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ECONOMIC IMPACT OF HYBRID DISTRIBUTED GENERATION IN AN ELECTRICAL DISTRIBUTION SYSTEM

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ABSTRACT

Distributed generation (DG) systems have attracted increased interest due to ever increasing energy consumption, rising public awareness of environmental protection, and steady progress in power deregulation. Different renewable energy sources in the distribution system are integrated through an AC bus. Dynamic models for the main system components, namely, wind energy conversion system (WECS), PV energy conversion system (PVECS), fuel cell, electrolyzer, power electronic interfacing circuits, battery, hydrogen storage tank, gas compressor and gas pressure regulator, are developed earlier. Based on the dynamic component models, a simulation model for the proposed hybrid energy system has been developed using HOMER (Hybrid Optimisation Model for Electric Renewables). The overall energy management strategy for coordinating the power flows among the different energy sources is presented with cost-effective approach.

Keywords**:** *Distributed Generation, Hybrid Energy System, Electrical Distribution System, HOMER*

1. INTRODUCTION

Rapid progress in wind, PV and fuel cell power generation technologies, the ever increasing energy consumption, and the rising public awareness for environmental protection have turned alternative energy and distributed generation as promising research areas. Due to natural intermittent properties of wind and solar irradiation, standalone wind/PV renewable energy systems normally require energy storage devices or some other generation sources to form a hybrid system. Because some of renewable energy sources can complement each other, multi-source alternative energy systems with proper control have great potential to provide higher quality and more reliable power to customers than a system based on a single resource. However, the issues on optimal system configuration, proper power electronic interfaces and power management among different energy sources are not resolved yet. Therefore, more research work is needed on new alternative energy systems and their corresponding control strategies. Fuel cells are good energy sources to provide reliable power at steady state, but they cannot respond to electrical load transients as fast as desired. This problem is mainly due to their slow internal electrochemical and thermodynamic responses [4]. Nevertheless, different renewable energy sources can complement each other, forms hybrid alternative energy systems with proper control have great potential to provide higher quality and more reliable power to customers than a system based on a single resource. And because of this, hybrid energy systems have caught worldwide research attention.

There are many combinations of different alternative energy sources and storage devices to build a hybrid system. The following lists some of the stand-alone or grid-connected hybrid systems that have been reported in this paper [4].

1) Wind/PV/FC/electrolyzer/battery system
2) Micro-turbine/FC system
3) Micro turbine/wind system

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4) Gas-turbine/FC system
5) Diesel/FC system
6) PV/battery
7) PV/FC/electrolyzer
8) PV/FC/electrolyzer/battery system
9) FC/battery, or super-capacitor system
10) Wind/FC system
11) Wind/diesel system
12) Wind/PV/battery system
13) PV/diesel system
14) Diesel/wind/PV system
15) PV / FC /Super-conducting Magnetic Energy Storage (SMES) system

From the above listed hybrid energy systems, it is noted that the main renewable energy sources are wind and photovoltaic power. Due to natural intermittent properties of wind and photovoltaic power, stand-alone wind and/or PV renewable energy systems normally require energy storage devices or some other generation sources to form a hybrid system. The storage device can be a battery bank, super-capacitor bank, SMES, or a FC-electrolyzer system. In this study, a multi-source hybrid alternative distributed generation system consisting of wind, connected with hydro-diesel and battery is proposed. Wind and hydro-diesel are the primary power sources of the system to take full advantage of renewable energy in the proposed system. The hydro-diesel combination is used as a backup and long term storage system. For a stand-alone application, a battery is also used in the system as short term energy storage to supply fast transient and ripple power. In the proposed system, the different energy sources are integrated through an AC link bus.

A hybrid alternative energy system can either be stand-alone or grid-connected if Utility grid is available. For a stand-alone application, the system needs to have sufficient storage capacity to handle the power variations from the alternative energy sources involved. A system of this type can be considered as a micro-grid, which has its own generation sources and loads .For a grid-connected application, the alternative energy sources in the micro-grid can supply power both to the local loads and the utility grid [5]. In addition to real power, these DG sources can also be used to give reactive power and voltage support to the utility grid. The capacity of the storage device for these systems can be smaller if they are grid-connected since the grid can be used as system backup. However, when connected to a utility grid, important operation and performance requirements, such as voltage, frequency and harmonic regulations, are imposed on the system.

