

Analysis of distributed energy resources for domestic electricity users

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Abstract

After over a century with utilization of the benefits of economics of scale, power systems planning and development gets bigger and transmission grids have needed to transmit wide bringing the concept of onsite or close-to-load generation back. The turnaround strategy is prompted by market liberalization, transmission expansion constraints, related technology advancements, environmental pollution, health hazards, fossil fuel depletion, and climate change concerns. In the last decade, many countries have started the process of liberalisation of the electric systems, opening access to transmission and distribution grids. Technical feasibility analysis of a hybrid energy system for two types of geographical regions in South Africa using Homer is performed in this paper. Wind-PV hybrid systems are modelled as a micro-power system using Homer. The simulation results analyses conducted for a typical middle income earner electricity load profile for both a coaster and inlander domestic users of electricity showed that Wind-PV hybrid system is technically feasible and economical.

Keywords: distributed energy resources, energy users, Homer, renewable energy resources, PV system, wind energy system

1. Introduction

The concept of locating power generation units close to users dates back to the times of Thomas Edison. When Edison set up his first heat and electricity plant near Wall Street in 1882, he envisioned a world of distributed generation and its associated benefits. He thought the best way to meet users' needs would be with networks of decentralized power plants in or near homes and offices. If the

DC power transmission technology available today was around then, our generation, transmission, distribution and utilization technology would be DC technology based. But it was not to be because Nikola Tesla and William Stanley inventions triumphed over Thomas Edison in the battle (conned the battle of the currents) between AC and DC power systems credited to the development of AC power transformer and polyphase machines.

After over a century with utilization of economics of scale, power systems planning and development gets bigger and transmission grids needed to transmit wider, the concept of onsite or close-to-load generation is back. The turnaround strategy is instigated by market liberalization, transmission expansion constraints, related technology advancements, environmental pollutions, health hazards, fossil fuel depletion, and climate change concerns (Turkson & Wohlgemuth, 2001).

Different definitions regarding distributed generation (DG) are used in the literature and in practice (Pepermans et al., 2005). However, Ackermann et al. (2007) proposed a definition of DG as an electric power source connected directly to the distribution network or on the customer side of the meter. The paper discussed why definitions based on DG purpose, location, rating, power delivery area, technology, environmental impact, mode of operation, ownership or penetration level are not relevant for the proposed definition.

In the last decade, many countries have started the process of liberalisation of the electric systems, opening access to transmission and distribution grids (Carley, 2009). South Africa recently allowed independent power producers to produce power and connect to the transmission system but the produced power can only be purchased by Eskom – the state owned power utility. Unbundling and independent operation of the generation, transmission, distribution system is what is needed for a level

playing field energy market which brings sustainable competition.

Energy cost saving is the main factor that will determine the participation of residential electricity users as owner of a distributed generation unit connected to the low voltage distribution system. Smart technology and other enabling technologies will accelerate domestic owners of distributed generators in the liberalized energy market. This may as well serve as a secondary or primary revenue sources for the benefit of an improved standard of living. Such participation in the energy market can be facilitated by government incentive programs for the promotion of sustainable energy development and deployment in South Africa (Winkler, 2005).

The next section analyses the energy requirements of a South African home. A photovoltaic energy system, wind energy system and battery energy storage system as typical distributed energy resources for domestic energy users in South Africa are discussed in section three. Section four introduces Homer as analytical and modelling software that is used in section five for the modelling and simulation of two case studies in South Africa – coaster domestic electricity user (CDEU) and islander domestic electricity users (IDEU).

2. Domestic energy requirements

Given the large inequalities within the South African market, arriving at a typical household load profile is apprehensive with difficulty. Figure 1 below shows a time average load profile of a typical middle-class household record during a weekend day (Fritz & Kallis, 2009). Renewable energy tech-

nology that is suitable and cost effective for rural users is biomass - thermal energy need. Accessibility and guaranteed energy resources are the main drivers. However, use for space heating is unsafe and hazardous, and is generally discouraged.

