Harnessing wave energy for sustainable and resilient power generation in Sri Lanka: A feasibility study

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Abstract— *Sri Lanka experiences an annual electricity demand growth of 5-6%, necessitating the introduction of new power plants. With most rivers already used for hydroelectric power, the country has turned to thermal and diesel power plants, despite their significant environmental impacts. Sri Lanka has maximized conventional renewable energy sources and introduced non-conventional ones, but wave energy remains largely untapped. The paper explores current wave energy harnessing technologies, criteria for selecting suitable locations and devices, environmental impacts, and proposes a new design and mathematical model considering technical, environmental, social, and economic factors specific to Sri Lanka. This study aims to contribute to the development of sustainable and resilient power generation systems, aligning with the advancements in modern technology and the growing demand for clean energy.*

Keywords— **Renewable Energy, Mathematical model, Wave Energy, Sri Lanka**

I. INTRODUCTION

Renewable energy sources are crucial due to their environmental benefits and the depletion of fossil fuels. Ocean energy, with its vast potential, is a key focus as oceans cover 71% of Earth's surface and contain 97% of its water. While hydroelectric power has been a major renewable energy source, future growth is shifting towards ocean-based solutions. Ocean waves, driven by wind, represent a promising renewable resource, with research suggesting that annual energy from ocean waves could be 100 times greater than global hydroelectric capacity. Sri Lanka faces an energy crisis, with a growing gap between supply and demand, compounded by concerns over traditional energy sources like hydro, coal, and gas. Smaller renewable plants like wind and solar are used but are limited by climate and seasonal changes. Ocean energy offers a consistent year-round source, making it viable for Sri Lanka's energy needs. This feasibility study aims to assess the potential for wave energy in Sri Lanka, identify optimal plant locations, and evaluate cost-effective generation methods, emphasizing the importance of expanding the nation's sustainable energy options.

II. LITERATURE REVIEW

A. History of Sea Wave Energy

In 1974, Stephen Salter's paper in "Nature" highlighted wave energy, prompting a British government research program in 1975, followed by Norway. The first wave energy conference was held in Canterbury in 1976, with subsequent conferences in Heathrow (1978), Edinburgh, and Gothenburg (both in 1978).

The second symposium on wave energy utilization took place in Trondheim, Norway, in 1982. By 1980, over a thousand patents were registered for wave energy conversion, with the first patent granted in 1799 to the Girard family in France. Yosio Masuda, the father of modern wave energy technology, designed a wave-powered navigation buoy with an air turbine, later known as the Oscillating Water Column (OWC), which was commercialized in Japan from 1965 and later in the USA.

The 1973 oil crisis spurred interest in renewable energy, leading Norway to build two Shoreline prototypes near Bergen despite the British program being defunded. Wave energy in Europe remained largely academic until the European Commission included it in their R&D program in 1991, funding about thirty projects and several conferences from 1993 to 2009. Notable prototypes included a 75 kW OWC in Scotland, a 60 kW converter in Japan, and a 125 kW plant in India. Ocean energy sessions have since become more frequent at major engineering and renewable energy conferences.

B. Methodologies of Harnessing Sea Wave Power

Sea wave energy technologies are highly diverse due to the various types of sea energy and the different methods for harnessing them. Wave energy systems are classified by location, operational principles, and scale. A review by B. Drew, A.R. Plummer, and M.N. Sahinkaya notes over 1,000 patented wave energy conversion techniques across Japan, North America, and Europe, each differing significantly based on these classifications. These include offshore systems that harness swell energy, nearshore systems that capture maximum wave amplitude, and embedded devices built into shorelines to receive breaking waves, despite some energy loss during wave breaking.

C. Physical Concept

Waves are created by wind transferring energy to the sea, influenced by air pressure differences, wind speed, duration, fetch, and underwater topography. Larger waves have more power, which depends on wave speed, wavelength, and water density. Oscillatory motion is strongest at the surface and decreases with depth, while wave energy moves horizontally as energy flow.

D. Theoretical Concept

1) Wave Energy: The sea's waves move in different directions and have various frequencies, making power measurement complex. To measure wave power (P) transported per meter of wave width, a special equation is used, quantifying the mechanical energy available in the waves. This estimation can be done using equation (01).

