular interest for system modellers.

Case study: Telecommunication system in Brazil
Systems solutions: Hybrid wind/PV/diesel system. 11 configurations evaluated
Software: Comparison of Hybrid2 and SOMES
Economics: Uses levelized COE to rate the performance of system alternatives

7.5 *Analysis of Village Hybrid Systems in Chile*. (Lew et al., 1996).

Abstract (rev.): Chile recently began a major rural electrification program to electrify those 240,000 families (about half of the rural people) who lack electricity access. In this paper, we discuss a pilot project to electrify three remote villages in Chile's Region IX using wind/genset/battery hybrids. The intent of this project is to demonstrate the reliability and cost-effectiveness of wind/genset/battery hybrids and to encourage replication of these types of systems in Chile's electrification program. For each village, electricity connections are planned for several residences, and also schools, health posts, community centers, or chapels. Projected average daily loads are small, ranging from 4 to 10 kWh. Using the optimization program HOMER and the simulation program Hybrid2, options are evaluated to maximize technical performance, minimize costs, and gain experience with a variety of systems and components. Wind/genset/battery hybrids are found to be able to provide cost-effective, reliable power for these sites. More importantly, their inherent flexibility allows for variations in load and resource without greatly affecting the cost of energy.

> Remarks: A demonstration of the use of the methodology & tools developed by NREL's village power programme, status medio 1996. Devel-

opment of methodology & tools continues, and a Village Power Handbook is in the works.

Methodology: Very similar to Risø's approach, containing essentially the same items (similar checklist), but the tools (HOMER & Hybrid2) are different. COE sensitivity included.

System solutions: Small integrated (class 4) system.

Case studies: Resources, loads & systems accounted for in some detail.

Software: Uses (and refers to) two technical-economic models developed as part of NREL's village power programme: 1) HOMER, spreadsheet based screeening / optimisation model, 2) Hybrid2, time history simulation model (refer to Section 9.1 and Section 9.2, respectively).

7.6 *Renewable Energy Options for the Electrification of Rural Schools in Argentina*. (Castedo et al., 1995).

Abstract (rev.): This paper evaluates different renewable energy options for the provision of basic electricity services to rural schools in the Argentine province of Buenos Aires. The renewable energy systems being considered, wind, photovoltaic (PV) and hybrid (wind/PV) are used to charge batteries. The life cycle cost of each system is calculated by determining the net present value of the costs of replacing components and O&M during the life of the system. The system's performance of different size components and battery configurations are examined using the HYBRID 1.1.1 model. The performance of different systems is then compared to their corresponding life cycle costs.

> Remarks: A demonstration of the use of the methodology & tools developed by NREL's village power programme, status early 1995. Development of methodology & tools continues, and a Village Power Handbook is in the works.

Methodology: Very similar to Risø's approach, containing essentially the same items (similar checklist), but the tool (Hybrid1) is different. Loss of Load Fraction (LOLF) sensitivity to NPV included.

Economics: Defines NPV of some items

System solution: Small integrated (class 4) system.

Case studies: Resources, loads & systems accounted for in some detail.

Software: Uses (and refers to) the technical-economic model Hybrid1 (previous version of Hybrid2) developed as part of NREL's village power programme (refer to Section 9.2.3).

7.7 *Incorporating Solar Electric Power into Rural Electrification Programs. A Case Study of Kenya*. (Singh, 1991).

Abstract (rev.): In recent year, photovoltaic (PV) solar electric technology has matured to the point where solar power is now cost competitive with fossil fuel generators for use in remote, low power (<5 kW) applications. In this article a case study of Kenya is performed, considering the opportunities for incorporating solar electric power into Kenya's rural electrification programs. The barriers preventing widespread deployment of this technology in Kenya are presented, and ways of overcoming these impediments are suggested.

Remarks: Arguments (including some numbers), but no specific calculations.

Concepts of applications: Argues for a number of rural applications of PV technology.

Programmes: Presents the case for PV as part of Kenya's rural electrification programme.

8 Programmes

The selected papers in this Chapter are supported by national programmes and donor programmes. Even though these papers are of more general nature, they contain valuable informations on the selected key issues.

8.1 National Programmes

8.1 *Hybrid Renewable Energy System Developments in Thailand.*
(Kruangpradit & Tayati, 1996).

Abstract (rev.): This paper describes the Provincial Electricity Authority programme on design, implementation and evaluation of pilot, hybrid renewable energy systems for electrification of remote villages in Thailand. Three hybrid energy systems are proposed to be installed, namely PV/Microhydro/Diesel/Battery, PV/Diesel/Battery and PV battery less grid connected power stations, in order to demonstrate and evaluate advanced renewable technologies. Methodologies used in systems design, description and operations of the systems are presented.

Remarks: A brief paper outlining a number of system solutions implemented as part of the programme.

Methodology: Refers to a methodology rather than presenting it.
Concepts of application: Mentions some rural applications
System solutions: Specifies 3 hybrid system solutions
Case studies: Reports on 5 systems implemented in 3 different layouts as part of the programme
Programmes: 5 systems actually implemented as part of a national programme

8.2 Donor Programmes

8.2 *Village Power Hybrid Systems Development in the United States.* (Flowers et al., 1994).

Abstract (rev.): The energy demand in developing countries is growing at a rate seven times that of the OECD countries, even though there are still 2 billion people living in developing countries without electricity. Many developing countries have social and economic development programs aimed at stemming the massive migration from the rural communities to the overcrowded, environmentally problematic, unemployment-bound urban centers. With the growing emphasis on environmentally and economically sustainable development of international rural communities, the US hybrid industry is responding with the development and

demonstration of hybrid systems and architectures that will directly compete with conventional alternatives for village electrification. Assisting the US industry in this development, the National Renewable Energy Laboratory (NREL) has embarked on a program of collaborative technology development and technical assistance in the area of hybrid systems for village power. Following a brief review of village-power hybrid systems application and design issues, this paper presents the present industry development activities of three US suppliers and the NREL.

> Remarks: An early presentation of NREL's village power programme, implemented to assist the US industry in development and application of village power systems.

Programmes: Presentation of a US programme to assist national industry to develop village power systems for international applications.
System solutions: Presents an overview of system design issues and of current US industry system solutions

8.3 *Renewables for Sustainable Village Power.* (Flowers, 1997).

