FEASIBILITY OF SCHEDULED RUNNING OF EXISTING MINI HYDRO POWER PLANTS

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DECLARATION

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ABSTRACT

The Electricity system load profile of Sri Lanka has a high evening peak demand and as a result has a low load factor.

The load curve has a close relationship with the human behavior and other economic activities of the country, having a morning peak, Day peak and a night peak. Even though it is desirable to have a flat load curve, due to this behavioral impact, the curve is having rather large variations. The extent of variation is so substantial that the maximum demand is having a greater value, which is about 2.24 times of the minimum demand.

During the dry season water level of the large hydro reservoirs is getting decrease rapidly and system demand fulfill by thermal generation of CEB and Private Power Plants. Therefore most of the high cost small thermal generators should be operated in the evening peak hours. Hence, CEB has to pay additional cost for power generation than income earns from electricity selling to the customer.

That reason is happened to fulfill the peak demand using high cost thermal generation. The objective of this feasibility study is prepared the system of scheduled running for existing mini hydro power plants to reduce high cost thermal generation at evening peak hours. The study has contained the energy mix of Sri Lanka, behavior of thermal generation in future, present mini hydro running pattern, possibility of schedule running of existing mini hydro plants and prepare the generalized system to operate mini hydro plant for schedule running.

According to the results, some of mini hydro plants in the existing system can operate under the scheduled running and the results of scheduled mini hydro plants have affect to reduce high cost thermal generation by small thermal generators.

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1.0 INTRODUCTION

1.1 Background

Renewable energy sources are continuously replenished by natural processes. Renewable energy system converts the energy found in sunlight, wind, falling water, sea-waves, geothermal heat or biomass into a form we can use such as heat or electricity without exhausting the source. Most of the renewable energy comes either directly or indirectly from sun and wind and can never be exhausted, and therefore they are called renewable.

Sri Lanka has exploited large conventional renewable resources (hydro) to almost its maximum economical potential. Non-Conventional Renewable Energy (NCRE) has become a prime potential source of energy for the future due to the low impact on environment compared with conventional sources of energy. Sri Lanka has a history of enabling local development of renewable energy resources in the electricity systems. This includes

- Hydro Power
- Wind Power
- Biomass (Dendro Power, Power from Agricultural & Industrial Waste)
- Solar Power
- Power from Municipal Solid Waste

As of 31st December 2015, approximately 455 MW of embedded NCRE plants are connected to the National Grid. Out of this, contribution from mini hydro is 306 MW while biomass penetration is 24 MW. Contribution to the system from solar power and wind power is 1.4 MW and 124 MW respectively.

According to the National Energy Policy and Strategies of Sri Lanka, the government reached minimum level of 10% of electrical energy supplied to the grid from Non-Conventional Renewable Energy sources by year 2015. Further, government of Sri Lanka has revised the target to reach 20% of electricity supply is expected to be generated by renewable energy by year 2020.

Currently, for a typical week day the total electricity generation in Sri Lanka is around 32 GWh. Also, the System Load Profile of Sri Lanka on a typical day is given in Figure 1. In this particular profile following characteristics can be identified.

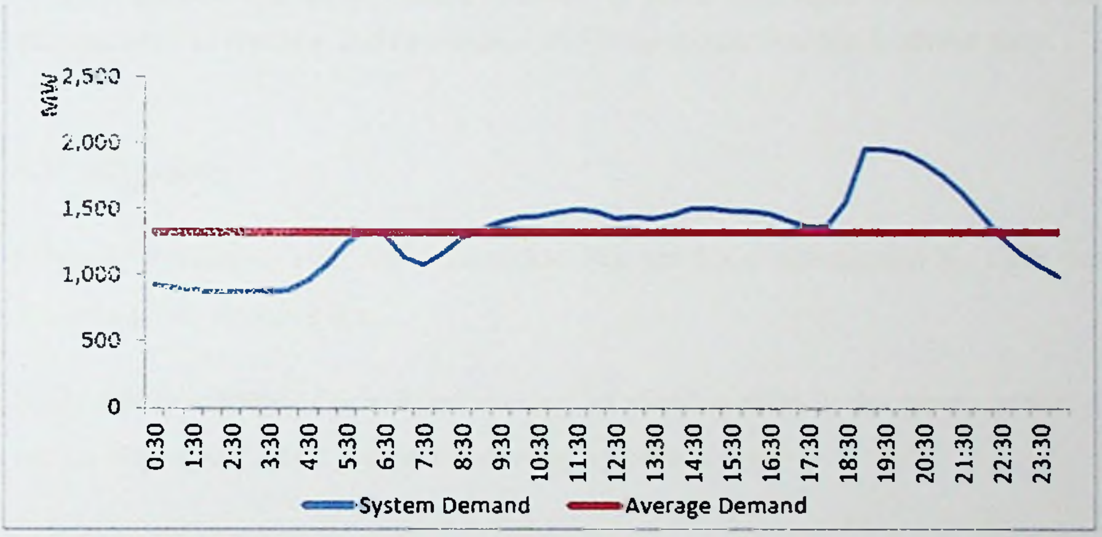


Figure 1: System Demand Curve & Average Demand Curve as at 01/09/2015

Maximum demand = 1954.7MW, has occurred at 19:00Hrs

Minimum demand = 871.6 MW, has occurred at 02:00Hrs

Average Demand = 1325.6 MW, is shown by a red line.

According to above mentioned typical demand curve, it has shown large variation away from the average demand during the period of day and night. It may cause very difficult situation to meet required demand, especially during the night peak in dry season.

1.2 Motivation

The water levels of reservoirs used for hydroelectricity have gone down to critical levels, making it difficult for the Ceylon Electricity Board (CEB) to meet the current demand. Because of that CEB schedule their power generation by considering the requirement of Water Board for drinking water demand and Irrigation Department for cultivation purpose.

During the dry season CEB has no alternatives without going to power cut. To mitigate this issue, CEB purchase high cost thermal power generation from private parties to meet required demand. Finally, the result will be the money loss of CEB.

As an Engineer, the author was motivated to select this topic to investigate and analysis present scenario and to mitigate the CEB income loss due to above facts.

1.3 Objective

Effect of scheduled mini hydro operation has not been investigated by CEB yet. Therefore, the objective is to,

Study the feasibility of scheduled running of existing mini hydro power plants to reduce high cost thermal generation at evening peak hours.

1.4 Scope of the Work

1. Data Collection
    - Conduct detail analysis of the electricity system load profile to find out present characteristics and future trends of the generation.
    - Data collection & running patterns of MHP during the dry season.
      Available Capacity of the MHPs
      Possible Capacity of the MHPs
      Present Operation Pattern
    - Calculate & Analyze the storage capacity of MHP and possible operate time under that storage capacity.

- Scheduling, Dispatching & Monitoring the pattern of the operations of mini hydro plant during peak hours.
- Comparative benefit analysis from high cost thermal generation to mini hydro generation and find out cost benefit analysis to the social, to suppliers and to the CEB.

2.0 THEORETICAL DEVELOPMENT

2.1 Generation Capacity Mix in Sri Lanka

The existing CEB generating system is mostly based on hydro power (i.e. 1376.95 MW hydro power out of 2820.95 MW of total CEB installed capacity). Approximately 49% of the total existing CEB system capacity is installed in 17 hydro power stations. In 2014, only 29.4 % of the total energy demand was met by the hydro plants, compared to 50% in 2013.

The major hydropower schemes already developed are associated with Kelani and Mahaweli river basins. Five hydro power stations with a total installed capacity of 354.5 MW (26% of the total hydropower capacity) have been built in two cascaded systems associated with the two main tributaries of Kelani River, Kehelgamu Oya and Maskeliya Oya (Laxapana Complex). Castlereigh and Moussakelle are the major storage reservoirs in the Laxapana hydropower complex located at main tributaries Kehelgamu Oya and Maskeliya Oya respectively. Castlereigh reservoir with storage of 60 MCM feeds the Wimalasurendra Power Station of capacity 2 x 25 MW at Norton-bridge, while Canyon 2 x 30 MW is fed from the Moussakelle reservoir of storage 115 MCM.

The development of the major hydro-power resources under the Mahaweli project added seven hydro power stations (Ukuwela, Bowatenna, Kotmale, Upper Kotmale, Victoria, Randenigala and Rantambe) to the national grid with a total installed capacity of 812 MW (59% of the total hydropower capacity with including three major reservoirs, Kotmale, Victoria and Randenigala). The latest power station in this system is 150MW Upper Kotmale hydro power plant.

Polgolla - diversion weir (across Mahaweli Ganga) diverts Mahaweli waters to irrigation systems via Ukuwela power station (40MW). After generating electricity at Ukuwela power station the water is discharged to Sudu Ganga, upstream of Amban

Ganga, which carries water to Bowatenna reservoir. It then feeds both Bowatenna power station (40 MW) and mainly Mahaweli System-H by means of separate waterways. Water discharged through Bowatenna power station goes to Elahera Ela and is available for diversion to Mahaweli systems D and G.

Unlike the Laxapana cascade, the Mahaweli system is operated as a multi-purpose system. Hence power generation from the associated power stations is governed by the down-stream irrigation requirements as well. These requirements being highly seasonal constrain the operation of power stations during certain periods of the year.

Samanalawewa hydro power plant of capacity 120 MW was commissioned in 1992. Samanalawewa reservoir, which is on Walawe River and with storage of 278 MCM, feeds this power plant. Kukule power project which was commissioned in 2003, is run-of river type plant located on Kukule Ganga, a tributary of Kalu Ganga. Kukule power plant is 70 MW in capacity and which provides an average of 300 GWh of energy per year.

The contribution of the three small hydro plants (Inginiyagala – 11.25 MW, UdaWalawe – 6 MW and Nilambe – 3.2 MW) to the National Grid is comparatively small (20.45 MW) and is dependent on irrigation water releases from the respective reservoirs.

Majority of the present thermal power generating capacity in the country is owned by CEB with a total capacity of 1444 MW. It is made up of Puttalam Coal plant 900 MW, Kelanitissa Gas Turbines 195 MW, Kelanitissa Combined Cycle plant 165 MW, Sapugaskande Diesel plants 160 MW, Colombo Barge 64 MW and 24 MW diesel plant at Chunnakam. The Puttalam Coal plant 900 MW funded by EXIM Bank China commissioned in 2011 (Phase I) and 2014 (Phase II) was the latest thermal power plant addition to the CEB system.

Apart from the thermal generating capacity owned by CEB, a 163 MW combined cycle power plant was commissioned in October 2003 by AES Kelanithissa (Pvt) Ltd at Kelanithissa and a 270 MW combined cycle power plant at Kerawalapitiya was commissioned in May 2010 by West Cost Power (Pvt) Ltd. Furthermore, a 51 MW plant at Sapugaskanda commissioned in June 1998 by Asia Power Ltd and a 30 MW plant at Jaffna commissioned in 2009 by Northern Power (Pvt) Ltd as furnace oil plants.

Government of Sri Lanka has taken a policy decision to develop hydropower plants below 10 MW capacities by the private sector. Many small hydro plants and other renewable power plants have been connected to the system since 1996. Total capacity of these plants is approximately 455 MW as at 31st December 2015. These plants are mainly connected to 33 kV distribution lines.

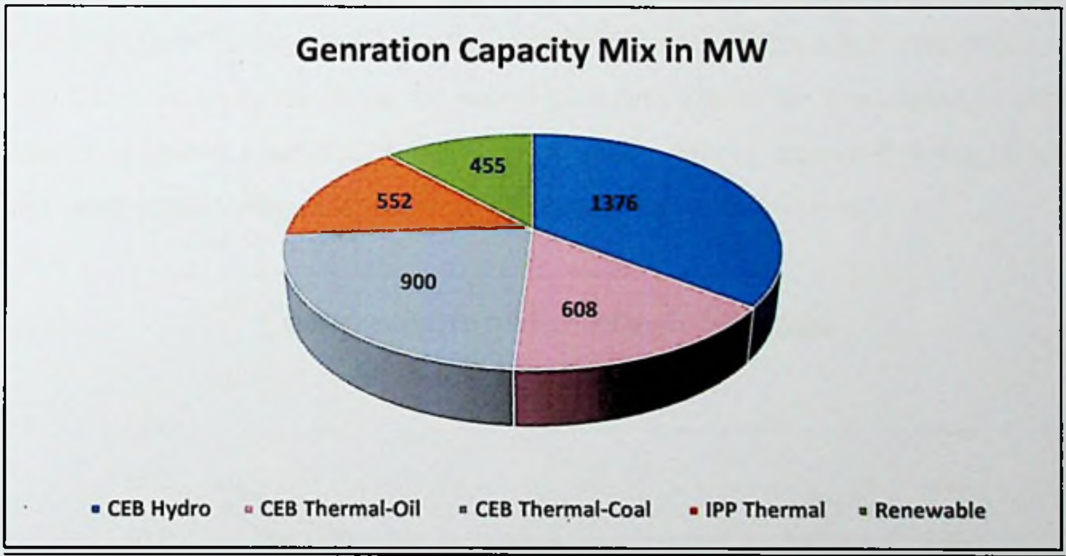


Figure 2: Generation Capacity Mix in Sri Lanka

2.2 Reservoirs Storages

Hydro power is one of the major sources of electricity generation in the Sri Lanka and most of the large scale hydro projects have been developed by CEB. The major hydropower schemes already developed are associated with Kelani and Mahaweli river basins. Maskeli Oya, Castlereigh and Moussakelle are the major storage reservoirs in the Laxapana complex and these all reservoirs are mainly used for power generation purpose. However, Mahaweli complex is difference from Laxapana complex. Because of that the reservoirs which are operating under Mahaweli complex are given priority for irrigation purpose and water release is controlled according to the irrigation plan. Kotmale, Victoria and Randenigala are three major reservoirs in Mahaweli complex.

In addition to above mentioned reservoirs Samanalawewa, which is on Walawe River, also can be considered as a large reservoir. And all the other small reservoirs which contribute to power up the run-of-river type plants are considered as ponds. Therefore having a satisfactory capacity of water in these reservoirs throughout the year is essential to dispatch the hydro power to a significant amount.

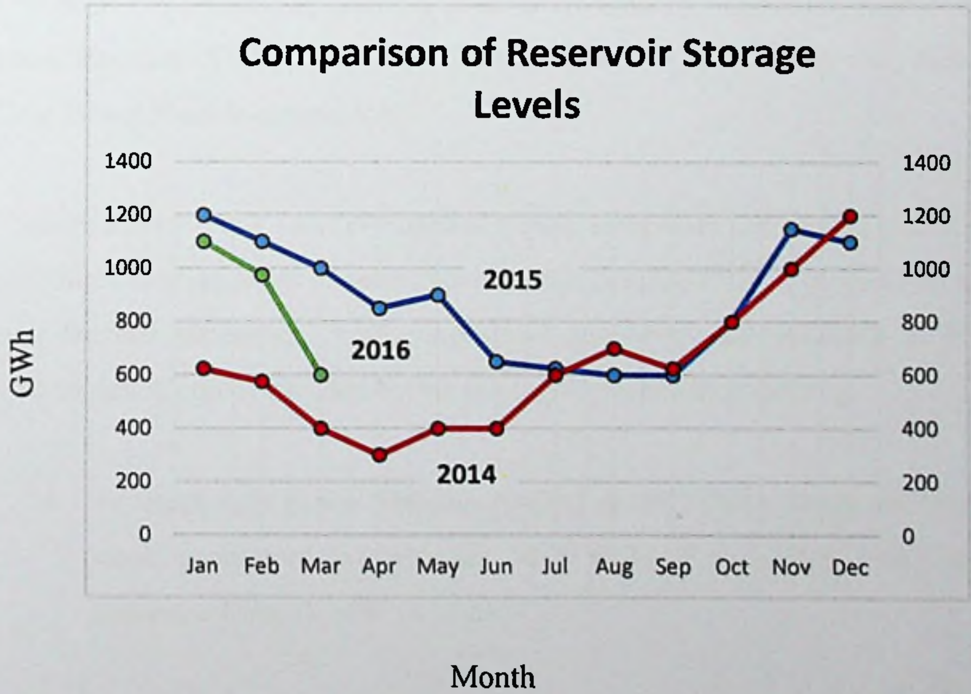


Figure 3: Comparison of Reservoir Storage Levels

2.3 High Cost Thermal Generation in Sri Lanka

Majority of the present thermal power generating capacity in the country is owned by CEB with a total capacity of 1444MW. It is made up of Puttalam Coal plant 900MW, Kelanitissa Gas Turbines 195MW, Kelanitissa Combined Cycle plant 165MW, Sapugaskande Diesel plants 160MW and 24MW diesel plant at Chunnakam.