Total stored energy per unit area of the sea surface.

$$E = E_P + E_K \quad (01)$$

Where,

E_p -Potential energy per unit area

E_k - Kinetic energy per unit area

$$E_P = E_K = {}^{1}/_{4}\,\rho A^2 g \quad (02)$$

Then, The total Energy from equation (01),

$$E = {}^{1}/_{2}\,\rho A^2 g \quad (03)$$

Power associated with the wave per unit width of the wave front,

$$P = C_g E \quad (04)$$

C_g is the group velocity,

$C_g = \frac{g}{2\omega}$, $\omega = 2\pi f$, $f = \frac{1}{T}$, $A = \frac{H}{2}$, $C_g = \frac{gT}{4\pi}$

$$P = \frac{\rho g^2}{32\pi} T H^2 \quad (05)$$

Where,

ρ- Density (kg/m^3)

g- Gravitational acceleration (ms^{-2})

H- Significant wave height (m)

T- Wave period (sec)

However, in order to have a clear idea about the energy concentration in a particular spot of the sea, wave measurements conducted for a long period is required. By analysing these values using furrier series, wave spectrum can be obtained.

E. Conversion Technologies

Several techniques harness sea wave power, including Oscillating Water Column (OWC), overtopping devices, and wave profiler devices. OWC devices are typically placed on shorelines and convert wave energy into air pressure. Overtopping devices capture wave movements to lift ocean water to a reservoir, converting it into potential energy. Wave profiler devices include point absorbers and linear absorbers, which absorb wave energy through various motions such as heave, surge, pitch, and yaw. For effective wave power usage, the float's wave force must react against a rigid or semi-rigid body like ballast plates or sea-floor anchors.

F. Wave Climate in Sri Lanka

Wave power is proportional to the square of wave height, making strong waves crucial for energy plants. Long-term wave measurements are ideal but challenging to obtain, so wind data is often used to predict wave energy. In Sri Lanka, the southern coast is most suitable for wave energy due to its exposure to high-energy waves from the Antarctic and the influence of both monsoons. The south, southeast, and southwest regions offer the best conditions, with an average wave power availability of 14-15 kW/m. The swell wave period ranges from 8 to 17 seconds.

G. Location Identification

Most sea wave power plants are located offshore due to the need for strong waves, but several factors must be considered in site selection:

1) Technical Constraints:

In evaluating wave energy potential, several factors must be considered to determine site suitability and project viability. Average wave power per meter of crest (kW/m) helps assess site suitability, while the maximum significant wave height indicates system survivability and risk of damage during storms. Water depth is crucial, with floating devices offering broader installation ranges. Distance to shore impacts the cost of underwater cables, and proximity to operation and maintenance bases affects deployment and maintenance expenses. Seabed geology also plays a role, as hard seabeds increase cable laying costs. In Sri Lanka, no wave power projects have been successfully implemented, and research is limited, relying on data from 1996.

III. DATA COLLECTION, ANALYSIS AND LOCATION IDENTIFICATION

A. Use of available sea wave data collection

According to a 1998 report by Dr. T.K.D. Tennakoon from the National Aquatic Resources Agency, key parameters such as wave height, wave period, beach profile, wind speed, and meteorological data were measured in 1996 at Palatupana, Bundala, Godawaya, and Unawatuna. Nearshore wave characteristics were observed at an 8-meter depth, revealing that water oscillation was notably higher at Unawatuna. Wave heights were recorded at 15-minute intervals during the SW monsoon and every 15 minutes to two hours during the NE monsoon.

B. Power at four locations; Palatupana, Bundala, Unawatuna, Godawaya

Palatupana is about 30 km from the Tissamaharamaya junction on the Colombo-Kataragama road. Bundala is located 5 km beyond the Udamalala junction on the same road. Unawatuna is near the well-known Unawatuna Beach in the Rumassala range. Godawaya is a small fishing village near Ambalantota, accessible from the Hambantota road. Annual average power potentials of each location are given in Table 1.