Abstract (rev.): It is estimated that two billion people live without electricity and its services. In addition, there is a sizeable number of rural villages that have limited electrical service, with either part-day operation by diesel gen-sets or partial electrification (local school or community center and several nearby houses). For many villages connected to the grid, power is often sporadically available and of poor quality. The U.S. National Renewable Energy Laboratory (NREL) in Golden, Colorado, has initiated a program to address these potential electricity opportunities in rural villages through the application of renewable energy (RE) technologies. The objective of this program is to develop and implement applications that demonstrate the technical performance, economic competitiveness, operational viability, and environmental benefits of renewable rural electric solutions, compared to the conventional options of line extension and isolated diesel mini-grids. These four attributes foster sustainability; therefore, the program is entitled Renewables for Sustainable Village Power (RSVP). The RSVP program is a multi-technology, multi-application program composed of six activities, including village applications development, computer model development, systems analysis, pilot project development, technical assistance, and Internet-based village power project data base. While the current program emphasizes wind, photovoltaics (PV), and their hybrids with diesel gensets, micro-hydro and micro-biomass technologies may be integrated in the future. NREL's RSVP team is currently involved in rural electricity projects in thirteen countries, with U.S., foreign, and internationally based agencies and institutions. The integration of the technology developments, institutional experiences, and the financial solutions for the implementation of renewables in the main line rural electrification processes in both the developing world and remote regions of the developed world is the goal.

> Remarks: An updated presentation of status 1997 of NREL's village power programme, implemented to assist the US industry in development and application of village power systems world-wide. In 1997 the pro-

gramme includes a number of case studies / pilot projects in a number of countries.

Programmes: Presentation of a US programme to assist national industry to develop village power systems for international applications.

System solutions: Presents an overview of system design issues and of current US industry system solutions

Software: Description of the models developed at NREL: The screening models HOMER / VIPOR and the system simulation model Hybrid2 that allows the user to specify system configurations with a high degree of flexibility.

Project design: Emphasises, based on experience, the importance of issues such as OM&R schedules for RE systems, training of staff etc.

8.4 *Implementation of Village Electrification Projects in Developing Countries: the Role of CASE*. (Thompson & Singh, 1996).

Abstract (rev.): The International Centre for Application of Solar Energy (CASE) is the United Nations Industrial Development Organisation's (UNIDO) agency for the promotion of renewable energy technology in developing countries. This paper presents the role of CASE and methodology that CASE is adopting for the sustainable development of renewable energy projects for the benefit of rural communities. In addition, various renewable energy options and a village electrification project model are outlined.

Remarks: A policy paper for CASE. Includes a systems / technology overview. Introduces the concept of integrated village development approach. Mentions pilot projects in South Asia.

Programmes: The CASE programme

Methodology: Presents a recommended project flow-chart

Economy: Presents a RE project financing model

Concepts of application: Integrated village development approach

Soft issues: OM&R, training & education

Project design: Presents a recommended project flow-chart

9 Software Tools

Most of the models found in the review are technical-economical performance type models, i.e. they aim at predicting technical performance in terms of energy production, fuel savings etc and economical performance in terms of COE, NPV and other life cycle cost measures.

Most of the models are time series simulation models, in a layout aiming at simulation of seasons or entire years of operation. This means that although they simulate time series events they are generally not suitable to model details in control or dispatch strategies.

Statistical models are scarce, and they have difficulties modelling features such as energy storage. On the other hand, when using the time series models it is usually overlooked, that in order to give statistically valid results these models should ideally be used in with the Monte Carlo technique.

The models appear in general to be conceived for cases where single busbar systems are considered, but the development trend is towards analysis of distributed or dispersed systems, where also the grid layout becomes important.

9.1 Optimisation Tools

The Homer model described below is the only genuine optimisation model found in the review, but some of the simulation models (e.g. SOMES) have a limited optimisation capability.

9.1.1 HOMER

9.1 *HOMER: The Hybrid Optimization Model for Electric Renewable.* (Lilienthal & Flowers, 1995).

Abstract: Hybrid renewable systems are often more cost-effective than grid extensions or isolated diesel generators for providing power to remote villages. There are a wide variety of hybrid systems being developed for village applications that have differing combinations of wind, photovoltaics, batteries, and diesel generators. Due to variations in loads and resources determining the most appropriate combination of these components for a particular village is a difficult modelling task. To address this design problem the National Renewable Energy Laboratory has developed the Hybrid Optimisation Model for Electric Renewables (HOMER). Existing models are either too detailed for screening analysis or too simple for reliable estimation of performance. HOMER is a design optimisation model that determines the configuration, dispatch, and load management strategy that minimises life-cycle costs for a particular site and application. This paper describes the HOMER methodology and presents representative results.

> Remarks: HOMER is a fast & comprehensive village power systems screening model, now (1998) supplemented with the VIPOR model for optimal layout of a supply area into grid connected versus independently supplied consumers. State of the art in this category, but not publicly available.

Software: State of the art in this category
Economics: Rates & chooses between the options based on minimum LPC
System solutions: Chooses among a large variety of system configurations and grid / off grid connectivities

9.1.2 IRES-KB

9.2 *Design Scenarios for Integrated Renewable Energy Systems.* (Ramakumar et al., 1995).

Abstract: The wide variety of renewable energy resources and their highly site-specific and variable nature, coupled with different types and qualities of energy needs, pose a challenging problem to the designers of Integrated Renewable Energy Systems (IRES). This paper discusses some typical design scenarios and the formulation of design using the knowledge-based design tool IRES-KB with the aid of KAPPA reg-sign-PC development tools. A remote village with no electrical grid connection is chosen for this study since renewables are most likely to make

their greatest impact in such locations. The versatility of IRES-KB is brought out in the discussion of the results.

> Remarks: As an interactive knowledge based tool it looke like an interesting alternative / supplement to the usual system simulation models. Applies an integrated approach to village power supply regarding both power supply (electricity, heat, water supply) and system configurations (all RE sources).

Software: An interesting alternative/supplement to usual system simulation models
Economy: Minimize capital cost alternatively to minimising levelized COE
Methodology: Applies an integrated approach to village power supply
Case study: Remote, unidentified (probably hypothetical) off grid village

9.2   System Simulation Tools

9.2.1   Ashling

9.3   *Ashling 6.0 – The Manual.* (O'Sullivan, 1995).