Apart from the thermal generating capacity owned by CEB, a 163 MW combined cycle power plant was commissioned in October 2003 by AES Kelanithissa (Pvt) Ltd at Kelanithissa and a 270 MW combined cycle power plant at Kerawalapitiya was commissioned in May 2010 by West Cost Power (Pvt) Ltd. Furthermore, a 51 MW plant at Sapugaskanda commissioned in June 1998 by Asia Power Ltd, a 30 MW plant at Jaffna commissioned in 2009 by Northern Power (Pvt) Ltd as furnace oil plants.

All above mentioned plants are operated by using Auto Diesel, Naphtha or Heavy Furnace Oil. These fuel types are high cost in the fuel market and therefore unit of generation cost is also high when compare with hydro generation. During the dry season in Sri Lanka still evening peak is covered by supporting high cost thermal plant. Because of that the country demand is unable to fulfill by only Norochcholei Coal Power Plant in dry season.

This feasibility study has developed a system to operate mini hydro plants under the scheduled running basis to cater evening peak demand fully or partially to avoid high cost thermal generation. Following small generators are available in the present system which can be avoided by the mini hydro scheduled running.

- Sapugaskanda Power Station – Station-A (64 MW) – There are four numbers small generators available as 16 MW each with load variation of each generator from 11 MW to 16 MW.

- Sapugaskanda Power Station – Station B (72 MW) – There are eight numbers small generators available as 9 MW each with load variation of each generator from 7 MW to 9 MW.
- Uthuru Janani Power Station (24 MW) – There are three numbers of small generators available as 8 MW each with load variation of each generator from 6 MW to 8 MW.
- Kelanithissa Power Station – Small GT (48 MW) – There are three numbers of small generators available as 16 MW each with load variation of each generator from 10 MW to 16 MW.
- Asia Power Station (48 MW) – There are eight numbers of small generators available as 6 MW each with load variation of each generator from 4 MW to 6 MW.

2.4 Merit Order of High Cost Thermal Small Generators

When the demand is fulfilled by existing generation, CEB has introduced the merit order which is prepared by considering many facts & information of the generation options. Basically it depends on the fixed cost and variable cost. Also that include unit cost, startup-stop cost, incremental cost and no load heat rate cost per hour.

According to that small generators are placed on evening peak at different places to fulfill peak demand which is shown well in dry season. The merit order decide the place and requirement of high cost small generator.

System Control Center has prepared & published merit order dispatch schedule based on average unit cost. Now a days, Small GT Kelanithissa is the highest average unit cost as Rs. 51.35. Average unit cost of all existing plants are listed below.

Table 1: Present Merit Order List of Small Generators

Plant Name	Fuel Type	No of Units	Average Unit Cost
Small GT – Kelanithissa	Auto Diesel	3 x 16 MW	Rs. 51.35
Asia Power – Sapugaskanda	HFO	8 x 6 MW	Rs. 21.76
Uthuru Janani – Jaffna	HFO	3 x 8 MW	Rs. 19.54
Sapugaskanda – Phase A	HFO	4 x 16 MW	Rs. 19.42
Sapugaskanda – Phase B	HFO	8 x 9 MW	Rs. 17.80

System controller call high cost thermal plants to dispatch during the evening peak hours based on their average unit cost. Following figure has shown demand variation during the evening peak demand and it helps to get an idea about the portion of demand which can be covered by mini hydro generation.

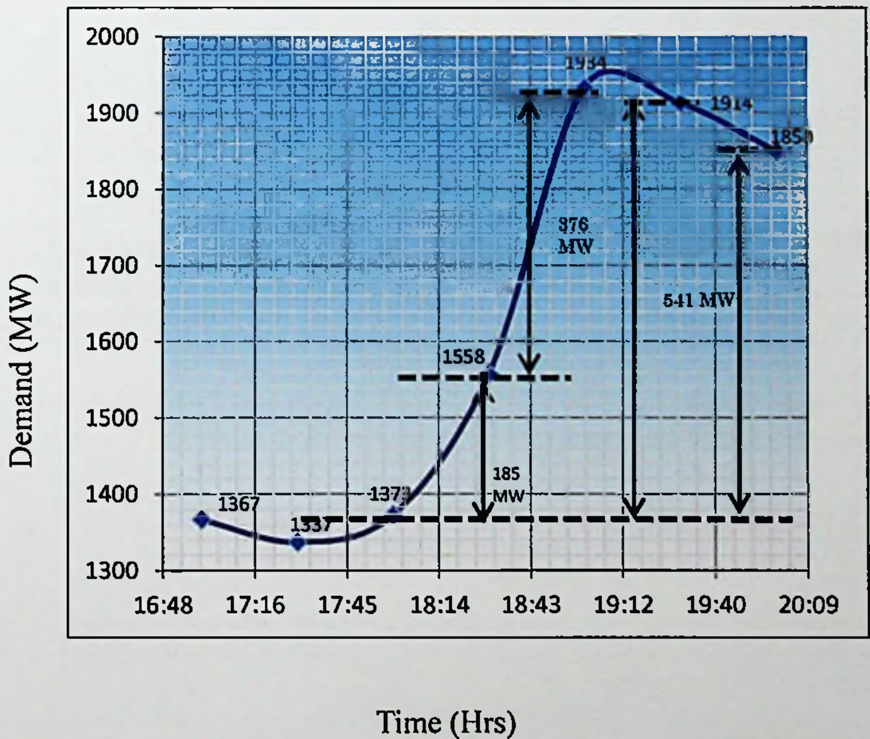


Figure 4: Night Peak of the Load Curve on 01/09/2015

2.5 Thermal Generation in future

Table 2: The Results of Generation Expansion

YEAR	RENEWABLE ADDITIONS	THERMAL ADDITIONS	THERMAL RETIREMENTS
2015	-	4x15 MW CEB Barge Power Plant	4x15 MW Colombo P. Plant 14x7.11 MW Ace Power Embilipitiya
2016	-	-	-
2017	35 MW Broadlands HPP 120 MW Uma Oya HPP	-	4x17 MW Kelanitissa Gas Turbines
2018	100 MW Mannar Wind Park Phase I	2x35 MW Gas Turbine	8x6.13 MW Asia Power
2019	-	1x35 MW Gas Turbine	4x18 MW Sapugaskanda diesel
2020	31 MW Moragolla HPP 15 MW Thalpitigala HPP 100 MW Mannar Wind Park Phase II	2x250 MW Coal Power Plants Trincomalee Power Company Limited	4x15 MW CEB Barge Power Plant 6x5 MW Northern Power
2021	50 MW Mannar Wind Park Phase II	-	-
2022	20 MW Seethawaka HPP 20 MW Gin Ganga HPP 50 MW Mannar Wind Park Phase III	2x300 MW New Coal Plant – Trincomalee -2, Phase – I	-
2023	25 MW Mannar Wind Park Phase III	163 MW Combined Cycle Plant (KPS – 2)	163 MW AES Kelanitissa Combined Cycle Plant 115 MW Gas Turbine 4x9 MW Sapugaskanda Diesel
2024	25 MW Mannar Wind Park Phase III	1x300 MW New Coal plant – Southern Region	-
2025	1x200 MW PSPP 25 MW Mannar Wind Park Phase III	-	4x9 MW Sapugaskanda Diesel Ext.
2026	2x200 MW PSPP	-	-
2027	-	1x300 MW New Coal plant – Southern Region	-
2028	-	-	-
2029	-	1x300 MW New Coal plant – Trincomalee -2, Phase – II	-
2030	-	1x300 MW New Coal plant – Trincomalee -2, Phase – II	-
2031	-	-	-
2032	-	2x300 MW New Coal plant – Southern Region	-
2033	-	-	165 MW Combined Cycle Plant (KPS) 163 MW Combined Cycle Plant (KPS –2
2034	-	1x300 MW New Coal plant – Southern Region	-

Several thermal power generation technologies were considered on the long term generation planning conducted by Ceylon Electricity Board (CEB) and it was recently published by the CEB. Following options are considered as the thermal power generation technologies for the future:

I. Coal Fired Thermal Power Plant
II. Oil fired Combined Cycle Power Plants
III. Oil fired Gas Turbine Plants
IV. Natural Gas fired Combined Cycle Power Plant
V. Super Critical Coal Fired Thermal Power Plant
VI. Nuclear Power Plant

2.5.1 Petroleum products

In the present context, all fossil fuel-based thermal generation in Sri Lanka would continue to depend on imports fuels. (However, it should be noted that oil exploration activity is presently on going in the Mannar basin). Ceylon Petroleum Corporation (CPC) presently provides all petroleum products (Auto Diesel, Fuel oil, Residual Oil, Naphtha) required for thermal power stations. In this feasibility study, oil prices used were obtained from Ceylon Petroleum Corporation and adjusted to reflect the economic values.

2.5.2 Coal

Coal is a commonly used fuel options for electricity generation in the world. CEB has identified coal as an economically attractive fuel option for electricity generation in 1980's. But No coal plants were built until 2011 due to several environmental and social issues. At present, 900MW first coal power plant is in operation at Puttalam which was built in three stages. However, coal power plant couldn't develop when it reach 60% of the total generation.

2.5.3 Liquefied Natural Gas

Liquefied Natural Gas (LNG) as a fuel for Gas Turbine and Combined Cycle plants is an attractive option from environmental perspective. LNG supply in Sri Lanka would add diversification to the country's fuel mix and in turn for the energy mix. Moreover, LNG has the advantage that it is readily burnt in combustion turbines which are characterized by high efficiency. There is no commercially developed gas field in Sri Lanka though discoverable gas reserves have been identified. India, Bangladesh and other gas sources are located far from Sri Lanka, which makes cross border pipeline projects economically unattractive. Hence natural gas transport by means of shipping as LNG is a better option for Sri Lanka.

2.5.4 Natural Gas

Natural Gas In September 2007, the Petroleum Resources Development Secretariat (PRDS) which was established under the Petroleum Resources Act, N0 26 of 2003 to ensure proper management of the petroleum resources industry in Sri Lanka, launched its first Licensing Round for exploration of oil and gas in the Mannar Basin off the north-west coast and in 2008 exploration activities initiated with the awarding of one exploration block (3000 sqkm) in Mannar Basin. Two wells namely 'Dorado and 'Barracuda' have been drilled, 'Dorado' indicates the availability of natural gas and it is estimated to have approximately 300 billion cubic feet of recoverable gas reserves. It is estimated that it could cater 1000MW capacity for approximately 15 years with a plant factor of 30-50%.

2.5.5 Nuclear

Nuclear plants are inherently large in capacity compared to other technologies for power generation. From technical point of view, the capacity of the present system is considerably small to accommodate a Nuclear power plant of typical size. However, cabinet approval has been given to consider nuclear as an option to meet the future energy demand and also to consider Nuclear Power in the present generation planning exercise and to carried out a pre-feasility study on the Nuclear Option.

Nuclear option was included in to the recently published generation plan as a candidate plant from year 2030 onwards.

2.6 Mini Hydro Development of Sri Lanka

Government of Sri Lanka established the Sustainable Energy Authority (SEA) on 01st October 2007, enacting the Sri Lanka Sustainable Energy Authority Act No. 35 of 2007 of the Parliament of the Democratic Socialist Republic of Sri Lanka. SEA is expected to develop indigenous renewable energy resources and drive Sri Lanka towards a new level of sustainability in energy generation and usage; to declare energy development areas; to implement energy efficiency measures and conservation programmes; to promote energy security, reliability and cost effectiveness in energy delivery and information management.

The objective of the SEA is to identify, promote, facilitate, implement and manage energy efficiency improvements and energy conservation programmes in domestic, commercial, agricultural, transport, industrial and any other relevant sector. SEA will guide the nation in all its efforts to conserve energy resources through exploration, facilitation, research & development and knowledge management in the journey of national development. Also SEA will promote energy security, reliability and cost-effectiveness of energy delivery to the country by policy development and analysis and related information management. Further the authority will ensure that adequate funds are available to implement its objects, consistence with minimum economic cost of energy and energy security for the nation, thereby protecting natural, human and economic wealth by embracing best sustainability practices. Relating to power development, SEA will hold two key sensitive parts namely declaration of energy development area and on-grid & off-grid renewable energy resources. CEB and SEA will have to play a complementary role to each other in the future in order to optimize the power generation from NCRE.

The existing mini hydro capacity of 308.9 MW was considered and annual capacity additions were taken according to the NCRE development targets for the study. According to the records of Energy Purchase Branch of CEB, the present status of the NCRE development has shown as follows.

Table 3: Present Status of Non-Conventional Renewable Energy (NCRE) up to 31st December 2015

No	Description	Project Type	No. of Projects	Capacity (MW)
1.	Commissioned Projects	**Mini Hydro Power**	**156**	**308.859**
		Wind Power	15	123.850
		Biomass-Agri. & Industrial Waste	4	13.080
		Biomass – Dendro Power	4	10.520
		Solar Power	3	1.360
		Total - Commissioned	182	457.669
2.	Standardized Power Purchase Agreements (SPPA) Signed Projects	**Mini Hydro Power**	**79**	**136.898**
		WindPower	1	1.100
		Biomass-Agri. & Industrial Waste	1	2.500
		Biomass – Dendro Power	11	53.740
		Biomass-Municipal Waste	1	10.000
		Solar Power	7	70.000
		Total – SPPA Signed	100	274.238
3.	Letter of Intent (LOI) issued Projects	**Mini Hydro Power**	**89**	**101.080**
		Biomass-Agri. & Industrial Waste	3	20.130
		Biomass – Dendro Power	2	8.500
		Total – LOI Issued	94	129.710
4.	Applications for Grid Interconnection Proposals	**Mini Hydro Power**	**159**	**166.820**
		Biomass-Agri. & Industrial Waste	01	0.080
		Biomass – Dendro Power	04	29.000
		Biomass-Municipal Waste	04	19.300
		Ocean Thermal	01	10.000
		Total – Applications	169	225.200

3.0 PLANT SELECTION METHODOLOGY

3.1 Methodology

The methodology followed in this study is listed below.

- Conduct detail analysis of the electricity system load profile of Sri Lanka and observe behavior of present characteristics and future trends of the generation.
- Prepare pipe lines for data collection & observe running patterns of existing mini hydro plants during the dry season.
- Calculate & Analyze the storage capacity of mini hydro plants and find possible operate time under the existing storage capacity.
- Prepare the model of scheduling system and Dispatching & Monitoring the pattern of the operations of mini hydro plant during the evening peak hours.
- Comparative benefit analysis from high cost thermal generation to mini hydro generation and find out cost benefit analysis to the social, to suppliers and to the CEB.

3.1.1 Installed Plant Capacity

Requirements specified in the grid interconnection proposal published by the Ceylon Electricity Board in December 2000, are applicable to all embedded generators with a maximum installed capacity up to and including 10 MW and for connection to CEB networks at or below 33 kV.

However, in practical situation most of the mini hydro plants operated by developers are having less than 1 MW capacity and they haven't enough height to cater enough water volume of up side of the weir due to the limitation of Central Environmental Authority (CEA) or less annual rainfall.
Considering All facts, it is considered only more than 1 MW Mini Hydro Power Projects for the scheduled running.

3.1.2 Location

The system control branch has recently introduced remotely accesses data download facility for all mini hydro plants. The most of the plants are available and working properly this facility. However, several plants don't have this facility due to the signal failure. Hence, the list of mini hydro plant is prepared on the basis of availability of remotely access facility.