Table 1. Annual power potential

Location	Annual Average power potential (kW/m)
Palatupana	40.49
Bundala	37.81

Unawatuna	39.93
Godawaya	28.42

IV. PLANT DESIGN

A.Working principle

Various power take-off systems, including hydraulic ones, convert wave energy into electricity. The described design uses a buoy and a double-acting cylinder to move water, which is then stored in a tank. To ensure efficient turbine operation, the inflow and outflow rates to the storage tank must be balanced. Excess water overflows if inflow exceeds the required rate. The system utilizes three buoys and cylinders to manage water pumping.

B.Power Calculations

The system's buoy is designed to move vertically (up and down) in response to wave forces and is considered rigid with one degree of freedom. Fluid load calculations assume that the fluid is incompressible and inviscid.

1). Buoy moves down: The buoy's mass is calculated based on gravitational force and fluid pressure, with hinge friction ignored. The buoy moves vertically, and its relationship with piston force (F_1) is determined by analyzing moments around the hinge. Key parameters include buoy mass, bar length, bar mass, distance from hinge to piston rod, and applied force. Details of moving down system is given in Figure 1.

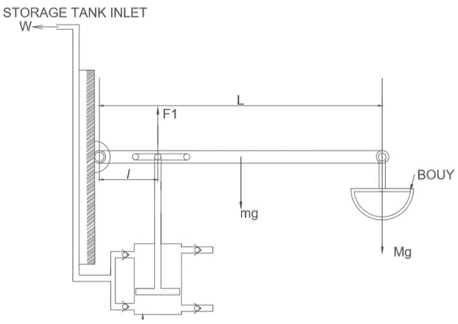

Figure 1. Details of moving down system

Considering the moment around hinged point to the wall,

$$Mg.L + mg.\frac{L}{2} - F_1.l = 0 \quad (06)$$

Thus,

$$F_1 = \frac{L.g}{l}\left[\ M + \frac{m}{2}\ \right] \quad (07)$$

Work done by the cylinder actuator

Assume the fluid is incompressible, meaning the mass density of a co-moving volume element remains unchanged with varying pressure. Frictional force on the cylinder surface is negligible compared to pressure forces, and boiler feed water is used to reduce friction losses inside the cylinder, with CaCO3 and MgCO3 removed. The relevant parameters include cylinder height (h), cylinder radius (R), pumping height (H_1), storage tank input velocity (W), and the force acting on the cylinder rod (F_1). The system can be modeled accordingly, as detailed in Figure 2.

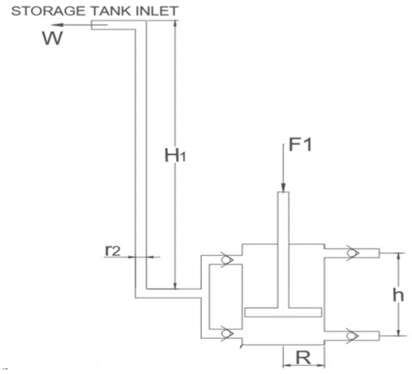

Figure 2. Details of work done by the cylinder

Then the force F_1 also can be expressed including the cylinder volume $\pi R^2 h$, the pipe flow rate, pumping height H_1, storage tank input velocity W, by equating the work done by the cylinder actuator, two equations can be written as follows.

$$F_1.\frac{h}{0.5T} = \frac{\pi R^2 h\rho}{0.5T} gH_1 + 0.5\frac{\pi R^2 h\rho}{0.5T} w^2 \quad (08)$$

Thus,

$$F_1 = \pi R^2 \rho\ [gH_1 + \frac{w^2}{2}] \quad (09)$$

$$F_1 = \frac{T\rho\pi r_2^2 w}{2h}\ [gH_1 + \frac{w^2}{2}] \quad (10)$$

2). Buoy moves up: When the buoy floats, it rises by the wave height and moves for half the wave period. The buoyancy force (F_b) acts upward, countering gravity. It results from greater pressure at the buoy's bottom compared to the top, calculated as,

$$F_b = V\rho g \quad (11)$$

where ρ is fluid density, V is buoy volume, and g is gravitational acceleration. Viscous drag force (F_{drg}) occurs when a body moves through a fluid, creating resistance opposite to the motion. It depends on the body's shape, size, velocity, and the fluid's properties. The drag force is given by the formula,

$$F_{drg} = \frac{1}{2} C_d \rho A U^2 \quad (12)$$

where C_d is the drag coefficient, ρ is the sea water density, A is the body's cross-sectional area, and U is the vertical fluid velocity.

