TECHNO-ECONOMIC VIABILITY OF LARGE SCALE SOLAR INTEGRATION WITH BATTERY STORAGE IN SRI LANKA

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Degree of Master of Science

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DECLARATION

I declare that this thesis is my own work and does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning. Further to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the due acknowledgement is made in the text.

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The above candidate has carried out research for the Masters/MPhil/PhD thesis/Dissertation under our supervision.

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3) Name of the supervisor: Eng. K.P.K. Shanthi

   Signature of the supervisor: Date:

ABSTRACT

In Sri Lanka, power is generated from fossil fuel, hydro power and other renewable sources while generation from solar power is prominent in non-conventional Renewable Energy Sources (RESs). Over the past few years large scale Solar PV Power plants (SPVPs) are being added to the national grid at Medium Voltage (MV) distribution network. However, the quality of the distribution networks can adversely be affected, if they are connected without the knowledge of optimum sizes and locations.

In the research performed for outlining of SPVPs in the distribution networks, the output power from the SPVPs are assumed dispatchable without considering the variations of solar potential, which affect the output of the PV modules. Besides this, utilization of electricity generated from the weather dependent SPVPs is also affected by the mismatches in the timings of the electrical supply and demand. The difficulties associated with proliferation of SPVPs could be alleviated by the proper use of Battery Energy Storage Systems (BESSs). The use of BESS for SPVPs has been proposed in many studies, however, the impact of installing BESS on the quality of distribution networks during the sizing of battery storage has been ignored in majority of those research. The computational methods in most existing studies for the sizing and placements of SPVPs and Battery connected SPVPs (B-SPVPs) have used different analytical approaches and heuristic techniques. The analytical approaches are favourable for small systems but are not suitable for large and complex networks.

In this research, the optimal planning for SPVPs and B-SPVPs in terms of size and location in the distribution networks is presented. Solar intermittency has also been considered for the output power from PV modules. The main objective of this study is the development of a model to find out the self-sufficiency level of a Grid Substation in terms of energy required to serve the energy demand within the distribution network as much as possible. Models for proposing sizing and placement of SPVPs and B-SPVPs using heuristic optimization technique called Mixed Integer Programming with Genetic Algorithm (MIGA) was developed, preserving power balances and voltage limits before and after either SPVP or B-SPVP is connected to the distribution network.

To building up the basic model and optimization, Backward-Forward Sweep Load flow was carried out on IEEE 33 Bus network. The outcomes from MIGA were verified using Particle Swarm Optimization (PSO). The objective function was taken as minimization of the percentage of loss reduced when SPVP or B-SPVP is installed with respect to neither SPVP nor B-SPVP is present in the distribution network. The built model was then used to assess self-sufficiency level of Tissa 1 Feeder of Hambanthota GSS. The variability of load over a day was also considered in the modelling. In addition to reduction in power losses resulted after installing SPVP and B-SPVP, the improvements in bus voltages were also found significant. A financial evaluation was carried out to inspect the viability of SPVP and B-SPVP in Tissa 1 feeder of Hambanthota GSS using the optimized results with respect to Simple Payback Period and Levelised Cost of Energy for Tissa 1 feeder. At the closure, suggestions have been put forward as future works for any interested researcher.

DEDICATION

This thesis is dedicated to my parents and husband for being my pillars of success.

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I would like to acknowledge Prof. J. Rohan Lucas and Dr. J. V. Upuli P. Jayatunga for inspiring my interest persistently and providing extensive personal and professional guidance while teaching me a great deal about both scientific research and life in general. I would especially like to thank my external supervisor Eng. K.P. Kusum Shanthi, the Deputy General Manager (Transmission Design & Environment). As my teacher and mentor in Ceylon Electricity Board, he has taught me more than I could ever give him credit for here.

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Nobody has been more important to me in the pursuit of this dissertation than the members of my family. I would like to commemorate my parents, whose love and guidance are with me in whatever I wish for. Most importantly, I wish to thank my loving and supportive husband, Isuru, caring brothers and my adorable child, Thisaja, who provide unending inspiration.

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EQUATIONS

ABBREVIATIONS

Abbreviation	*Description*
ADB	Asian Development Bank
BESS	Battery Energy Storage System
BFSF	Backward-Forward Sweep Flow
B-SPVP	Battery energy storage connected solar PV power plant
PDF	Probability Density Function
CEB	Ceylon Electricity Board
DG	Distributed Generator
DER	Distributed Energy Resource
DP	Dynamic Programming
GA	Genetic Algorithm
GSS	Grid Substation
IRR	Internal Rate of Return
IT	Information Technology
LCLTGEP	Least Cost Long Term Generation Expansion Plan
LCOE	Levelized Cost of Energy
LiB	Lithium-ion battery system
MIGA	Mixed Integer Genetic Algorithm for Linear Programming
MV	Medium Voltage
OE	Optimum Energy Level
PPA	Power Purchase Agreement
PSO	Particle Swarm Optimization
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
RES	Renewable Energy Sources
RTS	Reliability Test System
SPP	Simple Payback Period
SPVP	Solar PV power plant
TELI	Total Energy Loss Index
UNFCCC	United Nations Framework Convention on Climate Change
US	United States

1 INTRODUCTION

This chapter states the research problem and gives a detailed explanation of the purpose of this study. It presents the rationale of the study and indicates why it is worth doing, by describing the major issues and the boundaries of this research in order to provide a clear focus.

1.1 Problem Statement

In the recent years, the energy demand in Sri Lanka has been increasing drastically while the conventional energy sources are being depleted giving an inadequate supply. Thus it is important to conserve fossil fuel and utilize Renewable Energy (RE) Sources (RESs). In Sri Lanka, power is generated from main three sources; fossil fuel, hydro power and other non-conventional renewable sources while generation from solar power is prominent in non-conventional RESs. Over the past few years large scale solar power plants (SPVPs) are being added to the national grid at the Medium Voltage (MV) distribution network level, enabling supply of power to connected users where it is required. Exploitation of electrical power from sustainable power sources has been expanded further due to their money-saving feature and eco-friendliness. Together with the global push and Sri Lankan government's goal of achieving 100% RE share by the year 2050 and its accelerated programmes like Battle for Solar (A programme targeted on increasing rooftop based solar generation) and connection of 1MW solar power plants in 150 different locations in 17 Grid Substations (GSSs) at MV level, there is an increasing trend of solar power plants being added to MV network. As at June 2019, 166MW of rooftop based solar capacity is available in the power system. At the beginning of July 2019, the progress of the programme of connecting 1MW solar power plants can be summarized as Power Purchase Agreement (PPA) has been signed for 25MW, awarded total capacity of 53MW while 2MW of solar power plants have already been commissioned, out of the cabinet approval granted 150MW.

