Chapter 17
OPTIDAL: A New Software for Simulation of Climatic Impacts on Tidal Power

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Abstract Uncontrolled growth in population has increased the demand for energy, which is reflected in the ever-growing cost of crude oil and electricity. The rise in prices has increased the average cost of basic amenities around the world. That is why alternative, renewable sources of energy are now being explored so that the latter can share the responsibility of mitigating the power demand and reduce the stress on finite energy sources. But problems with renewable energy sources include the frequency of availability and absence of inexpensive methods/devices to store the energy. Available renewable energy sources like solar, wind, and hydro are available in infinite quantities, but to produce energy from these sources requires their availability for a specific amount of time. For example, solar energy can be converted into usable forms only during a specific period of time. Thus, to recover the cost of conversion, the amount of energy that can be produced from renewable sources in a day must either be stored or utilized optimally to mitigate energy requirements. But the availability of inexpensive methods/devices is scarce, and thus solar energy is still a luxury, not a necessity. The second option then becomes more attainable. The time and quantity of hydro energy turns out to be more predictable than other forms of renewable energy sources. The inexpensive conversion mechanism also increases the attractiveness of hydro energy as a possible energy source. But as is common, hydro

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power is unreliable with respect to duration and intensity of energy delivered compared to fossil fuels, and thus in the case of utilization, proper levels of intensity must be ensured to maximize energy use. Of the two forms of hydro energy, tidal energy is relatively new but its ease of use and availability favor it over hydro energy. The only requirement to convert such energy into usable form so that it can be used to share some of the responsibility for meeting energy demand lies in maximizing the usability of the available resources. The present study introduces a software that aims to optimize the use of tidal energy resources by maximizing profit. The software is tentatively called OPTIDAL (OPtimization of TIDAL sources).

Keywords Tidal power • Optimization • Decision support systems

17.1 Introduction

The increase in population and the demand for energy have increased the stress on fossil fuels throughout the world. It was found that "energy consumption in developing countries is only one-tenth of that in the developed countries" (Economic Watch 2010). But for developing countries to sustain the growth of their economies, consumption of energy must increase. Oil, coal, natural gas, hydro energy, nuclear energy, renewable combustible wastes, and other energy sources mainly satisfy the needs of energy in the world. It was found that, in 1999, the total supply of primary energy in the world was 9,744.48 million tons of oil equivalent (MTOE), but it was predicted that the total supply of energy in the world in 2010 will be 11,500 MTOE; in 2020 it is expected to be 13,700 MTOE (Tables 17.1 and 17.2).

According to the consumption of fuel, oil is the most important and abundant source of energy in the world, but the price of crude oil is volatile and is a function of market demand. Whereas developed industrialized countries consume, on average,

Table 17.1 Percentage contribution of different sources of energy to total supply of global energy

Fuel	Percentage of total supply
Oil	35.1
Coal	23.5
Natural gas	20.7
Renewable combustible waste	11.1
Nuclear	6.8
Hydro	2.3
Other sources	0.5

Table 17.2 Proportion at which energy from different sources was consumed

Source	Percentage of consumption
Oil	42.7
Coal	8.2
Electricity	15.4
Natural gas	16
Renewable combustible wastes	14.2
Other	3.5

about 43 million barrels daily, developing countries consume only about 22 million barrels per day.

The second most abundant finite source of energy is coal, which is widely used for power generation, although its consumption is not as high as that of oil. According to recent trends, natural gas has the highest rate of consumption growth.

In the case of renewable sources of energy, a 3.7% growth was projected over the 10-year period from 2000 to 2010. Among all other alternative energy sources, utilization of hydro energy was found to be maximum around the globe (Economy Watch 2010). Besides hydro energy, the utilization of tidal waves for generating electricity is now considered to be one of the most promising technologies to mitigate the present energy crisis if used optimally.

17.1.1 Importance of Tidal Energy

Two types of energy can be produced by the oceans: thermal energy from the Sun's heat and mechanical energy from the tides and waves.

Flood tide and ebb tide are daily phenomena that can be observed in coastal bays and river estuaries. Tidal waves are due to the combination of forces exerted by the gravitational pull of the Sun and Moon and the rotation of the Earth. Local effects like shelving, funneling, reflection, and resonance can also increase the intensity of tidal waves. The magnitude of tidal power is entirely site specific and requires mean tidal differences of more than 4 m with favorable topographical conditions, such as estuaries or certain types of bays, to reduce the installation cost.