Force acting on the buoy,

$$F_3 = F_b - Mg - F_{drg} \quad (13)$$

The key factors in the system include the buoy's volume (V), velocity (U), and buoyancy force (F_b). Additionally, the viscous drag force (F_{drag}) plays a role, alongside the radius of the pumping pipe and the force acting on the bar (F_4). The radius of the cylinder rod is also an important parameter.

To calculate the volume of the buoy, by taking moment around hinged point

$$F_3.L - mg.\frac{L}{2} - F_4.l = 0 \quad (14)$$

$$F_4 = \frac{L}{l}\left\{\left[V\rho g - Mg - F_{drag}\right] - \frac{mg}{2}\right\} \quad (15)$$

When it moves up and down the work done by the cylindrical actuator is equal. From equation (09),

$$F_4 = \pi(R - r_1)^2\rho\left[H_1 g + \frac{W^2}{2}\right] \quad (16)$$

C.Generation & Turbine selection

The selection of generator and Turbine was carried out according to the selection process in the mini hydro power plant.

1) *Turbine Selection:* The type, geometry, and dimensions of a turbine are determined by the following parameters: net head (H_{net}), range of discharges through the turbine, rotational speed, and cost. The preliminary design and choice of a turbine involve an iterative process that evaluates size, cost, and efficiency. Net head (H_{net}) is calculated by subtracting friction losses in the conduit from the gross head, which is the vertical distance between the upstream water surface level and the downstream water level or nozzle axis level for impulse turbines. The net head is the primary criterion for turbine selection, with the range of operating heads for each turbine type detailed in Table 2.

Table 2. Range of Turbine head

Turbine Type	Head range [m]
Kaplan and Propeller	$2 < H_{net} < 40$
Francis	$25 < H_{net} < 350$
Pelton	$50 < H_{net} < 1300$
Crossflow	$5 < H_{net} < 200$
Turgo	$50 < H_{net} < 250$

2) *Friction head Loss Calculation:* Determination of Friction Factor, f, assuming completely turbulent flow & pipe will construct by PVC. Head loss can be calculated,

$$H_f = f\frac{L}{D} \times \frac{V^2}{2g} \quad (17)$$

3) *Discharge:* The flow rate is crucial for selecting the right turbine design, considering the reserved flow of a power plant. Due to significant yearly fluctuations, a single flow value is insufficient for design. Turbines operate inefficiently or not at all at lower discharges, known as the minimum technical flow. Flow and head variations are detailed in Table 3.

Table 3. Flow & Head Variation

Turbine Type	Acceptance of flow variations	Acceptance of head variations
Pelton	High	Low
Francis	Medium	Low
Kaplan double regulated	High	High
Kaplan single regulated	High	Medium
Propeller	Low	Low

4) *Specific Speed:* The specific speed of a turbine is the rotational speed of a similar turbine with a unit net head operating at maximum efficiency and producing a unit power. This non-dimensional parameter, independent of size and fluid type, is scientifically defined by equations. One of that is given below in equations with their assumed dimensions.

$$n_{QE} = \frac{n\sqrt{Q}}{E^{3/4}} \quad (18)$$

where, Q= discharge [m3/s]

E= specific hydraulic energy of machine [J/kg]

E = gHnet

n= rotational speed of the turbine [t/s]

n_{QE}= specific speed

These parameters characterize any turbine, with manufacturers typically indicating the specific speed. Numerous statistical studies have established a correlation between specific speed and net head for each turbine type. Turbine types and specific speeds of the turbines are given in Table 4.