Abstract: Ashling, is a software environment for design, analysis, simulation and optimisation of photovoltaic (PV) power systems. It has been developed at the National Microelectronics Research Centre (NMRC) of Ireland in association with Ecole des Mines de Paris (EdM) of France as a part of the CEC JOULE II Renewable Energy Project entitled "Concerted Actions on PV Systems Technology and Co-ordination of PV Systems Development, Task 6 – Modelling and Simulation". Some of the main uses of Ashling include: PV system design, analysis of the performance of installed systems, fault diagnosis, optimisation of component ratings by repeated simulation, and as a training tool for engineers.

> Remarks: A technical simulation model with a radiation atlas for Europe embedded in the model. Considerable effort made to make a user friendly interface in order to make an out-of-house model. Offers a limited number of predefined system configurations and consumer load types. Comprehensive user manual.

Software: A bid for an out-of-house PV systems simulation model
System solutions: Offers a limited number of predefined system configurations and consumer load types

9.2.2   INSEL

9.4a   *Digital Simulation of Regenerative Electrical Energy Supply Systems.* (Schumacher-Groehn, 1991).

Abstract: The main point of this work introduced here is the newly-developed INSEL simulation system, whose characteristic properties can be summarised as follows. Main application area of the program is the simulation of regenerative electrical energy supply systems. Blocks which are defined by input/output relations and parameters can be connected into a simulation model. A simple simulation language makes it possible to convert a block diagram into an INSEL model which can run. The program can work in dialogue. There is the possibility of including

the user's own blocks via a freely programmable interface. The program is largely independent of the operating system, as the core is exclusively written in FORTRAN 77. The basic structure of INSEL is universal, so that the application of the program is not limited to the simulation of regenerative electrical energy supply systems.

9.4b *INSEL Reference Manual – Version 4.80*. (Renewable Energy Group, 1993).

Abstract (rev.): In the last two decades, several programs for the simulation of renewable energy systems have been developed. From a general point of view, these programs may be classified into three categories: 1) programs that use statistical information in order to predict the long term performance of systems, 2) programs that calculate a sequence of states of a predefined system structure in constant time steps, and 3) simulation systems, which give the user great flexibility in modelling different system structures. This manual provides the user with an introduction to INSEL, a tutorial to the main concepts and a library of existing standard blocks.

> Remarks: Offers the possibility for almost unlimited flexibility in specifying system configurations by allowing the user to specify the connectivity on a component level. In addition to the standard library of components the user may define his own components (new types/structures as well as new parameter values for existing types). Intended as an out-of-house-model, but (early version of) the user interface is not too easy to work with. Very detailed and complete model documentation. Comprehensive user manual.

Software: A bid for a model for predicting technical performance of RE hybrid systems with a very high flexibility in the definition of system configuration (but probably not in control strategy). No economics included.
System solutions: INSEL can – at least in principle – model any system configuration without the usual limitations

9.2.3 HYBRID2

9.5a *HYBRID2 – The Hybrid Power Systems Simulation Model*. (Baring-Gould et al., 1996).

Abstract (rev.): There is a large-scale need and desire for energy in remote communities, especially in the developing world; however the lack of a user friendly, flexible performance prediction model for hybrid power systems incorporating renewables hindered the analysis of hybrids as options to conventional solutions. A user friendly model was needed with the versatility to simulate the many system locations, widely varying hardware configurations, and differing control options for potential hybrid power systems. This paper provides an overview of the capabilities, features, and functionality of the Hybrid2 code, discusses its validation and future plans. Model availability and technical support provided to Hybrid2 users are also discussed.

9.5b *HYBRID2. The Hybrid System Simulation Model Version 1.0, User Manual.* (Baring-Gould, 1996).

Abstract: In light of the large scale desire for energy in remote communities, especially in the developing world, the need for a detailed long term performance prediction model for hybrid power systems was seen. To meet these ends, engineers from the National Renewable Energy Laboratory (NREL) and the University of Massachusetts (UMass) have spent the last three years developing the Hybrid2 software. The Hybrid2 code provides a means to conduct long term, detailed simulations of the performance of a large array of hybrid power systems. This work acts as an introduction and users manual to the Hybrid2 software. The manual describes the Hybrid2 code, what is included with the software and instructs the user on the structure of the code. The manual also describes some of the major features of the Hybrid2 code as well as how to create projects and run hybrid system simulations. The Hybrid2 code test program is also discussed. Although every attempt has been made to make the Hybrid2 code easy to understand and use, this manual will allow many organisations to consider the long term advantages of using hybrid power systems instead of conventional petroleum based systems for remote power generation.

> Remarks: The (presently, 1998) state-of-the-art time series model for prediction of technical-economical performance of hybrid wind / PV systems that is publicly available. Offers a very high flexibility in specifying system configurations by allowing the user to specify the connectivity of systems. Publicly available and quite widely used. The GUI is user friendly on a professional level. Quite extensive model documentation and good user manual.

Software: A model for predicting technical - economical performance of wind / PV hybrid systems with a quite high flexibility in the definition of system configuration.

System solutions: Hybrid2 can model a very wide range of system configurations. On-line component library (user may define parameter values) used to define the power system. No predefined system configurations, there is a very wide flexibility in the definition of a power system. There is a number of predefined control strategies with a large number of user defined parameter values.

Economics: Calculates the usual economic indicators (NPV, IRR, LPC etc)

Case Studies: Two local community systems (Norway, Mexico) used for validation with measured data and comparison with results from other models (e.g. SOMES, WDILOG, VINDEC of the European WD Software Package section 9.2.7)

9.2.4 SIMENERG

9.6a *SIMENERG: A Novel Tool for Designing Autonomous Electricity Systems*. (Chaer et al., 1993).

Abstract (rev.): This work describes the methodology and point of view adopted when developing SIMENERG. SIMENERG is a software tool-kit to help analysis of autonomous electricity systems. The developed tools are briefly described. The output of a simple application is presented.

9.6b   *SIMENERG: The Design of Autonomous Systems.* (Briozzo et al., 1996).

Abstract (rev.): This paper describes the methodology and a software tool-kit (SimEnerg) for the design of autonomous electricity systems. A criterion for comparing autonomous against grid connected systems is given, based on the annual energy deficit of the system with a given confidence. As an example, a map for choose the best technology with given power demand and geographical position in Uruguay is shown. The modelling of the wind velocity and the solar radiation as stochastic sources are described.