A major limitation of tidal power stations is that they can produce electricity during the tidal phase only. Besides this major drawback, the following limitations also are observed in the case of tidal power plants:

1. Development of a barrage between estuaries or coastal bays is a costly installation that impacts the environmental stability of the region. According to global estimates, the cost for the generation of tidal power varies between 13 and 15 cents/kWh.
2. It is often observed that installation of a barrage for the generation of tidal power can cause a reduction in flushing, winter icing, and erosion, which can change the vegetation of neighboring areas and disrupt the ecological balance.
3. The minimum eligibility requirement for installation of tidal power plants and production of electricity (at about 85% efficiency) is the availability of a mean amplitude difference of 7 m, and it is desirable that the location have semidiurnal tides. Such eligibility requirements greatly reduces the number of locations for the production of tidal electricity.
4. Barrages across river estuaries can change the flow of water and, consequently, the habitat for birds and other wildlife.
5. Barrages developed in the mouth of a river or coastal bay may affect fish migration and other wildlife. Turbine blades are known to kill fish or aquatic animals. That is why an extra passage or fish ladders are generally provided for the free movement of aquatic fauna.

6. Tidal barrages may induce shoreline flooding and can damage the coastal population if the stored water is not regulated as required.
7. Tidal power is not very useful for people living far from coastlines; the benefits of tidal energy are not enjoyed by the population living inland.

But as tides are totally predictable and their magnitude does not vary, such energy sources are reliable enough to supply electricity at a specific time of a day. The disadvantage of the discontinuous supply can be mitigated by hybridizing the source with a conventional option.

There are many other benefits of tidal power stations like protection against coastline damage, ready-made road bridges, development of recreational zones around stations, and, above all, the reduction in greenhouse gas emissions will automatically force city planners to opt for such a source of energy in meeting daily energy demand.

The largest tidal power station in the world is in the Rance estuary in northern France, near St. Malo. It was built in 1966. About 20% of Britain's coastland can be used for tidal power generation. There are eight main sites around Britain where tidal power stations could usefully be built, including the Severn, Dee, Solway, and Humber estuaries (Clara 2012).

The Gulf of Cambay and the Gulf of Kachchh on the west coast of India where the maximum tidal range is 11 and 8 m, respectively, with an average tidal range of 6.77 and 5.23 m, respectively, has tremendous potential for tidal power production. In eastern India, the Ganges Delta in the Sunderbans also has good locations for small-scale tidal power development. The maximum tidal range in Sunderbans is approximately 5 m, with an average tidal range of 2.97 m (EAI 2011).

"The economic tidal power potential in India is of the order of 8,000–9,000 MW with about 7,000 MW in the Gulf of Cambay, about 1,200 MW in the Gulf of Kachchh, and less than 100 MW in Sundarbans" (MNRE 2012).

17.1.2 Need for Optimization of Tidal Power Production

The magnitude and quality of tidal power depend on the tidal range. The minimum requirement, as discussed in the previous section, is 4 m. Thus a location with such a level head difference is generally selected for the installation of a tidal power plant. Also many other location-specific parameters are important for the success of a tidal power plant. For example, soil strength, flow turbulence, fish navigation, acceptance by the local population, and many other related parameters that vary from one location to another.

Tidal power plants can be optimized or their profitability can be maximized if the production of power can be maximized and the variable cost minimized. (Sullivan and McCombie 1968; Lee and El-Sharkawi 2008; Lee and Dechamps 1978; Swales and Wilson 1968).

Thus the selection of location followed by the optimization of profitability can help city planners decide about the feasibility of installing a tidal power plant. No software, to the authors' best knowledge, is presently available that can assist engineers in the identification of a suitable location and optimization of the production capacity for a tidal power plant.

OPTIDAL aims to identify suitable locations for tidal power plants as well as optimize the production capacity by varying related variables within specific limits. The software may help city planners in the selection of suitable sites for tidal power and also recommend conditions for getting optimal output from the proposed installation.

17.1.3 Software Objective and Scope

The main objective of the software is to identify suitable locations for tidal power development and optimize plant capacity by varying related variables like tidal range, power demand, interconnection points, flow turbulence, and net profit.

17.2 Input, Output, and Working Principle of Software

The input of the software can be divided into five different sections: climate, geophysical, ecological, socioeconomic, and electrical inputs. Figure 17.1 shows the input panel and Figs. 17.2, 17.3, 17.4, 17.5, and 17.6 show the required input variables that the user must enter to estimate the desired outputs. All the input panels of the software can be accessed from the home panel shown in Fig. 17.7. In the home panel, when either of two buttons – LOCATION SELECTOR or LOCATION OPTIMIZER – is clicked, the input panels will be displayed first. In the input panel, all sections of input variables will be displayed, and clicking on the corresponding button will open the data entry window for entering the required data.