Table 4. Specific Speeds of Turbines

Turbine type	Specific speed
Pelton one nozzle	$0.005 \leq n_{QE} \leq 0.025$
Pelton n nozzle	$0.005\times n^{0.5} \leq n_{QE} \leq 0.025\times n^{0.5}$
Francis	$0.05 \leq n_{QE} \leq 0.33$
Kaplan, propeller, bulb	$0.19 \leq n_{QE} \leq 1.55$

D.Calculating the rotational speed of the turbine

To calculate rotational speed of turbine, generator synchronization speeds were considered. According to the specific speed equation high rotational speed gives the low flow rate and low rotational speeds gives the high flow rates. Generator synchronization speeds with no of poles are given in Table 5

Table 5. Generation Synchronization Speed

No. of poles	2	4	6	8	10	12	14
Ns(rpm)	3000	1500	1000	750	600	500	428

V. RESULTS & DISCUSSION

A. Selecting water head

A 5m head is assumed for the design because pumping water to a higher elevation requires significant power. While the minimum required water head is 2m, 5m is selected to ensure sufficient elevation for effective operation.

B. Selecting turbine according to the head

To maximize efficiency and minimize friction losses, smooth glass tubes will be used for the piping system, and treated boiler feed water, a low-viscosity fluid, will be used as the circulation fluid. Consequently, friction head loss is assumed to be zero. According to the Equation (18), the specific speeds of the turbine types are as follows.

For Pelton $n_{QE} = \frac{0.0859}{5^{0.243}} = 0.0580$

For Francis $n_{QE} = \frac{1.924}{5^{0.512}} = 0.8439$

Kaplan $n_{QE} = \frac{2.294}{5^{0.486}} = 1.0492$

The calculated specific speed of 1.0492 falls within the range for Kaplan turbines, making them the preferred choice for optimal operation.

C. Calculating the rotational speed of the turbine

To calculate rotational speed of turbine, the generator synchronization speeds were considered. Rotational speed of the turbine,

$$n = \frac{n_{QE} \times E^{3/4}}{\sqrt{Q}} \tag{19}$$

The results indicate that as rpm decreases, the flow rate increases. Given the available water head and storage, the most suitable rpm is 3000. Detailed values for rotational speed and flow rate are provided in Table 6.

Table 6. Speeds & Flow Rates

No of Poles	rpm	n (t/s)	Q (m^3/s)
2	3000	50	0.151
4	1500	25	0.604
6	1000	16.66	1.359
8	750	12.5	2.416
10	600	10	3.77
12	500	8.33	5.437
14	428	7.13	7.42

Two 3000 rpm generators with a flow rate of 0.151 m³/s were selected. Details of the turbine flow is given in Figure 3.

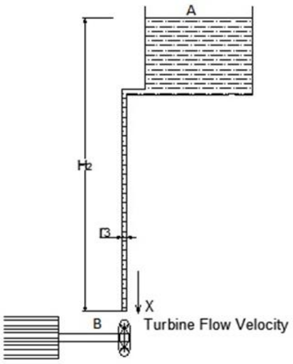

Figure 3. Details of the turbine flow

Applying Bernoulli's principal for the points A and B. Atmospheric pressure is maintained at these two points P_1 and P_2,

$$P_1 + \rho g H_2 = P_2 + \frac{1}{2}\rho X^2 \tag{20}$$

Where, H_2 = Turbine Head (m)

X = Turbine water Flow Velocity (ms-2)

$P_1 = P_2$ = Atmospheric pressure

H_2 = 5 m height

X= 9.89 ms-1

r_3 = Radius of the pipe

$Q = \pi r_3^2 X$ = Flow rate

$$r_3 = 0.069\ m$$

D. Selecting the storage tank input pipe radius & velocity

To maintain a constant head, the discharge and pump flow rates must be equal. Three floating devices, each with a pump rate of 0.050 m³/s, are used to transfer water to the storage tank. Excess water will overflow into a sump for recirculation. Details on the storage tank's input pipe radius and velocity variations are provided in Table 7.

Table 7. Output Velocity vs Pipe Radius

Pipe radius(m) (pumping)	0.01	0.02	0.03	0.04	0.05	0.06
output velocity (ms^{-1})	159	39.7	17.68	9.94	6.36	4.42

E.Calculating the cylinder details

The cylinder height is optimized with a 3m long arm placed 1m from the hinged point to achieve maximum stroke length. Details are provided in Figure 4.