> Remarks: The only model so far with a very high degree of flexibility in the control / dispatch strategy. At each time step the dispatch for the next time step is decided by a "market square" approach:
>
> The components in the immediate mix of offers for power are priced individually according to their availability and the components of power demands are given individual values depending on their urgency. Then the economically optimal subset of power sources that satisfy the power demand is dispatched in the time step.
>
> In this way the SIMENERG model is different from all other models reviewed with their by and large predefined control & dispatch strategies. However, the detailed workings of this are not clear.

Software: The only model so far with a very high degree of flexibility in the control / dispatch strategy.
System solutions: It is not clear how the system configurations are defined in SIMENERG, but a library of predefined systems is included.
Economics: Does not seem to calculate the usual economic indicators. Potential system solutions are evaluated on basis of their Service Quality Index (SQI) that includes predicted downtime (LOLP) etc.
Case study: Rural PV/Battery system for village/small town in Northern Uruguay.

9.2.5   SOMES

9.7a   *SOMES 3.0 User's Manual.* (Horst et al., 1992).

Abstract: A description is given of the user interface of the Simulation and Optimisation Model for renewable Energy Systems (SOMES) version 3.0. Technical details of the model are described in a separate publication. The SOMES computer model has been designed to evaluate the technical and economic performance of an electrical energy production system, consisting of renewable energy sources, a storage system and a diesel generator or grid connection. This performance is determined by simulating the functioning of the energy system on an hour-by-hour basis. In addition, the optimum system configuration can be determined by evaluation of the reliability of the energy supply by the energy system, and the economic performance of the energy system. The program allows the user to design his or her own energy system and examine its performance. User-defined systems can be stored in system configuration files for future use. In a next session the user can easily use and modify previously defined system configurations. This scheme is also used at a lower level. When defining a system configuration, a list of

previously defined components is available, to which new components can be added.

9.7b *Engineering Design Tools for Wind Diesel Systems. Volume 6A – Model Documentation for SOMES.* (Infield et al., 1995).

Abstract: This report contains specific model documentation and user guides for the simulation model SOMES (Simulation and Optimisation Model for renewable Energy Systems), which was developed as a part of the European Wind-Diesel Software Package. The report is one in a series.

> Remarks: Until Hybrid2, SOMES was the only out-of-house wind / PV hybrid systems model with a professional and user friendly GUI. SOMES is a full technical – economical performance prediction model, although only annual costs are calculated but not life cycle costs. SOMES operates with four predefined hybrid system configurations (three autonomous and one grid connected ones) and two basic control strategies with variations for systems with storage and / or converters.

Software: Until Hybrid2 the only out-of-house hybrid systems model with a professional and user friendly GUI. A full technical – economical performance prediction model.
System solutions: SOMES operates with four predefined hybrid system configurations and two basic control strategies.
Economics: Annual costs are calculated but no life cycle costs are calculated.

9.2.6 WINSYS

9.8a *High Wind Energy Penetration Systems Planning.* (Hansen & Tande, 1994).

Abstract: Power system expansion planning should determine the optimal power system mix including wind power, ideally containing cost of energy comparisons as well as estimates of economics for the society, including externalities. The analyses should be made for all relevant expansion scenarios supplying power at similar and acceptable reliability throughout the lifetime of equipment. This paper addresses the requirements to modelling in general and suggests a modelling approach attempting to take adequate account of statistical variations and uncertainties in input and assumptions as well as influence of future development scenarios. The paper particularly studies the question whether a change of or large uncertainty in the assumed development of consumer loads over a 20 year period has or should have an influence on decisions to invest in wind power capacity up to high penetration levels. A dedicated model for power system performance modelling when studying the impact of wind power up to high penetration levels, WINSYS, is presented and described in the paper. Recommendations regarding need for methodologies for studying system expansions with wind power are discussed for both small and large power systems.

9.8b *Assessing high wind energy penetration.* (Tande, 1995).

Abstract: In order to convincingly promote installing wind power capacity as a substantial part of the energy supply system, a set of careful analyses must be undertaken. This paper applies a case study concentrated on assessing the cost/benefit of high wind energy penetration. The case study considers expanding the grid connected wind power capacity in Praia, the capital of Cape Verde. The currently installed 1 MW of wind power is estimated to supply close to 10% of the electric energy consumption in 1996. Increasing the wind energy penetration to a higher level is considered viable as the project settings are close to ideal, including a very capable national utility company, Electra, a conventional power supply system based on imported heavy fuel and gas oil, and favourable wind conditions with an estimated annual average of 9.3 m/s at the hub height of the wind turbines. With the applied case study assumptions, simulations with WINSYS over the lifetime of the assessed wind power investment show that investments up to 4.2 MW are economically viable. The economic optimum is found at 2.4 MW reaching an internal rate of return of almost 8% p.a. This 2.4 MW of wind power would, together with the existing wind power, supply over 30% of the electric consumption in 1996. Applying the recommended practices for estimating the cost of wind energy, the life-cycle cost of this 2.4 MW investment is estimated at a 7% discount rate and a 20 year lifetime to 0.26 DKK/kWh.

Remarks: WINSYS differs from other models in that it is developed in the framework of a methodology for implementing high proportions of wind power into large diesel powered grids (Island Systems). WINSYS is a spreadsheet (QPW) based model implementing probabilistic representations of resources and demands, thereby anticipating the (upcoming) discussions of the need for using Monte Carlo techniques in time series simulation.

Other models represent technical performance by one year's performance measures (fuel savings etc), and uses an economic life cycle analysis to establish the economic indicators. This way the technical developments / extensions of the system during its life time are neglected. WINSYS incorporates the anticipated technical expansions during its life time in the technical performance measures, combined with a traditional economic life cycle cost assessment. Thus WINSYS represents a more real life cycle cost analysis that other models.

Methodology: A framework developed for implementing high proportions of wind power into large diesel powered grids, with potential for application in the context of village power / hybrid systems in general.

System solutions: Presently designed for multiple WTG / multiple DGS no storage systems. Control strategy implies priority to WTG power using diesels for load following. Optional use of dumped energy can be included. For each diesel the annual load expansion can be defined, and diesels can be phased in or out along the way.