3. Distributed energy resources

Smaller hybrid energy plants closer to the end-user consisting of multiple energy sources are emerging as an alternative to large energy and distribution power plants with competitive cost and improved reliability and security. Distributed energy resources (DERs) include both conventional and non-conventional energy sources connected to the primary feeder or secondary feeder of a distribution system (Alanne & Saari, 2006). Examples of DER are microturbines, small-scale hydropower, PV system, wind energy system (excluding wind farms), CHP, energy storage systems, diesel generator and fuel cells systems. Renewable energy resources that have matured and easily installed include the PV and wind energy (excludes wind farms) systems which are discussed in this paper. Distributed generation is attractive to domestic users from the following perspective: power is readily available (if not making use of renewable resources or renewable resource with adequate sized energy storage system), improved power quality and reliability for sensitive loads, cost of electricity usage is lower and co-generation capability (Alanne & Saari, 2006).

3.1 Photovoltaic system

Solar energy is converted directly into electricity with modules consisting of many photovoltaic solar

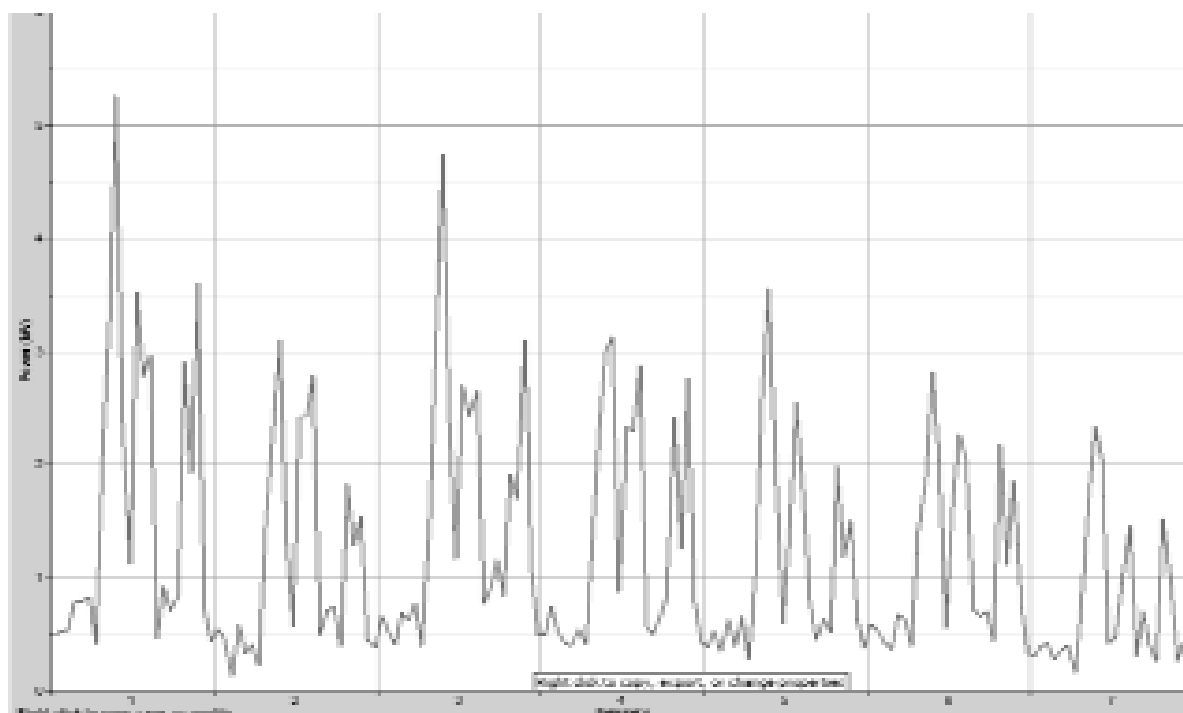


Figure 1: Domestic electricity user load profile

cells. Such solar cells are usually manufactured from fine films or wafer. They are semiconductor devices capable of converting incident solar energy into dc current, with efficiencies varying from 3% to 31%, depending on the technology, the light spectrum, temperature, design and the material of the solar cell. A solar cell could be understood to be a battery of very low voltage (around 0.6 V) continually recharged at a rate proportional to the incident illumination. The series-parallel connection of cells allows the design of solar panels with high currents and voltages. The balance of the PV system includes power electronic power conversion and conditioning equipment, energy storage and monitoring plus protection devices. Power electronics has been the great enabling technology in the diversification of a solar energy application. Figure 1 shows a solar energy conversion system.

