A Solar-Wind-Tide Scheme for Renewable Electricity production in Nigeria

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Abstract

In many countries of the world, the problem of large-scale utilization of renewable energy resources for electricity production is mainly due to lack of appreciable energy potentials for optimum production of electrical power using available technologies. In Nigeria, available data show that solar, wind and tidal potentials are high but with peaks at different times of the year. There are therefore severe limitations in using each separately for electricity production, owing to characteristic fluctuations. In this paper, we have shown that an integrated renewable energy electricity scheme utilizing inputs from solar, wind and tidal power can be developed in Nigeria. This will be an effective means of producing electrical power that is capable of running with high efficiency throughout the year. This will contribute substantially to the federal government programmes to generate more electrical power for the coming decades.

Keywords: Renewable Energy, Power Supply, Electricity Production, and Nigeria

1.0 Introduction

Fuel-based power sources like coal, natural gas and nuclear generally have very high capacity factors, between 70-95 per cent, so long as fuel supply is secure. Renewable energy technologies like wind and solar photovoltaic (PV) typically have capacity factors between 20-35 per cent, sometimes as high as 40, depending on the resource quality (Davis, 1980). Ocean energy facilities using first-generation Davis Hydro Turbine technology will generally have capacity factors between 40-60 per cent, the variance being due to site differences and predictable fluctuations in tidal flows. Although ocean energy is intermittent by nature, following the sinewave-like ebb and flow of the tides, these cycles are well established and occur with great consistency.

Power production from ocean energy facilities can be accurately predicted far in advance, permitting the convenient integration with energy grids. Power exchanges can count on schedules deliveries, giving ocean energy a higher value per megawatt (MW) of capacity. As tidal flows vary by region, different sites will have varying periods of peak power production (Davis, 1980). When the output from several ocean energy facilities is combined, the electricity levels complement one another, resulting in more consistent delivery while maintaining the already-high level of reliability. This makes integration with energy grids even easier, a definite advantage in countries with still-regulated energy markets and centralised power plants (Davis and Swan, 1981). Energy is one of the major determinants of economic development as the quantity of energy consumed by a society has been greatly linked with the level of industrialization and economic activity going on in the society. The United States, Canada, Japan, Switzerland, and European Economic Community countries, although with only about 24% of the world population use about 70% of the total energy consumed in the world (Bondi, 1979). The growth in World energy consumption is known to have increased exponentially from the 1940s. In Nigeria, exponential growth has been observed from 1975 and at such rates of demand, the present generating capacity cannot keep pace with development (Mgbenu *et al.*, 1995).

Nigeria with a present population estimated at about 130 million generated only about 1500 MW of electricity in 1999. The Federal Government of Nigeria is planning to increase this to about 10000 MW by the year 2005 (Obasanjo, 2002) which will help to drive an industrialized economy in addition to linking a good number of the rural communities to the national grid. We know that as of the year 2007, this is yet to be achieved by the government in spite of the huge investment by the federal government in the power sector. At present electricity production is accomplished through the hydro-electric power plants and thermal/gas power stations, which seek to utilize the abundant gas reserves in the country (Akujor *et al.*, 2007). There are however major limitations in the continued use of these traditional sources. First, hydro-electricity is widely exploited in the country at the moment but rather relies on outdated facilities and inconsistent water levels, while gas although with large potentials for future development is inherently finite with tremendous output of thermal and gaseous pollutants. Given these inherent disadvantages in hydro and thermal power production, a more sustainable approach must be adopted for power production in the coming decades and this certainly calls for a shift from tradition.

Renewable energy resources such as solar, wind and tides should as matter of policy be developed for the future to complement these traditional sources. Solar, wind and tidal energy have potentials as environmentally friendly and infinitely producing resources. These resources are abundant in Nigeria and are becoming increasingly exploited in other parts of the world either separately for small-scale electricity production or for integration into existing grids. A method for power generation combining a solar concentration system with pneumatic power tube system in a large open pit was studied by Di Bella and Gwiazda (2005). Their system effectively uses previously developed high temperature, solar energy technologies and improves solar rankine cycle efficiency which is helped by the integrated wind power. The primary motivation for the development of renewable energy schemes both for electricity production and other uses is usually based on environmental considerations as well as the economy of exploitation (Nwofor and Ezike, 2002). The environmental considerations for electricity production based on renewable energy systems have been well highlighted (Mgbenu et al., 1995; Chineke, 2002). The economy of exploitation is dependent on the balance between investment for technology and the energy output, and this is very much dependent on the local availability of the particular resource. The aim of this work is to show that an integrated renewable energy electricity scheme utilizing inputs from solar, wind and tidal power can be developed in Nigeria. This will serve as an effective means of producing electrical power that is capable of high efficiency throughout the year.