Economics: Applies true life cycle analysis of both technical and economical performance. Includes an option to represent externalities

Case studies: Three MW size island systems in Cape Verde.

Software: WINSYS is a spreadsheet (QPW) based model implementing probabilistic representations of resources and demands.

9.2.7 European Wind Diesel Software Package

The EWDS Package was developed in the framework of an EU Joule project. The package consists of a number of individual WD system simulation models, developed by European research institutions, embedded in a common integrated user environment. The package contains 6 logistic models and 1 dynamic model, the latter developed as part of the project.

9.9a *Engineering Design Tools for Wind Diesel Systems. Volume 6 – Logistic Package: User Documentation.* (Infield et al., 1995).

Abstract: This document is the user manual for the European Wind Diesel Logistic Modelling Package (WDL). The main text constitutes a guide to the integrated user environment. This logistic design tools package aids the design and assessment of Wind Diesel systems. The new combined software package offers to the user a comprehensive integrated environment, from which to create simulation specifications and access simulation results. This Shell is designed for user-friendliness. It is 'menu-driven' throughout, with on-line help available at most points. A range of functions are also supported to aid the user. These include; data synthesis routines, functions to partially generate component specifications, etc.

Remarks: The logistic package contains 6 models, 5 deterministic time series models and 1 probabilistic model. Each of the models are developed with emphasis on particular issues, and the total package thus provides access to a variety of facilities not available in any single model. The models are briefly described below.

SOMES (ECN, NL): Until Hybrid2, SOMES was the only out-of-house wind / PV hybrid systems model with a professional and user friendly GUI. SOMES is a full technical – economical performance prediction model, although only annual costs are calculated but not life cycle costs. SOMES operates with four predefined hybrid system configurations (three autonomous and one grid connected ones) and two basic control strategies with variations for systems with storage and / or converters.

VINDEC (EFI, N): VINDEC was originally developed in 1988 for investigating the economics of wind-diesel-battery systems as an alternative to existing power supply on remote Norwegian islands. Since 1988 the model has been further developed to represent different wind diesel configurations. VINDEC is based on the simulation engine ESIM developed by CYPROS (CAMO Cybernetics AS, 1994).

E_WISDA (ENEA, I): The model is a simulation tool developed in the framework of the EU JOULE project for prediction of technical performance of WD systems, based on the WISDA code, developed by Manens Intertechnica, an Italian representative of AeroVironment Inc. E_WISDA can employ a "dynamic" model of turbo-charged diesel engines as an optional addition to a simplified but more flexible quasi-static model.

WDILOG (Risø, DK): WDILOG was developed during the 1980's for investigation the technical-economical performance of wind diesel systems for international applications. The model is based on four types of systems, but emphasis is on a flexible representation of system architecture, control strategy and consumer load

representation. WDILOG is based on the simulation engine ESIM developed by CYPROS (CAMO Cybernetics AS, 1994).

RALMOD (RAL, UK): The model is based on a novel (1994) probablistic approach to calculating the logistic performance of WD systems. Stochastic process and statistical theory are applied to the calculation of diesel on/off cycling and the effect of short term storage.

TKKMOD (TKK, FI): This simulation model was developed at Helsinki University of Technology (TKK) for a specific wind diesel system layout, with special emphasis on the battery submodel and its use in simulation. The battery submodel represents parameters such as battery voltage, and the temperature dependent model is useful in studying the effect of the variation of different battery control limits.

9.9b *Engineering Design Tools for Wind Diesel Systems. Volume 7 – JODYMOD – Joule Dynamic Modular Model for Wind Diesel Systems.* (Lundsager et al., 1994).

Abstract: This document is the model description and user manual for JODYMOD - the Joule Dynamic Modular Model for wind diesel systems.

JODYMOD (EU): This modular dynamic simulation model was developed primarily at EFI (N) and Risø (DK) as part of the Joule project. It is modular in the sense that for the system specified by the user the overall system model is assembled by the program from modules of models each representing components such as wind turbine drive train, synchronous generator, asynchronous generator etc. JODYMOD is based on the simulation engine ESIM developed by CYPROS (CAMO Cybernetics AS, 1994), but a special user interface was developed for JODYMOD.

9.3   Grid Simulation Tools

For dispersed systems – large or small – the grid itself becomes a part of the system. Optimisation of the grid in terms of grid connectivity and cable dimensions are not included in any of the publicly available performance models (optimal connectivity is dealt with in the proprietary code VIPOR section 9.1).

9.3.1   PROLOAD

Due to the probabilistic nature of the power output from most RE components, cables in a grid should be dimensioned by probabilistic load flow techniques, in contrast to the conventional steady state load flow analyses. The proprietary program PROLOAD is developed to deal with this.

9.10a *Power Quality and Grid Connection of Wind Turbines. Part 1: Stationary Voltages.* (Jørgensen et al., 1996).

Abstract: Grid connection of wind turbines impact on power quality is described. The report concentrates on stationary voltages, whereas other aspects are described in: Summary report. Part 2: Flicker. Part 3: Har-

monics and operation of variable speed wind turbines. A probabilistic method for analysis of grid connection of wind turbines impact on the stationary voltages is developed. The method considers the stochastic variations in wind power production and consumer loads, and calculates the risk for over- and under-voltages in the grid. Application of the method has shown that voltage controlled stop of wind turbines may be applied for avoiding over-voltages and as an alternative to reinforcing the grid.

9.10b *On Minimising the Cost of Wind Turbine Grid Connection.* (Tande & Nørgaard, 1995).

Abstract: Installation of wind turbines may be associated with costly grid reinforcements for maintaining the power quality. The concept discussed in this paper is that rather than reinforcing the grid before connecting wind turbines, it may be cost effective to install wind turbines without reinforcing the grid, and then simply disconnect wind turbines during critical periods. This approach for minimising the grid connection cost of wind turbines has been investigated by using PROLOAD, a newly developed probabilistic load flow tool. In the paper, PROLOAD is briefly described and applied on a fictive, but realistic example. It is concluded that the grid connection costs can be reduced by stopping wind turbines in order to avoid unacceptable high voltages as an alternative to grid reinforcement. Disconnection of wind turbines with individual voltage relays is found theoretically possible. The practical implementation and administration of the concept is not assessed.