The most attractive features of solar panels are the nonexistence of movable parts, very slow degradation of the sealed solar cells, flexibility in the association of modules and the extreme simplicity of its use and maintenance.

3.2 Wind energy system

Wind energy is not a new form of energy, it has been around for decades. A wind energy conversion system consists of a rotor, turbine blades, generator, drive or coupling device, shaft and the nacelle that contains the gearbox and the generator drive. Modern wind energy conversion system can provide clean electricity as individual or as wind farms.

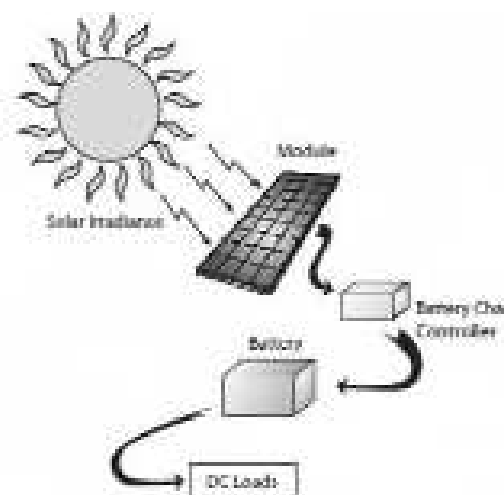


Figure 2: Solar energy conversion system

The energy in the wind is converted to rotational mechanical energy by the turbine which is coupled to the rotor of an electricity generator using a shaft. The electrical energy generator converts the rotational mechanical energy to the electrical energy either for grid-forming or grid-following applications. Figure 3 shows the wind energy conversion system.

4. Homer

Homer^(R) is used in this paper to model and simulate the cost and benefits of both PV and wind energy systems in grid-connected and stand-alone mode of operation.