Besides this being the prevailing scenario, the addition of RESs at the distribution network is controlled by capacity limitations that are based on outcomes of stability studies performed by Generation and Transmission planning unit of Ceylon Electricity Board (CEB), treating SPVPs as non-dispatchable. These studies do not execute stability analysis Grid Substation (GSS) wise, but for the entire network as a whole. The present practice is to determine the allowable RE share of the generation mix and allocate fractions of it to GSSs considering simulations for power system for stability. These studies include the addition of RE with the proposals for possible GSS and forecasts based on capital and operational costs while considering intermittency and uncertainty of RESs at the same time. This has caused a barrier for grid autonomy concept; a concept to which many countries are heading towards. Moreover, at present, Si Lankan power system is not enough to accept intermittency of RES based power generation as the frequency controlling is done by hydro power plants rather than fast responsive gas turbine based power plants. On the other hand, distribution divisional Planning & Development branches propose to have distributed generators as alternatives to curb the power system losses. Lengthy feeders and feeders those are unable to upgrade with higher current capacity conductors result in setting barriers to the local community's development. Thus CEB power system planners are eagerly searching for solutions to mitigate these bottlenecks to enhance distribution network performance and to maximize utilization of local resources at the same time.

To optimize the grid integration with solar Photovoltaic (PV) plants, current technology developments combine Battery Energy Storage Systems (BESS) with PV systems. These raise possibilities of reducing power fluctuation of RES, high power and high energy capability, fast response, flexible installation and feasible as well as practical serviceability. This is because of the fact that BESSs have the potential to support the stability of the power system and increase the reliability and power quality of supply drawing less power from the national grid. Even though extensive research has been done in this aspect of integrating RESs into the network, there are only few studies that have taken intermittency of solar irradiance and charging & discharging of BESS while considering technical losses of the connected distribution system. Most importantly, there has been neither study conducted in integration of large scale SPVPs with and without BESS in Sri Lanka, primarily owing to BESS's prohibitively high cost which however, displays a clear downward trajectory.

1.2 Research Objectives

The objectives of this research are as follows.

1. To determine the optimum size and location for a large scale SPVP that can make a GSS self-sufficient, subjected to voltage and energy loss constraints
2. To determine the optimum size and location for a battery storage connected large scale solar power plants (B-SPVP) that can make a GSS self-sufficient, subjected to voltage and energy loss constraints
3. Determine the capital cost of BESS (in USD/kWh) of B-SPVP to compete with highest cost power plant in the Sri Lankan power system

1.3 Scope of Work

The study considered solar energy as the RES while considering utility scale BESS as the energy storage option. Optimization of the distribution network was performed in terms of energy loss bounded by voltage constraint whereas the self-sufficiency is expressed in terms of energy penetration of either output energy from large scale SPVP or B-SPVP.

Further, the distribution networks were analysed by installing single generator units than considering installation of multiple units coupled to single BESS. The battery control logic was developed in order to maximize the output power from SPVP and B-SPVP.

1.4 Research Contribution and Novelty

In this research following developments which are novel to the Sri Lankan power system were made.

1. A general model that is capable of determining optimum location and size for both SPVP only and B-SPVP scenarios in order to optimize a GSS in terms of energy loss minimization by Mixed Integer Genetic Algorithm for Linear Programming (MIGA) and Particle Swarm Optimization (PSO) techniques
2. Determination of Capital Cost of BESS (in USD/kWh) of B-SPVP to compete with highest cost generator unit in Sri Lankan power system, at the optimum solution, to consider as a base case power plant in Least Cost Long Term Generation Expansion Plan (LCLTGEP) of CEB.

1.5 Thesis Structure and Organization

This thesis comprises of seven chapters. Chapter 1 provides an introduction to the research while detailing the research gap, objectives and narrowing down of the scope whereas Chapter 2 presents a comprehensive literature review with respective to the research area. A descriptive demonstration on the methodology followed when modelling the solar PV power output and the development of optimizing model based on loss minimization are delivered in Chapter 3 and 4. A detailed interpretation of the results obtained from modelling and simulations for standard IEEE 33 Bus test network is arranged under Chapter 5. Once the modelling and simulations are done for the standard IEEE 33 Bus test network and verified by two heuristic approaches, the techno-economic outcomes obtained for Tissa 1 feeder of Hambanthota GSS is described in detail under Chapter 6. This is followed by conclusions of the research work carried out are explicated in Chapter 7. For any researcher interested in carrying out similar studies, a list of proposals as future works are also listed along with a concise description at the end of Chapter 7.

1.6 Summary

The thesis presents a model to evaluate the techno-economic viability of large scale SPVP integration without and with BESS for self-sufficient GSS in Sri Lankan power system by optimizing in terms of energy loss minimization subjected to voltage constraint using two heuristic approaches, namely, MIGA and PSO.

2 LITERATURE REVIEW

This chapter presents a comprehensive literature review on published information on what has been done up to now in the world in terms of large scale RE integration, particularly solar energy to the distribution network for grid autonomy. The benefits that can be reaped from RESs by integrating with Distributed Generators (DGs) and key issues inherent with DGs are highlighted. Then the chapter is expanded by illustrating how co-location of BESS with SPVP has been done in terms of optimized size and location together with algorithms and optimization techniques that have been used previous studies. Finally the chapter concludes by explaining how the concepts of SPVP and B-SPVP in the view point of Sri Lankan power system.

2.1 Distributed Generators in present power systems

Penetration of Distributed Energy Resources (DERs) is overturning the traditional unidirectional power flow concept while giving prime concern to technical & economic aspects. Understanding the utilization and optimization of DGs has grabbed the curiosity of countless researchers.

2.1.1 Types of Distributed Generators

DGs exist in the current world are of many forms. Based on the electrical characteristics in terms of active and reactive power delivering capability, the available DGs can be classified into four major types which are provided as the followings [1].

1. Type 1 DGs:
   - Capable of injecting active power (P) only.
     E.g.: PV, micro turbines, fuel cells
2. Type 2 DGs:
   - Capable of injecting reactive power (Q) only.
     E.g.: Synchronous compensators (Gas turbines, Capacitor banks)
3. Type 3 DGs:
   - Capable of injecting both active power (P) and reactive power (Q) as well.

E.g.: Synchronous machines that uses cogeneration (Generates electricity from leftover energy from other forms of generation e.g. gas turbine)

4. Type 4 DGs:
   - Capable of injecting active power (P) and are capable of consuming reactive power (Q).

     E.g.: Wind turbines which use induction generators

Since the scope of this study is to investigate the self-sufficiency primarily with respective to integration of large scale SPVPs which use solar PV modules to generate power, investigation is carried out only in terms of active power subjected to the voltage constraint, use of unity power factor for SPVP's output is justifiable.

