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# Modelling of Mini Hydro Plants in Long Term Planning Studies - A Sri Lankan case study

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**Abstract:** The development of green energy and cutting down fossil fuel fired brown energy is now matured from the voluntary commitment stage up to a level of fixing national policy targets even in developing countries [1], [2] including Sri Lanka [3]. Thus, the share of Non Conventional Renewable Energy (NCRE) in electricity generation is becoming crucial in modern generation planning studies. As a result, many advanced research studies have been conducted around the world [8]-[13]. In particular, no national level detailed study has yet been conducted to model the macro impacts of large numbers of distributed mini hydro plants, in long term planning studies. Owing to the increasing share of contribution from mini hydro power plants, especially as embedded, non-dispatchable generation, simplified models such as the thermal equivalent model with high Forced Outage Rate (FOR) which is the current practise will no longer be justifiable. A suitable model should accommodate the seasonal variation of energy availability as well as the operational aspects specific to embedded generation.

This study proposes a probabilistic model to meet this vital requirement of the entire group of mini hydro plants. The operational aspects of the model have been verified by using the optimisation tool Wien Automatic System Planning (WASP), the same planning tool used by the Ceylon Electricity Board (CEB) and many other utilities worldwide for generation planning. Special attention has been paid to ensure that the model will be suitable for conducting sensitivity studies. The predictability of the model has been checked with past data.

Although a Sri Lankan case study was applied to validate the model, the technique is more general and can be adapted for any other case studies as well.

**Keywords:** Modelling, Mini-hydro, Non conventional renewable energy, Embedded generation, Long term generation planning, WASP

## 1. Introduction

Although Sri Lanka is enriched with NCRE resource development opportunities, only two NCRE technologies have been developed as yet.

- Mini hydropower
- Wind power

Bio-mass power (particularly Dendro, i.e. grown bio-mass) has attracted significant investor interest, but practically sustainable power plants are yet to be built.

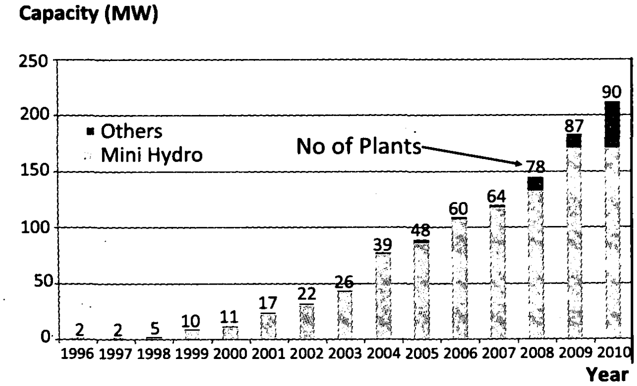


**Figure 1 - NCRE Development in Sri Lanka**

The evolution of NCRE-based generation in Sri Lanka (Figure 1) shows the major contribution to be from mini hydro. Grid connected mini hydro development commenced with the 75 kW Seetha-Eliya plant in 1996.

By 1998, there were only five mini hydro power plants connected to the grid. With a policy that promoted private investments through a standardised contract and standardised tariffs, more plants were commissioned and by August 2010, there were 83 operational plants with a cumulative installed capacity of 170.8 MW. The standardised Power Purchase Agreement (SPPA) had been signed for a further 89.2 MW (44 projects) and Letters Of Intent (LOI) have

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been issued for another 280.07 MW (177 projects). New developments of high and medium head hydro power plants are on the decline and the industry is heading for saturation in the future. Further potential remains to develop low-head power plants.

## 2. Literature Survey

Macro scale modelling of mini hydro power plants for long term planning has not been previously considered in Sri Lanka. Thereby, except individual feasibility studies for specific projects, an overall macro economic evaluation of mini hydro plants remains untouched so far.

It is a general practice not to treat small capacity embedded generating plants individually in long term planning but lump them into an equivalent plant so as to minimise the complexity of modelling [4]. Planners generally use a rule of thumb that if the installed capacity of NCRE/embedded generation is less than 5% of the total installed capacity, such lumped models will not lead to much error. Thus, NCRE-based generation has been usually modelled as a lumped equivalent thermal power plant with high FOR [4] which is the present practise used in preparation of long-term generation expansion plan of CEB. This model has worked satisfactorily in the past but has become less representative with the rapid development of NCRE in the Sri Lanka system, especially due to the favourable investment opportunities coupled with the National Energy Policy [3] declaring the intention of Sri Lanka to meet 10% of total grid energy requirement through NCRE resources by 2015.

In the present context, the lumped equivalent thermal model is inadequate for modelling NCRE plants in Sri Lanka due to the following reasons.