> Remarks: A probabilistic load flow analysis code, using Monte Carlo techniques, developed in co-operation with an electrical utility for dimensioning of distribution systems with wind turbines. Instead of the absolute measures, which often leads to expensive wind turbine grid connections, PROLOAD allows the use of probabilistic measures for e.g. voltage variations, and it also allows to weigh the value of e.g. a change of operating strategy against the cost of grid reinforcement measures in a technical-economical analysis.

Methodology: Offers the possibility of including the layout of the distribution system in the technical-economical analysis of dispersed systems, using probabilistic measures that are consistent with wind energy systems performance characteristics.

Software: Proprietary Pascal code for PC.

System solutions: Assumes the distribution system to consist of a 60/10 kV transformation system, 10 kV feeders and 10/0.4 kV transformers.

Economics: PROLOAD results are applicable in technical-economical analyses using the usual economical indicators for life cycle analysis.

Case studies: One fictive, but realistic, example weighing the disconnection of selected wind turbines against the costs of extra grid reinforcements.

10 Conclusions and Recommendations

10.1 General findings

The amount of wind energy literature related to the subject is excessively large, and a complete review in which every relevant abstract is identified and examined is not feasible within the framework of this (or probably any other) study.

By applying more detailed search criteria the amount of literature was reduced to a few subsets that were operational in extension and believed to be representative. Thus the literature review is based on systematic spot checks of the entire literature supplemented with random searches in "known" literature.

A great deal of work has been published conveying useful experiences within each of the topics to be covered by the methodology of the present study. This includes methods and tools for a number of specific issues, but no significant reference presents methods or tools that contradict the philosophy of Risø's methodology such as is implemented in the WINSYS model (Hansen & Tande, 1994).

It is therefore concluded that since Risø's methodology is in agreement with all significant references, it makes a good platform for further development.

10.2 Recommendations

Methodology & Guidelines
The most significant development in this respect is the appearance of the IEC/PAS 62111. Specifications for the use of RE in rural decentralised electrification, and the decision that such guidelines in the future should be structured as follows:

- Part A: Project specific guidelines or specifications for project implementation for e.g. rural electrification, large wind diesel grids or other specific applications, to be issued by main actors in the respective fields.
- Part B: Technology specific standards for Photovoltaics, Wind energy and other technologies, to be issued within the IEC standards framework. Only one part B will be issued, to be referenced by all Parts A.

It is concluded that with the exception of the IEC/PAS 62111 no work with the scope of the present study has been carried out before for the design and evaluation of isolated electric power systems with high wind energy penetration, i.e. no comprehensive and consistent methodology, operational on an engineering level, exists for those systems.

It is therefore recommended, that for the type of isolated systems relevant for Denmarks/Risø's field of experience, i.e. medium to large scale isolated electric power systems with high wind energy penetration, more specific guidelines should be developed in the form of checklists for relevant issues.

For each item on the checklist engineering operational methods & tools should be indicated, and the guidelines should be issued as a Part A guidelines as described above.

Economic principles:
It is concluded that the development of guidelines should continue with the economic principles already applied, i.e. levelised production costs based on life cycle cost analyses.

It is recommended that externalities should be quantified by methods like the Environmental manual (Herberg & Fritsche, 1996), and that other benefits like optional or deferrable loads, uninterrupted power supply etc. should be included as well. Furthermore the diversification of economic risks should be introduced.

Models and software:
It is concluded that the WINSYS model and similar models will be the workhorse in the technical-economical analyses of isolated systems with high wind energy penetration.

It is recommended that in addition to WINSYS extensions and similar models the needs for versatile screening models (spreadsheet based) and for system optimisation models should be considered as well as the need for genuine time history models. Furthermore, the models should be prepared for extension to (multiple) RE integration.

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Appendix A   Survey of Selected References

Table 2 presents an overview on the topics dealt with in each of the selected references. The markers "X" and "x" indicates "most relevant area" and "relevant area", respectively.

Table 2. Subjects dealt with in the selected references.

Ref.	Methods & Guides	Eco-nomics	Concepts of application	System solutions	Case studies	Pro-grammes	Soft-ware	Remarks/keywords
3.1	X	x			x			Guide book
3.2	X	x			x			Checklist
3.3	X	x						Frameworks, roles
3.4	X		x	x				Local involvement
3.5	X	x	x	x	x		x	IEA Annex
3.6a	x		x	x				Soft issues
3.6b	x		x	x				Soft issues
3.7	X		x	x				Specifications, guidelines
4.1		X	x	x	x			Cost terms: STMC/LTMC
4.2		X			x			LTMC concept
4.3		X						Life cycle cost
4.4		X		x	x			Economic indicators
4.5	x	x						Policy, checklist
4.6	x	x			x			Checklist
4.7	X	x	x					Project criteria
4.8	X	x			x			Criteria for remote applic.
4.9	X	X			x		x	Externalities
5.1	x		x		x			Socio-economics
5.2			x		x			Policy
5.3	X	x	x	x	x		x	Project implementation
5.4		x	x	X	x			Decentralized power supply
5.5	x				x			Small hydro
5.6	x	x					x	Integrated RE systems
6.1		x		x	X			Fairly rigorous design study
6.2				X				Interesting EMS concept
6.3				X	x			Modular integrated system
7.1				x	X		x	Part of NREL's methodology
7.2					x			Appetiser for a study report
7.3	x			x	X			Soft issues
7.4		x		x	x		X	Comparison of Hybrid2 and SOMES
7.5	x			x	X		x	NREL's methodology
7.6	x	x		x	X		x	NREL's methodology
7.7			x		X	x		Country case
8.1			x	x	x	x		A national programme
8.2				x		X		NREL's village power programme
8.3				x		X	x	NREL's village power programme update '97
8.4	x	x	x			X		CASE policy paper
9.1		x		x			X	HOMER - State-of-the-art screening
9.2	x	x		x	x		X	IRES – Integrated approach
9.3				x			X	Ashling – Technical PV performance