2.1.2 Merits of Distributed Generators

Distributed generation concept is captivating the interest of present power system planners mainly due to its remarkable advantages like enhanced efficiency and reliability in terms of peak power reduction and increased power quality, while giving prime high ground to energy loss and voltage stability [2]. When centralized large scale power plants transmit energy over long distances, some of that energy is lost in the conductors. With distributed generation, since the generators are in the proximity of electricity users, there is less waste of electrical energy. Many developed countries have been encouraging proliferation of DGs in their power network at distribution level, anticipating grid autonomy, because of DGs' inherent capability to operate independently without the power from main grid. The DGs are not defined by their size, but by their role in the connected power network. DGs can play their role either as back up or peak shavers by absorbing their freely available resources as their fuel for most of the types of DGs. Utilizing DGs in power system has its own superior benefits when compared with conventional generators. For instance, since DGs are smaller than decentralized supply units, DGs have proven to be capable of installing and deploying for electricity use when and where they are valued most. Even though when per unit production is at relatively low level, collection of such DGs are capable of imposing a significant effect on the main grid [3]. On the other hand, using more renewables means lessening toxic gas emissions which has resulted in DGs being most preferred by environmentalists. As mentioned in [4], energy-related carbon dioxide emissions increased by 1.7% in 2018 to an alarming high of 33.1 Giga tons of carbon dioxide, while approximately two-thirds of the growth in emissions resulted from the electricity power sector. Thus, resolution for active endeavours to overcome climate change challenges is inevitable.

2.1.3 Objectives of DG integration in distribution network

Several studies in available literature, use of RE technologies for the planning of DGs in distribution networks have been reported in terms of minimizing energy loss and voltage profile improvements in the considered network. However these two issues have been addressed separately giving special emphasis to selection of the most cost-efficient BESS configuration at the same time. Due to the increased invasion of RE sources at distribution level, analysis on the impact of connecting DGs on minimization of power losses and the impact of bus voltages is vital. According to the information written for optimizing electricity power network with DG integration, electricity network planners and responsible personnel have considered optimizing power grid with integration of DGs in power network having objectives in their mind as summarized in the Figure 2.1.

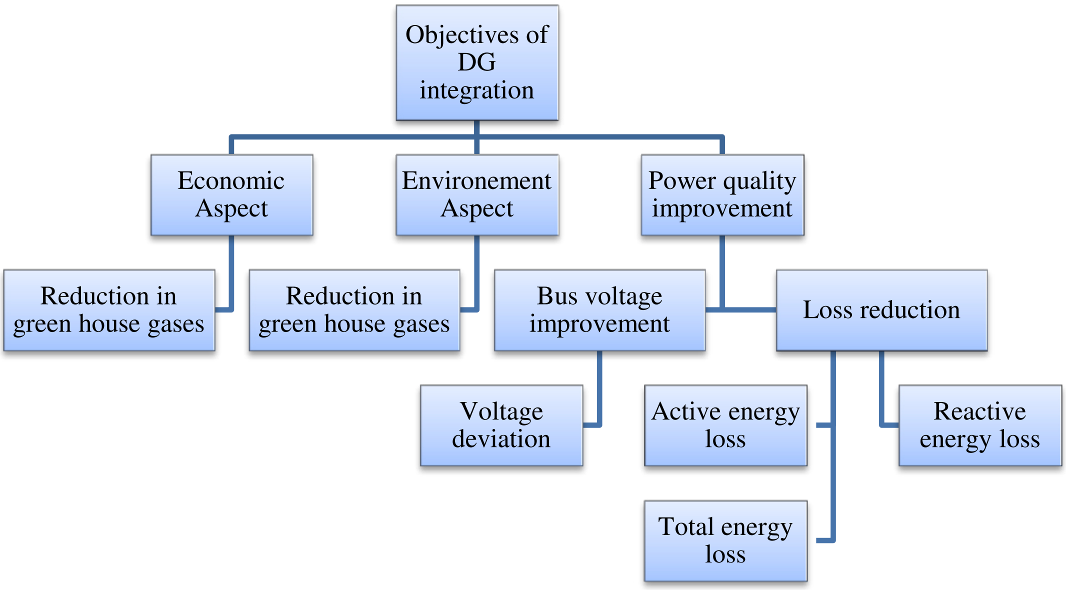

Figure 2.1: Objectives of DG integration in power system [1, 36]

Since many DGs use freely available indigenous resources, reduction in the emission of greenhouse gases is envisaged. There are extensive studies that have been carried out in DG integration in terms of power quality where consideration has been mainly given on energy loss reduction in tri folds as energy loss reduction, reactive power loss reduction and total energy loss reduction which is the reduction in sums of both active and reactive energies.

The penetration of DGs are paving the way for a two-way flow of energy and allowing incorporation of new, connected technologies for power generation but it has to overcome some obstacles. The biggest disadvantage is that utilities have to lessen the amount of electricity generated by power plants in the system which is still a must infrastructure to maintain the national grid. In addition, there are questions of security of firm supply and resiliency in a move away from baseload power sources. Since distributed electricity generation depends on small-scale, decentralized, local, on-site generation, preferably by tapping renewable energy sources, they avoid long-distance transmission losses. Once planned prudently its design improves supply stability and reliability and gives users more control.

Researchers like [7, 8] have quantified these challenges into quantifiable terms with respect to costs, reliability and greenhouse gas reduction by which assist in decision making process of integrating DGs into the power network extensively by optimization of these quantified values. Moreover, remote locations with poor power quality or locations without grid access require a specific mix of DGs. They often need fossil fuel energy sources as well as battery storage to ensure reliable power supply for a sustainable power supply that is cost-efficient at the same time.

2.1.4 Battery Energy Storage System as Distributed Generator

Electrochemical energy is another category of DGs which includes BESS comprising of different battery types. These diverse battery technologies have their own merits and demerits, mainly depending on their capacity and purpose of use in the distribution network as depicted in Figure 2.2.

BESSs have been identified to be fulfilling numerous objectives that serving benefits including integration of intermittent renewables, improvement in energy efficiency, reliability of electricity supply, and access to and security of energy in remote areas. Further these units perform a crucial role in converting energy systems that are unpolluted, sustainable, and efficient.