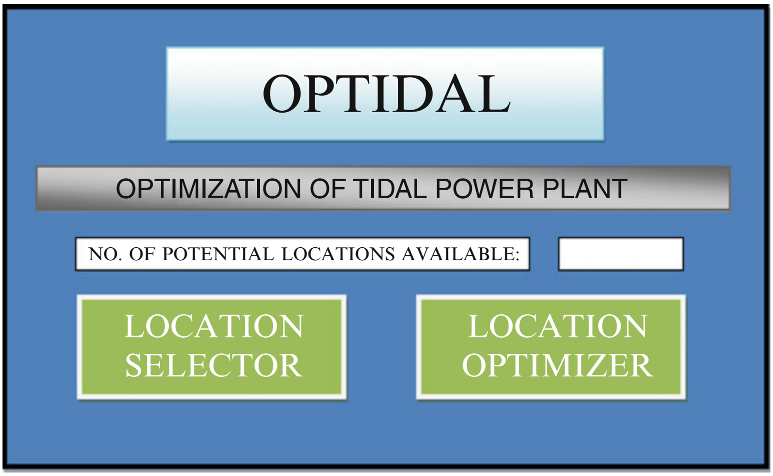

Fig. 17.1 Input panel for location selector and optimizer

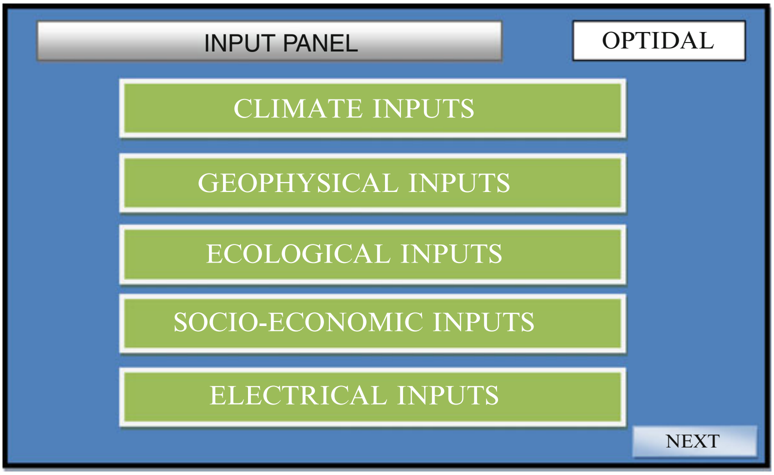

Fig. 17.2 Panel where climatic inputs are entered

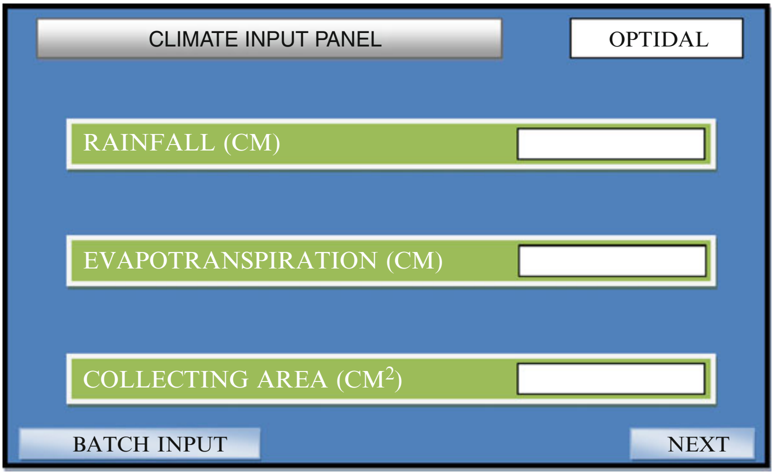

Fig. 17.3 Panel where geophysical inputs are entered

The data can be entered in batch mode (Batch Input button) if more than one options is available and in the single-window model if only one location is available for feasibility analysis.

All the variables are self-explanatory. The watershed loss and channel loss in the geophysical input panel have to be determined in terms of the ratio of the area of the impervious region and the total area of the watershed. Channel loss must be calculated by dividing the outflow volume by the inflow volume. The respective volumes can be measured by measuring the flow in the output and in the input or in the initial region of the channel.