The water flow rate of some plants are controlled by irrigation department. All irrigation controlled plants were not considered in this feasibility study as they are unable to operate independently due to the water releasing authority controlled by the Mahaweli Authority. The list of irrigation controlled plants are mentioned below.

Table 4: MHP List of Water controlling by Irrigation Department

up to 31st December 2015

S / No	Project Name	Capacity (MW)
i	Maduru Oya I (Left Bank Main Channel Sluice) MHP	5.00
ii	Branford MHP	2.50
iii	Koladeniya MHP	1.20
iv	Lenadora MHP	1.40
v	Rajjammana MHP	6.00
vi	Maduru Oya II (Left Bank Drop Structure 24+140)	2.00
vii	Ross Estate MHP	4.55
viii	Owala MHP	2.80
ix	Maduru Oya III (Left Bank Drop Structure 28+450)	0.60

3.1.3 Geography

All mini hydro plants with their capacity more than 1 MW were selected in this study except irrigation controlled plants. However, selected mini hydro plants have shown geographical relation. On that basis all selected plants are divided in to a few groups as follows.

3.1.3.1 Ratnapura, Kahawatta & Eheliyagoda Area

Ratnapura, Kahawatta & Eheliyagoda area show slightly similar rainfall pattern in both dry & wet season and that is the reason to include it in to the same group as follows. Geographically closer plants are considered in one group which helps to prepare the model of schedule running.

Table 5: Plants commissioned in Ratnapura, Kahawatta & Eheliyagoda area up to 31st December 2015

S/N	Project Name	Capacity (MW)
1	Delgoda MHP	2.65
2	Bambarabotuwa Oya MHP	3.20
3	Hapugastenne MHP-I	4.60
4	Bellihul Oya MHP	2.50
5	Hapugastenne MHP-II	2.30
6	Niriella MHP	3.00
7	Way Ganga MHP	8.93
8	Alupola Estate MHP	2.52
9	Rath Ganga MHP	2.00
10	Waranagala (Erathna) MHP	9.90
11	Gampola Walakada MHP	4.21
12	Kumburutheniwela MHP	2.80
13	Labuwawa Oya MHP	2.00
14	Guruluwana MHP	2.00
15	Batatota MHP	2.00
16	Koswatte Ganga MHP	2.00
17	Adavikanda MHP	6.50
18	Denawak Ganga MHP	1.40
19	Denawak Ganga MHP	7.20
20	Kokawita MHP – I	1.00
21	Bambarabotuwa Oya MHP – III	4.00
22	Rakwana Ganga MHP	1.00
23	Wembiyagoda MHP	1.30
24	Mulgama MHP	2.80
25	Bambarabotuwa Oya MHP – II	3.00
26	Kadurugaldola MHP	1.20
Total Capacity (MW)		**86.00**

3.1.3.2 Ginigathhena & Nawalapitiya Area

The following plants are considered in a same group by considering the geographically close to Ginigathhena & Nawalapitiya area.

Table 6: Plants commissioned in Ginigathhena & Nawalapitiya area up to 31st December 2015

S/N	Project Name	Capacity (MW)
1	Carolina I MHP	2.50
2	Carolina MHP-II	1.30
3	Kolapathana MHP	1.10
4	Kehelgamu Oya MHP	3.00
5	Barcaple MHP	2.00
6	Kadawala MHP-I	4.85
7	Blackwater Power MHP	1.65
8	Kadawala MHP-II	1.32
9	Agra Oya MHP	1.50
10	Kirkoswald MHP	4.00
11	Kiriwan Eliya MHP	4.65
12	Koladeniya MHP	1.20
13	Pathanahenagama MHP	1.80
14	Sanquhar MHP	1.60
15	Atabage Oya MHP	2.20
16	Korawaka Oya (Upper) MHP	1.50
17	Bowhill (Kadiyanlena) MHP	1.00
18	Barcaple MHP –II	4.00
19	Gampola MHP	1.00
Total Capacity (MW)		**42.00**

3.1.3.3 Nuwara Eliya Area

Nuwara Eliya area is considered as a separate area which has shown unique rainfall pattern.

Table 7: Plants commissioned in Nuwara Eliya area up to 31st December 2015

S/N	Project Name	Capacity (MW)
1	Glassaugh MHP	2.53
2	Kabaragala MHP	1.50
3	Agra Oya MHP	2.60
4	Dunsinanae MHP	2.70
5	Delta MHP	1.60
6	Manelwala MHP	2.40
7	Waltrim MHP	2.00
8	Waverly MHP	1.20
9	Mul Oya MHP	3.00
10	Stellenberg MHP	1.00
11	Devituru MHP	1.20
12	Lower Kotmale Oya MHP	4.30
13	Maa Oya MHP	2.00
Total Capacity (MW)		**28.00**

3.1.3.4 Ruwanwella Area

Ruwanwella area is also considered as a different area which has recorded the highest rainfall measurement.

Table 8: Plants commissioned in Ruwanwella area up to 31st December 2015

S/N	Project Name	Capacity (MW)
1	Mandagal Oya MHP	1.28
2	Nakkawita MHP	1.01
3	Wee Oya MHP	6.00
4	Gurugoda Oya MHP	4.48
5	Magal Ganga MHP	9.93
6	Halathura Ganga MHP	1.30
7	Amanawala MHP	1.00
8	Upper Magal Ganga MHP	2.40
9	Punagala MHP	3.00
10	Monaraela MHP	1.80
11	Punagala MHP	3.00
12	Monaraela MHP	1.80
Total Capacity (MW)		**37.00**

3.1.3.5 Kegalle & Kandy Area

Kegalle & Kandy area are treated as different group in this study due to the seasonal effect and relevant plants have shown as follows.

Table 9: Plants commissioned in Kegalle & Kandy area up to 31st December 2015

S/N	Project Name	Capacity (MW)
1	Deiyanwala MHP	1.50
2	Hulu Ganga MHP-I&II	6.50
3	Salawa Kudah Oya MHP	2.00
4	Giddawa MHP	2.00
5	Watakelle (Hulu Ganga) MHP	1.50
6	Ganthuna Udagama MHP	1.20
7	Falcon Valley MHP	2.40
8	Werapitiya MHP	2.00
9	Maha Oya MHP	3.00
Total Capacity (MW)		**22.00**

3.2 Hydro Power Generation Vs Rainfall of Sri Lanka

Rainfall in Sri Lanka has multiple origins. Monsoonal, Convectional and expressional rain accounts for a major share of the annual rainfall. The mean annual rainfall varies from under 900mm in the driest parts (south eastern and north western) to over 5000mm in the wettest parts (western slopes of the central highlands).

The Climate experienced during 12 months period in Sri Lanka can be characterized in to 4 climate seasons as follows.

I. First Inter - Monsoon Season (March – April)
II. South west – Monsoon Season (May – September)
III. Second Inter - Monsoon Season (October – November)
IV. Northeast – Monsoon Season (December – February)

The water in the reservoirs is used for multi-purposes: water supply, irrigation and power. The decisions regarding releasing the water in the reservoirs are taken by the CEB, irrigation, Mahaweli Authority and Water Secretariat officials collectively. The priority is always given to irrigation as that affects the Mahaweli farmers and food production in Sri Lanka. Issuing of water for cultivation in the Yala season was essential.

The total electricity requirement in the country is about 33.6 GWh/day at present. The power requirement varies during the day and the day time (from 6.30 am – 6.30 pm) demand is about 1200-1400 MW. The demand increases and reaches a peak of about 2150 MW during the night from 6.30 pm -9.30 pm. Again it drops to about 800 MW during the night bay which is from 9.30 pm -6.30 am. The utility has the responsibility of providing uninterrupted power supply to this varying daily demand.

The CEB needs to prioritize and operate the power plants owned by both the CEB and IPPs (Independent Power Producers) to minimize the cost of generation while ensuring uninterrupted power supply to the consumers. During the rainy seasons the hydro power plants are utilized to the optimum to minimize the cost of generation. On the other hand during the dry season the hydro power is used for peaking purposes only to minimize operating expensive diesel power plants. Some of the hydro power plants are used during the day time as spinning reserves to absorb the load fluctuations and hence to stabilize the system.

3.3 Operation Pattern of Existing Mini Hydro Plants

Existing mini hydro plants in Sri Lanka are operated according to the seasonal pattern. It has shown clearly; running pattern of the most of the mini hydro plants varies drastically from wet season to dry season and they are operated under the cyclic pattern during the dry season.

3.3.1 Running pattern of mini hydro plants – Wet Season

(1) Way Ganga Mini Hydro Plant – (8.925 MW – Ratnapura Area)

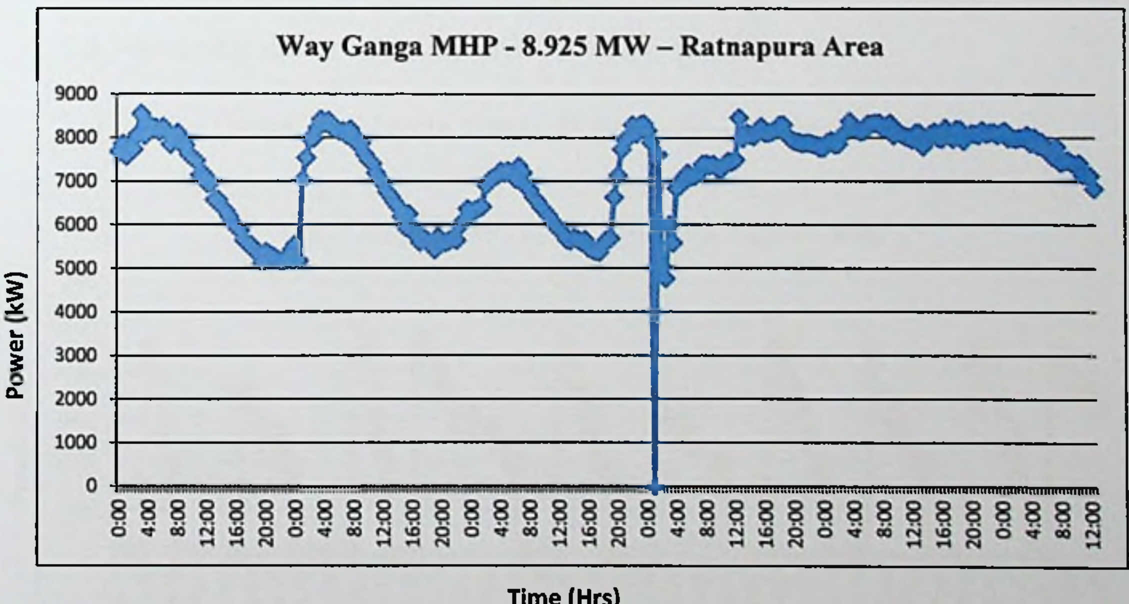


Figure 5: Wet Season Running Pattern of Way Ganga MHP (December 2014)

Ratnapura area has shown heavy rainfall during year end period from September to December. Mini hydro plants are operated by their full capacity or near equal to full capacity during that period.

(2) Black Water Mini Hydro Plant – (1.65 MW – Nawalapitiya Area)

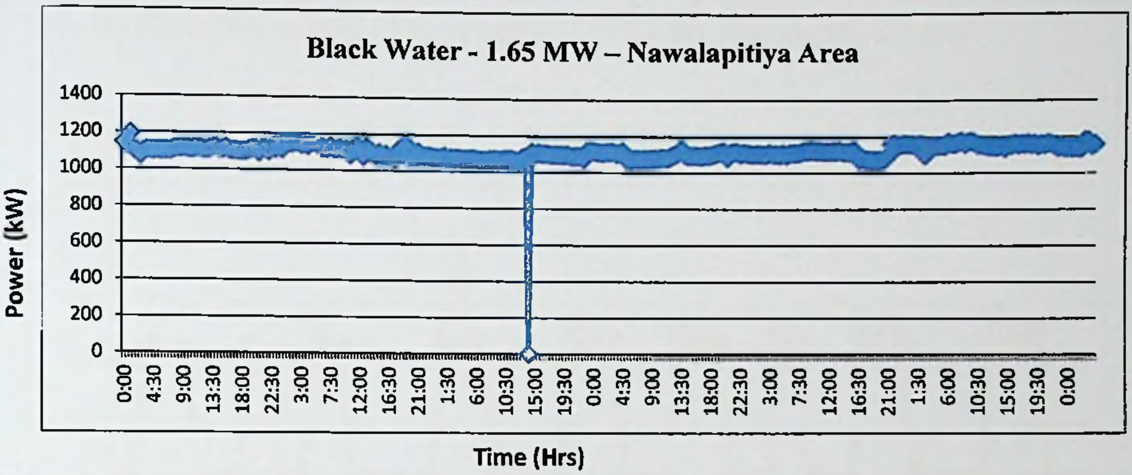


Figure 6: Wet Season Running Pattern of Black Water MHP (July 2014)

Nawalapitiya area has shown heavy rainfall during the midyear period from May to August. Mini hydro plants have operated by their full capacity during the above season.

3.3.2 Running pattern of mini hydro plants – Dry Season

(1) Way Ganga Mini Hydro Plant – (8.925 MW – Ratnapura Area)

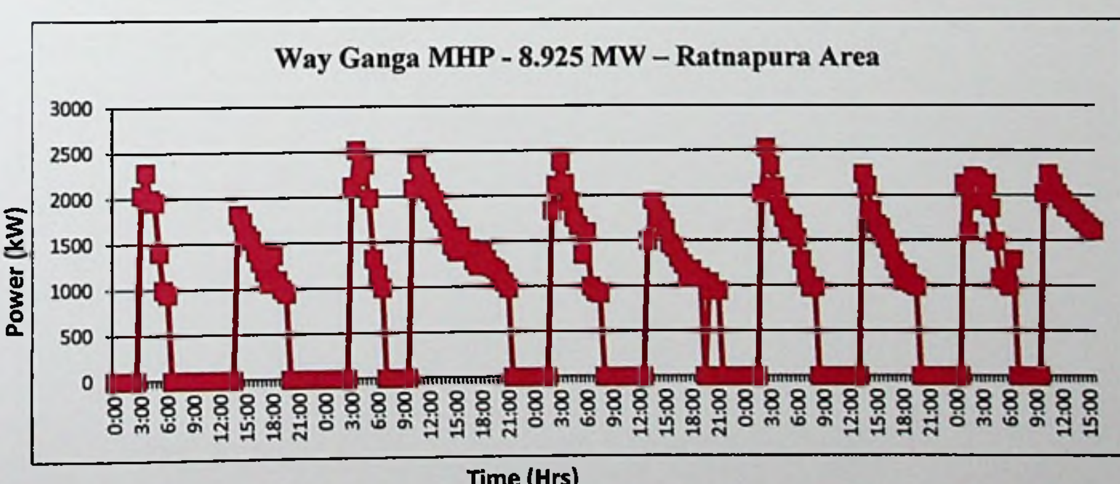


Figure 7: Dry Season Running Pattern of Way Ganga MHP (April 2014)

Ratnapura area shows the lowest rainfall during the period from March to April. Mini hydro plants are operated by their lowest capacity and run under cyclic operation.

(1) Black Water Mini Hydro Plant – (1.65 MW – Nawalapitiya Area)

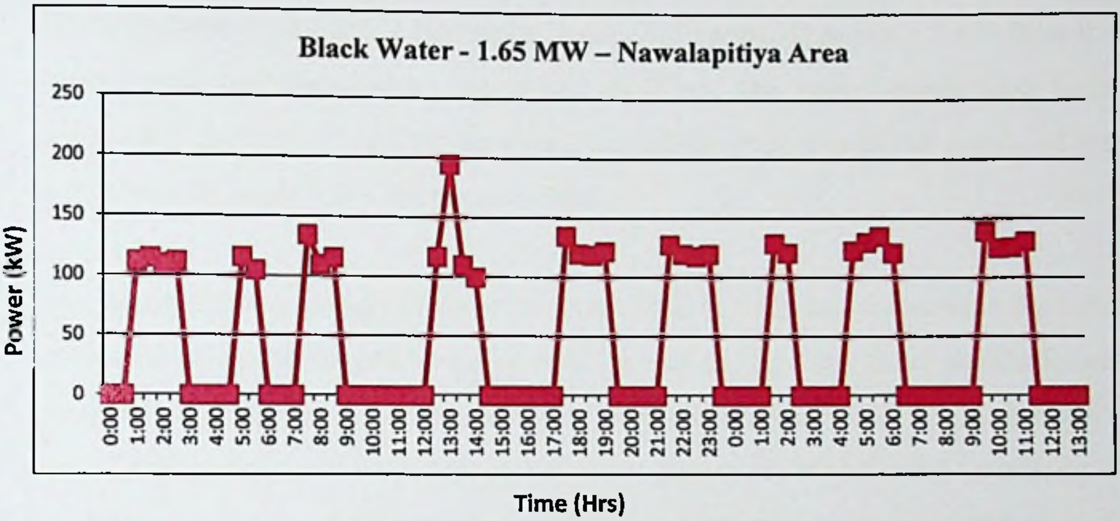


Figure 8: Dry Season Running Pattern of Black Water MHP (March 2014)

Nawalapitiya area has shown lowest rainfall during the period from February to April in most of the years. Mini hydro plants are operated by their lowest capacity and run under cyclic operation.