	Energy density (kW/kg)	Round Trip Efficiency (%)	Life Span (years)	Eco-friendliness
Li-ion	1st (150–250)	1st 95	1st (10–15)	Eco-friendliness
NaS	2nd (125–150)	2nd (75–85)	3rd (10–15)	X
Flow	2nd (60–80)	2nd (70–75)	3rd (20–25)	X
Ni-Cd	4th (40–60)	4th (60–80)	4th (5–10)	X
Lead Acid	5th (30–50)	5th (60–70)	5th (3–6)	X

Li-ion = lithium-ion, Na–S = sodium–sulfur, Ni–Cd = nickel–cadmium.

Figure 2.2: Differentiating Characteristics of Different Battery Technologies
Source : Handbook on battery energy storage system, December 2018 [4]

DGs, in general, are competent of delivering electricity at locations in the power grid where it is most worthwhile. If sited at the correct locations and operated at right times, DERs can deliver more site-based value. Moreover, as DERs tend to cost more on a per-unit basis than their centralized opponents due to economies of scale. The major obstacle for the development of DGs is their high cost [3]. However the costs have shown a significant decline over the recent years with the advancements in RE and BESS technologies thanks to Information Technology (IT) innovations and inventions. The unit costs of BESS technologies show a downward trajectory as they are installed in larger scales together with the improvement in reliability and efficiency simultaneously. Thanks to the recent spread of mobile IT devices and increased mass production of batteries due to the boosted demand, the costs have lowered. Therefore, a system with higher capacity of a given technology will typically cost less per megawatt than a system with lower capacity of the same technology. Technologies including solar PVs and electrochemical energy storage can enable exhibition of clear economies of scale [6]. Figure 2.3 extracted from [6] illustrate this point more strongly for solar PVs and lithium-ion battery systems (LiBs), respectively. The drawback in these studies is that they have not taken the societal benefit into account when calculating per unit costs. These kinds of DG technologies tend to provide locational value as alternatives to projects connecting capital-intensive large scale conventional power plants [6].

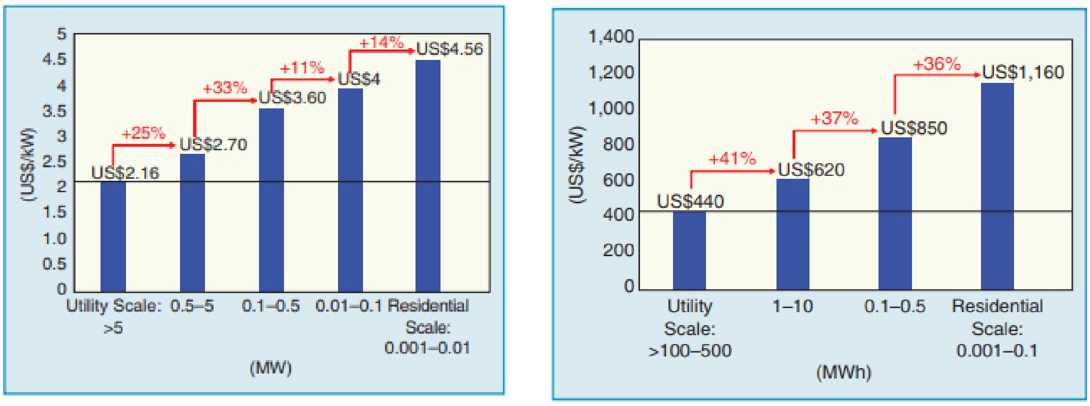

Figure 2.3: The economies of unit scale and incremental unit costs for Solar PV systems (2018 US$/kW-ac) [Left] & The economies of unit scale and incremental unit costs for LiBs (2017 US$/kWh) [Right] [3]

2.2 Combination of large scale SPVP and BESS in distribution systems

Interconnection of large scaled solar PV distributed generators into utility networks can adversely influence the operation of next generation smart power systems [9]. Output power of this type is random and hence one remedy is to suppress it by short-term to mid-term electrical storage systems. BESS is a remarkable example brought to this end. Services rendered by batteries can be tri fold for the three types of stakeholders of BESS involved in power system projects. They are network owners, network operators and "Behind-the-meter" customers. For network owners, peak-load management or investment deferral in system reinforcement to minimize power system losses, for network operators BESS assist as ancillary services such as frequency regulation or voltage support and for "Behind-the-meter" customer, BESS either helps in self-consumption of solar PV or as backup power. When large scale BESS grid applications are considered, they are numerous and each application is limited by optimal technical conditions. For example; BESS size, discharge duration and cycles per year [4, 11]. For instance, if BESS is installed with the intention of electric energy time-shift (arbitrage), the suitable BESS size range lies between 1-500 MW, targeting a discharge duration less than 1 hour with 250 or more cycles/year where as if BESS is installed having distribution upgrade deferral and voltage support in mind, the appropriate BESS size range lies between 500kW-10

MW, anticipating a discharge duration of 1-4 hours with 50 -100 cycles/year. Other grid applications include BESSs serving as electric supply capacity, spinning, non-spinning, and supplemental reserves, voltage support and black start, regulation of power flows in controlled areas, ramping of renewables like PV and wind, power transmission congestion relief and improving power quality etc., while each application is limited to the three main factors mentioned earlier.

It is envisaged that power systems will rely significantly on RESs while solar and wind being prominent. However, the variability and intermittency of solar PV and wind power generation has discouraged the combination of these RESs owing to insufficient reinforcement of network capacity to support system stability, forced curtailment of renewable in-feed to avoid over-voltage conditions and tendency of recovering the associated curtailment costs from end consumers by higher tariffs. Nonetheless, these non-dispatchable PV plants (or wind plants) can be made dispatchable with the integration of BESS technologies providing an opportunity to dispatch PV plants the same way as traditional thermal power plants offering benefits such as flexibility in connecting renewable power safely and securely while storing surplus energy while facilitating the use of existing network capacity, smoothing of renewable in-feed reducing and increased customer satisfaction with reduced curtailments etc. [10].

Even though the BESS market is still in its baby stage, their utilization has been increasing exponentially, mainly in Australia, Europe, Japan, and the United States (US), primarily because of fall in battery prices, improved stability of power systems, and ability of integration of alternative and renewable energy sources. However BESSs are still far too expensive and investors are very unlikely to investment in BESS related projects. The governments in countries like Australia, Japan, and the US inspire prospective power plant developers by providing subsidies to initial installation. Programmes like United Nations Framework Convention on Climate Change (UNFCCC) in which developed countries ready to provide at least USD 100 billion in support every year from 2020 onward assist developing countries to cope with climate change. To implement their commitments to reduce greenhouse gas emissions, the countries could introduce new and renewable energy in the power sector and increase energy efficiency by promoting broader adoption of energy storage devices, to supplement variable new and renewable energy sources. The Asian Development Bank (ADB) also has raised USD 600 million to help finance climate change mitigation with the intention of encouraging developing countries to think of linking BESSs with renewables in their least cost generation plans' base case scenarios.