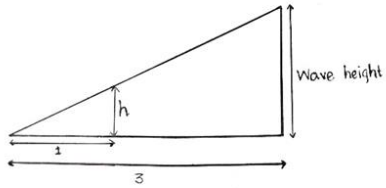

Figure 4. Calculation method of cylinder height

Where, h is the cylinder height and wave height 1.5m

Therefore, h = wave height / 3

= 1.5/3 = 0.5m

The design utilizes a maximum stroke length of 1 meter to accommodate extreme conditions, such as wave heights up to 3 meters. However, the calculation uses a stroke length of 0.5 meter. To calculate the force acting on the cylinder F_1, T=10 sec (Wave time period), average wave height 1.5 m, h = 0.5m and H_1 = 6m have been taken. From equation (10), F_1 is calculated taking velocity (W) & pipe radius variations as given in Table 8.

Table 8. Variations of pipe radius and force acting on the cylinder

Pipe Radius r_2 (m)	Velocity W(ms^{-2})	F_1 (N)
0.01	159	6343468.38
0.02	39.7	422478.19
0.03	17.68	107521.98
0.04	9.94	54061.82
0.05	6.36	39473.93
0.06	4.42	34276.57

With the help of Equation (09), the radius of the cylinder R, can be calculated and given in the Table 9.

Table 9. Variation of pipe radius and cylinder radius

Pipe Radius r_1 (m)	Velocity W(ms^{-2})	F_1 (N)	R(m)
0.04	9.94	54061.82	0.399
0.05	6.36	39473.93	0.398

0.06	4.42	34276.57	0.398

F. Calculating the mass of the Buoy, M

Taken as L = 3m, l = 1m, g = 9.8 ms^{-2}, mass of the arm m = 20kg, the variation of pipe radius and the buoy mass is calculated using the Equation (07) and given in the Table 10.

Table 10: Variation of Pipe radius & Buoy mass

Pipe Radius r_1 (m)	F_1 (N)	Cylinder R(m)	M(kg)
0.04	54061.82	0.399	1828.83
0.05	39473.93	0.398	1332.65
0.06	34276.57	0.398	1155.86

By considering the minimum buoy mass as 1156kg, the pipe radius & cylinder radius can be selected as 0.06m and 0.398m respectively.

G. Calculating the force acting on the buoy, F_3

By taking the drag coefficient of hemisphere C_d= 0.42, buoy radius R_1, velocity $U_{max} = a\omega = a\frac{2\pi}{T}$, a= 0.75 m ,T=10 sec, U_{max} = 0.471, A= πR_1^2 and sea water density 1025 kgm^{-3} , the viscous drag force, F_{drag} can be calculated using Equation (12).

$$F_{Drag} = 318.5\ R_1^2$$

From Equation (11), the buoyancy force, F_b can be calculated by taking the volume of the buoy as $V = {}^2/_3\, \pi R_1^3$.

$$F_b = \frac{2}{3}\pi R_1^3 \times 1025 \times 9.8$$

$$F_b = 21038.19\ R_1^3$$

Therefore the force acting on the buoy, F_3 can be calculated from Equation (13).

$$F_3 = 21038.19\ R_1^3 - 1675 \times 9.8 - 318.5 R_1^2$$

H. Calculating force acting on the arm, F_4

From Equation (15) and (16), by taking the piston rod radius selecting as r_1 =0.02m, R= 0.398m, H_1=6m, W= 4.42$ms^{-1}$and ρ= 1000kg/m^3, the F_4 can be calculated as,

$$F_4 = 30779.12\ N$$

Therefore, the radius of the buoy $R_1 = 1.088$ m

Buoy Details

Mass of buoy M= 1156 kg

Shape Hemisphere

Radius $R_1 = 1.088$m

Volume V = 2.69 m^3

Cylinder Details

Cylinder Height h=1m

Cylinder radius R=0.388m

Piston rod radius r_1=0.02m

I. Power output calculations at the plant locations

Turbine efficiency of Kaplan turbine can be assumed as 0.9 according to the small hydro turbine efficiency curve and induction generator efficiency is assumed as 0.92.