2. THE PROPOSED SYSTEM CONFIGURATION

Figure 1 shows the system configuration for the proposed hybrid alternative energy system. In the system, the renewable wind and hydro power are

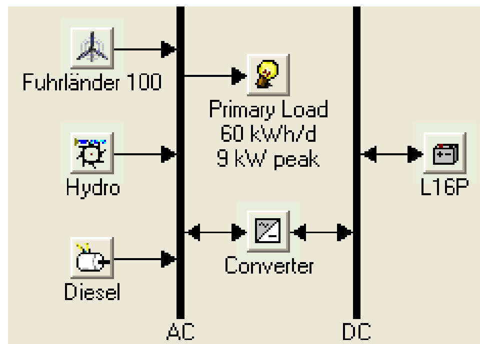

Fig1.Proposd Hybrid Hydro–Wind–Diesel system with battery backup and an AC–DC converter taken as the primary source while diesel and battery is used as a backup and storage system. This system can be considered as a complete “green” power generation system because the main energy sources and storage system are all environmentally friendly, and it can be. A battery bank is used to supply transient power to fast load transients, ripples and spikes in stand-al one applications. For grid-connected applications, the battery bank can be taken out from the system; the utility grid will take care of transient power.

HOMER can model grid-connected and off-grid distribution 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. The analysis and design of distribution systems can be challenging, due to the large number of design options and the uncertainty in key parameters, such as load size and future fuel price. Renewable power sources add further complexity because their power output may be intermittent, seasonal, and non-dispatchable, and the availability of renewable resources may be uncertain. This software was designed to overcome these challenges. The Proposed System Configuration has been performed by three

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principal tasks namely simulation, optimization, and sensitivity analysis.

3. SIMULATION

In the simulation process, it models the performance of a particular system configuration each hour of the year to determine its technical feasibility and life-cycle cost. Its higher-level capabilities, optimization and sensitivity analysis, rely on this simulation capability. 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. This software can simulate a wide variety of micro power system configurations, that is a micro power system is a system that generates electricity, to serve a nearby load. Such a system may employ any combination of electrical generation and storage technologies and may be grid-connected or autonomous, meaning separate from any transmission grid. Comprising any combination of a PV array, one or more wind turbines, a run-of-river hydro-turbine, and up to three generators, a battery bank, an ac–dc converter, an electrolyzer, and a hydrogen storage tank. This software system can be useful for grid-connected or autonomous and can serve ac and dc electric loads.

Figure 1 shows schematic diagram of proposed hybrid model that HOMER [13] could simulate. Systems that contain a battery bank and one or more generators require a dispatch strategy, which is a set of rules governing how the system charges the battery bank.

This software models a particular system configuration by performing an hourly time series simulation of its operation over one year and also steps through the year one hour at a time, calculating the available renewable power, comparing it to the electric load, and deciding what to do with surplus renewable power in times of excess, or how best to generate (or purchase from the grid) additional power in times of deficit. When it has completed one year's worth of calculations, HOMER determines whether the system satisfies the constraints imposed by the user on such quantities as the fraction of the total electrical demand served, the proportion of power generated by renewable sources, or the emissions of certain pollutants. HOMER also computes the quantities required to calculate the system's life-cycle cost, such as the annual fuel consumption, annual generator operating hours, expected battery life, or the quantity of power purchased annually from the grid.

The quantity uses to represent the life-cycle cost of the system is the total net present cost. This single value includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. The total net present cost includes the initial capital cost of the system components, the cost of any component replacements that occur within the project lifetime, the cost of maintenance and fuel, and the cost of purchasing power from the grid. Any revenue from the sale of power to the grid reduces the total NPC.