2.3 Algorithms and optimization techniques for locating and sizing of large scale SPVPs and B-SPVPs

Having identified the trend in co-locating PV plants with BESS due to extensive benefits offer, researchers have studied how the proliferation of large scale SPVPs and BESSs can be optimized subjected to many objective functions with the use of plentiful techniques. These studies have been carried out either in isolated microgrids or in microgrids that are connected with main power grid with tie lines. PV plants generate intermittent output by convention. But these can be reconfigured to be dispatchable with the integration of BESS technologies which have continuously advanced over the recent past [11]. Combination of PV plants with BESS can be done in numerous ways. It can be done either by charging BESS entirely from PV plant output and discharge the stored energy during non-solar generating times or use BESS output to supply the demand while excess energy is either sold to the electrical grid where Time-Of-Use electricity pricing is the electricity market or time shifting by storing in the battery to discharge later when the price is high. In studies related to the latter type of cases, the objective was to minimize the cost associated with net power purchase from the electric grid and the battery capacity loss while at meeting the load and reducing the peak electricity purchase from the grid simultaneously [12,13]. In the view point of Sri Lankan power system, due to the absence of a Time-Of-Use electricity market, better approach in analysing the merging of large scale SPVP with BESS is to optimization in terms of reduced energy loss and improvement in voltage profile.

Operations of diesel power plants which are massively subjected to oil price fluctuations, impose financial limitations on power system operations, posing RES based electricity to be qualified as viable options of power generation. Even though it seems as an inviable solution in the massive complex network, RESs are not only be able to meet the local electrical energy needs but also improving system reliability and contributing to reduction of energy production cost subjected to proper sizing while mitigating RESs' inherent stochastic nature [1]. Available literature suggests that sizing and placement of BESS with SPVP at distribution level have done in the view point of economy whereas decision of charging and discharging of BESS depend on the price of electricity purchase by the power distribution entity [2]. Even though SPVPs offer many benefits such as power flow reduction, loss minimization and voltage profile improvement by locating near loads, some challenges like power fluctuation, voltage rise comes along with them from utility perspective [1]. Unlike conventional thermal power plants that have invaded the power system of a certain electricity network, PV sources are dependent on time and weather extensively. In the studies [2, 14, 15, 16], the SPVPs' and B-SPVPs' sizes have been predetermined and non-generalized whereas the real requirement is to find the optimal size of B-SPVP in any given location. The main benefits of integrating DGs to distribution networks include the reduction in power losses and improvements in Bus voltage profiles. However, the technical benefits to distribution networks are greatly influenced by the size and locations where DGs are connected [17]. In present days, sizing and placement of DGs in distribution networks have become one of the hot topics for research in the field of power system planning. Over the last decade, the planning for DGs in distribution networks has been done through several approaches. These approaches include analytical methods, numerical methods and heuristic algorithms. A comparison of extensively used analytical and heuristic approaches is tabulated in the Table 2.1.

Table 2.1 : Comparison of analytical and heuristic concept

Analytical Approach	**Heuristic approach**
- Learns by Analyzing	- Learns by acting
- Uses step by step procedure	- Uses trial and error
- Values quantitative information and models	- Values experience
- Builds mathematical models and algorithms	- Relies on common sense
- Seeks optimal solution	- Seeks satisfying solution
E.g.: Lambda multiplier method	E.g.: Genetic Algorithm (GA), PSO

Table 2.2 : Summary of literature review on DG sizing and placement using heuristic methods

Reference	Load modelling	DG Type	Target	Objective/Technique	Tested system
[22]	Constant	Wind Turbines	DG location	Loss minimization	11 Bus feeder system & IEEE - 30 Bus system
[23]	Constant	P & Q by unknown sources	DG size and location	Electric losses, reliability, and voltage profile	Reliability test system
[24]	Constant	P & Q by unknown sources	DG size and location	Voltage profile, line-loss, and environmental impact	12 Bus system
[25]	Constant	P & Q by unknown sources	DG size and location	Electric losses, voltage profile, line capacities and protection	IEEE 34-Bus radial feeder
[26]	Constant	P by unknown sources	DG size and location	Loss sensitivity factor	IEEE-30, 33 and 69 Bus systems
[27]	Constant	P by unknown sources	DG size and location	Loss minimization using sensitivity factor	12, 34 and IEEE- 69 Bus systems
[28]	Constant	P & Q by unknown sources	DG size and power factor	Loss minimization	16, IEEE-33 and 69 Bus systems
[29]	Constant	P & Q by unknown sources	DG size	Power stability index	12, and IEEE 69 Bus systems
[30]	Constant	P & Q by unknown sources with Q by capacitors	DG and capacitor size and location	Real power losses using sensitive factor	12, and IEEE- 33 Bus systems
[31]	Constant	P & Q by unknown sources	DG size and location	System losses using sensitive factor	IEEE- 33 and 69 Bus systems
[32]	Constant	Biomass, Solar PV and Wind Turbines	DG size, location, and power factor	System losses using capacity factor	IEEE- 33 and 69 Bus systems

Reference	Load modelling	DG Type	Target	Objective/Technique	Tested system
[33]	Constant	P & Q by unknown sources	DG size and location	Active power losses using power factor	IEEE- 14 and 30 Bus systems
[34,35,36]	Constant	P by unknown sources with Q by capacitors	DG and capacitor size and location	Loss minimization	687 and IEEE- 33 Bus system
[37]	Constant	P & Q by unknown sources	DG size and location	Loss minimization and voltage	IEEE- 33 and 69 Bus systems
[38,39,40]	Constant	P by unknown sources	DG size and location	Loss minimization and voltage	IEEE 69 Bus systems
[41]	Constant	P by unknown sources	DG size and location	Loss minimization	IEEE- 33 and 69 Bus systems
[42]	Constant	P & Q by unknown sources	DG size and power factor	Loss minimization and voltage	IEEE- 30 and 69 Bus systems
[43,44]	Constant	Solar PV and Wind Turbines	DG size and location	Loss minimization	IEEE- 33 and 69 Bus systems

To be concise, analytical approach needs a thorough understanding of mathematical programming concepts and utilization of special solvers are necessary (E.g. Lambda multiplier method) whereas heuristic approach produce a feasible solution that is good enough to quickly solve a particular problem and achieve immediate goals – but not necessarily an optimal solution. A summary of literature review from heuristic techniques is provided in Table 2.2.