- Problems in accommodating plants with different installed capacities
- Difficulties in modelling frequent addition of plants of different types of NCRE on annual or monthly basis
- Inability to track seasonal variation of energy availability
- Inaccurate dispatch of plants, ie., dispatch outside the correct operating region

Therefore, this study developed a model to address as many of the above shortcomings as possible.

## 3. Categorising Generation Patterns

For the preparation of the proposed model, monthly generation statistics of each commissioned plant were collected for the period January 1998 to December 2009. During preliminary investigations on the available data, the following shortcomings were observed.

- Abnormal data - might be caused by human error, erroneous meters, frauds, etc.
- Unequal monthly reading roster ie., date on which the meter reading is taken varies from month to month

An effort was made to collect data from individual plants but this was found extremely difficult due to

- Non-availability of suitable recording loggers in power plants
- Reluctance of private investors to release data
- Non-availability of analytical records on the operating period of plants, especially relating to hydrology and power generation

Therefore data collection was initiated by referring the monthly review reports released by the System Control Centre of CEB. All recorded data was divided into several capacity ranges (MW<0.5, 0.5<MW<1, 1<MW<2.5, 2.5<MW<5, 5<MW<7.5 and MW>7.5) and analysed to investigate possible patterns in seasonal variations of generation [7]. The summary results are as follows.

**Pattern-1**

Generation was observed to be high during the two monsoon periods: May to August (South-West monsoon) and October to January (North-East monsoon).

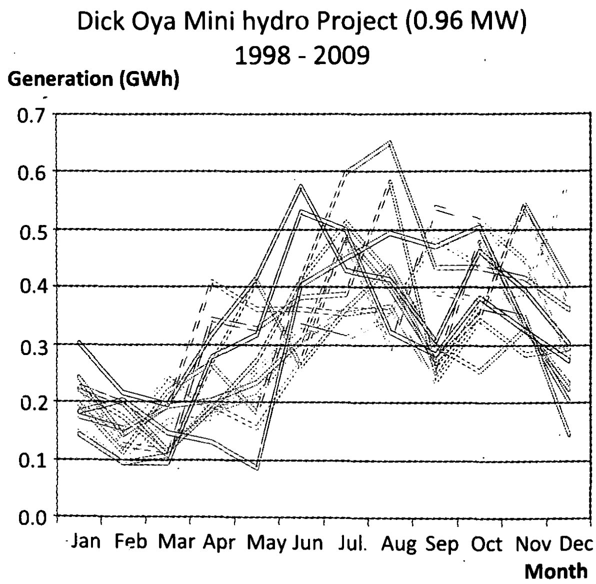


**Figure 2 - Sample Generation of Pattern-1**

Further, generation during the South-West monsoon period was found to be higher than during the North-East monsoon period. Inter-monsoon periods recorded the lowest generation. Twenty one (21) [14] mini hydro plants were found to have similar patterns under this category. Depending on the plant locations, some deviations from the basic pattern were observed but the basic pattern was preserved. A sample pattern is given in Figure 2.

**Pattern-2**

The basic features of pattern 2 were similar to those of pattern-1, except that the generation potential during the North-East monsoon was higher than the potential during the South-West monsoon. Twenty six (26) [14] mini hydro plants were identified to be under this category. A sample pattern is given in Figure 3.

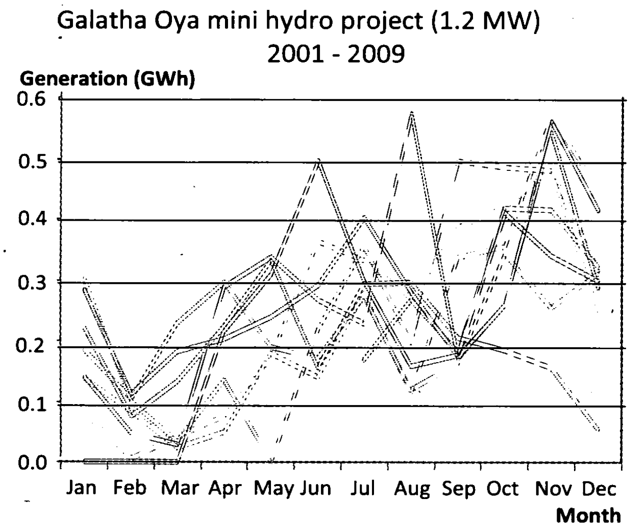


**Figure 3 - Sample Generation of Pattern-2**

**Pattern-3**

Pattern 3 represents the generation dominated by the North-East monsoon period. From the location map of these plants, it was observed that most of the plant catchments did not receive the torrents of South-West monsoon rains due to mountain ranges in the upcountry. Nine (9) [14] mini hydro plants were found to have a pattern under this category. A sample pattern is given in Figure 4.