4.0 DATA COLLECTION AND ANALYSIS – CASE STUDY

The case study has done for Way Ganga Mini Hydro Power Project.

4.1 General Information of selected Mini Hydro Plant

The project site is situated at Poronuwa Estate, Kahawatta. It is about 8 km from the nearest town Nivithigala since the power canal and the power house have been constructed on the left bank of the river. The whole project area lies inside of the Pelmadulla Division in the Ratnapura district.

The project has been developed to utilize gross head of 61 m and comprising the weir intakes on the main river followed by head race canal, fore bay, steel penstock and power house. The total installed capacity of the project is around 8,925 kW. It has 03 sets of horizontal axis Francis type turbines and generators for efficient operation of the plant. The net average annual output of the plant has been estimated as 32.5 GWh. the estimated plant factor is 32 %.

4.1.1 Flow Diversion Weir

The weir was constructed at the 122 m MSL across the Way Ganga stream. The height of the weir is 2.5 m and the length of the weir is approximately equal to 40 m.

Figure 9: Weir & Intake Structure of the Way Ganga MHP

4.1.2 Open Headrace Channel

The channel brings water from either stream in to the fore bay over 3,710 m through reinforced concrete, and approximately 3.6 m wide by 2.15 m deep.

Figure 10: Headrace Channel of the Way Ganga MHP

4.1.3 Penstock

The penstocks are welded mild steel pipe with approximately 1,600 mm, reducing to 1,400 mm close to the power house, while the thickness of penstock is 12 mm to 16 mm. The total length of penstock is around 279 m.

Figure 11: Penstock of the Way Ganga MHP

4.1.4 Power House

The power house was built in two storied structure, with the upper floor containing the control equipment, control module, operator's room and office and etc. while the ground floor contained the turbines, generator units and associated control gear. A gantry crane was installed in the power house to handle the heavy equipment.

Figure 12: Power House of the Way Ganga MHP

4.1.5 Electro-Mechanical Plant

The Way Ganga project has 03 numbers Francis Turbine with horizontal shaft orientation. The generator capacity is 3,500 kVA with 0.85 plant factor each, synchronous type with external excitation. The preferred generating voltage for this capacity is 400 V.

4.1.6 Interconnection Line

The transmission line has been designed to connect plant to the CEB network through 4.0 km length pole line raccoon conductor and the interconnection point which has located within 100 m from the power house.

4.1.7 Power Plant Design Parameters

Main design parameters of the power plant.

Gross Design Head	: 61 m
Net Design Head	: 58 m
Design Flow	: 15.99 cumecs
Length of Penstock	: 279 m
Outer Diameter of Penstock	: 1.6 m / 1.5 m & 1.4 m
Turbine Type	: Horizontal Axis Francis
Number of Turbine	: 03
Turbine Ratings (kW)	: 2,975 kW
Turbine Design Speed	: 750 rpm
Generator Type	: Horizontal Axis Synchronous
Number of Generator	: 03
Generator Rating	: 3,500 kVA / 0.85 pf
Grid Interconnection Line Distance	: 4.0 km

4.2 Running Pattern of Way Ganga MHP

Way Ganga MHP also runs cyclic operation during the dry season like all other mini hydro plants. It has been found that plants run using their maximum water volume until water level reach to shut down level of the fore bay tank. When plants shut down and gates are closed, water filling start for a few hours. Then again plant operates their pre decide capacity and plant runs until water level drop to shut down level.

Although the designed flow rate of Way Ganga Mini Hydro Plant is 15 m^3/s. The actual flow rate drops to around 3.25 m^3/s during that period. Also it was observed that the plant operators have run the plant according to their pre decide capacity value from 4.5 MW to 2.0 MW.

Way Ganga MHP uses three Francis Turbines and the Head Flow Diagram for the Francis Turbine has been published by the manufacture. Therefore it helps to found the flow rate value related to the particular power output value.

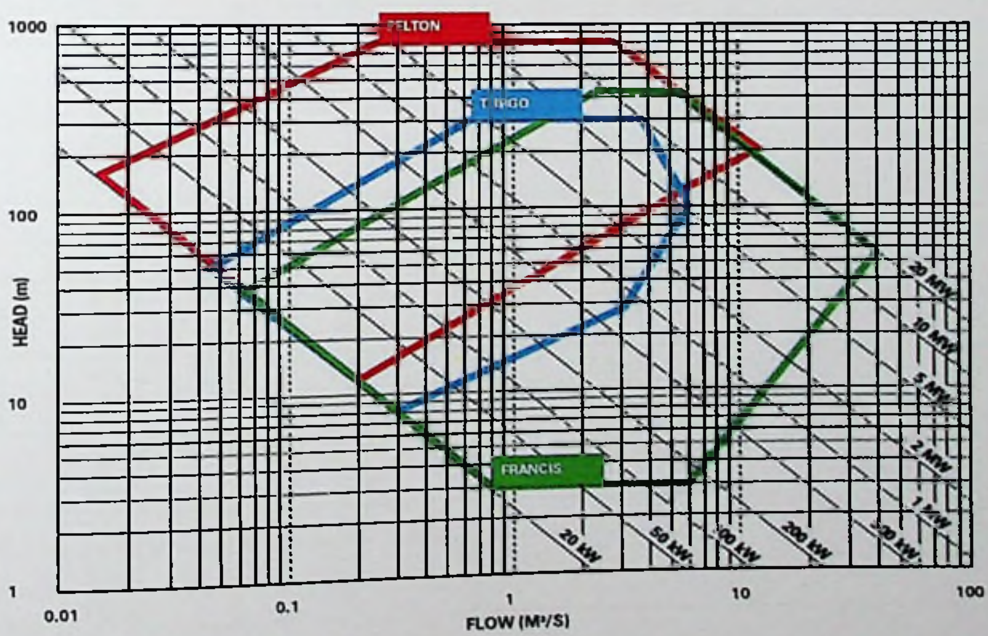


Figure 13: Head (m) Vs Flow (m^3/s) diagram

According to conversion of flow rate values against respective power values have been tabulated follows.

Table 10: Power (kW) Vs Flow Rate (m^3/s) during the Dry Season

Time	Power (kW)	Flow (m^3/s)	Remarks
7:00	2400	4.5	Day 01
8:00	1960	4	
9:00	1730	3.5	
10:00	1560	2.75	
11:00	1470	2.5	
12:00	1150	2.25	
13:00	0	0	
14:00	0	0	
15:00	0	0	
16:00	0	0	
17:00	0	0	
18:00	0	0	
19:00	2490	4.5	
20:00	2080	4	
21:00	1820	3.75	
22:00	1610	3	
23:00	1000	2	
0:00	980	1.75	
1:00	0	0	
2:00	0	0	
3:00	0	0	
4:00	0	0	
5:00	0	0	
6:00	0	0	
7:00	2420	4.5	
8:00	2260	4.25	Day 02
9:00	2040	4	
10:00	1460	2.5	
11:00	1190	2.3	
12:00	1140	2.25	
13:00	1000	2	
14:00	0	0	
15:00	0	0	
16:00	0	0	

Above values are graphically represent as follows.

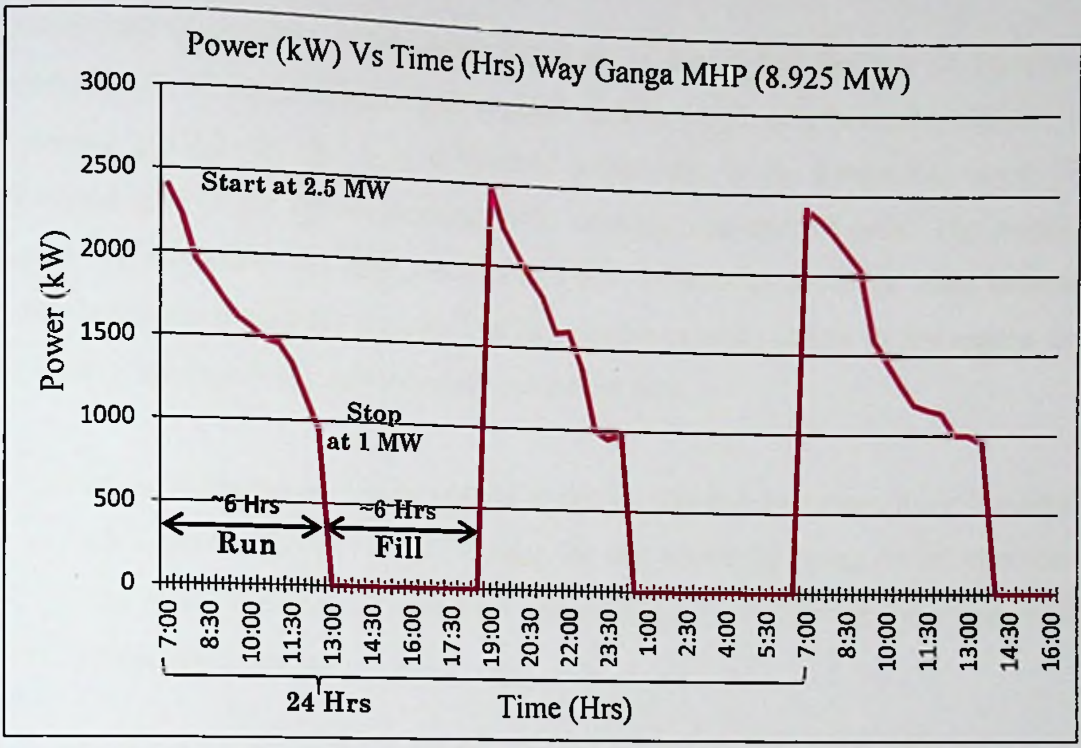


Figure 14: Running Pattern of Way Ganga MHP during the dry season

As shown above, Way Ganga MHP has run under the cyclic operation for 6 hrs running cycle and 6 hrs filling cycle according to their predefined running capacity.

4.3 Define Objective Function

According to objective of this feasibility study, it should find the way of scheduled running of existing mini hydro power plants to reduce high cost thermal generation at evening peak hours. As it is mentioned previously, in Sri Lanka the electricity demand pattern has shown morning peak, evening peak and off peak. The evening peak has normally very high demand and it is difficult to cover by using existing supply system during dry season. The large hydro capacity is low in dry season due to unavailability of enough rainfall to catchment area.

If there are operating mini hydro plants as per the scheduled running; their maximum possible capacity should be used during the dry season by using cyclic operation. Then the following schematic diagram can be raised by considering the variations of the system water volume.

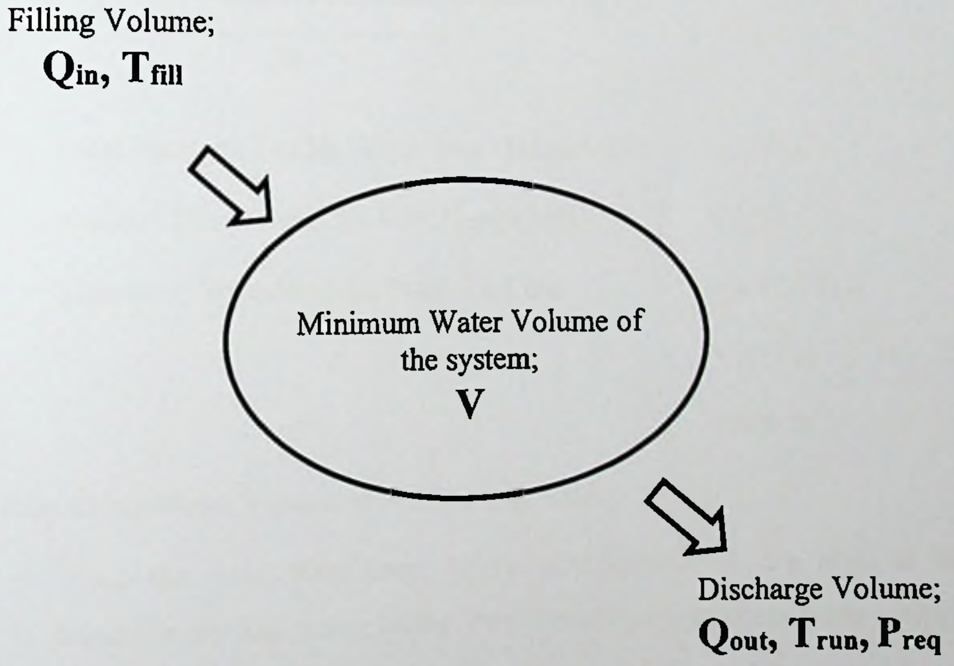


Figure 15: Change of water volume of the system.

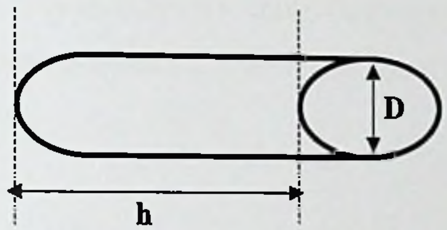
The formula can be illustrated to change of water volume in the system when plant is operated by useing their minimum water volume during the dry season as follows.

$$V = [\, Q_{in} \, X \, T_{fill} \,] - [\, Q_{out} \, X \, T_{run} \,]$$

4.3.1 Minimum Water Volume Remaining in the System; V

When the plant shutdown, the water level reaches to the shutdown level of the fore bay tank. Water remaining in the system is equal to the volume of penstock line and minimum volume of the fore bay tank.

(a) Volume of the Penstock Line;



Total Penstock Length of the Way Ganga MHP	= 279 m
Average Diameter of the Way Ganga MHP	= 1.5 m
Therefore, Volume of the Penstock Line	$= \pi\ (D^2/4)\ h$
	$= 22/7 \times 1.5^2 /4 \times 279\ m^3$
	$\approx 500\ m^3$

(b) Remaining Water Volume of the Fore bay Tank;

When the water level drops to the shutdown level, the plant is stopped automatically and water filling start. Therefore minimum water volume can express as follows.

Minimum Water Volume in Fore bay Tank	= 10 m
Length of the Fore bay Tank of Way Ganga MHP	= 8 m
Width of the Fore bay Tank of Way Ganga MHP	= 8 m

Height of the Fore bay Tank of Way Ganga MHP = 15 m

Therefore, Minimum Water Volume in the Fore bay Tank of Way Ganga MHP = 10 x 8 x 8 m3 ≈ 640 m3

Minimum Water Volume remaining in the system = 500 + 640 m3 = 1140 m3

4.3.2 Input Water Flow Rate to the System; Q_{in}

The time (t) in seconds elapsed to travel floating object along the canal path a certain length (L) in meter is recorded. The surface speed (m/s) is given as;

$$V_{rs} = L / t \quad m/s$$

However, average flow speed is different from surface speed. Because of that the surface speed should be corrected with considering roughness against to the water flow in a bottom of the stream, canal or river bank. The correction factor is assumed as 0.75 for this system.