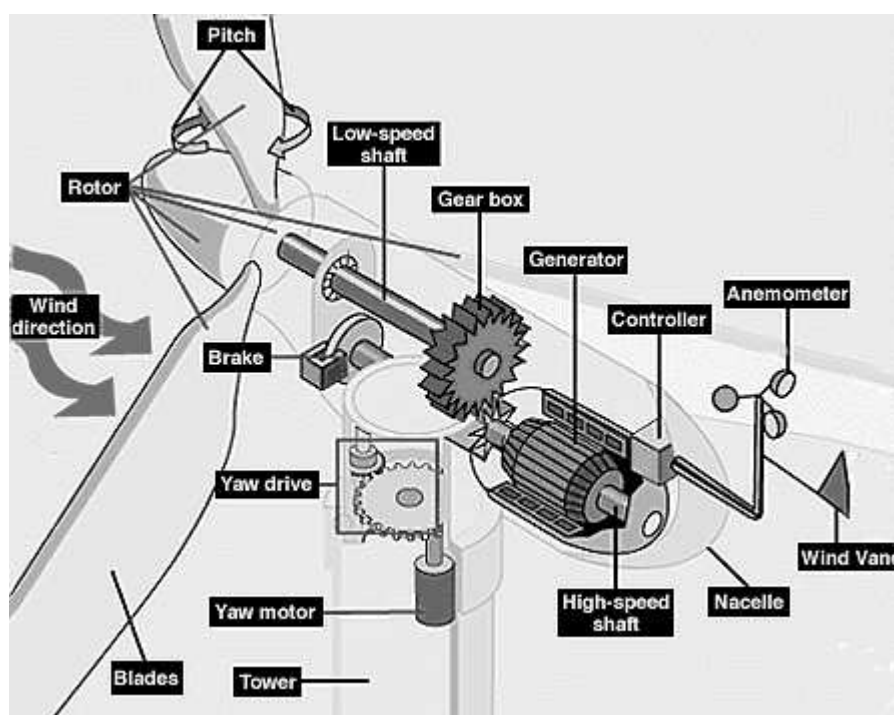


Figure 3: Wind energy conversion system

Homer is modelling software that simplifies the task of evaluating design options for both island and grid-connected power systems for remote, stand-alone and distributed generation applications. It is also a powerful tool for designing and analysing hybrid power systems, which contain a mix of conventional generators, cogeneration, wind turbines, solar photovoltaic, hydropower, batteries, fuel cells, hydropower, biomass and other inputs. Homer's optimization and sensitivity analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainties in technology costs, energy resource availability, and other variables. Homer models both conventional and renewable energy technologies.

Homer models the PV panel as a device that produces dc electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and the voltage to which it is exposed. Homer calculates the power output of the PV panel using the equation:

$$P_{PV} = f_{PV} Y_{PV} (I_T / I_s) \quad 1$$

where, f_{PV} is the PV derating factor, Y_{PV} the rated capacity of the PV panel (kW), I_T the global solar radiation and I_s is 1 kW/m^2 , which is the standard amount of radiation used to rate the capacity of the PV panel.

To describe the cost of the PV panel, the user specifies its initial cost, replacement cost and operating and maintenance cost per year. The replacement cost is the cost of replacing the PV panel at the end of its useful lifetime, which the user specifies in years. By default the replacement cost is equal to the capital cost, but the two can differ for several reasons. For example, a donor organization or utility subsidy (Eskom) may cover some or all of the initial capital cost but none of the replacement cost.

Homer models a wind turbine as a device that converts the kinetic energy of the wind into ac or dc electricity according to a particular power curve, which is a graph of power output versus wind speed at hub height. It assumes that the power curve applies at a standard air density of 1.225 kg/m^3 , which corresponds to standard temperature and atmospheric pressure.

Each hour, Homer calculates the power output of the wind turbine in a four-step process. First, it determines the average wind speed for the hour at the anemometer height by referring to the wind resource data. Second, it calculates the corresponding wind speed at the turbine's hub height using either the logarithmic law or the power law. Third, it refers to the turbine's power curve to calculate its power output at that wind speed assuming standard air density. Fourth, it multiplies that power output value by the air density ratio, which is the ratio of

the actual air density to the standard air density. To describe the cost of the wind energy system, the user specifies its initial cost, replacement cost and operating and maintenance cost per year. The replacement cost is the cost of replacing the energy system at the end of its useful lifetime, which the user specifies in years (Homer Version 2.1).

5. Distributed energy resources home case studies

Solar radiation data for Cape Town and Johannesburg cities were obtained from the NASA Surface Meteorology and Solar Energy website (Geographical Information) via the HOMER solar resource input interface.

The Homer model for the case studies showing the AC and Dc grids, primary load, inverter system, energy storage system, PV system and wind turbine system is depicted in Figure 4.

The primary load is the electrical load that must be served by the micro power system. This electrical load is modelled by the load profile of a typical middle income South African domestic electricity user derived in section 2.