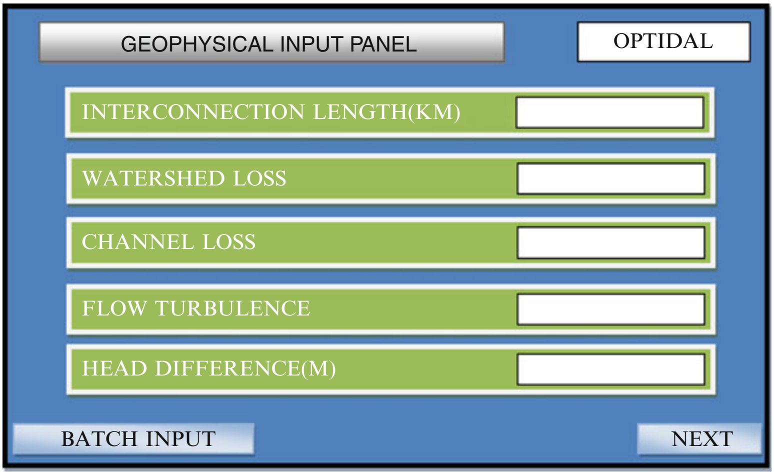

Fig. 17.4 Panel where ecological inputs are entered

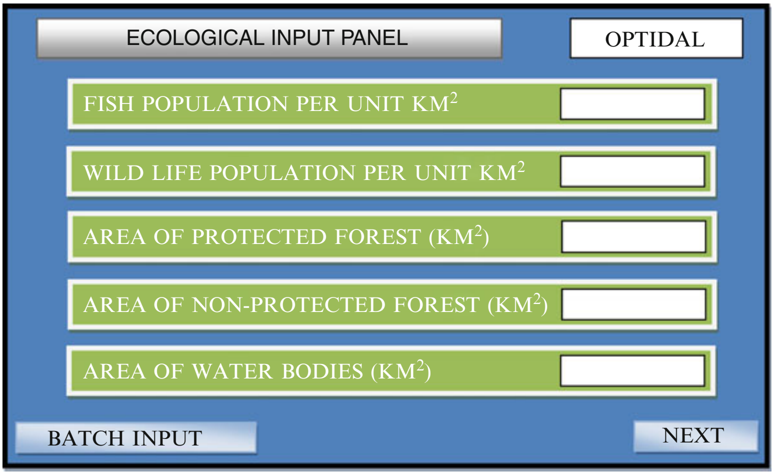

Fig. 17.5 Panel where socioeconomic inputs are entered

Flow turbulence can be determined with the help of the Reynolds number at the mouth of the channel. The value must be determined in numerous locations within the channel output. The average of the numbers must be entered in the input field. The difference between the outside and inside water levels has to be entered in the head-difference field. The difference between the maximum head attained inside the channel during flood tide and the minimum water level that can be observed during ebb tide will determine the maximum tidal range possible in the location, whereas the average of the head difference measured at specific time intervals will estimate the average head difference of the region. In the field of head difference, the user has to enter the latter value so that locations can be compared for a general situation.