For many types of renewable energy systems, particularly those involving intermittent distributed energy sources, a one-hour time step is necessary to model the behavior of the system with acceptable accuracy. In this proposed hybrid system, it is not enough to know the monthly average (or even daily average) wind power output, since the timing and the variability of that power output are as important as its average quantity. To predict accurately the diesel fuel consumption, diesel operating hours, the flow of energy through the battery, and the amount of surplus electrical production, it is necessary to know how closely the wind power output correlates to the electric load, and whether the wind power tends to come in long gusts followed by long lulls, or tends to fluctuate more rapidly. HOMER's one-hour time step is sufficiently small to capture the most important statistical aspects of the load and the intermittent renewable resources, but not so small as to slow computation to the extent that optimization and sensitivity analysis become impractical.

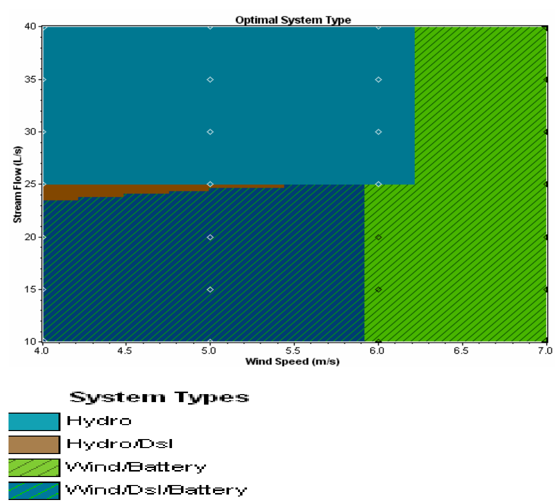

Fig2.portion of hourly simulation results for the proposed hybrid system.

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Figure 2 shows a portion of the hourly simulation results that when modeling a wind-hydro-diesel system connected to AC grid Wind Turbine; the proposed hybrid system 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.

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 calculate the air density ratio at the site elevation it is assumed 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.

4. OPTIMIZATION RESULTS

In the optimization process, the proposed system was simulated with many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, it was performed with multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. 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. 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. It models a particular system configuration by performing an hourly time series simulation of its operation over one year. it steps through the year one hour at a time, calculating the available renewable power, comparing it to the electric load, and deciding what to do with surplus renewable power in times of excess, or how best to generate (or purchase from the grid) additional power in times of deficit. When it has completed one year's worth of calculations, this model determines whether the system satisfies the constraints imposed by the user on such quantities as the fraction of the total electrical demand served, the proportion of power generated by renewable sources, or the emissions of certain pollutants. It also computes the quantities required to calculate the system's life-cycle cost, such as the annual fuel consumption, annual generator operating hours, expected battery life, or the quantity of power purchased annually from the grid.

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. The simulation process serves two purposes. First, it determines whether the system is feasible. And also considers the system to be feasible if it can adequately serve the electric and thermal loads and satisfy any other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. The life-cycle cost is a convenient metric for comparing the economics of various system configurations. Such comparisons are the basis of optimization process, described in the table1 below gives the overall optimized results of a proposed hybrid system in the Overall Optimization Results. The below mentioned table displays a list of the four system configurations that it found to be feasible. They are listed in order (from top to bottom) of most cost-effective to least cost-effective.

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Table1: Important overall optimization results for the proposed hybrid system