**Other Patterns**

This refers to all other readings which could not be categorised under any of the patterns defined above. These abnormalities may have been caused by fraudulent readings, improper plants designs and catchment locations that lay in the intercepting areas of two monsoons. Eighteen (18) [14] mini hydro plants were found to have patterns under this category.

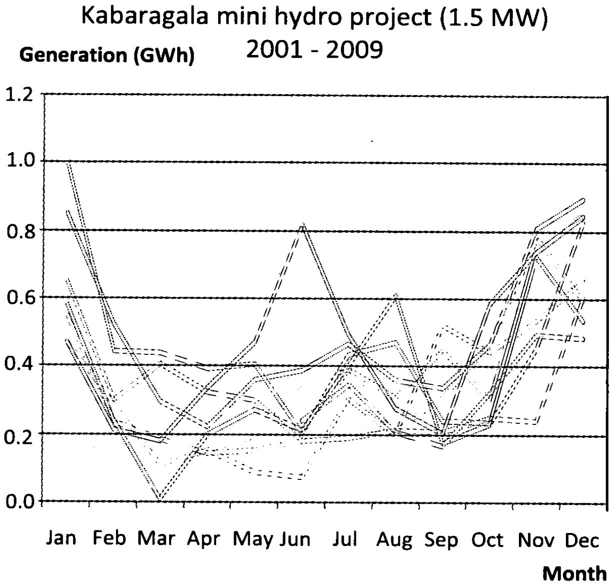


**Figure 4 - Sample Generation of Pattern-3**

The validity of the categorisation into three patterns was further verified with power plant location maps in GIS platform [14]. The requirement of a more detailed study on this was identified, but such a study is beyond the main scope of this study. It was concluded that the model should not be based on one particular pattern but should address all patterns, and that the contribution of each power plant needed to be considered. Monthly generation statistics of all existing mini hydro power plants from 1998 up to 2009 with generation records of at least one year, were included in the model. Hence 74 mini hydro plants (Appendix A2) were used to develop this model. Eight more operational power plants were not considered due to the absence of one year of generation records at the time of the study. The generation capability index (a new index defined by dividing generation by its capacity) was calculated on a monthly basis from 1998 to 2009 for all eligible plants. This approach enabled the smoothening out of the irregularities caused by mid-year commissioning of power plants and differences in installed capacities (this refers to possible capacity enhancement of existing plants and prolonged outages of generation units). Then possible outliers were removed from the data sets. The model was developed on the basis of hydrological months rather than on the basis of hydrological year, due to the following reasons.

- Non-availability of adequate historical data

- WASP software needs monthly generation records

Fine-tuned data sets were structured to enable a probability distribution analysis based on five hydrological conditions. The hydrological conditions defined and their respective weighting factors are given in Table 1.

**Table 1 - Hydrological Conditions and Weighting Factors**

| Hydrological Condition | Weighting |
|---|---|
| Very Wet | 0.1 |
| Wet | 0.2 |
| Medium | 0.4 |
| Dry | 0.2 |
| Very Dry | 0.1 |

This method can accommodate the maximum resolution available in the WASP model. An approximate weighted annual plant factor of 37.44% was observed. For the sake of better understanding detailed figures and values of a capacity addition of 20 MW (please note 20 MW is selected arbitrarily) are given in Figure 5 and Table 3, respectively. The Figure 5 was drawn by calculating the weighted values of the energy and capacity values given in Table 3.

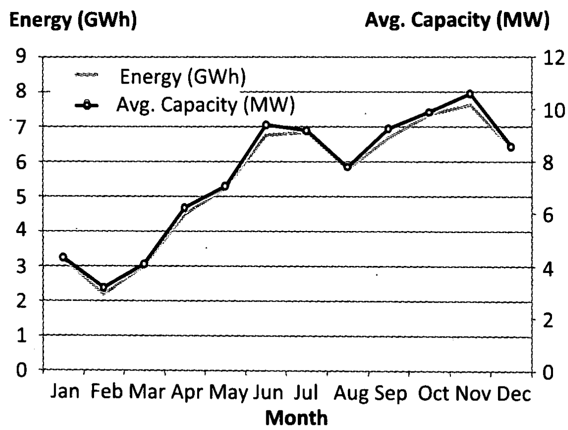


**Figure 5 - Energy and Capacity Variation**

According to the findings, the highest generation potential was recorded in November and the lowest was in February. This result was further verified by comparing with the actual generation records and a summary is given in Table 2. It was seen that the highest generation could be expected in the latter part of a year, and does not directly correlate to the South-West monsoon period which normally provides the highest rainfall. A higher energy is expected from the very wet condition in June compared to November. However, in a very dry condition, monthly energy yield is expected to be reversed, with a higher energy yield in November, compared with June (Please see Table 3). Widely scattered nature of mini hydro plant locations is responsible for this unexpected observation. Thus, regular monitoring of plant performance and updating the model would be vital to preserve its accuracy for future studies.