2.0 Utilization of Solar, Wind and Tide Resources in Electricity Production

2.1 Solar

The world can be divided into about 5 major solar performance regions based on the yearly average of daily hours of sunshine and denoted by the numbers; 2, 3, 4, 5, and 6, called “area factors” according to Srinivas (2002). Nigeria with a yearly average of about 6.26 sunshine hours (Figure 1) can be said to belong to the area of maximum solar energy utilization. Photovoltaic systems are used to convert sunlight to electricity. The techniques of photovoltaic conversion have been described by Mgbenu *et al.* (1995). Both small and large photovoltaic systems are being used in different parts of the world and especially in Nigeria to provide electricity but mostly on a small scale (Chineke, 2002). The limitations of large scale utilization in most parts of the world is due to the low economy of delivery using available technologies, compared to that for traditional resources, arising from low solar energy potentials. There is also a problem of intermittence in solar radiation in a locality implying large fluctuations in solar power for instance in the night and rainy periods.

Table 1: Wind potentials and corresponding wind velocities in United States of America

W/m^2	200	300	400	500	600	800
m/s	5.6	6.4	7.0	7.5	8.0	8.8

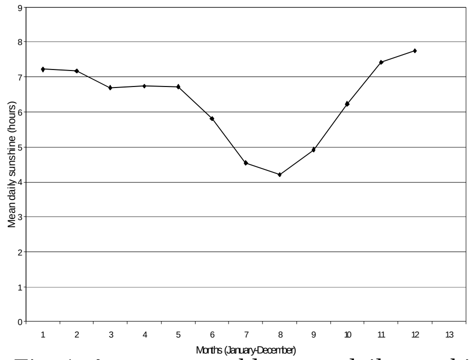

Fig. 1: Average monthly mean daily sunshine hours (1951-1986) for 34 cities in Nigeria

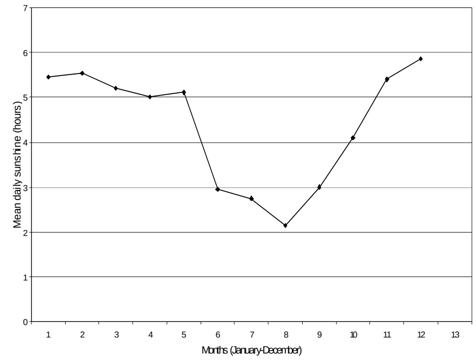

Fig. 2: Monthly mean daily sunshine hours for Owerri between 1951-1986.

2.2 Wind

Wind energy is not new and has been used thousands of years ago to power the first industries. In Denmark, a system of 88 windmills had supplied about 0.5 MW of electricity in 1944. Presently, wind accounts for about 80% of the total electric power in the country. In the United Kingdom, 74 projects utilizing 950 turbines supply 499.29 MW to the electricity grid (http://www.bwea.com). There are also projects in Germany, Spain, United States and other countries. It is estimated that by the year 2007 wind generated electricity shall account for between 4-8% of the total energy in Europe. In Asia, India has installed capacity to generate over 900 MW from wind while China was generating 24 MW by 1998. Wind power can actually be developed in most places since there is enough overland wind occurring globally (Srinivas, 2002). The theoretical power (P_{wt}) that is available in a wind mill is

$$P_{wt} = \frac{\pi}{8} PD^2V^3 \qquad ...(1)$$

Usually a constant Kr which is associated with wind dynamics and the efficiency of the rotor can be introduced (Elliot and Shwartz, 1993) so that equation (1) becomes

$$P_{wt} = KrD^2V^3 \qquad ...(2)$$

The energy produced per annum (in KWh) by the wind mill is

$$Ew = KrD^2V^3K_s h \qquad ...(3)$$

Wind electricity production is constrained by the available turbine efficiencies. For advanced turbines, efficiency is projected to be between 30–35% (Elliot and Shwartz, 1993). Several factors determine the feasibility of a wind electricity project. These include the availability of reasonable wind energy potentials on the ground, the percentage of land exposed; which must be reasonable and the topography which should be relatively flat (Chineke, 1993). Just like in the case of solar energy, the intermittence of wind supplies is well established (Mgbenu *et al.*, 1995). They are generally low at night and higher during the day, with erratic and almost unpredictable seasonal variations that tend to peak in Nigeria during the harmattan weather in January.