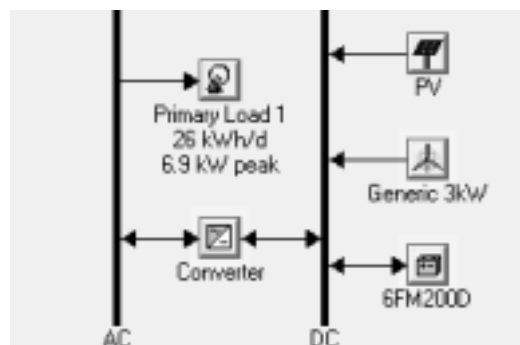


Figure 4: Homer model of a studied hybrid system

5.1 Cases study 1: Islander domestic electricity user

Johannesburg (lat. $28^{\circ}08'$ and long. $28^{\circ}14'$) is the economic hub of South Africa at an altitude of 5567 feet above sea level. Wind and solar resources data for Johannesburg is obtained (Geographical Information: online), (Metrological Data: online), (Eskom: online) and used for the Homer model simulation analysis. The hourly simulated results for the wind and solar irradiance data is shown in Figure 5. Negative correlations exist between the two resources such that when the sun is not shining, the wind is blowing and vice versa.

The Wind-PV hybrid system cost of electricity production is lower than only installed PV system. However, the capacity shortage of the hybrid system is higher than only an installed PV system supplying the load as shown in Table 1. Only an installed wind turbine system is not economically viable and feasible for Johannesburg for the load

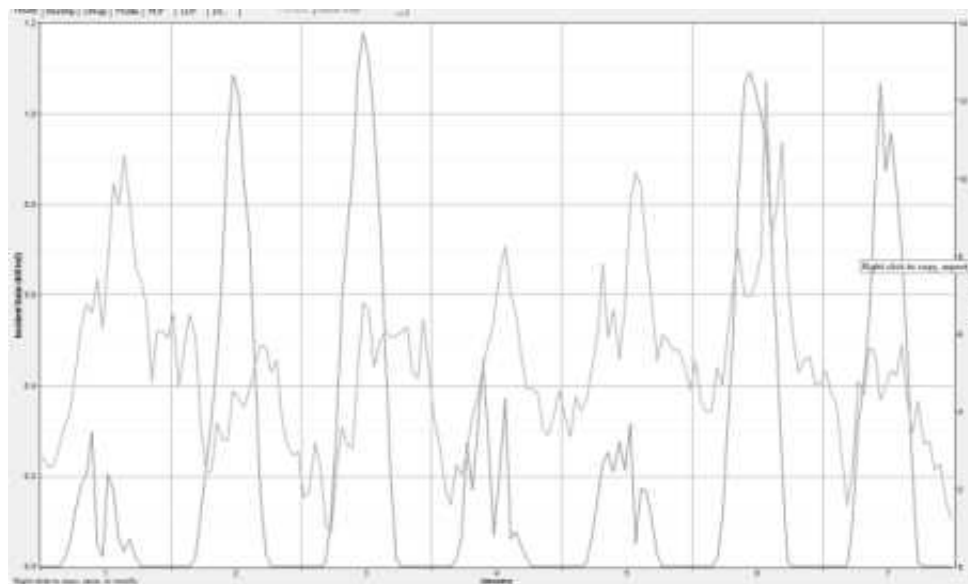


Figure 5: Solar and wind resources data variability profile

Table 1: Optimization results for IDEU

	PV (kW)	G10	6FM200D	Conv. (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Capacity Shortage
☀️ 🌬️ ☑️ ☑️	5	1	16	10	\$ 3,500	410	\$ 8,736	0.061	1.00	0.08
☀️ 🌬️ ☑️ ☑️	10		16	10	\$ 3,500	455	\$ 9,316	0.062	1.00	0.02

Table 2: Optimization result for CDUE

	PV (kW)	G10	6FM200D	Conv. (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Capacity Shortage
☀️ 🌬️ ☑️ ☑️		1	16	10	\$ 2,500	334	\$ 6,767	0.048	1.00	0.09
☀️ 🌬️ ☑️ ☑️	5	1	16	10	\$ 3,500	365	\$ 8,166	0.054	1.00	0.01
☀️ 🌬️ ☑️ ☑️	10		16	10	\$ 3,500	446	\$ 9,205	0.065	1.00	0.08

profile used for the modelled system. The feasibility of such system is possible with increase in the overall system cost with proportional increase in load demand otherwise it will be uneconomical.

Only an installed PV system has a higher total net present cost but lower capacity shortage.