The benefits and limitations of different optimization techniques used for the sizing and placement of DGs are well documented in [18] and [19]. Furthermore, it was also known that installation of multiple DGs could provide more benefits to distribution network as compared to benefits from installation of a single DG unit. The analytical expressions and Dynamic Programming (DP) search method were proposed for determining the sizes and locations of multiple DG units in distribution network [20, 21]. Heuristic methods are generally considered robust and provide optimal solutions for large and complex problems. Among the various heuristic methods, Genetic Algorithm (GA) and Particle Swarm Optimization are well famous and hence frequently used by researchers for solving the complex optimization problems due to their powerful search and optimization capabilities.

When sizing of B-SPVP is considered, based on literature review, following can be concluded.

- The methods for the sizing and placements for DG with time-series generation and load models followed by analytical approaches for solving the optimization problems.
- The analytical methods, although well-matched for small systems, perform adversely for large and complex objective functions. The planning for PV plants using time-varying generation and load models would become more complex, if the size of the distribution network is large.
- The research for the planning of solar PV generation in the distribution networks has been carried out in several studies. However, methods used in most studies have considered only peak loads for the sizing and placement of DG units. Use of historical weather data is ignored in many studies.
- Most of the research pertinent to BESS sizing have followed those similar techniques used for standalone PV systems, meanwhile other proposed models

do not guarantee the justification of energy balance under certain network constraints. Sizing and placement of BESS for PV systems at distribution level has been done in viewpoint of economy.

2.4 SPVP and BESS under the purview of Sri Lankan Power System

With the understanding gained from previous sections under literature review on DGs' roles with their benefits when optimized mainly for loss minimization with integrating in distribution network in rest of the countries in the world in general, it is vital to get an understanding on how these SPVP and B-SPVP concepts have comprehended by power system planners in Sri Lanka. Sri Lanka, due to its geo-climatic condition resulted from residing within equatorial belt, gets plenty of solar throughout the year. According to [45], SPVPs have proved to be cost-effective in serving far-flung electrical loads and in providing a distributed source of electricity without the requirement of money and time consuming network expansions. As far as the current Sri Lankan energy mix is considered, Sri Lanka has reaped the fullest economical potential of major RES in terms of large hydro while, mini hydro, solar and wind have been recognized as outstanding RESs among other RE technologies. Further [45] emphasizes that other RESs will be predominant in forthcoming years as it will exceed the major hydro capacity by 2023. Figure 2.4 extracted from [45] illustrates the energy contribution of dominant other RESs and percentage of energy share variation over the next 20 years period development of RE technologies in Sri Lanka, treating solar and wind power to be non-dispatchable. As presented in [45], due to the fact of considering solar and wind cannot be dispatched on demand, mini hydro appears to be the main dominator in the RE sector in the energy mix and solar together with wind reserving equal shares in the energy mix and seems progressively escalate as the planning horizon goes on. Another positive aspect that can be observed from Figure 2.4 is that the RE share (as a percentage) expands over the time irrespective of the slight decrease projected in the latter part of planning horizon owing to the inability of curbing the ever increasing energy demand only with large hydro as they have been saturated to their maximum economic capability.

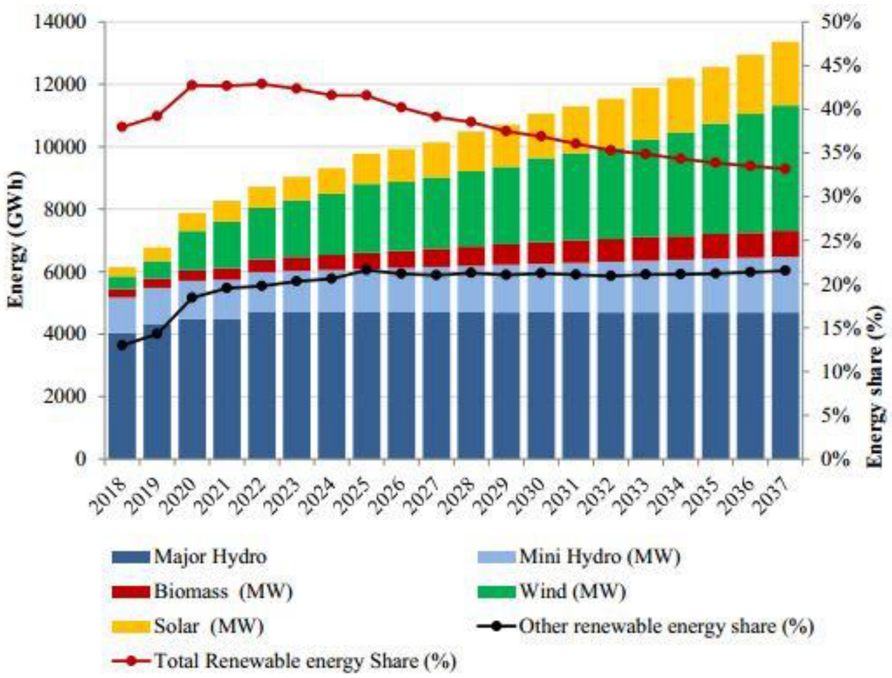

Figure 2.4 : Energy Contribution of Renewable Energy Sources and Energy Share for Next 20 Years
Source: Ceylon Electricity Board Long Term Generation Expansion Plan 2018-2037

Even though there is abundance of solar energy to be reaped in Sri Lanka, the obstacle is that Sri Lanka is not in a financially stable position to afford BESS technologies to store this plentiful resource. This is same for wind resource as well. As BESS price makes up a large portion of a BESS installing project cost, still Sri Lanka has not considered utility scale BESS as a viable option in long term generation plan prepared by the CEB owing to BESSs' alarmingly high cost. Presently the capital cost per unit of B-SPVP is 2000 USD/kWh [50] approximately and has barred considering BESS as a viable option in Sri Lankan power system. However, the current price falloff trajectory provides a green light for the acceptance and use of BESS since battery prices are expected to drop even further in the future as economies of scale can be realized through investment in research and development (R&D) and expansion of productive capacity in the rest of the world.

As appeared in [47], thanks to the ongoing R&D activities; BESS unit price is forecasted to come to a value that is commercially viable by the year 2025 which is not too far. Therefore by having performed viability check studies and developed models to assess the integration of large scale SPVP and B-SPVP concepts in distribution level in Sri Lankan power system, it will ease the burden of Sri Lankan power system planners and keep Sri Lanka ready to welcome BESS technologies into these SPVP and B-SPVP concepts once the cost of BESSs falls to a number that is feasible in Sri Lankan context.