2.3 Tide

Harnessing electricity from the ocean although recognized as a possibility more than forty years ago had been greatly hampered by the perceived low economic feasibility of its exploitation. In Europe several technologies for the harnessing of tidal energy have been developed since the 1990s and now have advanced to the point where reliable and cheap electricity from the ocean is becoming a possibility. Devices that can harness tidal energy are of two types; sea based and shore based. Sea based systems transform the impact of the wave to electrical power. A device such as the “ Salter duck “ which bobs up and down with the water wave causes a turbine to rotate and produce electricity. In the United Kingdom, Salter ducks which can produce electricity at the cost of under $ 0.10 per KW adjudged to be the point at which electricity production becomes economically viable have been developed (Osborne, 1998). Sea based systems are prone to the destructive possibilities of turbulent sea waves. Shore based systems include the Oscillating Water Column (OWC), which works when water is enclosed in a basin in an incoming tide and causes air to be sucked into a chamber connected to a turbine as it recedes. The energy can be doubled in a two way process in which the turbine is turned both by the incoming and receding tides. Such an arrangement is being used to produce electricity in Canada, Russia and France. In France, about 320 MW of electricity is generated in the Rance River http://www.waterpower.hypermart.net/tidal.html. Although a high tidal range enhances the output of power from tidal schemes, lower ranges can be properly managed to produce optimally through the employment of more turbines just like in the case of wind**.** Unlike solar and wind potentials, tidal potentials are predictable using the harmonic method with only slight variabilities due to meteorological effects (Pugh, 1987).

There are usually, two high tides and two low tides each day. Each type is separated by 12 hours 25 minutes from the previous one, hence each high and low tide occurs twice every day. These are called semidiurnal tides. In some parts of the world, there is only one high tide each day. This is the diurnal tide. A semidiurnal tidal regime harbors twice as much power as a diurnal regime. It records its highest peak twice in a month (spring tides). The difference in amplitudes between a high tide and a low tide in a semidiurnal regime or between two high tides in a diurnal regime gives the tidal range. Areas with very high tidal ranges are the most suitable for electricity production. The potential energy (E_{tide}) contained in a basin of area A, filled at high tide, and discharging into the open sea at low tide is given by (Pugh, 1987)

$$E_{tide} = 2A\rho gH^2 \qquad ...(4)$$

For a two way system the total theoretical energy available is

$$E_{tide} = 4A\rho gH^2 \qquad ...(5)$$

The mean rate of power production, P_{tt} is therefore

$$P_{tt} = {4A\rho gH^2}\big/{T} \qquad ...(6)$$

In addition to the OWC, power can also be generated from tidally generated coastal currents, where underwater turbines are constructed to intercept water currents along estuaries and narrow channels. Although the technology is still elementary, it has been shown that the method will be economically feasible at locations where currents are between 2-2.5m/s. At such a place a 15m diameter turbine will generate as much energy as a 60m diameter windmill (Elliot and Shwartz, 1993).

3.0 Realizable Power from Solar, Wind, and Tide Electricity Schemes in Nigeria

With the infinite supply and environmental friendliness of solar, wind and tidal (SWT) schemes established, the major determinant for government investment for large-scale applications in electricity production will be that of resource availability to enhance production outputs. If the estimates of the realizable power from decentralized SWT schemes are appreciable then the projects will be worth embracing. Such estimates will however depend on available data of resources at specific points where generating modules or turbines are to be located, and also on the efficiencies of the adopted harnessing technologies. At present such data are only marginal and sparse. We can however establish using available information some lower limit preliminary feasibilities.

