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Islanded microgrid energy system parameter estimation using stochastic methods

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ABSTRACT

The Design Optimisation of small energy Microgrids involves establishing the equipment configuration (size and capacity of components) and the operational rules for ongoing in service use. Existing techniques support the analysis of individual days of incident solar energy. In this paper a technique that uses Stochastic programming is proposed. The new technique allows the probability of occurrence of a particular day of incident solar energy, and the probability occurrence of particular consecutive days of incident solar energy to be considered by the optimisation process. The technique outlined supports the pre processing of incident solar energy and system loads as discrete probability functions which subsequently allows simple linear programming techniques to be utilised. This results in the ability to create easy to modify and easily scalable design tools.

1. Introduction

Islanded Microgrids are a special form of Distributed Energy System. Here they refer to electrical power systems that are not connected to a larger electrical distribution network or grid. Distributed Energy (DE) Systems provide a technically and economic efficient architecture for the incorporation of renewable generation technologies into the electrical power supply system. DE systems are an effective early action greenhouse gas mitigation option for Australia when it is considered within a portfolio of other mitigation options and further Islanded operation of distribution networks is in principle highly effective in realising the full value from embedded generation (Lilley et al., 2009; He et al., 2008; Shenai and Shah, 2011).

This paper uses a highly simplified 'reference system' to explore issues surrounding the design optimisation of Islanded Microgrids. The refence system is shown as Fig. 1.

The optimisation of Microgrid energy systems involves both the analysis of the energy system configuration during the design phase and then the optimisation of system operation once it starts to produce energy.

For the reference system the key variable that impacts on the optimum design solution is the amount of incident solar energy on a given day. For an Islanded energy system comprised of a photovoltaic (PV) array, a diesel engine driven generator and a storage battery and for any given day of incident energy, the design optimisation involves increasing the size of the PV array and battery (increased capital cost) while reducing the size (capital cost) and running time (daily cost) of the generator. There will be an 'optimal' solution (size of PV array, battery, generator and generator running time) that produces the lowest Cost of Energy (COE). That optimal solution will only be valid for days with the same cumulative incident solar energy and electrical load requirement (where the load has partial weather dependency). On days with different incident energy characteristics the solution will not be optimal.

1.1. Existing approaches

An initial review of existing work addressing the modelling of energy systems, and energy system optimisation showed that the work could be separate categories:

Work focused on optimisation techniques where the energy systems are an example application. This category or work was found to be useful in exploring the relationship between objective function formulation and mathematical technique. This work was focussed on expanding mathematical techniques.

Work focussed on solving problems with the optimisation of energy systems. This body of work is focussed on investigating the detailed modelling of energy systems and tends to focus on defining the optimisation problem.

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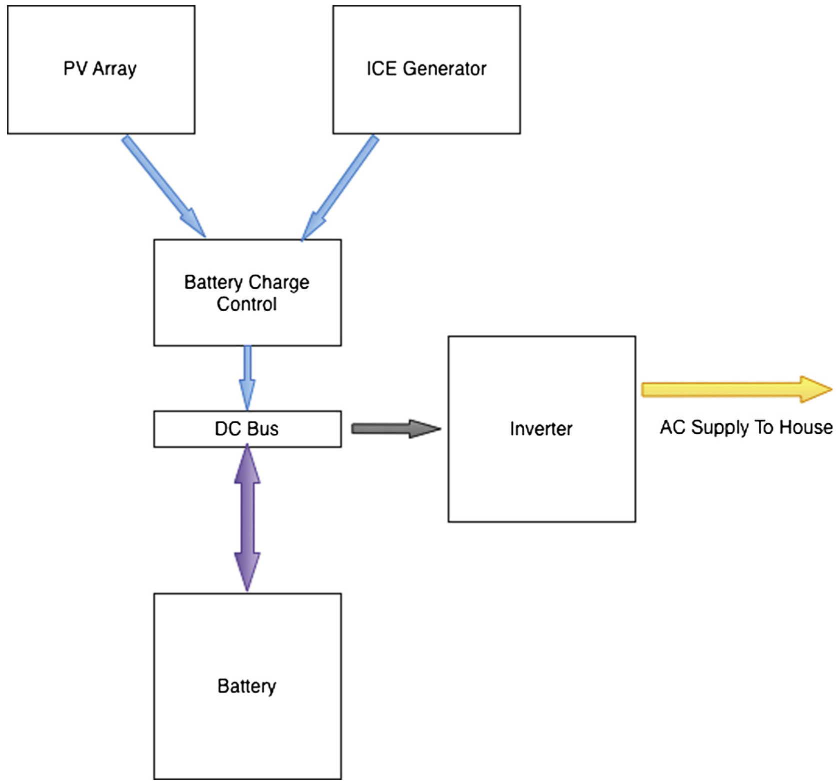