FL 100	Hydro (kW)	Dsl (kW)	L16P	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction
2		10	24	2	$ 70,840	4,193	$ 115,601	0.494	0.95
	16.6	10	16	10	$ 68,360	4,430	$ 115,652	0.495	0.86
		10	12	10	$ 17,520	9,235	$ 116,097	0.497	0.00
2		10	24	10	$ 78,040	3,573	$ 116,179	0.497	0.97
	16.6	10	4	8	$ 64,040	4,888	$ 116,223	0.497	0.86
		10	4	6	$ 12,240	9,748	$ 116,297	0.497	0.00
		10	8	10	$ 16,680	9,334	$ 116,323	0.498	0.00
	16.6	10	56	6	$ 73,160	4,046	$ 116,347	0.498	0.85
	16.6	10	24	10	$ 70,040	4,340	$ 116,365	0.498	0.86
	16.6	10	40	10	$ 73,400	4,052	$ 116,658	0.499	0.85
	16.6	10	12	10	$ 67,520	4,610	$ 116,733	0.499	0.86
	16.6	10	8	10	$ 66,680	4,700	$ 116,857	0.500	0.86
	16.6	10	56	8	$ 74,960	3,937	$ 116,990	0.500	0.85
2		10	16	6	$ 72,760	4,147	$ 117,033	0.501	0.96
	16.6	10	48	10	$ 75,080	3,934	$ 117,079	0.501	0.85
	16.6	10	32	10	$ 71,720	4,268	$ 117,276	0.502	0.85
	16.6	10	48	2	$ 67,880	4,645	$ 117,462	0.502	0.87
	16.6	10	56	4	$ 71,360	4,373	$ 118,043	0.505	0.86
	16.6	10	4	10	$ 65,840	4,906	$ 118,212	0.506	0.86
		10	4	8	$ 14,040	9,766	$ 118,286	0.506	0.00
2		10	32	2	$ 72,520	4,320	$ 118,638	0.507	0.95
2		10	8	4	$ 69,280	4,630	$ 118,709	0.508	0.95
	16.6	10	56	10	$ 76,760	3,954	$ 118,973	0.509	0.85
2		10	16	8	$ 74,560	4,265	$ 120,083	0.514	0.96
		10	4	10	$ 15,840	9,783	$ 120,275	0.514	0.00
	16.6	10	56	2	$ 69,560	4,772	$ 120,499	0.515	0.87
1	16.6	10	12	2	$ 89,320	3,179	$ 123,260	0.527	0.97
1	16.6	10	8	2	$ 88,480	3,264	$ 123,327	0.528	0.97
2		10	12	8	$ 73,720	4,650	$ 123,357	0.528	0.95
1	16.6	10	24	4	$ 93,640	2,799	$ 123,514	0.528	0.97
		10			$ 6,000	11,038	$ 123,832	0.530	0.00
2		10	4	6	$ 70,240	5,058	$ 124,229	0.531	0.94
1	16.6	10	16	4	$ 91,960	3,030	$ 124,304	0.532	0.97
1	16.6	10	16	2	$ 90,160	3,217	$ 124,502	0.533	0.97
2		10	48	2	$ 75,880	4,575	$ 124,713	0.533	0.95
2		10	8	10	$ 74,680	4,721	$ 125,076	0.535	0.95
2		10	12	10	$ 75,520	4,668	$ 125,346	0.536	0.95
1	16.6	10	32	4	$ 95,320	2,843	$ 125,668	0.538	0.98
2		10	4	8	$ 72,040	5,075	$ 126,218	0.540	0.94
1	16.6	10	12	4	$ 91,120	3,290	$ 126,243	0.540	0.97
1	16.6	10	32	6	$ 97,120	2,775	$ 126,747	0.542	0.98
1	16.6	10	24	6	$ 95,440	2,939	$ 126,809	0.542	0.98
1	16.6	10	4	2	$ 87,640	3,674	$ 126,860	0.543	0.96
1	16.6	10	24	2	$ 91,840	3,341	$ 127,501	0.545	0.97
2		10	56	2	$ 77,560	4,702	$ 127,751	0.546	0.95
2		10	4	10	$ 73,840	5,093	$ 128,207	0.548	0.94
1	16.6	10	40	4	$ 97,000	2,940	$ 128,382	0.549	0.98
1	16.6	10	8	4	$ 90,280	3,573	$ 128,417	0.549	0.96
1	16.6	10	16	6	$ 93,760	3,259	$ 128,549	0.550	0.97
1	16.6	10	40	6	$ 98,800	2,788	$ 128,565	0.550	0.98
1	16.6	10	32	8	$ 98,920	2,789	$ 128,688	0.550	0.98
1	16.6	10	24	8	$ 97,240	2,987	$ 129,127	0.552	0.98

The table2 below gives the categorized results of a proposed hybrid system. In the Categorized Optimization Results table, the result displays only the most cost effective configuration of each system design.