Hydroelectric power P_{avg}, can be calculated by Equation (15).

$$P_{Avg} = Q\rho gH \qquad (21)$$

where, H = Wave Height (m)

h = cylinder Stroke (m)

Q= Storage tank inlet flow rate (m^3/s^1)

ρ = Density of treated water (1000 kg/m^3)

g= gravitational acceleration (9.8ms^2)

Pout can be calculated from Equation (16), by taking Turbine efficiency μ_T = 0.91 and Generator efficiency μ_G = 0.95.

$$P_{Out} = \mu_T \mu_G Q\rho gH \qquad (22)$$

Wave characteristic and output power calculations at Bundala point is given in Table 11.

Table 11. Output Power Calculations at Bundala point

Month	Avg H (m)	h(m)	Avg T(s)	Flow Rate(q) (m^3/s)	3Q (m^3/s)	P Avg (W)	P out (W)	Rated Output Power (KW)
Jan	1.34	0.45	11.23	0.04	0.119	5821.59	5032.77	Shut Down
Feb	1.37	0.46	11.46	0.04	0.119	5832.47	5042.17	Shut Down
Mar	1.56	0.52	11.21	0.05	0.139	6789.47	5869.50	Shut Down
Apr	1.78	0.59	10.78	0.05	0.164	8055.97	6964.39	6.39
May	2.54	0.85	10.62	0.08	0.238	11668.80	10087.67	6.39
Jun	2.86	0.95	9.89	0.10	0.288	14108.69	12196.96	6.39
Jul	2.35	0.78	9.92	0.08	0.236	11557.74	9991.67	6.39
Aug	2.12	0.71	10.34	0.07	0.204	10003.04	8647.63	6.39
Sep	1.89	0.63	10.67	0.06	0.176	8642.00	7471.01	6.39
Oct	1.78	0.59	10.93	0.05	0.162	7945.42	6868.81	6.39
Nov	1.56	0.52	10.46	0.05	0.148	7276.29	6290.35	Shut Down
Dec	1.45	0.48	10.89	0.04	0.133	6496.16	5615.93	Shut Down

Wave characteristic and Calculations at Palatupana Point are given in Table 12.

Table 12. Output Power Calculations at Palatupana Point

Month	Avg H(m)	h(m)	Avg T(s)	Flow Rate q (m^3/s)	Q (m^3/s)	P Avg (W)	P out(W)	Rated Output Power (KW)
Jan	1.21	0.40	10.42	0.04	0.116	5665.45	4897.78	Shut Down
Feb	1.24	0.41	10.23	0.04	0.121	5913.75	5112.44	Shut Down
Mar	1.67	0.56	11.45	0.05	0.145	7115.87	6151.67	Shut Down
Apr	2.34	0.78	12.73	0.06	0.183	8968.18	7752.99	6.39
May	2.65	0.88	11.78	0.07	0.224	10975.33	9488.17	6.39
Jun	2.78	0.93	10.73	0.09	0.258	12640.43	10927.65	6.39
Jul	2.25	0.75	10.43	0.07	0.215	10524.83	9098.72	6.39
Aug	1.89	0.63	10.98	0.06	0.171	8398.01	7260.08	6.39
Sep	1.78	0.59	10.21	0.06	0.174	8505.72	7353.20	6.39
Oct	1.67	0.56	11.03	0.05	0.151	7386.83	6385.91	6.39
Nov	1.65	0.55	11.31	0.05	0.145	7117.68	6153.23	Shut Down
Dec	1.45	0.48	11.63	0.04	0.124	6082.82	5258.60	Shut Down

Wave characteristic and Calculations at Godawaya Point are given in Table 13.

