Homer micropower systems modelling engineering essay

Engineering

The objective of this thesis is to assess the feasibility of different Hybrid-renewable systems configurations, which can be modeled on houses in different regions of the country. The systems are assessed in terms economical and technical aspects . The different system models were designed and simulated with HOMER energy software, the version 2. 68 beta, also known as the HOMER Micropower Optimization Model.

3. 1 Introduction

The full form of HOMER is " Hybrid Optimization Model for Electric Renewables " . The HOMER Micropower Optimization Model is a computer model developed by the U. S. National Renewable Energy Laboratory (NREL) to assist in the design of micropower systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models a power system’s physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs. A micropower system is one that generates electricity, and possibly heat, to serve a nearby load. HOMER can model grid-connected and off-grid micropower systems serving electric and thermal loads, and comprising any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, reciprocating engine generators, microturbines, fuel cells, batteries, and hydrogen storage. HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis. SimulationIn the simulation process, HOMER models the performance of a particular micropower system configuration each hour of the year to determine its technical feasibility and life-cycle cost. The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time. OptimizationIn the optimization process, HOMER simulates many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost. Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. SensitivityIn the sensitivity analysis process, HOMER performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. Sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price.

3. 2 PHYSICAL MODELING

In HOMER, a micropower system must comprise at least one source of electrical or thermal energy (such as a wind turbine, a diesel generator, a boiler, or the grid), and at least one destination for that energy (an electrical or thermal load, or the ability to sell electricity to the grid). It may also comprise conversion devices such as an ac–dc converter or an electrolyzer, and energy storage devices such as a battery bank or a hydrogen storage tank. In the following subsections , it is described how HOMER models the loads that the system must serve, the components of the system and their associated resources, and how that collection of components operates together to serve the loads.

3. 2. 1 Loads

In HOMER, the term load refers to a demand for electric or thermal energy. Serving loads is the reason for the existence of micropower systems, so the modeling of a micropower system begins with the modeling of the load or loads that the system must serve. HOMER models three types of loads. Primary load is electric demand that must be served according to a particular schedule. Deferrable load is electric demand that can be served at any time within a certain time span. Thermal load is demand for heat.

Primary load

Primary load is electrical demand that the power system must meet at a specific time. Electrical demand associated with lights, radio, TV, household appliances, computers, and industrial processes is typically modeled as primaryload. When a consumer switches on a light, the power system must supply electricity to that light immediately—the load cannot be deferred until later. If electrical demand exceeds supply, there is a shortfall that HOMER records as unmet load. The value of the primary load, in kilowatts for each hour, is entered in to the software either by importing a file containing hourly data or by allowing HOMER to synthesize hourly data from average daily load profiles. When synthesizing load data, HOMER creates hourly load values based on user-specified daily load profiles. HOMER can model two separate primary loads, each of which can be ac or dc. Among the three types of loads modeled in HOMER, primary load receives special treatment in that it requires a user-specified amount of operating reserve. Operating reserve is surplus electrical generating capacity that is operating and can respond instantly to a sudden increase in the electric load or a sudden decrease in the renewable power output. HOMER attempts to ensure that the system’s operating capacity is always sufficient to supply the primary load and the required operating reserve.

Deferrable load

Deferrable load is electrical demand that can be met anytime within a defined time interval. Water pumps, ice makers, and battery-charging stations are examples of deferrable loads because the storage inherent to each of those loads allows some flexibility as to when the system can serve them. The ability to defer serving a load is often advantageous for systems comprising intermittent renewable power sources, because it reduces the need for precise control of the timing of power production. If the renewable power supply ever exceeds the primary load, the surplus can serve the deferrable load rather than going to waste. When simulating a system serving a deferrable load, HOMER tracks the level in the deferrable load tank. It will put any excess renewable power into the tank, but as long as the tank level remains above zero, HOMER will not use a dispatchable power source (a generator, the battery bank, or the grid) to put energy into the tank.

Thermal load

HOMER models thermal load in the same way that it models primary electric load, except that the concept of operating reserve does not apply to the thermal load. The system supplies the thermal load with either the boiler, waste heat recovered from a generator, or resistive heating using excess electricity.

3. 2. 2 Resources

The term resource applies to anything coming from outside the system that is used by the system to generate electric or thermal power. That includes the four renewable resources (solar, wind, hydro, and biomass) as well as any fuel used by the components of the system. Renewable resources vary enormously by location. The solar resource depends strongly on latitude and climate, the wind resource on large-scale atmospheric circulation patterns and geographic influences, the hydro resource on local rainfall patterns and topography, and the biomass resource on local biological productivity. The careful modeling of the renewable resources is therefore an essential element of system modeling. In the following sub-section, it is described how HOMER models the renewable resources .