Fig. 1. Simple system being examined.

1.1.1. General optimisation with energy systems as an example

Assessment of energy system sizing is addressed a range of papers where the focus was found to be the exploration of mathematical techniques with the use of Microgrid optimisation as an example. There are a large number of these papers and in 2012 they where reviewed by Erdinc and Uzunoglu (2012). This review paper categorises work according to the mathematical approach adopted. Key mathematical categories looked at included Genetic Algorithms (GA), Particle Swarm optimisation (PSO), Simulated Annealing (SA), design space based approaches, simulation approaches, evolutionary algorithms (EA), stochastic/probabilistic approaches. It is noted that this review paper takes a very generic view of the nature of small energy systems and it is only when such papers are examined in detail is it possible to gain a view of the effectiveness of any particular approach.

Evolutionary strategies are found to suite energy system problems where the technology models are non linear or otherwise complex. Logenthiran et al. (2010) provides an example of this class of paper. This paper establishes a simple objective function of the form

$$MinC_T = \sum_{i=1}^{N} C_{DERi} N_{DERi} + OMC \text{ where}$$

C_T is the total cost of the distributed energy resources, C_{DERi} is the capital cost of DER_i and OMC is the ongoing operational and maintenance costs.

This simple objective function is subject to simple constraints of the form

$$LPSP_{max} \text{ where}$$

$LPSP$ is the probability of the loss of power supply.

Complexity is introduced by the system component modelling which introduces non-linear relationships to model wind plant and photovoltaic plant. This combination of simple objective functions and constraints together with complex plant models is a problem definition that suites the Evolutionary Strategy (ES) approach explored. The focus of the paper is on processing efficiency (and convergence) as much as it is on the Distributed Energy design issue. The ES approach explored does support the analysis of different system configurations (by amending the form and content of the ES ‘chromosome’). Further because the Genetic Algorithm concept allows the systematic review of a large number of scenarios this paper can look at the performance of systems over an entire year (while processing on a day by day 24 h period).

This approach of using Genetic Algorithms is explored in depth by Bustos et al. (2012) in a paper which introduces two objective functions (Expected Energy not Supplied and Levelised Cost of Energy) together with a wide range of generating sources. This paper also introduces the concept of using Weibull distributions to estimate solar radiation and wind speed. This paper shows that scalability of using a Genetic Algorithm approach but is limited to analysis of systems over a 24 h period.

In (Kayal and Chandra, 2014) Kayal introduces probability estimation of wind and solar incident energy is combined with complex technology models and objective functions for the minimisation of annual average power loss and maximisation of power stability and network security indices. The combination of the probabilistic estimation of generator output with complex technical models, load requirements and system constraints results in a question that is best suited to some form of GA approach. In this example a form of Particle Swarm Optimisation (PSO) is adopted. This approach is suitable for the form of the problem developed, especially given the nature of the objective function, but it can be seen that it would not support a assessment of consecutive day performance, since the difference between consecutive days is hidden in the probability distribution created. As