2.5 Summary

This chapter presented the existing literature about the integration of RESs in distribution networks. The key issues in existing energy generation and demand balance were highlighted, followed by motivations toward the use of solar PV energy at utility scale. The basics of DGs and sources of electricity for DGs, technical benefits and objectives that have been used in literature for the sizing of DGs were also highlighted. Further, the methods for sizing and placement of DGs and energy storage systems were discussed. Finally, sizing and placement of SPVP and B-SPVP studies with respect to Sri Lankan power system was discussed as well. All these literature emphasizes the impression that sooner or later Sri Lanka need to implement self-sufficient GSS concept with SPVPs and B-SPVPs since the RE technologies are advancing with the global push to a level where inherent variability in RE like solar is no longer be an issue with advancement in utility scale BESSs.

3 DEVELOPMENT OF SOLAR PV MODULE POWER OUTPUT MODEL

Main constituents of developing solar PV module power output model based on solar irradiance data collected from Hambanthota area in Sri Lanka and the outcomes of the built model are elaborated in this chapter.

3.1 Weather Data Collection

Meteorological data for weather data modelling was taken from the weather station located in Hambanthota Saga Solon Solar Power Park site at geographic coordinates 29°19'25.6"N, 71°49'11.8"E. For this study, weather data of the site acquired starting from 30th May 2017 to 29th July 2018 was considered. Initially data was processed to mitigate erroneous of the input due to weather station failure to communicate in certain days and to maintain consistency of data. This was achieved by filling the missing/erroneous timestamp data with the next available timestamp data, assuming the nearest next value of solar irradiance data is the best value to represent the missing value. Once the data were processed to preserve consistency, output from a solar PV module was modelled.

3.2 Output from a Solar PV module for Hambanthota Area

The methodology which uses Beta probability density function (PDF) to generate 24 hour solar irradiance curve and the equations to express solar PV module output probability based on solar irradiance data mentioned in [46], the processed solar data collected from Hambanthota was used and modelled using MATLAB. In this approach, intermittency of solar resource was captured as it is an essentiality in SPVP or B-SPVP planning.

In order to investigate whether there is any seasonality effect of solar irradiance, the collected weather data was partitioned into 4 seasons as depicted in [51]. These four seasons have been divided basically depending on the rainy seasons of Sri Lanka as North-East, South-West, and the two inter-monsoonal periods. The categorizations of these four seasons on monthly basis are according to the Table 3.1.

Table 3.1: Months for seasons considered

Season	Months
Inter monsoonal period 1 (IM1)	March, April
Inter monsoonal period 2 (IM2)	October, November
North-West Monsoon (NW)	December, January, February
South-West Monsoon (SW)	May, June, July, August, September

In order to generate output from solar PV module model as described in Table 3.3, data extracted from PV module specification [52] as specified in the Table 3.2 was incorporated in the equations presented in the Table 3.3.

Table 3.2 : Characteristics of PV module

I_{SC} (Short circuit current in A)	45
V_{OC} (Open circuit voltage in V)	6.85
IMPP (Current at maximum power point in A)	34.45
VMPP (Voltage at maximum power point in V)	7.18
NOCT (Nominal operating temperature of cell in ^{0}C)	42.32
K_V (Voltage temperature coefficient in V/^{0}C)	0.058
K_i (Current temperature coefficient in A/^{0}C)	-0.33

Table 3.3 : Output power from PV module (in W) for a given time segment (in h) [46]

$PV_{OUT}\text{ (h)} = \int_0^1 PV_{NET}\, p(s) ds$	P_{OUT} - Output power of PV module (W)
$PV_{NET} = FF \times V_{NET} \times I_{NET}$	P_{NET} - Net output power of PV module (W)
$FF = \frac{V_{MPP} \times I_{NET}}{V_{OC} \times I_{SC}}$	FF - Fill Factor
$V_{NET} = V_{OC} - K_V \times T_C$	T_C - Cell Temperature
$I_{NET} = s[I_{SC} + K_i \times (T_C - 25)\}$	T_A - Ambient Temperature
$T_C = T_A + s(\frac{(NOCT - 20)}{0.8})$	$p(s)$ – Probability density of solar irradiance s

Statistical parameters obtained for the four seasons of Hambanthota area are tabulated in the Table 3.4 for the 12th hour.

Table 3.4: Statistical parameters for historical seasonal solar irradiance data for the 12th hour based on Hambanthota weather data

Season	Statistical Parameter			
	Mean	Standard Deviation	Beta	Alpha
Inter monsoonal period 1	0.687	0.325	3.126	6.858
Inter monsoonal period 2	0.718	0.290	3.841	9.770
North-West Monsoon	0.741	0.236	5.744	16.465
South-West Monsoon	0.790	0.238	5.015	18.908

The overall efficiency of the solar PV plant was assumed as 95% and the inverter power factor was considered as unity. Since the Solar PV modules are Type 1 generators and the objective of this research is optimization in terms of energy, use of unity power factor is justifiable.

3.3 Variation of solar irradiance for Hambanthota Area

Results of the models developed based on Hambanthota weather data to investigate seasonal solar irradiance probability variation and solar PV module power output obtained are discussed in this section.

3.3.1 Seasonal Solar Irradiance Probability Variation

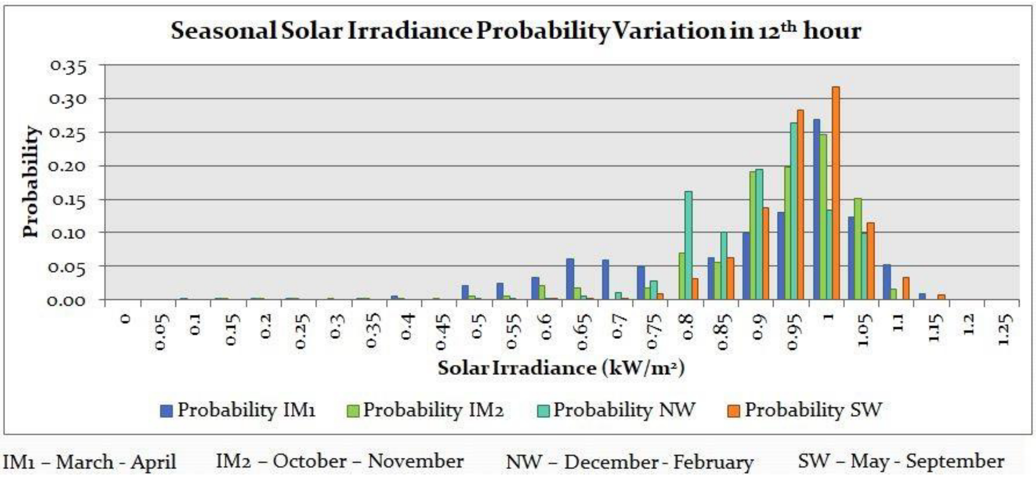

Figure 3.1 : Seasonal solar irradiance probability variation for 12th hour for Hambanthota

As appeared in the Figure 3.1, the solar irradiance of 1 kW/m^2 is the frequent solar irradiance that Hambanthota area receives based on the weather data collected and it occurs in the South-West monsoon period (May-September). During South-West monsoon period, a marked increase in solar radiation is shown as an effect of the central highland acting as an orographic barrier to South-West monsoonal blowing making it a dry desiccating wind when reaching the dry region. Therefore this value is extensively site-specific.