3.1 Solar

A 55W photovoltaic module with typical dimensions, 1293mm by 239mm (Siemens, 1998) will have an available power output in Nigeria of 55 x 6 = 330W in a day (6 being the yearly average sunshine hours per day obtained using Figure1). Solar modules covering an area equivalent to 800 football fields scattered in the country would supply a total of about 5000 MW of electric power to the SWT grid. This is 50% of the total projected capacity to be generated by the federal government from all sources by the year 2007. The low population densities in the northern part of the country are a major advantage for the solar project. A typical football pitch according to Federation Internationale de Football Association (FIFA) should measure 90-120 meters long by 45-90 meters width (FIFA, 2006). If we take the dimension of the minimal FIFA-standard football field which should be 4050 m^2 and divide by the dimension of a 55-Watt solar panel which is 0.3 m^2, it implies that we can set up to 700 of such 55-Watt solar panels in a football field and obtain up to 0.5 MW. With such a setup in each of the about 800 local government and development areas in the country, we can generate up to 500 MW from solar photovoltaic alone and integrate into the wind and tide scheme.

3.2 Wind

Areas suitable for wind energy development are found in Nigeria particularly in the North where there are large arable lands with low population densities and also in the coastal areas. In order to generate large capacities, an area can be mapped out and designated as a “wind farm” and several mills erected. Values of wind potentials corresponding to measured wind velocities in the United States (Table 1) were obtained by Elliot and Shwartz (1993). At 30% turbine efficiencies and in the lowest (5.6 m/s) wind regime, 100 football fields in each of the 6 geopolitical zones of the Nigeria will produce a total of about 45 MW of electricity assuming only 10% of the wind farm is occupied by wind mills. This is comparable to the output of most gas turbines in Nigeria. Wind turbine is more cost effective than the gas turbine considering the fact that the resource is infinite, clean and with low maintenance cost.

3.3 Tides

With over 1000km of shoreline, Nigeria stands at an advantage to utilize the tidal resources of the ocean. Predictions of the tides along the Nigerian coast (Flater, 1997) show a semidiurnal regime, which enhances the generating potentials of the tides. It is difficult to estimate the possible capacities that can be generated from tides in Nigeria because of inadequate data, the nature and size of basins, and the possible tidal ranges. However the marginal marine basins in the Niger delta areas of Nigeria can present good sites for tidal power production when properly dredged, and enclosed with dams to create differences in the water levels between the ocean and the basins. The oscillatory flow of the water filling and emptying the basins can drive installed turbines. Tidal predictions of some ports in Nigeria such as Bonny, Akasso, Calabar and Lagos, have given ranges up to 3 meters in the major tide (Flater, 1997). If such a range were to be transmitted through a basin, of area 6m^2 about 50 MW of electricity would be generated using equation (5). Although tidal power stations are quite expensive to build, the long term cost effectiveness highlighted for other renewable energy systems is also applicable.

4.0 Integrating the Solar, Wind and Tide Schemes

The variability of solar, wind and tidal potentials in a locality as we have considered earlier implies pronounced intermittence in power production from these resources when used separately. This can be a major handicap for large-scale power production. If however the installed power of solar modules, wind turbines and tides are fed into the public electricity grid, the power outputs of the various sources are summed together. That done, pronounced power variation inherent in a decentralized scheme is avoided in addition to increasing the capacity. For instance solar power fed directly to the grid does not yield outputs in the night. But the wind and tide schemes deliver power to the grid. In the day all the three schemes deliver power to the grid.

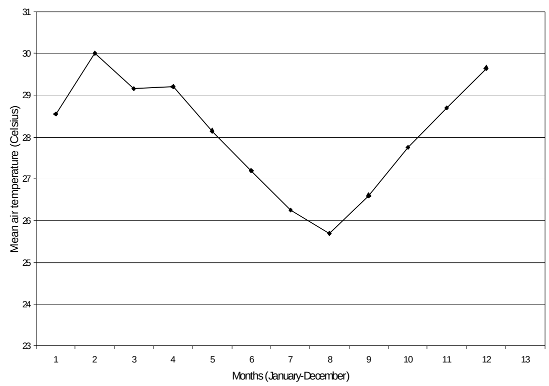

Fig. 3: Monthly average temperatures for Owerri in 2001

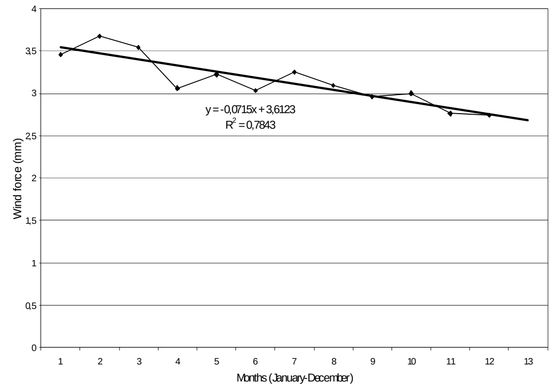

Fig. 4: Monthly average of maximum wind force in Owerri for 2001

Since night- time electricity demand is lower than that in the day, an integrated solar-wind-tide (SWT) scheme is advantageous.