Therefore average flow rate is estimated as follows;

$$V_r = 0.75 \times V_{rs} \qquad m/s$$

Also, cross sectional area should be estimated to calculate input flow rate. The natural water course or canal should be divided in to a series of trapezoids. The cross section would be given as;

$$A_r = \frac{(a + b)}{2} \times \frac{(h_1 + h_2 + \dots\dots\dots + h_k)}{k} \qquad m^2$$

Where,

a = width of top surface of stream or canal (m)

b = width of bottom surface of stream or canal (m)

$\frac{(h_1 + h_2 + \dots\dots\dots + h_k)}{k}$ = Average water height of the stream or canal (m)

By using above all facts and formula, the input flow rate can be expressed as follows.

$$\mathbf{Q_{in} = Ar \times Vr} \qquad m^3/s$$

4.3.3 Plant Operate Time Duration; T_{run}

According to the daily load profile of Sri Lanka, the evening peak hours are shown from 6:30 pm to 9:30 pm. When the mini hydro plants are operated under scheduled running during the evening peak; it may help to avoid high cost thermal generation.

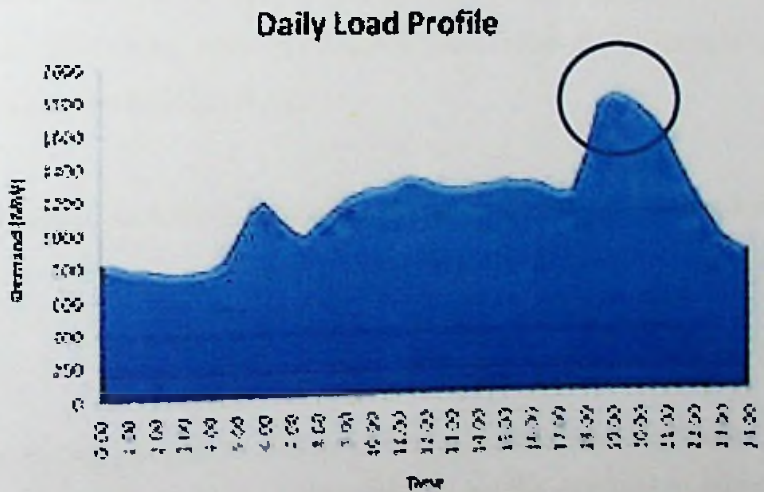


Figure 16: General Daily Load Profile of Sri Lanka

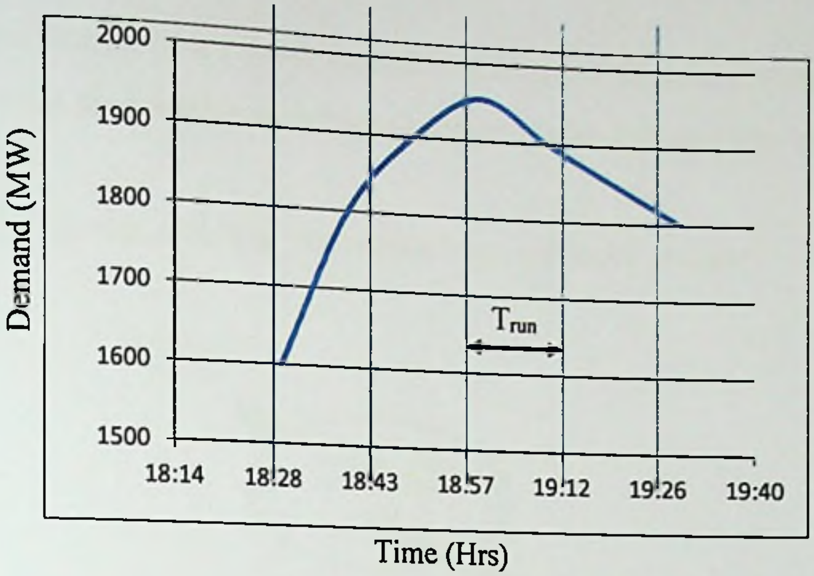


Figure 17: Evening Peak of Daily Demand Curve

Above figure has shown the operating time of selected Mini Hydro Plants. The demand peak is divided to 15 minutes slot and it can be selected according to scheduler preference and easiness.

4.3.4 Water Filling Time Duration; T_{fill}

It was observed that some of the mini hydro plants can hold high amount of water during the less filling time. However some of mini hydro plants require long time to satisfy the allocated scheduled power.

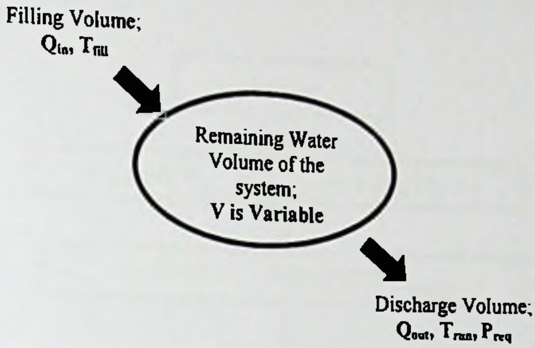
Now, all parameters are known except T_{fill}. By using the objective function;

$$T_{fill} = \{ V + [Q_{out} \times T_{run}]\} / Q_{in}$$

According to above formula the system control operator issues the filling time (Plant Stop & Start Time) to mini hydro developers as per the required running power and expected running time during the evening peak. Transmission losses of the network, generation losses and transformer losses are neglected at that stage.

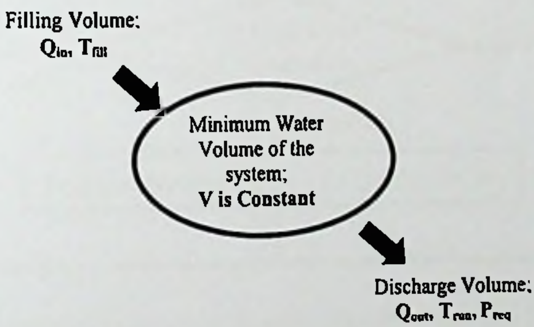
There are two available running mode during the cyclic operation of the mini hydro plants. It has been derived according to remaining water volume of the system, **V**

(a) If **V** is variable, then $\mathbf{T_{fill}}$ will be remaining unchanged as above;



$$\mathbf{T_{fill} = \{ V + [Q_{out} \times T_{run}]\} / Q_{in}}$$

(b) If **V** is constant, then $\mathbf{T_{fill}}$ will be change as follows;



$$\mathbf{T_{fill} = [Q_{out} \times T_{run}] / Q_{in}}$$

As mentioned above T_{fill} of the objective function will be changed according to the variations of the remaining water volume of the system (V). However during the dry season most of the mini hydro plants are operated with minimum water volume. As they have not enough water volume to reach for their requested power. Hence, the second option is the most suitable method to run the objective function in this feasibility study.

4.4 Generalize System for Objective Function

As mentioned above, the objective function is defined for selected mini hydro plant to find out the T_{fill}. However it should be generalized to whole system. From beginning to end it should be logically corrected and the function is to be operated correctly under all possible condition. Following flow chart has shown how it work properly.

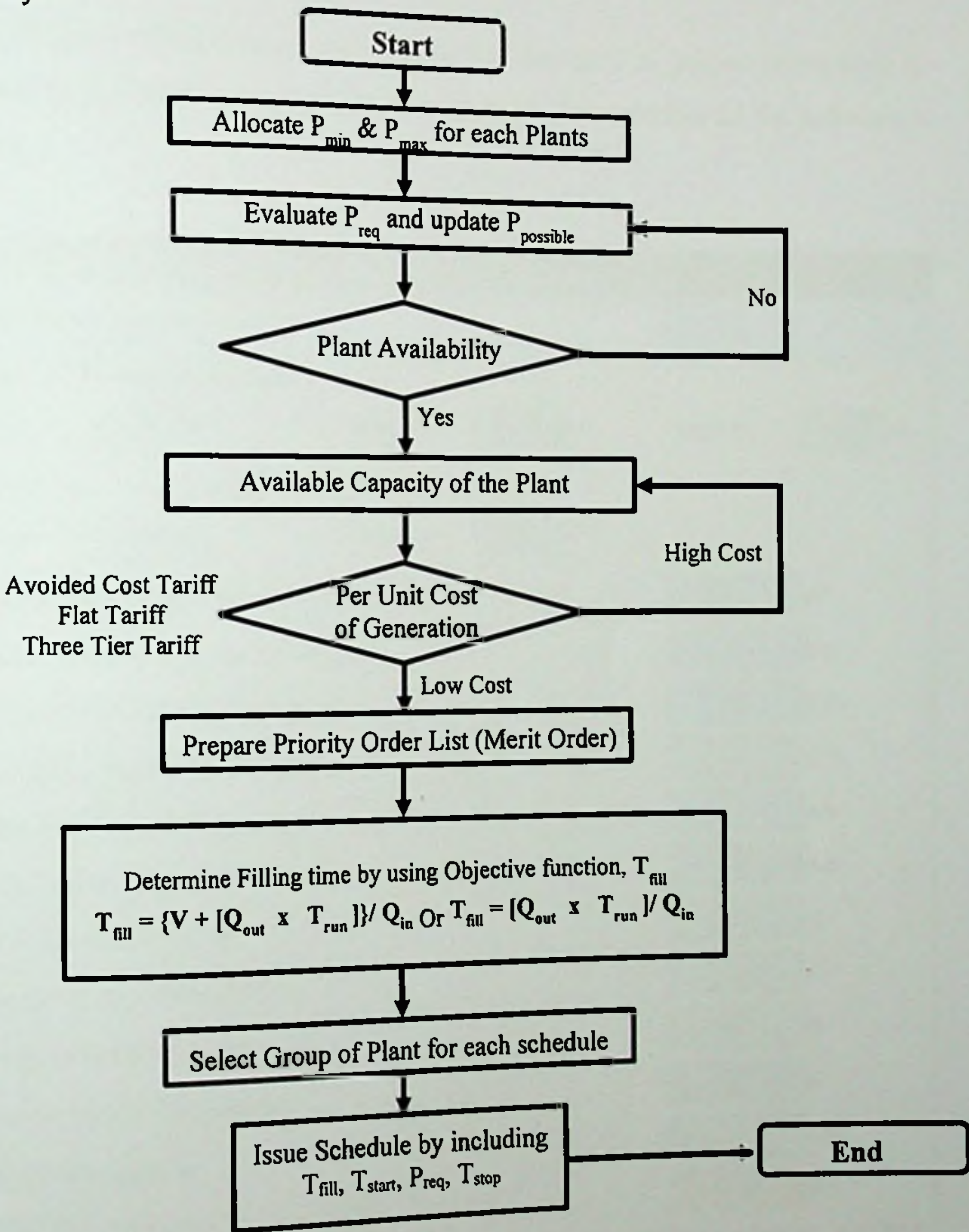


Figure 18: Flow Chart for Schedule Running

4.5 Existing Plants Data Base

According to the plant selection scenario of this study; 97 mini hydro plants are selected initially for schedule on 31/12/2015. During this study all required information are collected from developers by requesting over the phone or e-mail. Information table was prepared according to that and attached as Annex 01.

Using all data and information; the software was simulated to find out filling time for any mini hydro plant under changes of parameters. The interface of the software as follows,

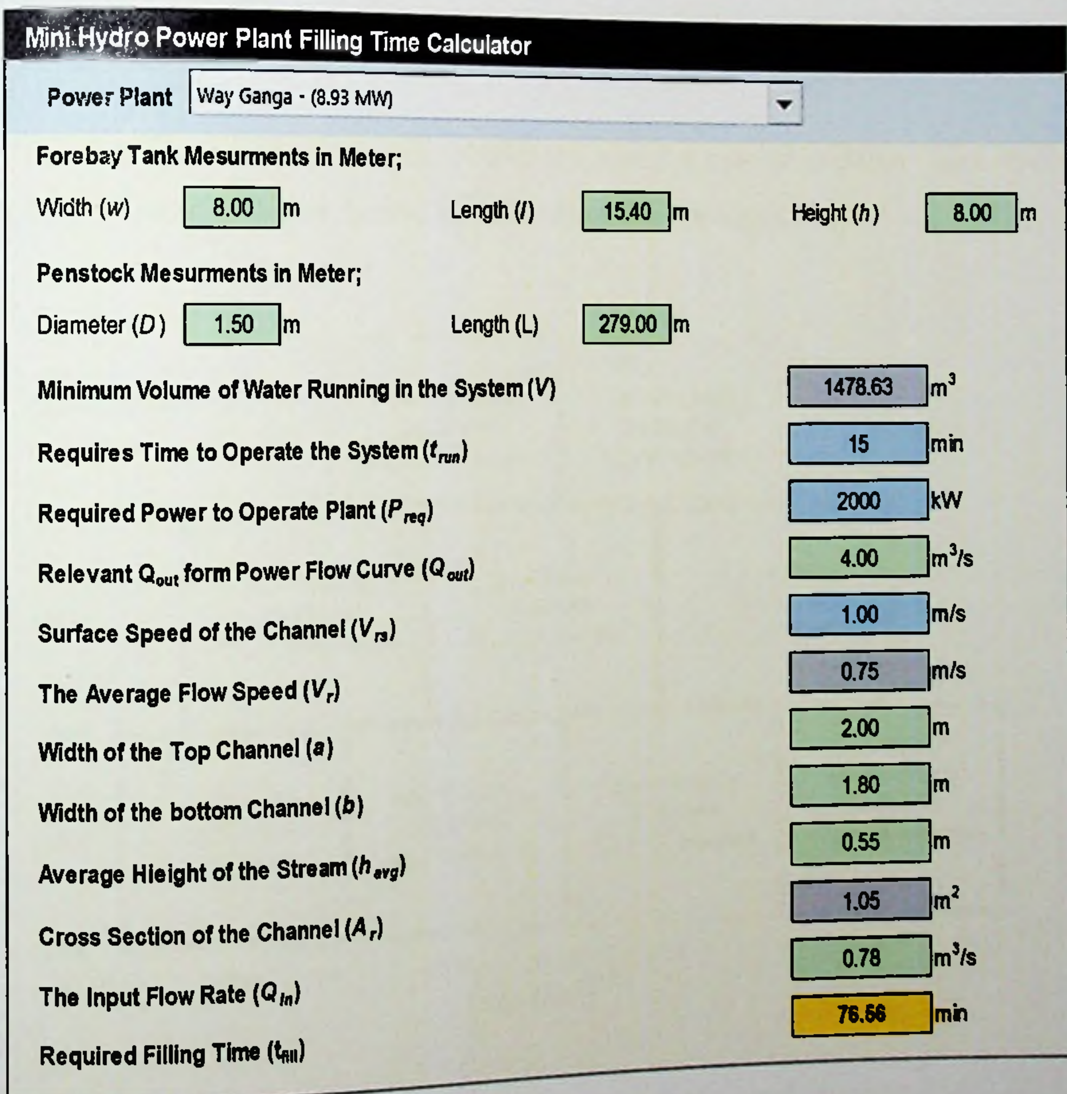


Figure 19: Filling Time Calculator for Mini Hydro Plant

4.6 Example for Scheduling

As mentioned in figure 20, the scheduling period has been selected from 18:56 Hrs to 19:56 Hrs in evening peak. According to possible capacities of available mini hydro plants, 54 MW demand value has been selected to avoid high cost thermal generation in above mentioned time duration.

Under the scheduled running, there are several option to prepare the schedule. Following example has described how it works the scheduled running when plants are operating 50% of their commissioned capacity.

$$P_{req} = 50\% \text{ of } P_{commissioned}$$

The daily demand variation on 01/09/2015 and a group of available mini hydro plants to avoid high cost thermal plant are shown below figure 21.