**Table 2 - Month of Maximum Energy Delivery**

| Year | Month | Year | Month |
|---|---|---|---|
| 1998 | August | 2004 | November |
| 1999 | October | 2005 | November |
| 2000 | October | 2006 | November |
| 2001 | October | 2007 | October |
| 2002 | August | 2008 | December |
| 2003 | November | 2009 | December |

**Table 3 - Typical Results of the Model**

| January | | | February | | |
|---|---|---|---|---|---|
| Prob. | GWh | MW | Prob. | GWh | MW |
| 0.1 | 8.08 | 10.86 | 0.1 | 6.44 | 9.58 |
| 0.2 | 4.98 | 6.70 | 0.2 | 3.58 | 5.33 |
| 0.4 | 2.72 | 3.65 | 0.4 | 1.68 | 2.50 |
| 0.2 | 1.20 | 1.61 | 0.2 | 0.57 | 0.84 |
| 0.1 | 0.88 | 1.18 | 0.1 | 0.54 | 0.80 |
| **March** | | | **April** | | |
| Prob. | GWh | MW | Prob. | GWh | MW |
| 0.1 | 8.28 | 11.13 | 0.1 | 10.59 | 14.70 |
| 0.2 | 4.87 | 6.55 | 0.2 | 6.54 | 9.09 |
| 0.4 | 2.40 | 3.22 | 0.4 | 4.01 | 5.57 |
| 0.2 | 0.93 | 1.25 | 0.2 | 1.96 | 2.72 |
| 0.1 | 0.75 | 1.01 | 0.1 | 1.24 | 1.73 |
| **May** | | | **June** | | |
| Prob. | GWh | MW | Prob. | GWh | MW |
| 0.1 | 12.00 | 16.13 | 0.1 | 14.36 | 19.94 |
| 0.2 | 7.43 | 9.99 | 0.2 | 9.74 | 13.53 |
| 0.4 | 4.70 | 6.31 | 0.4 | 6.42 | 8.91 |
| 0.2 | 2.56 | 3.45 | 0.2 | 3.10 | 4.30 |
| 0.1 | 1.67 | 2.25 | 0.1 | 1.93 | 2.68 |
| **July** | | | **August** | | |
| Prob. | GWh | MW | Prob. | GWh | MW |
| 0.1 | 13.65 | 18.35 | 0.1 | 13.35 | 17.94 |
| 0.2 | 9.96 | 13.39 | 0.2 | 8.46 | 11.37 |
| 0.4 | 6.54 | 8.80 | 0.4 | 5.22 | 7.02 |
| 0.2 | 3.29 | 4.43 | 0.2 | 2.55 | 3.43 |
| 0.1 | 2.04 | 2.75 | 0.1 | 1.69 | 2.27 |
| **September** | | | **October** | | |
| Prob. | GWh | MW | Prob. | GWh | MW |
| 0.1 | 13.83 | 19.21 | 0.1 | 13.72 | 18.44 |
| 0.2 | 9.78 | 13.59 | 0.2 | 9.89 | 13.30 |
| 0.4 | 6.31 | 8.77 | 0.4 | 7.14 | 9.60 |
| 0.2 | 3.13 | 4.35 | 0.2 | 4.41 | 5.93 |
| 0.1 | 1.77 | 2.46 | 0.1 | 2.66 | 3.58 |
| **November** | | | **December** | | |
| Prob. | GWh | MW | Prob. | GWh | MW |
| 0.1 | 13.78 | 19.14 | 0.1 | 13.29 | 17.86 |
| 0.2 | 10.36 | 14.40 | 0.2 | 8.88 | 11.94 |
| 0.4 | 7.26 | 10.08 | 0.4 | 5.87 | 7.89 |
| 0.2 | 4.76 | 6.61 | 0.2 | 3.44 | 4.63 |
| 0.1 | 3.20 | 4.44 | 0.1 | 2.32 | 3.12 |

The model represents a typical Run-of-River (ROR) hydro plant. Although the WASP software version 4.0.1 cannot accommodate an NCRE model separately, provision was made to model mini hydro power plants as an equivalent ROR model with certain limitations. Commissioning of hydro plants each year followed by decommissioning of previous year hydro plants exceeded the maximum permissible number of such operations by the WASP model (a limitation of WASP software) [5], [6] for a moderate planning window of 20 years. This limitation was overcome by only commissioning the expected annual hydro addition on top of the hydro capacity of the previous year. The concept of this is illustrated in Figure 6.