Table2: Categorized results of proposed hybrid DG system

FL 100	Hydro (kW)	Dsl (kW)	L16P	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction
1		10	32	4	$ 45,320	3,304	$ 80,595	0.345	0.92
		10	12	2	$ 10,320	8,383	$ 99,811	0.427	0.00
	16.6	10	12	2	$ 60,320	4,263	$ 105,822	0.453	0.87
1		10			$ 35,000	7,227	$ 112,143	0.480	0.82
	16.6	10			$ 56,000	5,389	$ 113,528	0.486	0.84
1	16.6	10	12	2	$ 89,320	3,179	$ 123,260	0.527	0.97
		10			$ 6,000	11,038	$ 123,832	0.530	0.00
1	16.6	10			$ 85,000	4,496	$ 132,990	0.569	0.95

In the Optimization results using the proposed wind – Hydro-diesel with grid results gives us economic details about each system configuration has been displayed in which the highlighted row indicates that the proposed hybrid DG system gives less operating cost of $3179 per year with 97% of utilization of renewable sources.

From the simulation of the proposed hybrid system using HOMER the fig 3 gives the average wind speed versus the time for an year is shown below.fig 4 shows the impact of wind speed of the proposed hybrid system versus the ac power .fig 5and fig6 shows frequency variation in % versus change in wind speed over 1 hour and 24 hour respectively. Similarly the Fig7shows power output (KW) versus wind speed (m/s) of a sample wind plant is also presented.

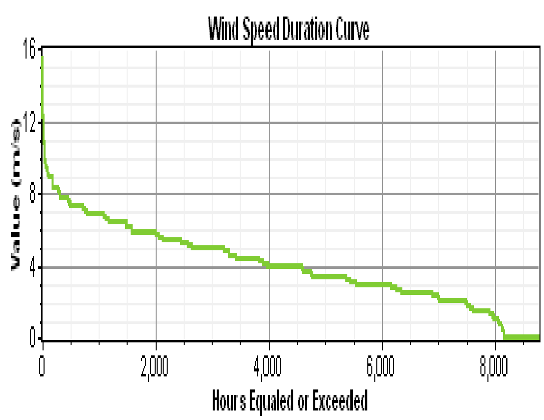

Fig 3. Average wind speed versus time for an year

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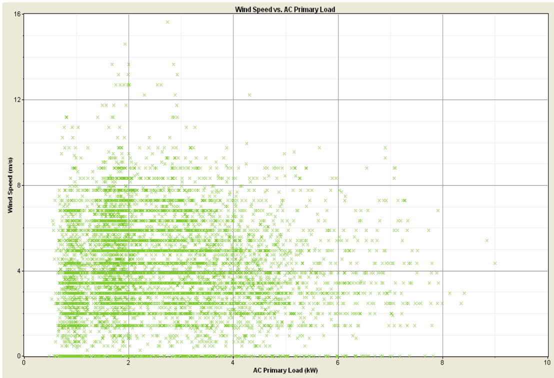