The strengths of the SWT scheme for reducing power fluctuations in Nigeria can better be appreciated when we consider data on sunshine hours, temperature, wind force and rainfall in Owerri (Latitude 05^o 29^{l}N; Longitude 07^o 02^{l}E), a site in the south east of Nigeria. The data used for plotting Figures 2-5 was obtained from the Federal Meteorological Department in Owerri, Other parts of the country are known to show similar trends (Chineke, 1993). Monthly average of daily sunshine hours between the years 1951-1986 for Owerri are shown in figure 2. The peak sunshine occurs during the months of December, January, and February that is the peak of the dry season. The lowest values, on the other hand, occur during the months of June, July, August and September; the rainy season. Expectedly this correlates well with the average monthly temperatures across the year shown in figure 3 for 2001 except for January where the observed low values can be attributed to the reduced intensity of the sun due to the effect of the harmattan weather (Utah and Ngadda, 1994).

Monthly averages of wind force measured with the aid of a wind vane placed 10.15 m above the ground is shown in figure 4. The wind force decreases linearly (R^2=0.78) across the year at the rate of 0.07mm/ month. The expected yearly power output from solar will be proportional to the available sunshine, and the output of a tidal scheme will most certainly be enhanced in the rainy season when like hydroelectricity, the pools or basins will overflow to increase the speed of the turbines. Hence in a yearly cycle, the expected maximum of tidal power will correspond with the minimum for solar power with wind likely to offer only slight modulations on the SWT scheme. This strong complimentarity offers peculiar advantages in reducing yearly fluctuations. A schematic of an SWT electricity scheme, which utilizes inputs from solar, wind, and tides, fed to a common grid is shown in figure 6. The solar component from photovoltaic modules is first passed through a regulator; a charge-discharge controller, to facilitate storage in solar batteries if need be, and then through an inverter to convert the voltage from DC to AC. Together with the wind and tide components passed through dynamos separately, the output is fed to a power station where the necessary stepping up is accomplished by means of transformers. The output is now moved to power lines from where it is conveyed to homes and offices after the necessary stepping down.

Electric utility distribution system impacts are associated with the integration of renewable energy sources such as solar PV and wind turbines (Zaininger et al., 1994). The impacts are expected to vary from site to site according to the local solar insolation and/or wind characteristics, renewable energy source penetration level, whether battery or other energy storage systems are applied, and local utility distribution design standards and planning practices. Small, distributed renewable energy sources are connected to the utility distribution system like other, similar kW- and MW-scale equipment and loads. Residential applications are expected to be connected to single-phase 120/240-V secondaries. Larger kW-scale applications may be connected to three-phase secondaries, and larger hundred-kW and MW-scale applications, such as MW-scale windfarms or PV plants, may be connected to electric utility primary systems via customer-owned primary and secondary collection systems. In any case, the installation of small, distributed renewable energy sources is expected to have a significant impact on local utility distribution primary and secondary system economics. Small, distributed renewable energy sources installed on utility distribution systems will also produce non-site-specific utility generation system benefits such as energy and capacity displacement benefits, in addition to the local site-specific distribution system benefits. Although generation system benefits are not site-specific, they are utility-specific, and they vary significantly among "utilities" in different regions. In addition, transmission system benefits, environmental benefits and other benefits may apply which is expected to vary significantly among utilities and regions (Pimental et al., 1994; Zaininger et al., 1994; Pimental et al., 2002).