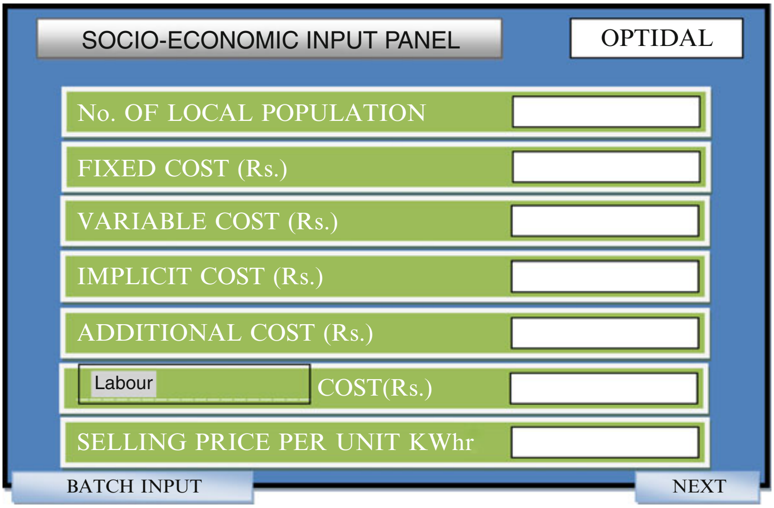

Fig. 17.6 Panel where electrical inputs are entered

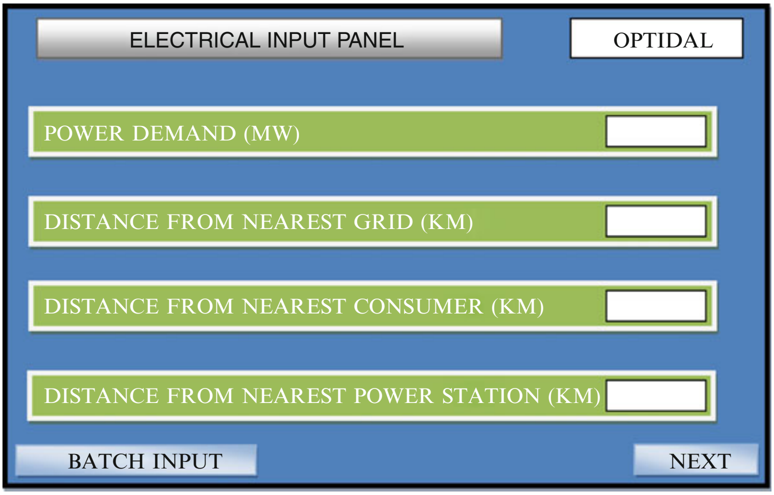

Fig. 17.7 Home panel of OPTIDAL software

The different types of production unit can be classified into four major groups in which all the expenditures incurred by a production unit can be categorized:

1. Explicit costs
   Explicit cost is expenditures that include payments made by the employer or by the owner of the production unit to those factors of production that do not belong to the employer himself. Explicit costs include payments made for raw materials, power, fuel, wages and salaries, land rent payments, and interest on capital. Explicit costs are also referred as accounting costs. These costs are entered in the accountant's list.

2. Implicit costs
   The implicit or imputed costs arise in the case of those factors that are owned and supplied by the owner him- or herself. The owner of any production unit, including power plants, contributes to increasing the efficiency of those units from the initial phase. The land is generally purchased by the owner unless donated by the government. A certain part of the work load can also be shared by the owner. Thus, the owner receives some remuneration for his or her services in the development of the unit. The cost incurred to remunerate the owner for his or her services is known as implicit cost and is generally not itemized explicitly. All these items would be included under implicit or imputed costs and are payable to the owner. Usually producers ignore these implicit costs when computing total costs. Thus total cost should include both explicit and implicit costs. In this regard, readers may note that in the case of power plants that are included in the essential category of service, the owner may not be an individual or a private trust; it may be the government itself. In that case the remuneration is paid to the government in taxes and dividends if the government becomes a shareholder of the company in which it exercises regulatory power.
3. Fixed costs
   These are costs that are incurred on a unit independently of the volume of production from that unit. Such costs do not change with changes in output. They remain the same regardless of the volume of production. Examples of fixed cost include interest on capital, salaries of permanent staff, insurance premiums, property taxes, and rents. Fixed costs are also known as supplementary costs.
4. Variable costs
   Variable costs are costs that vary with the volume of production. Variable costs are more or less dependent upon increases and decreases in the volume of production. Variable costs are also known as prime costs. Examples of variable costs include costs of labor, raw materials, and chemicals.

Considering the fixed, variable, and implicit costs incurred during installation and in the production phase can estimate the profit of the unit. Or in analyzing the impact of certain types of cost the software has a provision that allows the user to enter a type of cost that may be included in the fixed or variable costs, but if the user wishes to observe the influence of such costs on the profit or optimized variable they can be entered separately. But in that case the user must not include the said cost in the variable, fixed, implicit, and additional costs.

Under additional costs the user may include those costs that cannot be categorized into fixed, variable, or implicit. Explicit costs are not considered as all such costs can be included in either fixed or variable costs.

The cost at which a power plant will sell a unit of electricity produced can be entered in the Selling Cost per unit kWhr field. The selling cost, where the plant attains full capacity, can be estimated so that a comparison can be made that includes the future production capacity of the plant.