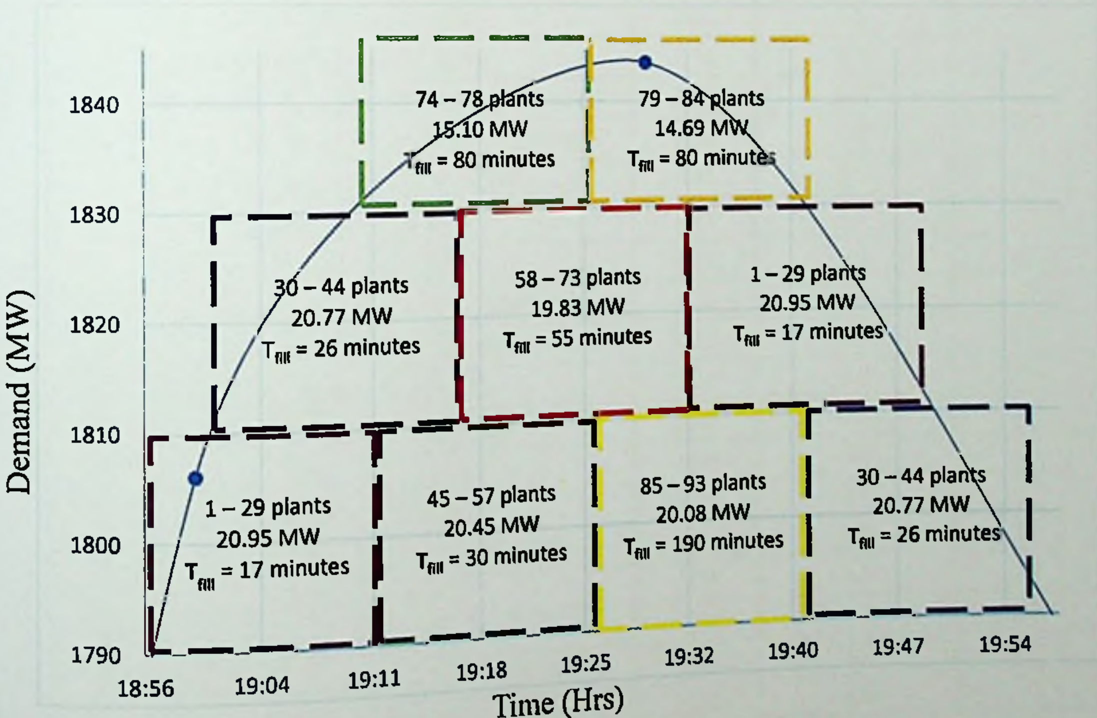


Figure 20: Mini Hydro Plants Scheduled on Peak of the Load Curve on 01/09/2015

As mentioned previously, following table shows, how it works and how to get the schedule optimization.

Table 11: 1st Schedule (18:56 - 19:11) & Repeat on 8th Schedule (19:32 - 19:47)

1st Schedule (18:56 - 19:11) & Repeat on 8th Schedule (19:32 - 19:47)				
S/N	Project Name	Capaciy (MW)	P_{req} = 50% Commissioned Capacity	$T_{filling}$ (Minutes)
1	Pathaha Oya MHP - (1.20 MW)	1.20	0.6	7
2	Falcon Valley MHP - (2.40 MW)	2.40	1.2	13
3	Barcaple MHP - (2.00 MW)	2.00	1.0	16
4	Agra Oya MHP - (1.50 MW)	1.50	0.8	17
5	Waverly MHP - (1.20 MW)	1.20	0.6	17
6	Kadurugaldola MHP - (1.20 MW)	1.20	0.6	17
7	Devituru MHP - (1.20 MW)	1.20	0.6	17
8	Blackwater Power MHP - (1.65 MW)	1.65	0.8	17
9	Sanquhar MHP - (1.60 MW)	1.60	0.8	17
10	Delta MHP - (1.60 MW)	1.60	0.8	17
11	Kabaragala MHP - (1.50 MW)	1.50	0.8	17
12	Deiyanwala MHP - (1.50 MW)	1.50	0.8	17
13	Korawaka Oya (Upper) MHP - (1.50 MW)	1.50	0.8	17
14	Watakelle (Hulu Ganga) MHP - (1.50 MW)	1.50	0.8	17
15	Lower Neluwa MHP - (1.45 MW)	1.45	0.7	17
16	Kadawala-II MHP-(1.32 MW)	1.32	0.7	17
17	Carolina - II MHP-(1.30 MW)	1.30	0.7	17
18	Halathura Ganga MHP - (1.30 MW)	1.30	0.7	17
19	Mandagal Oya MHP - (1.28 MW)	1.28	0.6	17
20	Galatha Oya MHP - (1.20 MW)	1.20	0.6	17
21	Wembiyagoda MHP - (1.30 MW)	1.30	0.7	17
22	Koladeniya MHP - (1.20 MW)	1.20	0.6	17
23	Lemastota MHP - (1.30 MW)	1.30	0.7	17
24	Ganthuna Udagama MHP - (1.20 MW)	1.20	0.6	17
25	Rideepana MHP - (1.75 MW)	1.75	0.9	17
26	Theberton MHP - (1.30 MW)	1.30	0.7	17
27	Lower Atabage Oya II MHP - (1.25 MW)	1.25	0.6	17
28	Mille Oya MHP - (1.20 MW)	1.20	0.6	17
29	Guruluwana MHP - (2.00 MW)	2.00	1.0	18
			20.95	

Table 12: 2nd Schedule (19:02 - 19:17) & Repeat on 9th Schedule (19:41 - 19:56)

2nd Schedule (19:02 - 19:17) & Repeat on 9th Schedule (19:41 - 19:56)				
S/N	Project Name	Capacity (MW)	P_{req} = 50% Commissioned Capacity	$T_{filling}$ (Minutes)
30	Mulgama MHP - (2.80 MW)	2.80	1.4	26
31	Punagala MHP - (3.00 MW)	3.00	1.5	26
32	Mul Oya MHP - (3.00 MW)	3.00	1.5	26
33	Maha Oya MHP - (3.00 MW)	3.00	1.5	26
34	Upper Magal Ganga MHP - (2.40 MW)	2.40	1.2	26
35	Bambarabotuwa Oya MHP (Phase II) - (3.00 MW)	3.00	1.5	26
36	Niriella MHP - (3.00 MW)	3.00	1.5	26
37	Kehelgamu Oya MHP - (3.00 MW)	3.00	1.5	26
38	Kumburutheniwela MHP - (2.80 MW)	2.80	1.4	26
39	Glassaugh MHP - (2.53 MW)	2.53	1.3	26
40	Alupola Estate MHP - (2.52 MW)	2.52	1.5	26
41	Delgoda MHP - (2.65 MW)	2.50	1.3	26
42	Carolina I MHP - (2.50 MW)	2.50	1.3	26
43	Bellihul Oya MHP - (2.50 MW)	2.50	1.3	26
44	Soranathota MHP - (2.50 MW)	2.50	1.3	26
			20.77	

Table 13: 3rd Schedule (19:11 - 19:25)

3rd Schedule (19:11 - 19:25)				
S/N	Project Name	Capaciy (MW)	P_{req} = 50% Commissioned Capacity	$T_{filling}$ (Minutes)
45	Kehelwatta MHP - (2.50 MW)	2.5	1.3	26
46	Mulgala MHP- (2.80 MW)	2.8	1.4	26
47	Madugeta MHP - (2.50 MW)	2.5	1.3	26
48	Naya Ganga MHP - (3.00 MW)	3	1.5	28
49	Bambarabotuwa Oya MHP (Phase III) - (4.00 MW)	4	2	28
50	Upper KadurugaldolaMHP - (1.40 MW)	1.4	0.7	30
51	Denawak Ganga MHP - (1.40 MW)	1.4	0.7	30
52	Waranagala (Erathna) MHP - (9.90 MW)	9.9	5	30
53	Dunsinanae MHP - (2.70 MW)	2.7	1.4	33
54	Bulathwaththa MHP - (3.80 MW)	3.8	1.9	36
55	Agra Oya MHP - (2.60 MW)	2.6	1.3	36
56	Kalupahana Oya (Lower) MHP - (2.50 MW)	2.5	1.3	36
57	Monaraela MHP - (1.80 MW)	1.8	0.9	36
			20.45	

Table 14: 4th Schedule (19:17 - 19:32)

4th Schedule (19:17 - 19:32)				
S/N	Project Name	Capaciy (MW)	P_{req} = 50% Commissioned Capacity	$T_{filling}$ (Minutes)
58	Pathanahenagama MHP - 1.80 MW)	1.80	0.9	36
59	Wallawaya MHP - (1.20 MW)	1.20	0.6	38
60	Ross Estate MHP - (4.55 MW)	4.55	2.3	40
61	Gampola Walakada MHP - (4.21 MW)	4.21	2.1	43
62	Barcaple MHP (Phase II) - (4.00 MW)	4.00	2.0	45
63	Giddawa MHP - (2.00 MW)	2.00	1.0	45
64	Maa Oya MHP - (2.00 MW)	2.00	1.0	45
65	Hapugastenne - II MHP - (2.30 MW)	2.30	1.2	50
66	Salawa Kudah Oya MHP - (2.00 MW)	2.00	1.0	50
67	Labuwawa Oya MHP - (2.00 MW)	2.00	1.0	50
68	Bambarabotuwa Oya MHP - (3.20 MW)	3.20	1.6	52
69	Werapitiya MHP- (2.00 MW)	2.00	1.0	55
70	Manelwala MHP - (2.40 MW)	2.40	1.2	55
71	Rath Ganga MHP - (2.00 MW)	2.00	1.0	55
72	Koswatte Ganga MHP - (2.00 MW)	2.00	1.0	55
73	Waltrim MHP - (2.00 MW)	2.00	1.0	55
			19.83	

Table 15: 5th Schedule (19:10 - 19:25)

5th Schedule (19:10 - 19:25)				
S/N	Project Name	Capacity (MW)	P_{req} = 50% Commissioned Capacity	$T_{filling}$ (Minutes)
74	Denawak Ganga MHP - (7.20 MW)	7.20	3.6	68
75	Kirkoswald MHP - (4.00 MW)	4.00	2.0	73
76	Hulu Ganga-I&II MHP- (6.50 MW)	6.50	3.3	81
77	Adavikanda MHP - (6.50 MW)	6.50	3.3	81
78	Rajjammana MHP - (6.00 MW)	6.00	3.0	81
			15.10	

Table 16: 6th Schedule (19:25 - 19:40)

6th Schedule (19:25 - 19:40)				
S/N	Project Name	Capaciy (MW)	P_{req} = 50% Commissioned Capacity	$T_{filling}$ (Minutes)
79	Badulu Oya MHP - (5.80 MW)	5.80	2.9	81
80	Bogandana MHP - (5.00 MW)	5.00	2.5	81
81	Kadawala - I MHP-(4.85 MW)	4.85	2.4	81
82	Kiriwan Eliya MHP - (4.65 MW)	4.65	2.3	81
83	Hapugastenne - I MHP - (4.60 MW)	4.60	2.3	81
84	Gurugoda Oya MHP - (4.48 MW)	4.48	2.2	81
			14.69	

Table 17: 7th Schedule (19:25 - 19:40)

7th Schedule (19:25 - 19:40)				
S/N	Project Name	Capacity (MW)	P_{req} = 50% Commissioned Capacity	$T_{filling}$ (Minutes)
85	Asupiniella MHP - (4.00 MW)	4	2	81
86	Loggal Oya MHP - (4.00 MW)	4	2	81
87	Lower Kotmale Oya MHP - (4.30 MW)	4.3	2.2	84
88	Wee Oya MHP - (6.00 MW)	6	3	91
89	Way Ganga - (8.93 MW)	8.93	4.5	121
90	Magal Ganga MHP - (9.93 MW)	9.93	5	145
91	Bowhill (Kadiyanlena) MHP - (1.00 MW)	1	0.5	194
92	Stellenberg MHP - (1.00 MW)	1	0.5	194
93	Thebuwana MHP - (1.00 MW)	1	0.5	194
			20.08	

Above example has proven, 50% of commissioned plant capacity of scheduled mini hydro plants can be achieved to avoid 54 MW high cost thermal plants during the dry season.

5.0 CALCULATION & RESULTS

5.1 Calculation & Results

After analyzing the results of this feasibility study; it has clearly shown that not only direct cost benefits but also indirect cost benefits are available in scheduled running of Mini Hydro Plants. Most of the mini hydro plants which are available for scheduled running are categorized under the Avoided Cost Base Tariff. All other plants are categorized under the Flat Tariff & Three Tier Tariff. Therefore following calculations are based on 2014 tariff schedule.

If Mini Hydro Plants are operated by scheduled basis, each schedule has shown the amount of cost as follows.

Table 18: Running Cost of Scheduled Mini Hydro

Schedule Number	Cost (Rs)
First Schedule	80,007
Second Schedule	76,224
Third Schedule	76,556
Forth Schedule	76,516
Fifth Schedule	56,749
Sixth Schedule	54,610
Seventh Schedule	73,666
Eighth Schedule & Repeat on First Schedule	80,007
Ninth Schedule & Repeat on Second Schedule	76,224
Total Cost	650,559

Following plants can be avoided by scheduled mini hydro plants according to the Merit Order list of Dispatch plants which has been published by system control branch on 01/09/2015.

If Kelanithissa Small – GT and Asia Power were operated under normal condition, CEB has to pay following cost for relevant IPP developers.

Small GT – Kelanithissa	$= 16 \times 10^3 \times 3 \times 1 \times 51.35$	= Rs. 2,464,800
Asia Power	$= 6 \times 10^3 \times 1 \times 21.76$	= Rs. 130,560
		= Rs. 2,595,360

Each set of mini hydro plants do not contribute to cater the demand during the filling time and therefore the amount of energy loss should be covered by another generation source. It is shown in following diagrams.