Fig 4.Wind speed versus ac load

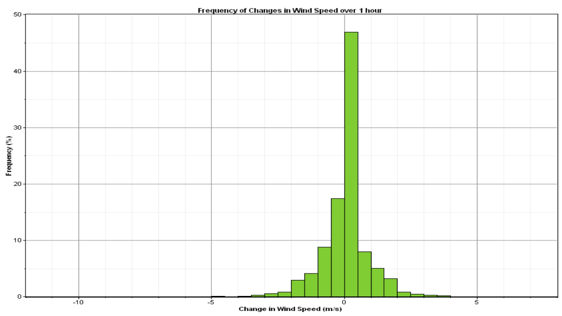

Fig 5. Frequency variation in % versus change in wind speed over 1 hour

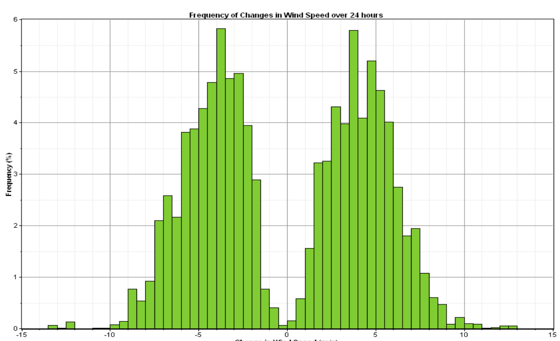

Fig 6. Frequency variation in % versus change in wind speed over 24 hour

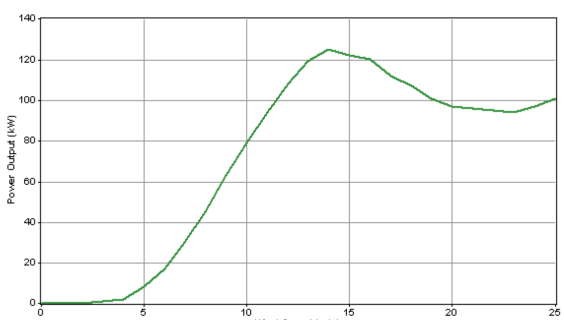

Fig7. Power output (KW) versus wind speed (m/s) of a sample wind plant.

5. CONCLUSIONS AND RECOMMENDATIONS

The simulation and optimized results presented in this paper suggest the role of the hybridDG generation system is a reliable power source and the suitability of developed model for energy management studies of hybrid distributed generation systems with electrical distribution systems. In particular the ability of the Wind energy conversion system in picking up the load whenever wind is available, and the ability of the Micro power system (working as a backup generator) in meeting the load demand whenever there is not sufficient wind, are demonstrated. Also, simulations results shows that the economic advantages of the studied combination of hybrid power systems gives less operating cost of $3179 per year with 97% of utilization of renewable sources. For economical reasons the technical challenges of interconnecting the distributed generation units with the distribution lines are ignored and the results are analysed based on cost factors.

6. ACKNOWLEDGEMENTS

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APPENDIX

The machine and controller parameters that have been used in this paper during the simulations are given below.

1. Battery

Description: Trojan L16P

Nominal Capacity: 360 Ah

Nominal Voltage: 6 V

Round trip efficiency: 85 %

Min. State of Charge: 30%

2.Wind Data

Description; Fuhrlander 100 (FL)

Rated Power: 100kW AC

S. No.	Wind Speed (m/s)	Power Output (kW)
1	0.00	0.000
2	1.00	0.000
3	2.00	0.000
4	3.00	1.000
5	4.00	2.000
6	5.00	8.000
7	6.00	17.000
8	7.00	30.000
9	8.00	45.000
10	9.00	63.000
11	10.00	79.000
12	11.00	94.000
13	12.00	108.000
14	13.00	119.000
15	14.00	125.000
16	15.00	122.000
17	16.00	120.000
18	17.00	112.000
19	18.00	107.000
20	19.00	101.000
21	20.00	97.000
22	21.00	96.000
23	22.00	95.000
24	23.00	94.000
25	24.00	97.000
26	25.00	101.000

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3. Hydro Turbine

Nominal Power: 16.6kW

Generated Type: AC

Available Head (m): 90

Design flow rate (L/s): 25

Minimum flow ratio (%): 75

Maximum flow ratio (%): 150

Pipe Head Loss: 10.49

Efficiency (%): 75

4. Primary Load

Hour	Load (kW)
00:00 - 01:00	10.000
01:00 - 02:00	6.000
02:00 - 03:00	6.000
03:00 - 04:00	6.000
04:00 - 05:00	6.000
05:00 - 06:00	12.500
06:00 - 07:00	20.000
07:00 - 08:00	22.500
08:00 - 09:00	18.750
09:00 - 10:00	12.000
10:00 - 11:00	12.000
11:00 - 12:00	17.500
12:00 - 13:00	17.500
13:00 - 14:00	11.000
14:00 - 15:00	11.000
15:00 - 16:00	11.000
16:00 - 17:00	11.000
17:00 - 18:00	17.500
18:00 - 19:00	27.000
19:00 - 20:00	29.000
20:00 - 21:00	40.000
21:00 - 22:00	29.750
22:00 - 23:00	22.750
23:00 - 00:00	12.750

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