In the Electrical Input panel the Distance from the Nearest Power Plant field must contain the distance from the tidal power station to the nearest power station

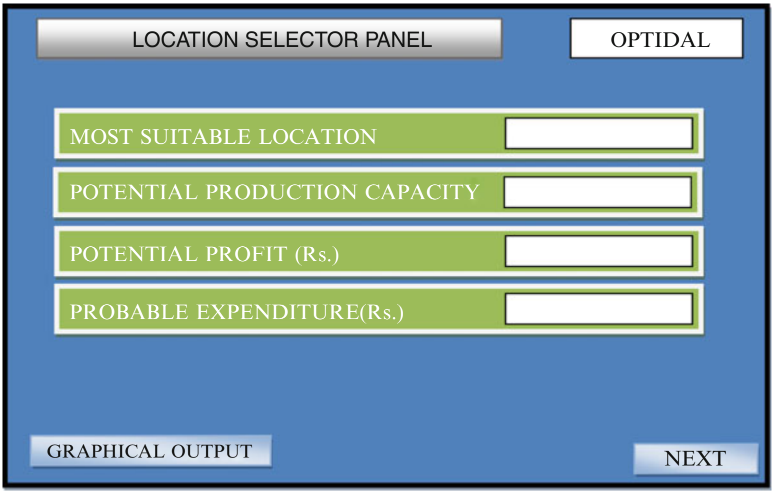

Fig. 17.8 Location selector panel where, based on index, the most suitable location is selected

so that transmission loss for bringing power to the station in the installation phase can be calculated and considered while selecting the most suitable location among the available options.

When the foregoing input data are entered in the software, the data will be processed by OPTIDAL to calculate an index. This index is simply a weighted average of the values of the inputs where the positive variables are placed in the numerator and other variables are naturally placed in the denominator. The weights of the variables are decided with the help of the knowledge gained from different scientific studies and discussions with experts in related fields.

Once the values of the input are entered, the user can either go on to the LOCATION SELECTOR panel (Figs. 17.8 and 17.9) or click to open the LOCATION OPTIMIZER panel (Fig. 17.10). In the Optimization panel, the user can optimize the dependent variables like amount of power produced and net profit. In the first panel to be displayed once the LOCATION OPTIMIZER button is clicked, the name of the variables (included in the drop-down field) and the necessary values of the constraints (lower and upper limit) must be entered. After the values are assigned to the respective fields, the NEXT button must be clicked to see the output (Fig. 17.10) and if the user wants to graphically analyze the impact of the independent variable on the objective, the GRAPHICAL OUTPUT button may be clicked to observe the variation in the LOCATION OPTIMIZER PANEL-GRAPHICAL panel (Fig. 17.11).

Before going to the result panel of the optimizer, the user must enter the serial number of the location for which the user wants to optimize the desired output so that the software can identify the location for which it must optimize the desired variables.

The results of the output from the optimization are displayed in Fig. 17.11, where the numerical optimal values of the independent variables are displayed, and

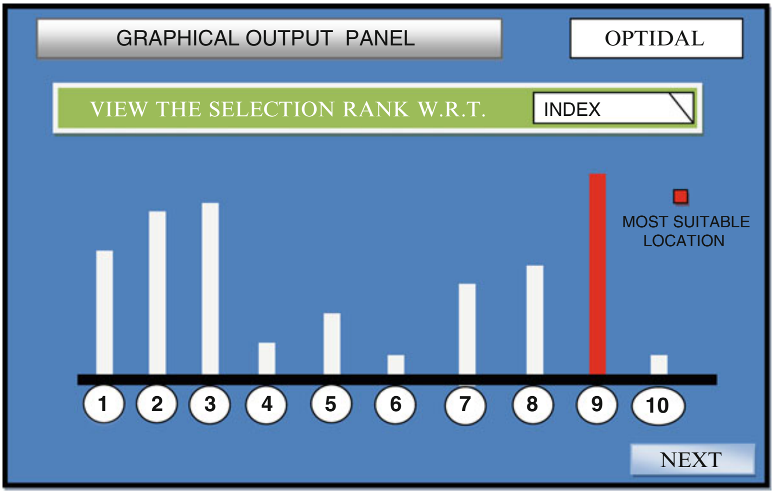

Fig. 17.9 Graphical output panel where graphical comparison of available locations can be made with respect to head difference, flow volume, flow turbulence, net profit, size of local population, wildlife and aquatic faunal population, area of protected and unprotected forest, distance from grid and consumers, and, above all, index value determining location ratings