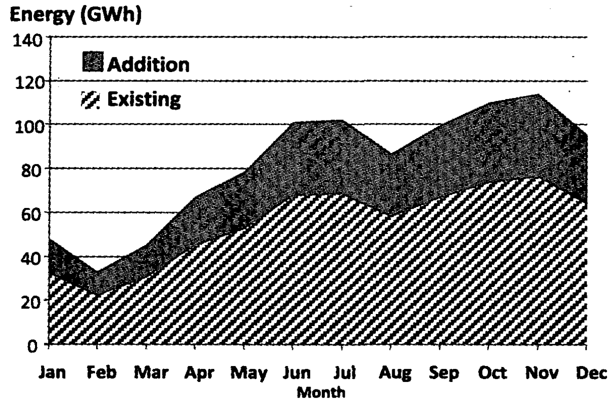


**Figure 6 - Concept of Plant Addition**

# 4. Model Reliability

## 4.1 Sensitivity of the Model

Mini hydro plants were operated for about 10 years. The model sensitivity was verified by comparing with actual past data and the level of accuracy under different capacity additions. The results proved that the model can reach adequate accuracy for long term planning studies.

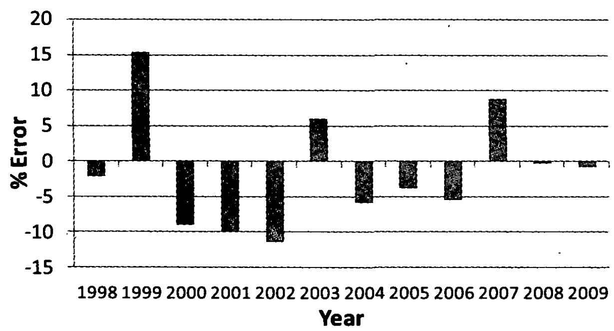


**Figure 7 - Model Error with Actual Figures in the ROR Model**

The error results of the ROR mini hydro model against the actual recordings are given in Figure 7. It was seen that during initial years of the study period, the levels of error were fairly high but with higher installed capacities, the predictions become more accurate. This implies that when the system NCRE penetration increases, the level of error propagation decreases. It is a justifiable assumption that with high economic life of hydro facilities (typically 30 - 50 years), commissioning rate of plants will be fairly high compared with the decommissioning rate. For the next 20 years, it was assumed that the annual commissioning rate of plants will decrease gradually and saturate during the latter part of the planning window. Hence it can be concluded that for the study period of next 20 years, this model works accurately but with periodic revisions as explained earlier.

## 4.2 Adaptability of the Model in WASP

Irrespective of the level of model accuracy; it should conveniently be adopted in the long term planning process. For example, a ROR model (inherently non-dispatchable, embedded generation), never operates to cater to the peak demand. To verify this fact, the model was used in trial runs with WASP tool with tentative figures. After inspecting the output files, it was confirmed that the plant never operates in peak region. Depending on the hydrology data of each hydro plant provided by the user, WASP automatically defines a suitable plant type out of its six predefined plant types [5], [6]. By inspecting the output file, it was observed that WASP always defines the model as a ROR type hydro plant. This was the strongest evidence the model being accurately identified by the software itself. Hence the plant is expected to be delivering energy in base, but never contributed to specifically displace thermal capacity in peak hours. Further, by inspecting the annual energy balance for the study period, energy dispatch with the expected annual plant factor of 37.44 % was also confirmed.

# 5. Model Compatibility and Limitations

The model was used for three scenario studies including (i) an energy policy scenario and (ii) a least cost scenario to verify its accuracy, respectively, (i) in a committed environment and (ii) under economic plant selection. It was verified that the model not only works correctly, but does not hinder the conventional practice of interpreting results such as energy balance, capacity balance and fuel requirements. Since WASP can accommodate only two types of hydro plant categories (up to a maximum of 30 plants from each category) [5], [6] and thereby only two Operation & Maintenance (O & M) costs can be assigned for all hydro equivalent plants. Hence this model is not suitable to assess individual plant characteristics or to measure performance.

## 6. Software Environment

No specific advanced software support has been used in preparation of this mini hydro model. The original data base was created in spread sheets in MS Excel of MS Office package. A considerable number of macro programming needed to be done to automate the analysis process thereby saving time. Mainly due to the requirement of large number of data manipulation, cross-checking & double checking techniques were incorporated by using macros so that minimise generation and propagation of errors in the analysis process. The block diagram of the basic algorithm of how the model is prepared is given in Appendix A3. The results of the model were directly used for the optimisation studies by using WASP software. A briefed explanation of WASP tool is given in Appendix A1.

## 7. Data Preparation for WASP

WASP is a widely used generation expansion optimisation tool (see Appendix A1 for details).