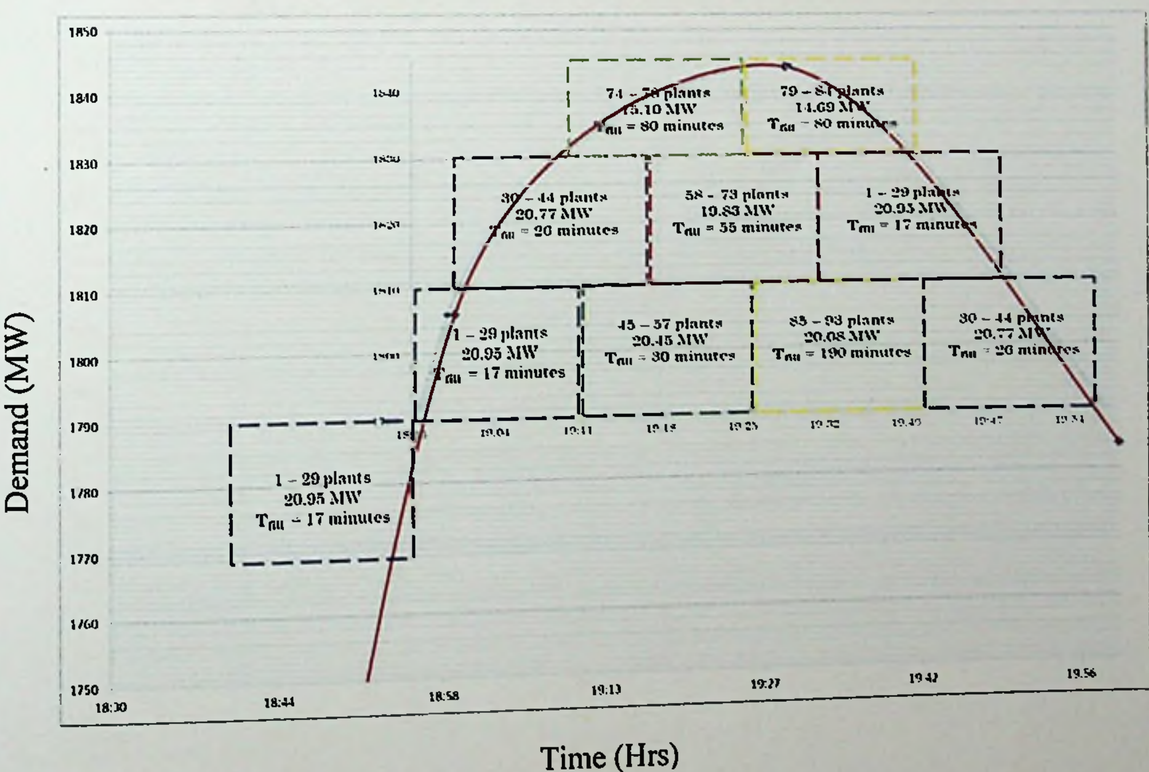


Figure 21: Energy Loss by implementing the First Schedule

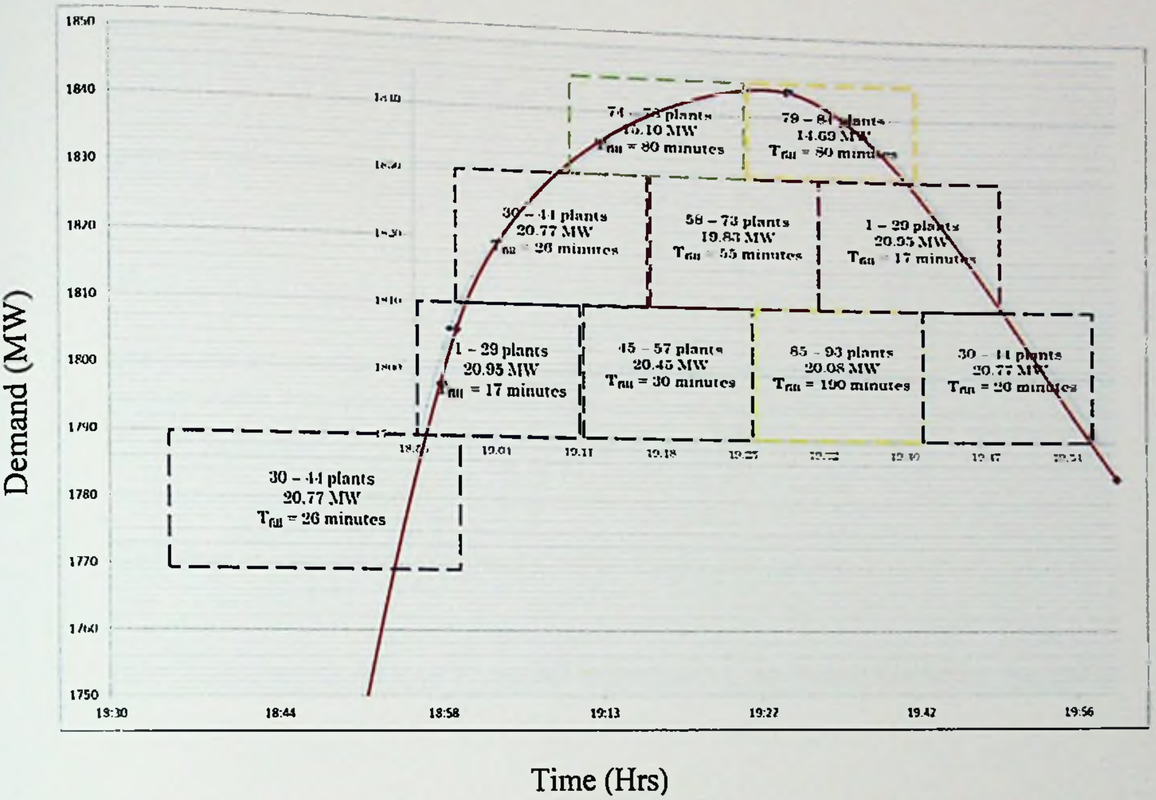


Figure 22: Energy Loss by implementing the Second Schedule

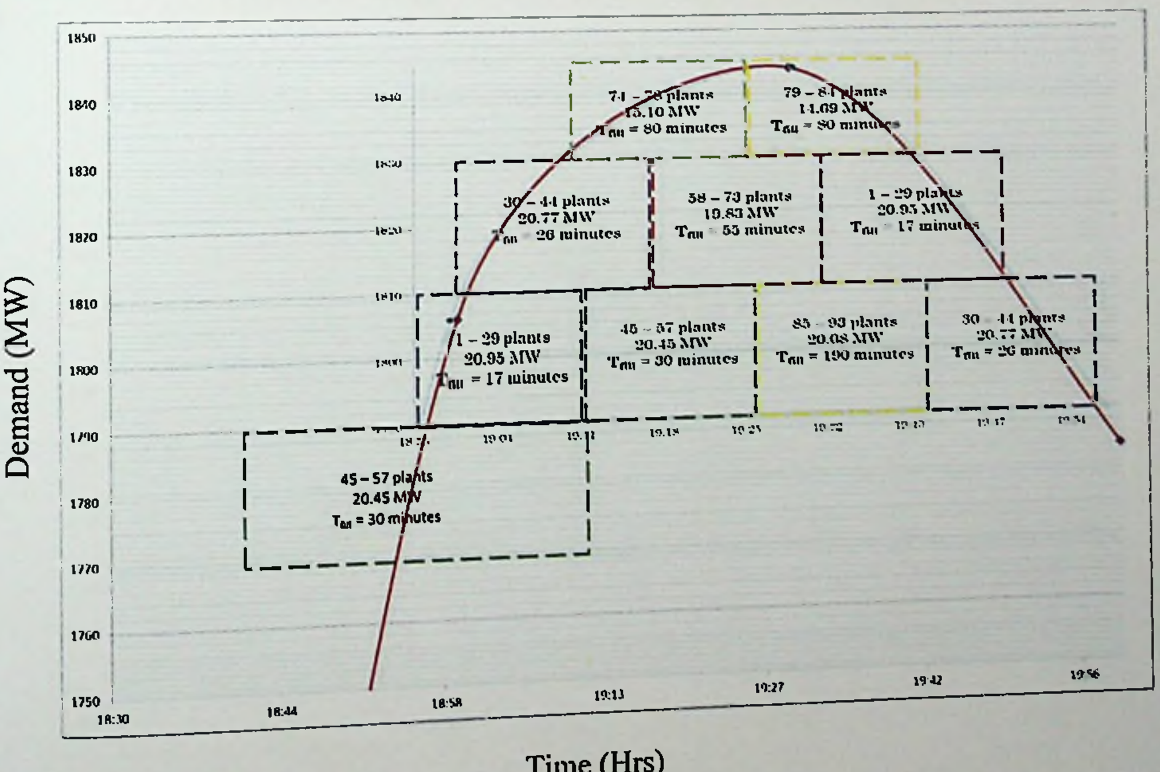


Figure 23: Energy Loss by implementing the Third Schedule

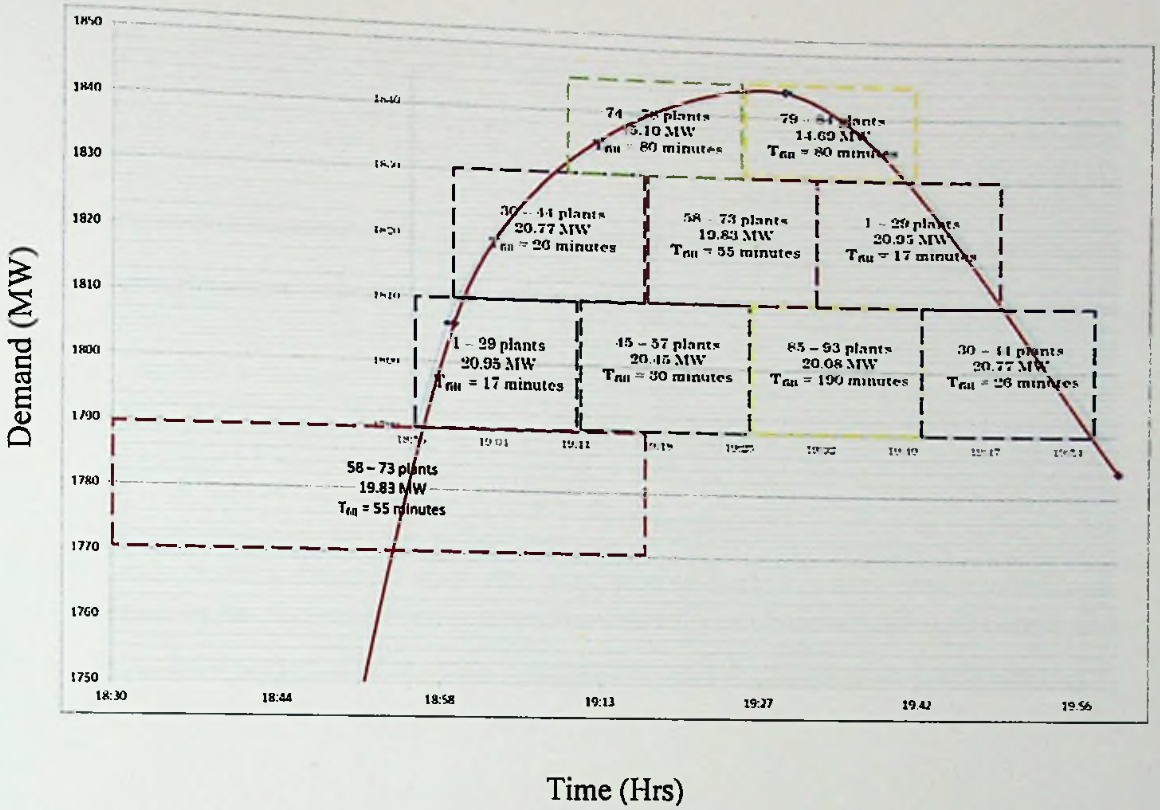


Figure 24: Energy Loss by implementing the Forth Schedule

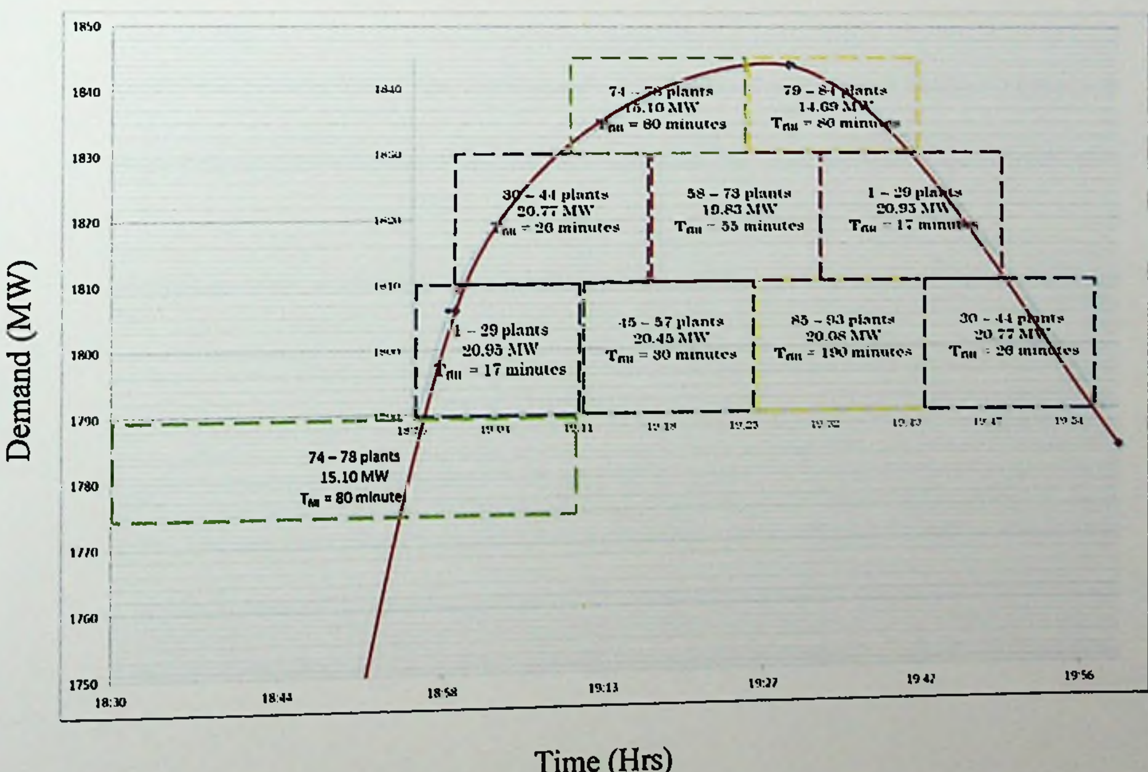


Figure 25: Energy Loss by implementing the Fifth Schedule

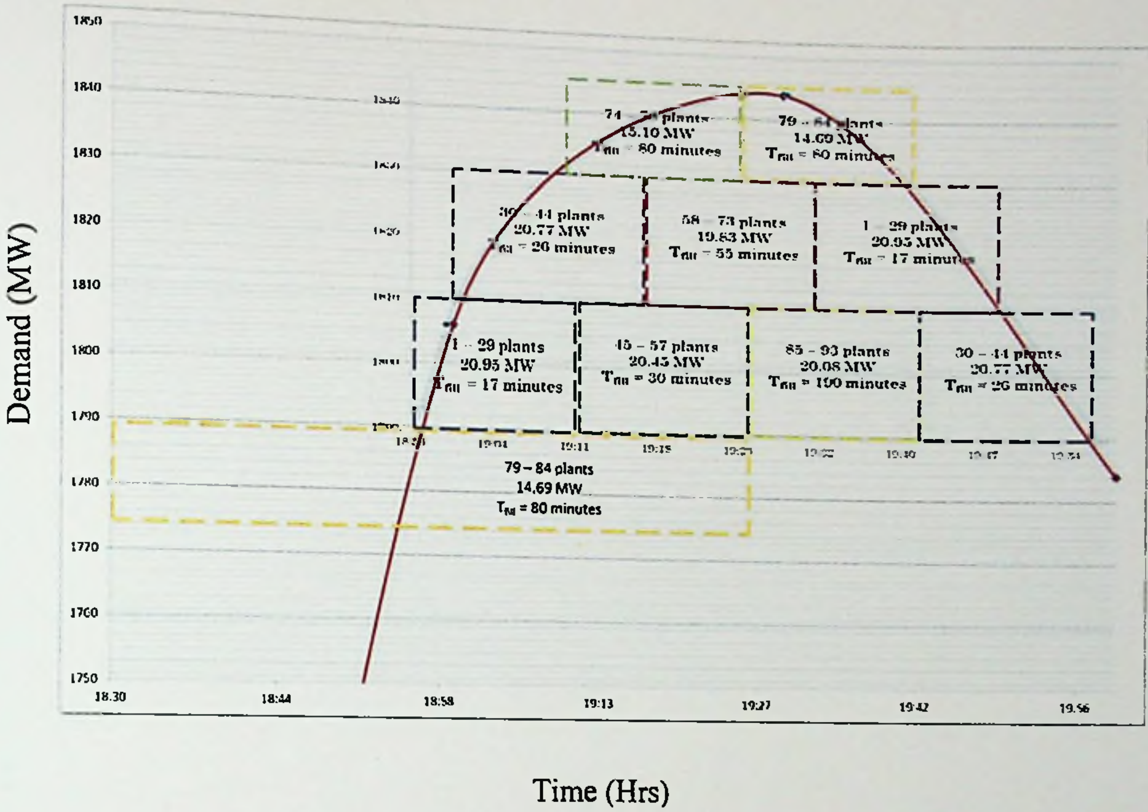


Figure 26: Energy Loss by implementing the Sixth Schedule

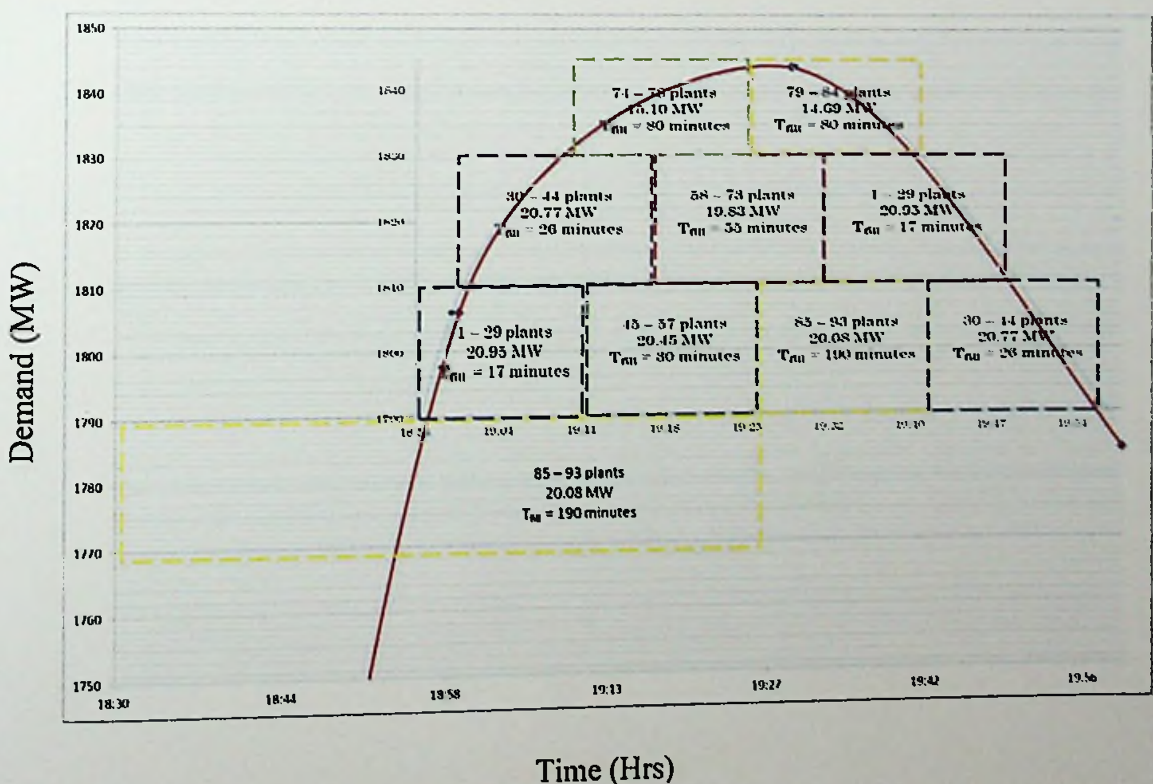


Figure 27: Energy Loss by implementing the Seventh Schedule

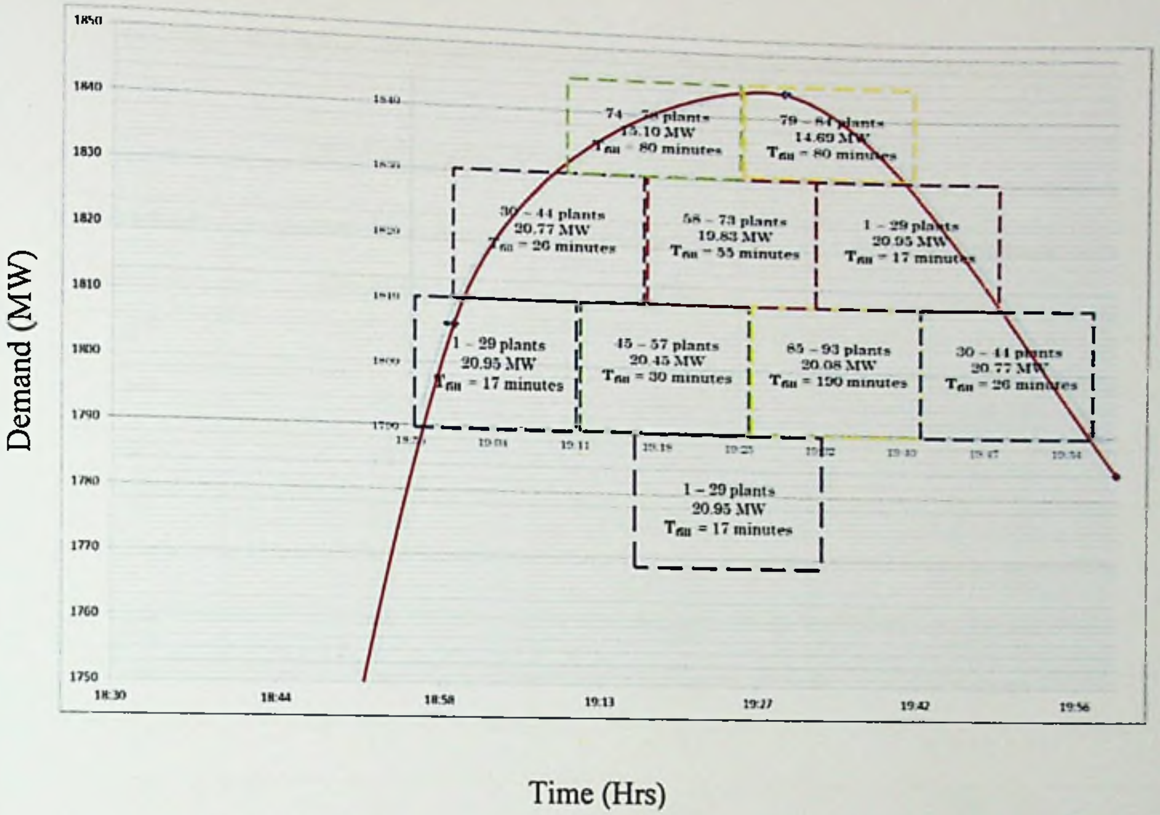


Figure 28: Energy Loss by implementing the Eighth Schedule

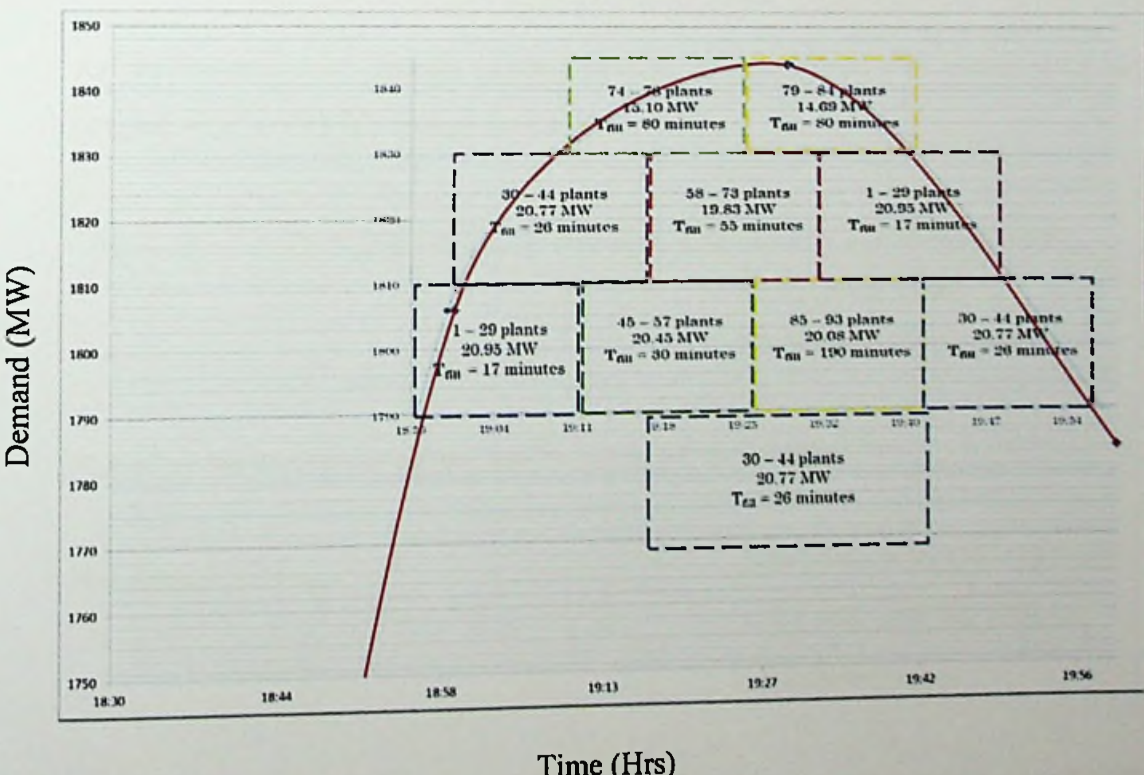


Figure 29: Energy Loss by implementing the Ninth Schedule

According to the above diagrams total energy loss can be calculated as follows.

Table 19: Energy Loss due to scheduled operation

Schedule Number	Actual time loss (Minutes)	Generation loss (MW)	Energy loss (kWh)
1st	N / A	-	-
2nd	5	20.77	1,730.83
3rd	15	20.45	5,112.50
4th	22	19.83	7,271.00
5th	15	15.10	3,775.00
6th	29	14.69	7,100.17
7th	29	20.08	9,705.33
8th	17	20.95	5,935.83
9th	26	20.77	9,000.33
Total Energy Loss			49,630.99

As per the record of System Control Branch, Sapugaskanda – B power plant has covered 49,630.99 kWh energy loss in 2015/09/01.

Therefore CEB has to pay for Sapugaskanda – B due to covering of energy loss

= 49,630.99 x 17.80

= Rs. 883,432.00 per day

Therefore the annual net saving can be expressed as follows.

Net Annual Saving = 2,595,360 - 650,559 – 883,432

1,061,369 x (28+31+30)

95 million rupees

Above calculation is made by assuming that the dry seasons are on February, March & April in each year.

6.0 CONCLUSION & RECOMMENDATIONS

6.1 Conclusions

CEB has not yet adopted any streamlined process for schedule running for mini hydro plants. Under this feasibility study, an effort has been taken to introduce a mechanism to prepare schedule running of mini hydro plants during the dry season and the way of optimizing the benefit by reducing high cost thermal generation.

Maximum electricity demand recorded in the year 2015 was 2151.7 MW and it is expected to be risen to 2311 MW in 2016 subjected to the peak demand growth rate of 7.4% as specified by the Long Term Generation Expansion Plan (2015-2034). To achieve this demand a system capacity of 3353MW is available to dispatch during the year 2016. Therefore there will be a Reserve Margin of 45% when the peak demand of year 2016 is reached, assuming that all the power plants are readily available to dispatch with their full capacities. But when it comes to the practical state it is obvious that all the plants will not be available fully at every time.

Sri Lanka is unable to meet night peak demand by operating all plants without any outage. CEB has to find high cost thermal small generator to recover demand gap.

95 million rupees per annum can be saved by using this model of scheduled mini hydro operating system as discussed earlier. It has given direct benefit to the CEB.

Direct cost benefit as well as indirect cost benefit are shown in this feasibility study. The indirect cost benefits are mentioned below.

Thermal Plants pollute the atmosphere by producing of large amount of smoke and fumes. Also it causes to the Global Warming due to high CO_2 production. However, mini hydro plants are used renewable source of energy and it is non-polluting in nature.

Mini Hydro Plants can be started or stopped instantaneously, providing for load variation management. It improves reliability of the power system. Therefore, experts of the power sector consider it as the best choice to meet the peak load.

Running Cost of thermal plants are expensive with compared to mini hydro power plants due to fuel, maintenance, etc.

The heated water that comes from thermal power plant has an adverse effect on the lives in the water and disturbs the ecology.