Table 13. Output Power Calculations at Godawaya Point

Month	Avg H (m)	h(m)	Avg T (s)	Flow Rate q (m^3/s)	Q (m^3/s)	P Avg (W)	P out (W)	Rated Output Power (KW)
Jul	2.31	0.77	11.43	0.07	0.201	9860.13	8524.08	6.39
Aug	2.38	0.79	11.12	0.07	0.213	10442.13	9027.22	6.39
Sep	1.87	0.62	10.78	0.06	0.173	8463.30	7316.52	6.39
Oct	1.67	0.56	10.54	0.05	0.158	7730.24	6682.79	6.39
Nov	1.36	0.45	10.12	0.04	0.134	6556.55	5668.14	Shut Down
Dec	1.14	0.38	10.24	0.04	0.111	5431.52	4695.55	Shut Down
Jan	1.17	0.39	10.65	0.04	0.109	5359.86	4633.60	Shut Down
Feb	1.06	0.35	10.72	0.03	0.098	4824.23	4170.55	Shut Down
Mar	1.21	0.40	10.48	0.04	0.115	5633.02	4869.74	Shut Down
Apr	1.38	0.46	10.65	0.04	0.129	6321.88	5465.27	Shut Down
May	1.76	0.59	10.36	0.06	0.169	8288.38	7165.31	6.39
Jun	2.08	0.69	10.69	0.06	0.194	9492.98	8206.68	6.39

Wave characteristic and Output Power Calculations at Unawatuna Point are given in Table 14.

Table 14. Output power Calculations at Unawatuna point

Month	Avg H(m)	h(m)	Avg T(s)	Flow Rate q (m^3/s)	Q (m^3/s)	P Avg (W)	P out (W)	Rated Output Power (KW)
Jan	1.03	0.34	11.31	0.03	0.091	4443.16	3841.11	Shut Down
Feb	1.21	0.40	11.42	0.04	0.105	5169.35	4468.91	Shut Down
Mar	1.46	0.49	10.98	0.04	0.132	6487.35	5608.31	Shut Down
Apr	2.12	0.71	10.78	0.07	0.196	9594.76	8294.67	6.39
May	2.83	0.94	10.65	0.09	0.265	12964.44	11207.76	6.39
Jun	2.78	0.93	10.34	0.09	0.268	13117.20	11339.82	6.39
Jul	2.67	0.89	10.72	0.08	0.248	12151.60	10505.06	6.39
Aug	2.25	0.75	10.32	0.07	0.217	10637.01	9195.70	6.39
Sep	1.87	0.62	10.48	0.06	0.178	8705.57	7525.96	6.39
Oct	1.65	0.55	10.62	0.05	0.155	7580.12	6553.02	6.39
Nov	1.45	0.48	10.83	0.04	0.133	6532.15	5647.05	Shut Down
Dec	1.32	0.44	10.78	0.04	0.122	5974.09	5164.60	Shut Down

The flow rate must be 0.151 m^3/s to maintain 3000 rpm and constant power output. If the flow rate falls below this, the plant should be shut down. This ensures a consistent flow rate and power output.

Calculating rated power output by Equation (22),

$$P_{Out} = \mu_T \mu_G Q \rho g H$$

$$P_{out} = 0.91 \times 0.95 \times 0.151 \times 1000 \times 9.8 \times 5$$

$$= 6.396 \text{ kW}$$

Therefore, minimum rated power output of this model is 6.396 kW. If the power factor assumed as 0.85. Then the output power equal to the 7.5kVA.

J. Calculating plant factor

Plant factor can be estimated by following equation,

$$Plant\ factor = \frac{Actual\ anual\ energy\ generation}{Maximum\ plant\ capacity * 8760} \quad (23)$$

At Bundala point

$$\text{Plant Factor} = {214 \times 24 \times 6.39}/{6.39 \times 8760}$$

$$= 0.58$$

Calculated Plant Factor values are given in Table 15.

Table 15. Annual plant factor of power plant locations.

Location	Annual average power Potential (kW/m)	Plant factor
Bundala	37.81	0.58
Palatupana	40.49	0.58
Unawatuna	39.93	0.58
Godawaya	28.42	0.50

Three phase, 7.5 kVA, 10.86 A, 400 V, 50/60 Hz, 3000 rpm induction generator is used to produce electricity in this model.

VI. CONCLUTION

The proposed sea wave energy system is feasible and can increase capacity by enhancing tank height or flow rate and using multiple units. It can connect directly to the 33kV system or specific complexes like hotels. This method is economically comparable to other renewable sources like mini-hydro, wind, and solar. Challenges include low wave height and potential impacts on tourism. Given recent power cuts, sea wave energy is a promising, low-cost, and environmentally friendly solution for Sri Lanka's energy needs.

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