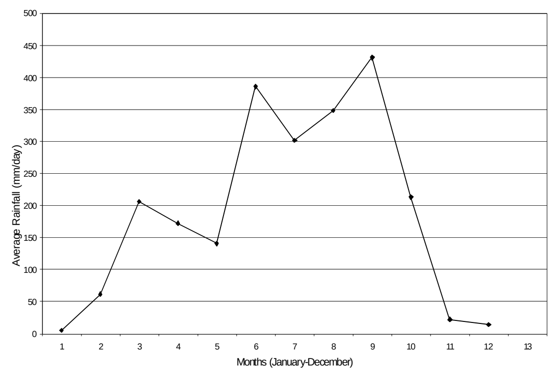

Fig. 5: Monthly average rainfall for Owerri in 2001

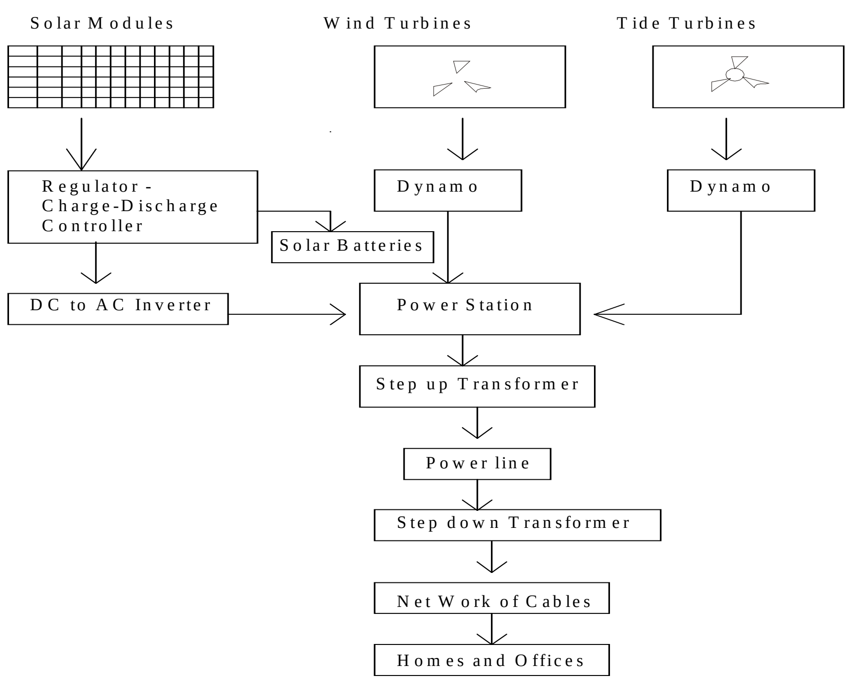

Fig. 6: Schematic of the SWT scheme

5.0 Conclusion

The problem of providing electricity in Nigeria, enough to keep pace with the projected explosion in the population in the coming decades and to drive an industrialized economy requires that more radical approach be adopted towards the issue of electricity production. Nigeria enjoys a peculiar advantage by geographical location, experiencing considerable potentials of the renewable energy resources; solar, wind, and tides. These resources are known to be infinite in supply. The technologies of their exploitation are available and cheap at least in the long run and the environmental effects minimal. When these are developed and incorporated into the national grid, the total generated capacity of the Power Holdings Company of Nigeria (PHCN) will increase by enormous percentage. A major advantage of integrating solar, wind and tidal energy schemes into the grid are that the expected fluctuations of decentralized schemes, as one experiences with Kainji in the dry season will be minimized. To realize the SWT scheme, initial technical difficulties are envisaged but these would be overcome with time. The realization of the full project should be on a long-term basis. This has to start with feasibility studies on the availability and predictability of solar, wind and tidal potentials across the country and the selection of suitable sites for the schemes. Such studies will also include the cost benefit analyses both in the short and long runs (Chineke, 1993; Utah and Ngadda, 1994). With such projects in place now the future of Nigeria's economic development can at least be said to be enhanced. Although most of the results of the work are for a single site, Owerri, research using relevant data from other parts of the country is ongoing at the Atmospheric Physics Group of Imo State University, Owerri where the mandate includes evolving and strengthening schemes aimed at harnessing electricity from alternative sources. Our focus is to contribute in the government's present efforts at improving the electricity supply scenario which will kick-start the nation's development, generate employment thereby alleviating poverty.

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Appendix A

Nomenclature

P= pressure
D = diameter of the rotor blades
V = wind velocity
h = number of hours in a year
K_s is a factor associated with the statistical nature of wind recovered
H = tidal amplitude
ρ = water density
g = gravitational acceleration
T = tidal period (12.417 hours)