5.2 Case study 2: Coaster domestic electricity user

Cape Town (lat. 33°59' and long. 18°36') is a coastal city and a very popular tourist destination in South Africa. Wind and solar resources data for Cape Town is obtained and used for the Homer model simulation analysis. The hourly simulated results for the wind and solar irradiance data are shown in Figure 6. Inverse correlations exist between the two resources such that when the sun is not shining, the wind is blowing and vice versa.

The wind system is the best option for the coastal areas because of abundant wind resources. The cost of electricity production is marginally lower than a Wind-PV hybrid system. However, the

capacity shortage of the Wind-PV hybrid system is lower than an only installed wind system supplying the load as shown in Table 2. An installed PV system only ranked last for Cape Town for the load profile used in the model.

6. Conclusion

The simulation results analyses conducted for a typical middle income household electricity load profile for both coastal and inlander domestic users showed that a Wind-PV hybrid system is more economically viable for the islanders compared to other configurations and a wind energy system is more economically viable for the coasters compared to other configurations as well.

The cost of electricity production and the net present cost of the optimized systems for each region for the modelled scenario are competitive with the grid cost of electricity.

If in the near future Eskom allows a grid connection of distributed generation units to the low voltage distribution network with a kind of prof-

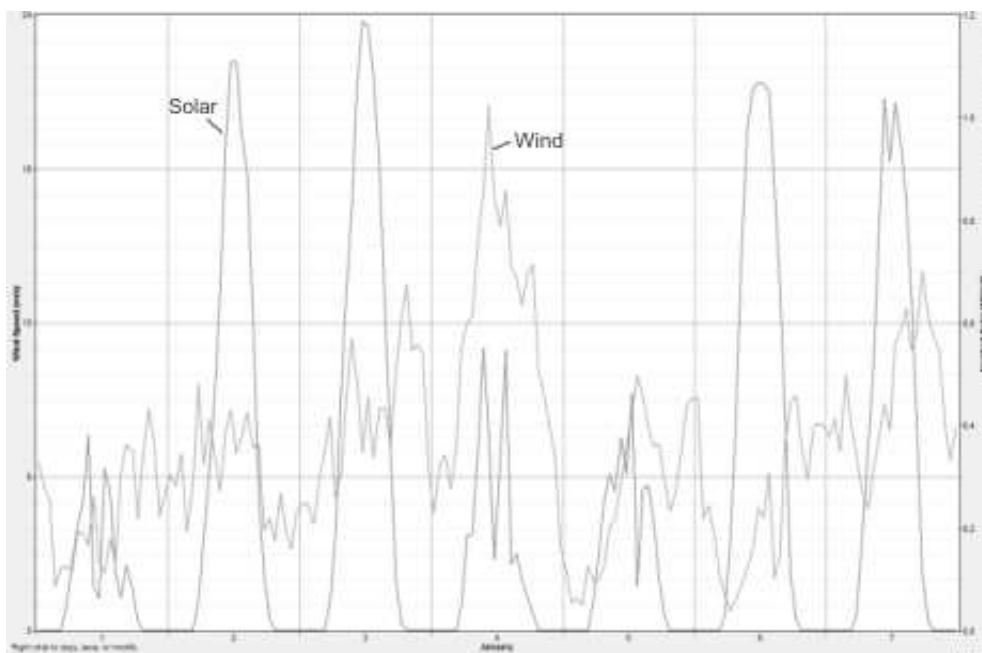


Figure 6: Solar and wind resources data variability profile

itable renewables buy back energy market, owners of DER will possibly increase (Turkson & Wohlge-muth, 2001). Benefits to utility will include capital investment deferral, an increased reserve margin, a more stable system, and increased adequacy and increased reliability (Mendez *et al.*, 2006), (Pecas Lopes *et al.*, 2007).

Not only is there a tremendous energy cost sav-ings but also the non-existent of hazardous environ-mental pollutions because the primary energy sources is renewable and infinite (Panwar *et al.*, 2011).

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