Finally, it can be concluded that the feasibility study is successful and it has shown the scheduled running of the mini hydro plants is possible to avoid high cost thermal small generators especially during the dry season.

6.2 Future Recommendation

Mini hydro plants are governed by the Sustainable Energy Authority. Mini hydro developers have to obtain several approval from local authorities such as Central Environment Authority, Irrigation Department, Forrest Department, Relevant Pradeesieya Saba, Divisional Secretary.......etc. The developers have legally bounded to CEB and to the all above local authorities when they operate their power project after commissioning by CEB.

This study initially considered two methodology to optimize the capacity. The first method was not success as the permission was not given by The Central Environmental Authority and The Irrigation Department. The developer can make a small reservoir in upstream of the weir if the permission grant by the above authorities to increase the height of the weir level. It should be discussed further with the above authorities without violating of their regulations.

However, it can be suggested to extend this study further to find out the payable amount for contribution of mini hydro developers to their effort.

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ANNEXES

Annex 01: Commissioned Mini Hydro List of Sri Lanka (> 1 MW)

SN	Plant Name	Com Cap (MW)	SN	Plant Name	Com Cap (MW)
1	Bowhill (Kadiyanlena) MHP	1.00	52	Wee Oya MHP	6.00
2	Stellenberg MHP	1.00	53	Kumburutheniwela MHP	2.80
3	Naya Ganga MHP	3.00	54	Asupiniella MHP	4.00
4	Thebuwana MHP	1.00	55	Korawaka Oya (Upper) MHP	1.50
5	Lenadora MHP	1.40	56	Agra Oya MHP	2.60
6	Mulgama MHP	2.80	57	Dunsinanae MHP	2.70
7	Bulathwaththa MHP	3.80	58	Delta MHP	1.60
8	Agra Oya MHP	1.50	59	Salawa Kudah Oya MHP	2.00
9	Lower Kotmale Oya MHP	4.30	60	Labuwawa Oya MHP	2.00
10	Denawak Ganga MHP	1.40	61	Gurugoda Oya MHP	4.48
11	Upper Magal Ganga MHP	2.40	62	Kolapathana MHP	1.10
12	Punagala MHP	3.00	63	Batatota MHP	2.00
13	Wallawaya MHP	1.20	64	Kehelgamu Oya MHP	3.00
14	Waverly MHP	1.20	65	Lower Neluwa MHP	1.45
15	Gampola MHP	1.00	66	Kadawala - I MHP	4.85
16	Kadurugaldola MHP	1.20	67	Blackwater Power MHP	1.65
17	Werapitiya MHP	2.00	68	Koswatte Ganga MHP	2.00
18	Mul Oya MHP	3.00	69	Kadawala-II MHP	1.32
19	Devituru MHP	1.20	70	Loggal Oya MHP	4.00
20	Maha Oya MHP	3.00	71	Manelwala MHP	2.40
21	Way Ganga MHP	8.93	72	Giddawa MHP	2.00
22	Barcaple MHP	2.00	73	Magal Ganga MHP	9.93
23	Barcaple MHP (Phase II)	4.00	74	Soranathota MHP	2.50
24	Gampola Walakada MHP	4.21	75	Halathura Ganga MHP	1.30
25	Bambarabotuwa Oya MHP (Phase II)	3.00	76	Badulu Oya MHP	5.80
26	Bambarabotuwa Oya MHP (Phase III)	4.00	77	Amanawala MHP	1.00
27	Falcon Valley MHP	2.40	78	Adavikanda MHP	6.50
28	Kalupahana Oya (Lower) MHP	2.50	79	Watakelle (Hulu Ganga) MHP	1.50
29	Bogandana MHP	5.00	80	Kiriwan Eliya MHP	4.65
30	Nakkawita MHP	1.01	81	Denawak Ganga MHP	7.20
31	Guruluwana MHP	2.00	82	Rajjammana MHP	6.00
32	Pathaha Oya MHP	1.20	83	Waltrim MHP	2.00
33	Delgoda MHP	2.50	84	Monaraela MHP	1.80
34	Carolina I MHP	2.50	85	Wembiyagoda MHP	1.30
35	Glassaugh MHP	2.53	86	Branford MHP	2.50
36	Mandagal Oya MHP	1.28	87	Koladeniya MHP	1.20
37	Kabaragala MHP	1.50	88	Kokawita-I MHP	1.00
38	Bambarabotuwa Oya MHP	3.20	89	Lemastota MHP	1.30
39	Galatha Oya MHP	1.20	90	Kirkoswald MHP	4.00
40	Hapugastenne - I MHP	4.60	91	Ganthuna Udagama MHP	1.20
41	Bellihul Oya MHP	2.50	92	Owala MHP	2.80
42	Carolina - II MHP	1.30	93	Rideepana MHP	1.75
43	Hapugastenne - II MHP	2.30	94	Demodara II MHP	1.00
44	Deiyanwala MHP	1.50	95	Lower Atabage Oya II MHP	1.25
45	Hulu Ganga-I&II MHP	6.50	96	Theberton MHP	1.30
46	Niriella MHP	3.00	97	Ross Estate MHP	4.55
47	Sanquhar MHP	1.60	98	Maa Oya MHP	2.00
48	Alupola Estate MHP	2.52	99	Rakwana Ganga MHP	1.00
49	Rath Ganga MHP	2.00	100	Pathanahenagama MHP	1.80
50	Waranagala (Erathna) MHP	9.90	101	Madugeta MHP	2.50
51	Atabage Oya MHP	2.20	102	Mille Oya MHP	1.20