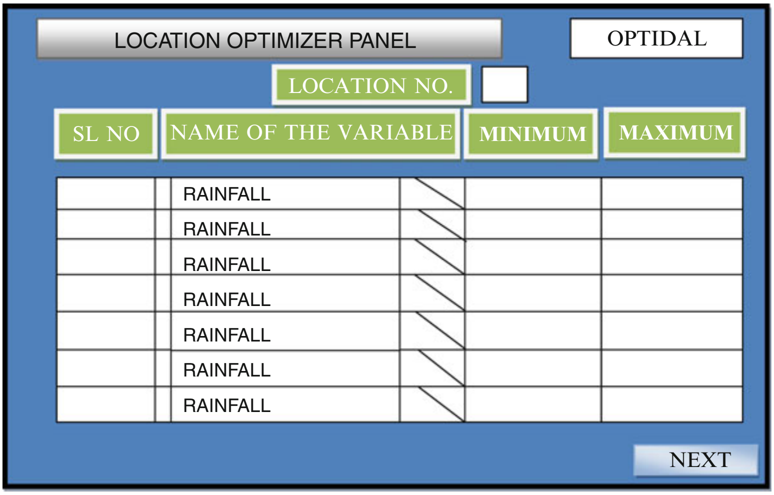

Fig. 17.10 Location optimizer panel where the dependent (optimized) variables and independent variable (variable with which the dependent variable is optimized) can be defined along with their upper and lower limits

Fig. 17.12, where the variation of the numerical optimal values with respect to two independent variables are shown graphically. The user may tweak the maximum and minimum values in the OPTIMIZER panel to identify the impact of constraints on resource availability with respect to the objective variable.

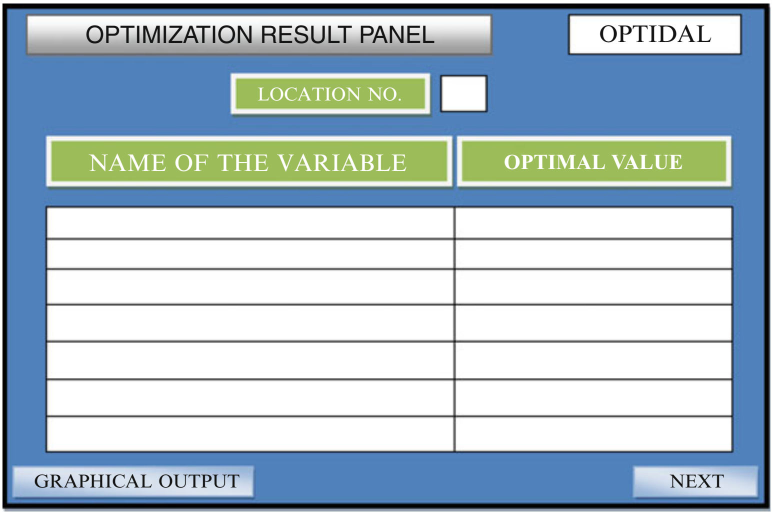

Fig. 17.11 Optimization result panel where optimal values of variables at he point of optimization are displayed

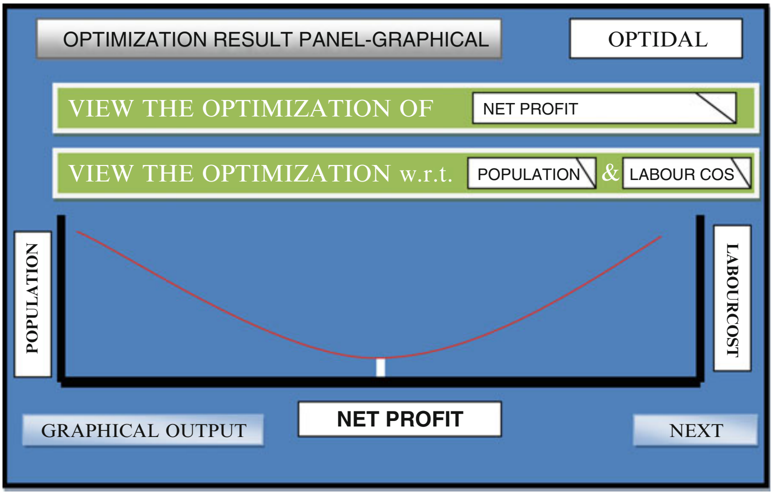

Fig. 17.12 Optimization results panel, where a graphical comparison of dependent and independent variables can be made

17.3 Benefits of OPTIDAL Software

The OPTIDAL software was developed to assist engineers in conducting a comparative feasibility study where different locations within a common geographic region (i.e., different channels within the same coastal zone) can be analyzed for a feasibility study to develop tidal power plants in those locations.

The potential of each of the prospective locations can be analyzed and compared with each other so that the best ones are selected. The values of different necessary inputs can be compared so that a logical and informed decision can be made where the chance of uncertainty will be negligible.