Table continued

Ref.	Methods & Guides	Eco-nomics	Concepts of application	System solutions	Case studies	Pro-grammes	Soft-ware	Remarks/keywords
9.4a 9.4b				x			X	INSEL – Flexible system definitions
9.5a 9.5b		x		x	x		X	Hybrid2 – state-of the-art simulation
9.6a 9.6b				x	x		X	SIMENERG – Flexible Dispatch Strategy definition
9.7a 9.7b		x		x			X	SOMES – Professional out-of-house model
9.8a 9.8b	X	x		x	x		X	WINSYS – Probabilistic WD system performance
9.9a 9.9b		x		x			X	WDLTools – Toolbox of simulation models. Logistic models: SOMES VINDEC E_WISDA WDILOG RALMOD TKKMOD Dynamic model: JODYMOD
9.10a 9.10b	X	x		x	x		X	PROLOAD – probabilistic load flow analysis

Appendix B Survey of Search Results

In this appendix, search results using "wind" as main keyword are presented. Using "wind" as keyword results in 20,978 hits (the entire period 7/88 to 6/97). In order to get on idea of the distribution of information in such a search, "wind" is combined with the list of keywords described in Section 2.1. The distribution of these keyword combinations is listed in Table 3 for three periods. The first period is the present available time period in the ETDE Energy Database, while the second and third period are partial update periods.

Table 3. Base: wind.

Keyword combinations	Number of hits		
Period	7/88 - 6/97	1/95 - 9/96	10/96 - 6/97
base	20978	4644	1968
and autonomous	175	26	21
and (battery or batteries)	532	111	80
and diesel	677	115	70
and domestic	192	33	28
and (economic or economics)	3108	710	415
and economy	373	89	39
and energy	14469	3206	1427
and hybrid	757	160	78
and (hydraulic or hydraulics)	303	63	19
and hydro	724	157	83
and guidelines	229	66	25
and isolated	240	46	24
and (methodology or methodologies)	359	92	40
and model	4363	1023	429
and (modeling or modelling)	1319	318	150
and power	9337	2095	1040
and renewable	5181	1253	727
and (review or reviews)	1036	211	69
and rural	432	98	50
and (simulation or simulations)	2772	670	261
and software	288	82	38
and storage	1349	247	170
and (study or studies)	6124	1346	601
and (system or systems)	8130	1828	822

This search result shows that "wind" combined with one of the other keywords yields comprehensive numbers of hits. It is noted that literature reference containing e.g. "wind", "autonomous" and "diesel" will be counted as a hit in both *wind and autonomous* and in *wind and diesel*. This kind of redundant information can be excluded by combining two or more of the search profiles using the "or" operator. But first of all, the search profiles applied in Table 3 have to be further refined in order to limit the number of hit.

For further refinement of the base of the search profile, let the base be the combination of *wind and (energy or power)*. This base does reduce the numbers of hits, but not significantly. Therefore, the base is extended to *wind and (energy or power) and (system or systems)*. For this base, the distribution of the "re-

maining" keyword combinations is listed in Table 4 – for the three periods described above. As it can be observed in Table 4, the number of hits for the third period approaches a manageable amount of hits.

Assessing just a small part of the literature references from the search result presented in Table 4, it turns out that the applied search profiles provides literature reference beyond the scope of this review. Meanwhile, it is difficult to refine the base of the search profile further, without limiting the general scope this review.

Table 4. Base: wind and (energy or power) and (system or systems).

Keyword combinations	Number of hits		
Period	7/88 - 6/97	1/95 - 9/96	10/96 - 6/97
base	6810	1511	701
and autonomous	153	21	18
and (battery or batteries)	487	103	74
and diesel	578	103	60
and domestic	101	12	14
and (economic or economics)	1445	289	208
and economy	196	44	23
and hybrid	610	134	70
and (hydraulic or hydraulics)	189	29	12
and hydro	387	82	46
and guidelines	83	24	11
and isolated	146	26	16
and (methodology or methodologies)	140	30	18
and model	1100	253	116
and (modeling or modelling)	432	107	58
and renewable	2481	601	372
and (review or reviews)	368	75	25
and rural	232	61	28
and (simulation or simulations)	996	242	98
and software	170	43	27
and storage	876	147	122
and (study or studies)	1635	349	157

Appendix C Miscellaneous References

Relevant references, but not placed in context:

- *Testing of a 50-kW Wind-Diesel Hybrid System at the National Wind Technology Center.* (Corbus et al., 1996).

Abstract (rev.): To further the development of commercial hybrid power systems, the National Renewable Energy Laboratory (NREL), in collaboration with the New World Village Power Corporation (NWVP), a NWVP 50-kW wind-diesel hybrid system connected to a 15/50 Atlantic Orient Corporation (AOC) wind turbine is tested. A main objective of the testing was to better understand the application of wind turbines to weak grids typical of small villages. Performance results contained in this paper include component characterization, such as power conversion losses for the rotary converter systems and battery round trip efficiencies. In addition, systems operation over this period is discussed with special attention given to dynamic issues. Finally, future plans for continued testing and research are discussed.

- *A Framework for the Financial Evaluation of Household Biogas Plants in India.* (Sinha & Kandpal, 1990).

Abstract: A generalised procedure for quantifying the benefits of household biogas plants is presented. The sensitivity of the procedure to the uncertainty in input prices is reduced through the assumption of incremental benefits from the biogas plant. These benefits are quantified in terms of the quantity of fuelwood for which the biogas substitutes in cooking, the quantity of kerosene replaced through the use of biogas for lighting and the diesel fuel displaced through the use of a biogas fuelled dual-fuel engine for motive power. Sensitivity of the monetary benefits for these parameters is examined in order to identify variables which influence the viability of the technology to the end user.

- *Integration of Wind Power in the Danish Generation System. EC Wind Power Penetration Study, Phase 2.* (Jysk-Fynske Elsamarbejde, 1989).

Abstract (rev.): The Commission of the European Communities has asked utilities in the member countries to carry out a coordinated study of the wind energy potential. The main objective is to show the consequences for the future electricity system when integrating wind power production covering 5, 10 or 15% of total demand. In addition to the best estimate scenario believed to be operational, some additional calculations have been carried out: wind power production as a negative load only (not operational for the total system); different levels of investment in wind farms. The analysis is based on the following steps: define a reference scenario for year 2000; define an alternative scenario with a certain amount of wind power production; calculate time-series for electrical load and district heating from combined heat/power production; calculate time-series for wind power production; make economic evaluation and sensitivity analysis; show environmental differences. Incorporation of wind power into the ELSAM power system, with the wind energy meeting, about 5% of demand will give rise to additional control capacity, or call for new contracts with neighbouring countries. The economic analy-

ses and the sensitivity analyses have been carried out using spread-sheets. The conclusion concerning profitability - based on the best estimate assumptions - is that the studied wind power scenarios are unprofitable.