System demand data at 30 minute time intervals for year 2009 were collected from the System Control Centre of CEB. Data records for each month were closely monitored for possible abnormal readings. Several readings on 9th October 2009 were rectified to eliminate the sudden reduction of demand owing to a total blackout. Then the total annual energy demand, annual peak demand and the corresponding calculated annual load factor were crosschecked with corresponding statistical publications of CEB. Then the load duration curve of year 2009 was prepared and used as the basic load duration curve for the study and is given in Figure 8. Load factor variation for the planning period was also addressed. Annual load factor variation forecast prepared by the Generation Planning and Design (GP & D) branch of CEB was directly used for the study. To enhance the level of accuracy, a breakdown of monthly load factors of each year was prepared. It was assumed that Sri Lanka national grid will extend to the Jaffna peninsula by early 2013 and the estimated demand for the northern part of the island will be served from there onwards. All existing, committed and candidate power plants identified by the GP & D branch of CEB were directly used for study

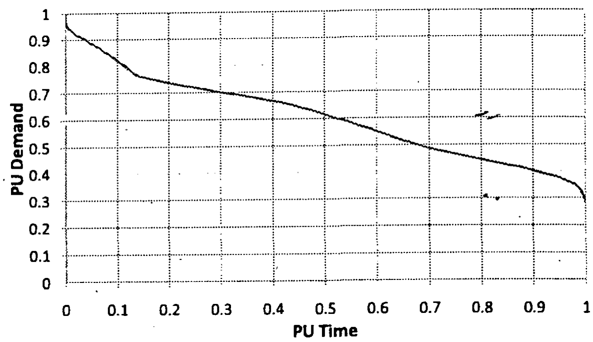


**Figure 8 - Basic Load Duration Curve Year 2009**

with a single exception; the inclusion of pumped storage hydro power plants as a candidate. However, the total pumped storage capacity was limited to 500 MW and the earliest commissioning date was shifted to 2020. Tentative technical and economic data used for the analysis is given in Table 4.

All studies used a moderate discount rate of 10%. No fuel escalation rates were applied for any study and conducted in real terms only.

**Table 4 - Details of the Pumped Storage Plants used in the Study**

| Topic | | Value |
|---|---|---|
| Fixed O & M cost ($/kW-month) | | 0.778 |
| Installed Capacity (MW) | | 125 |
| Cycle Efficiency (%) | | 70 |
| Capital Cost ($/kW) | Foreign | 960 |
| | Local | 240 |
| Interest During Construction | | 19.21 |
| Construction Time (yrs) | | 5 |
| Economic Life (yrs) | | 50 |

A least cost generation expansion study was conducted under the constraint of imposing the maximum permissible NCRE penetration level. The limitations imposed are as follows.

Mini hydro - 15 MW/year

Biomass - 10 MW/year

Wind - 36 MW/year

The dispatch schedule for the period 2011 - 2025 results in maximum mini hydro power plant developments (i.e. 15 MW) each year. The names and capacities of all mini hydro plants (along with the names of developers) used for the preparation of the model are given in Appendix A2.

## 8. Conclusion

The concept of modelling mini hydro power plants as ROR power plants with a five state probabilistic distribution in long term planning is found to be not only realistic but also could achieve the required accuracy. After verifying and testing the model, it was firmly concluded that the model can effectively be used to fill the long felt need of modelling non-dispatchable embedded generation in long-term generation expansion planning studies. Therefore it is recommended to replace the present practise of using lumped thermal equivalent plant model by this new ROR equivalent mini hydro plant model. Also it is important to note that NCRE resources for power generation have to be evaluated not only for their economic viability but also for constraints in grid interconnection, environmental and social impacts, as well.

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## Appendix A1 - Software Tool WASP

WASP is a widely-used generation expansion optimisation tool distributed by International Atomic Energy Agency (IAEA) among its member countries and member institutions. The program utilises probabilistic estimation of system production costs, cost of Energy Not Served (ENS) and reliability, linear programming technique for determining the dispatch policy satisfying constraints such as environmental emissions, fuel availability and optimal electricity generation by some plants, and a dynamic programming technique to optimise the cost of alternative system expansion policies. WASP permits finding the cost of optimal expansion plan for a power generating system over a user defined period (maximum up to 30 years), within the constraints provided by the planner. Every possible sequence of power plant units added to the system (including committed and candidate plants along with the retirement schedule of the existing plants) meeting the constraints defined, is evaluated in terms of economic costs. The objective function (cost function) used for the optimisation is given below.

$$B_j = \sum_{t=1}^{T} \left[ \bar{I}_{j,t} - \bar{S}_{j,t} + \bar{F}_{j,t} + \bar{L}_{j,t} + \bar{M}_{j,t} + \bar{O}_{j,t} \right]$$

Where,

Bj is the cost function for expansion plan j

t is the time in years (1,2,3,......,T)

T is the length of the study period in years

Bar over the symbols represents the discounted values to a given discount rate i

I stands for capital investment

S stands for salvage value of investment cost

F stands for fuel costs

L stands for fuel inventory costs

M stands for non-fuel operation and maintenance costs

O stands for cost of energy not served

WASP software consists of eight sub modules and each module consists of three basic stages as follows.