Solar resource

To model a system containing a PV array, solar resource data must be inserted into the software for the location of interest. Solar resource data indicate the amount of global solar radiation (beam radiation coming directly from the sun, plus diffuse radiation coming from all parts of the sky) that strikes Earth’s surface in a typical year. The data can be in one of three forms: hourly average global solar radiation on the horizontal surface (kW/m2), monthly average global solar radiation on the horizontal surface (kWh/m2 _day), or monthly average clearness index. The clearness index is the ratio of the solar radiation striking Earth’s surface to the solar radiation striking the top of the atmosphere. A number between zero and 1, the clearness index is a measure of the clearness of the atmosphere. If the monthly solar resource data is entered then HOMER generates synthetic hourly global solar radiation data using an algorithm developed by Graham and Hollands. The inputs to this algorithm are the monthly average solar radiation values and the latitude. The output is an 8760-hour data set with statistical characteristics similar to those of real measured data sets. One of those statistical properties is autocorrelation, which is the tendency for one day to be similar to the preceding day, and for one hour to be similar to the preceding hour.

Wind resource

To model a system comprising one or more wind turbines, wind resource data, indicating the wind speeds the turbines would experience in a typical year, must be entered into the HOMER software. The hourly wind data can be directly inserted if it is available. Otherwise, HOMER can generate synthetic hourly data from 12 monthly average wind speeds and four additional statistical parameters: the Weibull shape factor, the autocorrelation factor, the diurnal pattern strength, and the hour of peak wind speed. The Weibull shape factor is a measure of the distribution of wind speeds over the year. The autocorrelation factor is a measure of how strongly the wind speed in one hour tends to depend on the wind speed in the preceding hour. The diurnal pattern strength and the hour of peak wind speed indicate the magnitude and the phase, respectively, of the average daily pattern in the wind speed. HOMER provides default values for each of these parameters. The anemometer height, meaning the height above ground at which the wind speed data were measured or estimated needs to be inserted into the software. If the wind turbine hub height is different from the anemometer height, HOMER calculates the wind speed at the turbine hub height using either the logarithmic law or the power law. The elevation of the site above sea level also needs to be entered into the software. HOMER then uses this value to calculate the air density according to the U. S. Standard Atmosphere. HOMER makes use of the air density when calculating the output of the wind turbine.

3. 2. 3 Components

A component is any part that generates, delivers, converts, or stores energy of a micro power system. HOMER models 10 types of components. Three generate electricity from intermittent renewable sources: photovoltaic modules, wind turbines, and hydro turbines. PV modules convert solar radiation into dc electricity. Wind turbines convert wind energy ac into dc electricity. Hydro turbines convert the energy of flowing water into ac or dc electricity. Another three types of components, generators, the grid, and boilers, are dispatchable energy sources, meaning that the system can control them as needed. There are two other types of components, converters and electrolyzers , convert electrical energy into another form. Finally, two types of components store energy: batteries and hydrogen storage tanks.

PV Array

HOMER models the PV array as a device that generates 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 array using the equation below.(3. 1)Where, PPV is the power output of the PV, is the PV derating factor, the rated capacity of the PVarray (kW), IT the global solar radiation incident on the surface of the PV array (kW/m2) and, IS is 1 kW/m2, which is the standard amount of radiation used to rate the capacity of the PV array. The rated capacity of a PV array is the amount of power it would produce under standard test conditions of 1 kW/m2 irradiance and a panel temperature of 25 0C. The size of a PV array is specified in terms of rated capacity. Each hour of the year, HOMER calculates the global solar radiation incident on the PV array using the HDKR model, of Duffie and Beckmann . This model takes into account the current value of the solar resource, the orientation of thePV array, the location on Earth’s surface, the time of year, and the time of day. The orientation of the array may be either fixed or varied according to one of several tracking schemes. The derating factor is a scaling factor, which accounts for effects of dust on the panel, wire losses, elevated temperature, or anything else that would cause the output of the PV array to deviate from that expected under ideal conditions. HOMER does not account for the fact that the power output of a PV array decreases with increasing panel temperature, but the HOMER user can reduce the derating factor to roughly correct for this effect when modeling systems for hot climates. In reality, the output of a PV array does depend strongly and nonlinearly on the voltage to which it is exposed. The maximum power point depends on the solar radiation and the temperature. If the PV array is connected directly to a dc load or a battery bank, it will often be exposed to a voltage different from the maximum power point, and performance will suffer. A maximum power point tracker (MPPT) is a solid-state device placed between the PV array and the rest of the dc components of the system that decouples the array voltage from that of the rest of the system, and ensures that the array voltage is always equal to the maximum power point. By ignoring the effect of the voltage to which the PV array is exposed, HOMER effectively assumes that a maximum power point tracker is present in the system. To describe the cost of the PV array, the user specifies its initial capital cost, replacement cost, and operating and maintenance (O&M) cost. The replacement cost is the cost of replacing the PV array at the end of its useful lifetime, which the user specifies in years. By default, the replacement cost is equal to the capital cost.