- *Philosophy of RAPS Design.* (Butler, 1994).

Abstract: Current designs of Remote Area Power Supplies (RAPS) are often the reverse of the model that will yield least cost least fossil fuel usage systems. This paper discusses the design of high reliability RAPS with special emphasis on redundancy and system supervision. Power systems based on renewable resources with backup generator systems are a high energy cost option used by those who find the cost of a diesel battery hybrid system too expensive. They require large relative energy storage capacities and are subject to many hidden inefficiencies. The diesel based hybrid with renewable energy as fuel reduction has major savings in storage costs, use of electric freezers and refrigerators instead of gas and have a least cost per kWh for stand alone systems. The use of lead acid batteries introduce issues such as depth of discharge, voltage boosting, and battery temperature. Supervision of RAPS is important to their efficient functioning and can be achieved by the installation of microprocessors and dial-up communication to enable the system integrator/ provider to perform accurate diagnosis of system problems without a site visit.

- *Investigating Wind Power's Effective Capacity: A Case Study in the Caribbean Island of La Martinique.* (Perez et al., 1996).

Abstract: In this paper, we report on the experimental determination of the effective capacity of wind and photovoltaic (PV) power generation with respect to the utility load requirements of the Island of La Martinique. La Martinique is a French Overseas Department in the Caribbean Sea. The case study spans two years, 1990 and 1991. We consider wind generation at three locations in different wind regimes, and PV generation for fixed and tracking flat plate systems. The results presented include: (1) An overview of typical solar and wind power output at each considered site, presented in contrast to the Island's electric load requirements; and (2) Effective capacities quantified for each resource as a function of penetration in the utility generation mix.

- *Current and Future Plans for Wind Energy Development on San Clemente Island, California.* (Hurley & Cable, 1996).

Abstract: The Navy is considering possible ways to maximize the use of wind energy technology for power supply to their auxiliary landing field and other facilities on San Clemente Island. A summary of their past analysis and future considerations is presented. An analysis was performed regarding the technical and economic feasibility of installing and operating a sea-water pumped hydro/wind energy system to provide for all of the island's electric power needs. Follow-on work to the feasibility study include wind resource monitoring as well as procurement and preliminary design activities for a first-phase wind-diesel installation. Future plans include the consideration of alternative siting arrangements and the introduction of on-island fresh water production.

- *Artificial Intelligence Approach for Operational Planing of Renewable Energy Interconnected Systems in Isolated Area.* (Kandil et al., 1993).

Abstract: Operational planning (OP) of interconnected renewable energy sources (IRES) in isolated area is expected to be more difficult and complex than that in the case of conventional units. This is due to the major differences in installation and running costs, start up and shut down times and costs. Moreover the original input to the generating units of IRES is variable and uncertain. The problem needs a heuristic approach to restrict the number of strategies and feasible states at each stage in its solution. The problem also obeys several logical rules and human experts can play a crucial role in the trade-off evaluation. This paper represents a knowledge base system based on experience through simulation of IRES' planning, design and operation. This knowledge base is formulated in production rule forms and artificial intelligence (AI) language (PROLOG) is used for its implementation. Finally the use of this knowledge base and its effect on charging and discharging policy of the power system are considered.

- *Entirely Renewable Energy-based Electricity Supply System for Remote and Isolated Areas (System Design).* (Zahedi, 1996).

Abstract: Future energy needs will be supplied by a combination of many different sources, ranging from small wind turbine to provide power for a single house to central power stations that provide power in very large scale fed into the national grid. Computer control systems will integrate the performance of all these systems to make sure that as much power as possible comes from environmentally friendlier sources. Investigations are being carried out into the feasibility of an entirely renewable energy-based electricity supply system. For this purpose a power supply system has been developed and simulated in the computer. This paper presents the results obtained from computer simulation of an entirely renewable energy based power system. The developed system has many applications as it can be used as a small scale power system for Remote Area Power Supplies, wind/battery or solar/battery as well as large scale for interconnection with the national grid.

- *Renewable Energy Control using Expert System.* (El-Khashad, 1996).

Abstract: With the rapid development of renewable energy systems, particularly photovoltaic (PV) and wind energy, large scale generation stations have been built. Due to large variations in input and output parameters of the system throughout the day and the seasons, the system must have considerable intelligence and memory to calculate the optimum mode of operation, especially for isolated areas. This paper discusses a proposed computer control system which can be applied to renewable energy systems. The application of an expert system (ES) to hybrid PV-wind energy and its components (converter, inverter, storage batteries, and load) are discussed. ES is used to assist the user in the storage of input data especially in relation to climatic conditions, energy management, during design and operation. A case study using ES is implemented, and the interpretation of simulation results is demonstrated. An economic model is proposed to assist users to choose the most suitable system components for their situation.

Title and authors

Review of Relevant Studies of Isolated Systems

Lars Henrik Hansen and Per Lundsager

Abstract (max. 2000 characters)

The report presents the results of a review of studies relating to integration of wind energy in isolated power supply systems, based on a systematic literature survey. The purpose of the study is to develop a methodology consisting of a set of guidelines for wind energy projects in isolated energy systems and a set of tools and models that are operational on an engineering level. The review is based on a literature search in the ETDE Energy Database with a main search covering the period 7/88 to 6/97 and supplemented by partial update periods. A few newer references have been included in the review, most notably the IEC/PAS 62111 specification. The amount of wind energy literature related to the subject is excessively large, and a complete review in which every relevant abstract is identified and examined is not feasible within the framework of this (or probably any other) study. The review results have been organised according to the following keywords: methods & guides, economics, concept of application, system solutions, case studies, financial programmes, dedicated software tools. None of the found references presents methods or tools that contradict the philosophy of Risø's methodology as it is described in the report. It is therefore concluded that Risø's methodology makes a good platform for further development.

Descriptors INIS/EDB
COMPUTER CODES; ECONOMICS; FINANCIAL INCENTIVES; MIUS; ON-SITE POWER GENERATION; POWER SYSTEMS; RECOMMENDATIONS;REMOTE AREAS; REVIEWS; RURAL AREAS; WIND POWER;