The second benefit of the software is its ability to optimize the two objectives of any tidal power plant. The first one is net profit and the second is the amount of power that can be generated based on the available input variables. The amount of rainfall or area of the protected forest can be varied to display the impact on the objective variables. The GRAPHICAL OUTPUT panel provides a visual display of the influence of two variables on the objective variable.

Based on the output, inferences regarding the impact of different uncertainties (like extreme events, erosion, sedimentation in the channel, urbanization, sudden rise in demand, and cost imbalances in the domestic or international market) can be analyzed and necessary decisions can be taken to mitigate the harmful effects of the abnormalities.

Implementation of the software in practical problem solving may help different people from different fields. For example, business owners will realize immense benefits if they analyze the potential before investing in the development of a tidal power plant.

Government can also use the software to calculate benefits before utilizing coastal areas for the development of tidal-based power. An educated decision in this regard will benefit both the people and the government without risking hostility from the displaced population.

Environmentalists concerned with deforestation activities worldwide will also find benefits in using the software because they will be able to analyze the impact on the environment of the development of a proposed tidal power plant. The impact on aquatic fauna and wildlife can also be compared and analyzed to come to a decision that will benefit everyone.

Energy efficiency managers can also use the software to calculate an overall energy audit of a tidal-based power plant where both expenditures and income in terms of energy can be calculated.

The list of beneficiaries would also include the local people, who can analyze the level of rehabilitation, land loss, and variation in income from pisciculture due to the proposed tidal plant in their watershed.

Because the impact of flow turbulence can also be estimated, the software can be used by designers in selecting suitable turbines for the power plant. The generator and exciters can also be improvised from the output of the OPTIDAL software.

17.4 Drawbacks

The software can be analyzed from the point of view of drawbacks and reliability. The application is still in alpha version, and testing is not yet completed.

Initial observations indicate that having to enter so many data points can become a hindrance for users. In future versions, an automatic data retrieval mechanism may be introduced so that users can automatically determine input values. Another feature that may be introduced is the representation of the spatial variation of the output through Google Earth or Wikimapia. An interface can be made to automatically retrieve data like interconnection length or water level difference from Google Earth images.

A feature for importing data in Microsoft Excel format may also be introduced, although batch data entry is possible in the present version of the product.

17.5 Conclusion

This study introduced OPTIDAL software program, which can be utilized in the selection of suitable regions for tidal power plants so as to maximize output, i.e., maximization of either profit or generation of renewable energy. The location selector capability of the software will help governments invest where needed and avoid wasting money, which will happen if investments are allocated without proper feasibility studies. The Optimization panel of the software will help engineers and designers to vary different related input variables to see their effect on the output. The software thus will help engineers and concerned laypeople to perform risk analysis in the case of newly developed power plants. The reduction of greenhouse gases and the increased income from carbon credits can also be optimized with the help of the software. The effects of deforestation, flow turbulence, and fish navigation can also be visually analyzed with the help of the OPTIDAL software. Besides the drawbacks like lack of automatic retrieval of data from satellite images, the software may be further developed to introduce additional features that will create a state-of-the-art platform for optimization studies in the field of renewable energy.

References

Clara D (2012) Energy resources: tidal power. Retrieved from http://www.darvill.clara.net/altenerg/tidal.htm. Mar 2012

Economy Watch (2010) World consumption of energy, 30th April 2010. Retrieved from http://www.economywatch.com/energy-economy/scenario.html. Feb 2012

Energy Alternatives India (EAI) (2011) Ocean energy in India. Retrieved from http://www.eai.in/ref/ae/oce/oce.html. Feb 2012

Lee ST, Dechamps C (1978) Mathematical model for economic evaluation of tidal power in the Bay of Fundy. IEEE Trans Power Appar Syst 5:1769–1778.

Lee KY, El-Sharkawi MA (eds) (2008) Modern heuristic optimization techniques: theory and applications to power systems, vol 39. Wiley-IEEE press, Hoboken.

Ministry of New and Renewable Energy (MNRE) (2012) Tidal energy. Retrieved from http://www.mnre.gov.in/schemes/new-technologies/tidal-energy/. Feb 2012

Sullivan P, McCombie P (2013) Optimisation of tidal power arrays using a genetic algorithm. Proc Inst Civil Eng-Energy sar:1–10.

Swales MC, Wilson EM (1968) Optimization of tidal power generation. Water Power 20(3): 109–114.