Wind Turbine

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. Figure below is an example of a power curve. Homer assumes that the applies at a standard air density of 1. 225 kg/m3, which corresponds to standardtemperature and pressure conditions. 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. As mentioned before, HOMER calculates the air density ratio at the site elevation using the U. S. Standard

Atmosphere. HOMER assumes that the air density ratio is constant throughout the year. In addition to the turbine's power curve and hub height, the user specifies the expected lifetime of the turbine in years, its initial capital cost in dollars, its replacement cost in dollars, and its annual O&M cost in dollars per year.

Battery bank

The battery bank is a collection of one or more individual batteries. HOMER models a single battery as a device capable of storing a certain amount of dc electricity at a fixed round-trip energy efficiency, with limits as tohow quickly it can be charged or discharged, how deeply it can be discharged without causing damage, and how much energy can cycle through it before it needs replacement. HOMER assumes that the properties of the batteries remain constant throughout its lifetime and are unaffected by external factors such as temperature. In HOMER, the key physical properties of the battery are its nominal voltage, capacity curve, lifetime curve, minimum state of charge, and round-trip efficiency. The assumption that lifetime throughput is independent of cycle depth means that HOMER can estimate the life of the battery bank simply by monitoring the amount of energy cycling through it, without having to consider the depth of the various charge–discharge cycles. The lifetime of batteries are calculated as follows: whereNbatt is the number of batteries in the battery bank, Qlifetime the lifetime, throughput of a single battery, Qthrpt the annual throughputand Rbatt; the float life of the batteryThe user stipulates the battery bank's capital and replacement costs and the O&M cost. Since the battery bank is a dispatchable power source, HOMER calculates its fixed and marginal cost of energy for comparisonwith other dispatchable sources. For its marginal cost of energy, HOMER uses the sum of the battery wear cost and the battery energy costThe battery wear cost is calculated as follows: where Crep; batt is the replacement cost of the battery bank , Nbatt is the number of batteries in the battery bank, Qlifetime is the lifetime throughput of a singlebattery (kWh), and Zrt is the round-trip efficiency. HOMER calculates the battery energy cost each hour of the simulation by dividing the total year-to-date cost of charging the battery bank by the total year-to-date amount of energy put into the battery bank.

Grid

HOMER models the grid as a component from which the micropower system can purchase ac electricity and to which the system can sell ac electricity. The cost of purchasing power from the grid can comprise an energy charge based on the amount of energy purchased in a billing period and a demand charge based on the peak demand within the billing period. HOMER uses the term grid power price for the price that the electric utility charges for energypurchased from the grid, and the demand rate for the price the utility charges for the peak grid demand. A third term, the sellback rate, refers to the price that the utility pays for power sold to the grid. The HOMER user can define and schedule up to 16 different rates, each of which can have different values of grid power price, demand rate, and sellback rate. The schedule of the rates can vary according to month, time of day, and weekday/ weekend. For example, HOMER could model a situation where an expensive rate applies during weekday afternoons in July and August, an intermediate rate applies during weekday afternoons in June and September and weekend afternoons from June to September, and an inexpensive rate applies at all other times. HOMER can also model net metering, a billing arrangement whereby the utility charges the customer based on the net grid purchases (purchases minus sales) over the billing period. Under net metering, if purchases exceed sales over the billing period, the consumer pays the utility an amount equal to the net grid purchases times the grid power cost. If sales exceed purchases over the billing period, the utility pays the consumer an amount equal to the net grid sales (sales minus purchases) times the sellback rate, which is typically less than the grid power price, and oftenzero. The billing period may be one month or one year. In the unusual situation where net metering applies to multiple rates, HOMER tracks the net grid purchases separately for each rate. Two variables describe the grid’s capacity to deliver and accept power. The maximum power sale is the maximum rate at which the power system can sell power to the grid. The maximum grid demand is the maximum amount of power that can be drawn from the grid. The maximum grid demand acts as a control parameter that affects the operation and economics of the system. The user also enters the grid emissions coefficients, which HOMER uses to calculate the emissions of six pollutants associated with buying power from the grid, as well as the avoided missions resulting from the sale of power to the grid. Because it is a dispatchable power source, HOMER calculates the grid’s fixed and marginal cost of energy. The fixed cost is zero, and the marginal cost is equal to the current grid power price plus any cost resulting from emissions penalties.