- Data input
- Run the input file
- Results

A brief account on each of eight modules is given below.

1. LOADSY (LOAD SYStem description)

   Data related to the expected system load demand for the total study period
2. FIXSYS (Fixed SYStem description)

   Data related to all existing and committed plants. This module basically includes hydro, thermal and pumps storage plants.
3. VARSYS (VARiable SYStem description)

   Data related to all candidate hydro, thermal and pump storage plants.
4. CONGEN (CONfiguration GENerator)

   Provides plant selection configuration user defined system constraints such as Reserve Margin, etc.
5. MERSIM (Merge and Simulate)

   Run the model for all technically feasible system configurations
6. DYNPRO (DYNamic PROgraming Optimisation)

   Economic evaluation of all technically feasible solutions and verifying the least cost paln
7. REMERSIM (REMERSIM Procedure)

   Basically run MERSIM file for the least cost plan
8. REPROBAT (Report Writer)

   Prepare a final report on the completed analysis

The key parameters used for the input files of WASP are fuel costs, operation and maintenance costs of plants (Fixed and Variable components), pure capital costs (Foreign and Local components), cost of Energy Not Served (ENS - 1.196 US$/kWh), etc were updated and appropriately escalated (both for local and foreign components) if applicable. Technical and other relevant data such as rated unit capacities, minimum operating levels, economic plant life, construction period for power plants, reserve margin, Loss of Load Probability (LOLP - 0.822%) constraints, spinning reserve, Interest During Construction (IDC), Forced Outage Rates (FOR), planned outages of plants, heat rates applicable to thermal plants, heating values of fuels, expected emission levels, etc.