Converter

A converter is a device that converts electric power from dc to ac in a process called inversion, and/or from ac to dc in a process called rectification. HOMER can model the two common types of converters: solid-state and rotary. The converter size, which ias a decision variable, refers to the inverter capacity, meaning the maximum amount of ac power that the device can produce by inverting dc power. The user specifies the rectifier capacity, which is the maximum amount of dc power that the device can produce by rectifying ac power, as a percentage of the inverter capacity. HOMER assumes that the inverter and rectifier capacities are not surge capacities that the device can withstand for only short periods, but rather, continuouscapacities that the device can withstand for as long as necessary. The HOMER user indicates whether the inverter can operate in parallel with another ac power source such as a generator or the grid. Doing so requires the inverterto synchronize to the ac frequency, an ability that some inverters do not have. The final physical properties of the converter are its inversion and rectification efficiencies, which HOMER assumes to be constant. The economic properties of the converter are its capital and replacement cost in , its annual O&M cost in, and its expected lifetime in years.

ECONOMIC MODELING

Economics play an integral role both in HOMER’s simulation process, wherein it operates the system so as to minimize total net present cost, and in its optimization process, wherein it searches for the system configuration with the lowest total net present cost. Renewable and nonrenewable energy sources typically have dramatically different cost characteristics. Renewable sources tend to have high initial capital costs and low operating costs, whereas conventional nonrenewable sources tend to have low capital and high operating costs. In its optimization process, HOMER must often compare the economics of a wide range of system configurations comprising varying amounts of renewable and nonrenewable energy sources. To be equitable, such comparisons must account for both capital and operating costs. Life-cycle cost analysis does so by including all costs that occur within the life span of the system.

Net present cost

HOMER uses the total net present cost (NPC) to represent the life-cycle cost of a system. The total NPC groups all the costs and revenues that occur within the project lifetime into one lump sum, with future cash flows discounted back to the present using the discount rate. The modeler specifies the discount rate and the project lifetime. The NPC includes the costs of initial construction, component replacements, maintenance, fuel, plus the cost of buying power from the grid and miscellaneous costs such as penalties resulting from pollutant emissions. Revenues include income from selling power to the grid, plus any salvage value that occurs at the end of the project lifetime. With the NPC, costs are positive and revenues are negative. This is the opposite of the net present value. As a result, the net present cost is different from net present value only in sign. HOMER assumes that all prices escalate at the same rate over the project lifetime. With that assumption, inflation can be factored out of the analysis simply by using the real (inflation-adjusted) interest rate rather than the nominal interest rate when discounting future cash flows to the present. The HOMER user therefore enters the real interest rate, which is roughly equal to the nominal interest rate minus the inflation rate. All costs in HOMER are real costs. For each component of the system, the modeler specifies the initial capital cost, which occurs in year zero, the replacement cost, which occurs each time the component needs replacement at the end of its lifetime, and the O&M cost, which occurs each year of the project lifetime. The user specifies the lifetime of most components in years, but HOMER calculates the lifetime of the battery and generators as described before. It may happens that the replacement cost and the initial cost of components varies. For example, in the case of a wind turbine, the tower and foundation will last for the life of the project and the wind nacelle may have to be replaced after only 15 use of use. In that case, the replacement cost would be considerably less than the initial capital cost. Donor agencies or buy-down programs might cover some or all of the initial capital cost of a PV array but none of the replacement cost. In that case, the replacement cost may be greater than the initial capital cost. HOMER combines the capital, replacement, maintenance, and fuel costs, along with the salvage value and any other costs or revenues, to find each component's annualized cost. This is the hypothetical annual cost that if it occurred each year of the project lifetime would yield a net present cost equivalent to that of all the individual costs and revenues associated with that component over the project lifetime. HOMER performs an addition of the annualized costs of each component, along with any miscellaneous costs, such as penalties for pollutant emissions, to find the total annualized cost of the system. This value is an important one because HOMER uses it to calculate the two principal economic figures of merit for the system: the total net present cost and the levelized cost of energy. HOMER uses the following equation to calculate the total net present cost: whereCann; tot is the total annualized cost, i the annual real interest rate (the discountrate), Rproj the project lifetime, and CRF(_) is the capital recovery factor, given by the equation: Wherei is the annual real interest rate , and N is the number of years. Levelized cost of energyThe levelized cost of energy is the average cost per kilowatthour of useful electrical energy produced by the system. HOMER uses the following equation to calculate the levelized cost of energy: WhereCann; tot is the total annualized cost, Eprim and Edef are the total amounts of primary and deferrable load, respectively that the system serves per yearandEgrid; sales is the amount of energy sold to the grid per year. The denominator in equation (15. 14) is an expression of the total amount of useful energy that the systemproduces per year. The levelized cost of energy is the average cost per kilowatt-hour of useful electrical energy produced by the system. The primary economic figure of merit that Homer use is the NPC instead of the levelized cost of energy. In its optimization process, HOMER ranks the system configurations according to NPC rather than levelized cost of energy.