## Appendix A2: List of Mini Hydro Plants used for the Model

| Plant & Developer Name | Capacity (MW) | Plant & Developer Name | Capacity (MW) | Plant & Developer Name | Capacity (MW) |
|---|---|---|---|---|---|
| **Dickoya MHP**, Hydro Tech Lanka Ltd | 0.960 | **Brunswick MHP**, Maskeliya Plantations Ltd | 0.600 | **Labuwawa MHP** - Aqua Power (Pvt) Ltd | 2.000 |
| **Seetha Eliya MHP**, Seetha Eliya Tea Factory | 0.072 | **Sitagala MHP**, Energy Reclamation (Pvt) Ltd | 0.800 | **Kolapathana MHP** - Natural Resources Hydro Power (Pvt) Ltd | 1.100 |
| **Rakwanaganga MHP**, Zyrex Power Co. Ltd | 0.760 | **Way Ganga MHP**, Didul (Pvt) Ltd | 8.925 | **Nilambe Oya MHP** - Weswin Power Galaha (Pvt) Ltd | 0.747 |
| **Thalawakelle MHP**, Maskeliya Plantations Ltd | 0.112 | **Alupola MHP**, Eco Power (Pvt) Ltd | 2.522 | **Gurugoda Oya MHP** - Bhoruka power Lanka (Pvt) Ltd | 4.480 |
| **Kolonne MHP**, Ceylon MKN Eco Power (Pvt) Ltd | 0.780 | **Rathganga MHP**, Panasian Power (Pvt) Ltd | 2.000 | **Guruluwana MHP** - Samangiri Hydroelectric Co (Pvt) Ltd | 2.000 |
| **Weddemulle MHP**, Agalawatte Plantations Ltd | 0.200 | **Erathna (Waranagala) MHP**, Vallibel Power Erathna Ltd | 9.900 | **Forest Hill MHP** - Nora & Nera Hydro Power (Pvt) Ltd | 0.300 |
| **Ellapita Ella MHP**, Eco Power (Pvt) Ltd | 0.550 | **Nakkawita MHP**, Weswin Construction Nakkawita (Pvt) Ltd | 1.008 | **Batatota MHP** - Vidullanka (Pvt) Ltd | 2.000 |
| **Carolina MHP-I**, Mark Marine Services (Pvt) Ltd | 2.500 | **Gampola Walakada MHP**, Pantak Power Co Ltd | 4.206 | **Kehelgamu Oya MHP-I** - Pams Hydro (Pvt) Ltd | 3.000 |
| **Mandagal Oya MHP**, Eco Power (Pvt) Ltd | 1.284 | **Miyanawita Oya MHP**, Midland Energy (Pvt) Ltd | 0.600 | **Kotanakanda MHP** - Pasindu Power (Pvt) Ltd | 0.150 |
| **Delgoda MHP**, Zyrex Power Co. Ltd | 2.650 | **Atabage Oya MHP**, Hydrodynamics (Pvt) Ltd | 2.200 | **Lower Neluwa MHP** - Neluwa Cascade Hydro Power (Pvt) Ltd | 1.450 |
| **Glassaugh MHP**, Eco Power (Pvt) Ltd | 2.526 | **Battalgala MHP**, Kelani Valley Plantations Ltd | 0.100 | **Barcaple MHP**-Didul (Pvt) Ltd. | 2.000 |
| **Minuwanella MHP**, Sunro Co (Pvt) Ltd | 0.640 | **Hemingford MHP**, Paulownia Plantations (Pvt) Ltd | 0.180 | **Kadawala MHP-I**-Unit Energy Lanka (Pvt) Ltd | 4.850 |
| **Kabaragala MHP**, Natural Power (Pvt) Ltd | 1.500 | **Kotapola (Kiruwana Oya) MHP**, Nilwalabase Hydro Power (Pvt) | 0.600 | **Black Water MHP** - Black Water Power (Pvt) Ltd | 1.650 |
| **Bambarabotuwa Oya MHP**, Vidulanka Ltd | 3.200 | **Wee Oya MHP**, Powerbase Technology (Pvt) Ltd | 3.000 | **Koswatta Ganga MHP**-Weswin Power (Pvt) Ltd | 2.000 |
| **Galatha Oya MHP**, Hydrodynamics (Pte) Ltd | 1.200 | **Radella MHP**, Talawakelle Plantations Ltd | 0.200 | **Kadawala MHP-II**- Saman Jala Viduli Company(Pvt) Ltd. | 1.320 |
| **Hapugastenne-I**, Eco Power Power (Pvt) Ltd | 4.602 | **Kumburuteniwela MHP**, Ceypower Cascades (Pvt) Ltd Ltd | 2.800 | **Loggal Oya MHP**-Cey Hydro Developers (Pvt) Ltd | 3.000 |
| **Belihul Oya**, Nividu (Pvt) Ltd | 2.500 | **Assupiniella MHP**, Nividhu Assupiniella (Pvt) Ltd | 4.000 | **Manelwala MHP**-Manelwala Hydro Power (Pvt.) Ltd | 2.400 |
| **Carolina-II**, Mark Hydro (Pvt) Ltd | 1.300 | **Kalupahana MHP** - Kalupahana Power Co (Pvt) Ltd | 0.800 | **Somerset MHP** - TTEL Somerset Hydro Power (Pvt) Ltd | 0.800 |
| **Niriella MHP**, Powerbase Technology (Pvt) Ltd | 3.000 | **Upper Korawaka MHP** - Santak Power (Pvt) Ltd | 1.500 | **Sheen MHP** - Elpitiya Plantations Ltd. | 0.560 |
| **Hapugastenne-II**, Eco Power (Pvt) Ltd | 2.301 | **Coolbawn MHP** - Coolbawn Hydro (Pvt) Ltd | 0.750 | **Palmerston MHP** - TTEL Hydro Power Company (Pvt) Ltd. | 0.600 |
| **Deiyanwala MHP**, Hydro Jet (Pvt) Ltd | 1.500 | **Henfold (Agra Oya) MHP** - Senok Mark Hydro (Pvt) Ltd | 2.600 | **Giddawa MHP** - Giddawa Hydro Power (Pvt) Ltd. | 2.000 |
| **Hulu Ganga MHP-I&II**, Eco Power (Pvt) Ltd | 6.500 | **Dunsinane MHP** - Dunsinane Power Co (Pvt) Ltd | 2.700 | **Magal Ganga MHP** - Magal Ganga Power Co.(Pvt) Ltd | 9.928 |
| **Ritigaha Oya Phase II**, Serendib Energy (Pvt) Ltd | 0.800 | **Delta MHP** - Hydro Power Free Lanka (Pvt) Ltd | 1.300 | **Soranathota MHP** -Access Energy (Pvt) Ltd | 1.400 |
| **Sanquhar MHP**, Hydro Power Free Lanka (Pvt) Ltd | 1.600 | **Gomala Oya MHP** - Bhagya Hydro (Pvt) Ltd | 0.800 | **Lower Atabage Oya MHP** - Agrodynamics (Pvt) Ltd | 0.450 |
| **Kandureliya (Karawila Ganga) MHP**, Kandureliya Hydro Power | 0.750 | **Kudah Oya MHP** - Hydrotrust Lanka (Pvt) Ltd | 2.000 | | |

## Appendix A3: Basic Algorithm of the ROR Equivalent Mini Hydro Model