3.3.2 Seasonal solar PV module power output based on Hambanthota weather data

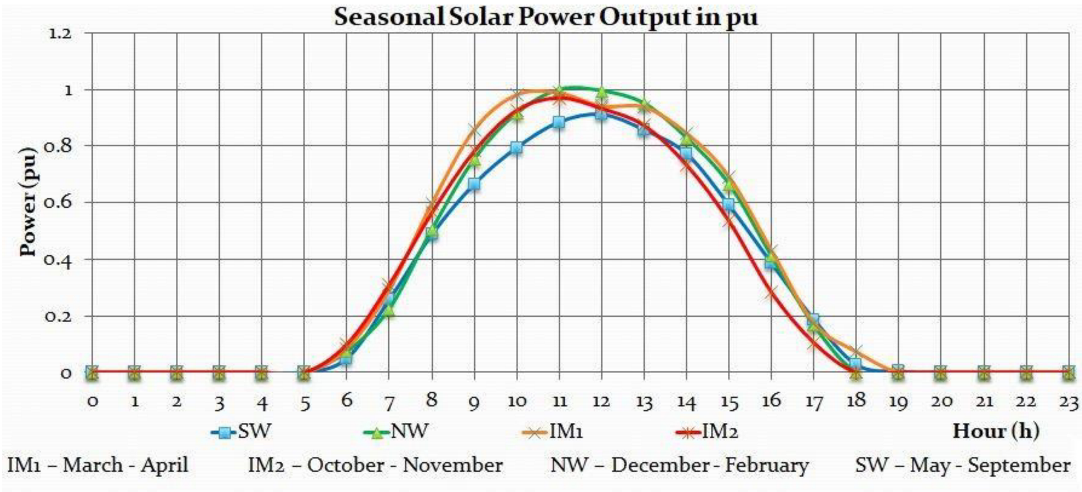

Figure 3.2 : Seasonal solar power output in pu

Figure 3.2 summarizes the seasonality effect on solar module power output based on the collected weather data, for the four weather seasons concerned for Hambanthota area. Insignificant variation was observed on the output from solar PV module in pu between the four seasons. As a result it can be concluded that Hambanthota area does not experience sharp seasonal changes in solar resources in terms of solar irradiance. Thus the rest of the research works were carried out assuming there is no seasonality effect on the collected weather data from Hambanthota area and was used in analyzing the two distribution networks' behaviors.

4 OPTIMATION OF LARGE SCALE SPVP PLUS BATTERY INTEGRATION BASED ON LOSS MINIMIZATION

Main components of the research work in building up a concrete model in achieving the objectives of this study are defined descriptively in this chapter. Starting from specifying what the inputs and modelling parameters are, optimizing subjected to constraints and verifying algorithms followed by how problem formulation was done are illustrated in the subsections respectively. The generalised models were developed in such a way that the model can be employed for optimization of any given network when resistance and reactance of each line sections together with their respective starting and ending bus numbers are known.

4.1 Main components for the execution of research work

In expediting the research study, flow of the works carried out is summarized in the Figure 4.1 in which the inputs, modelling steps and simulation steps are clearly visible.

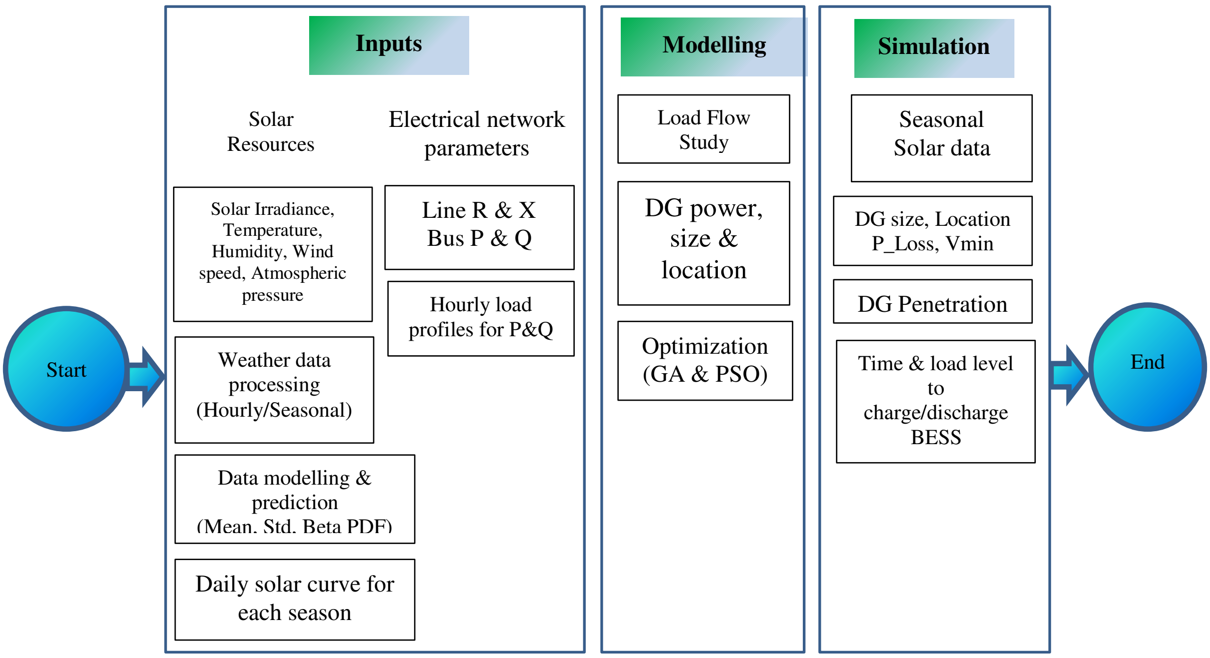

Figure 4.1: Flow of Research work

Technical viability of grid integration of large scale SPVP with BESS was investigated as per the Figure 4.1 by developing optimal power flow analysis for

IEEE 33 test bus system (details are given in Annexure I). In analysing the techno-economic viability of large scale SPVP integration with BESS, the proposed optimal power flow analysis was applied to a practical 33 kV MV network in Sri Lanka - Tissa 1 feeder of Hambanthota GSS whose network details are provided in ANNEXURE II. Three operational scenarios were developed as shown in Figure 4.2 in order to elaborate the research direction.

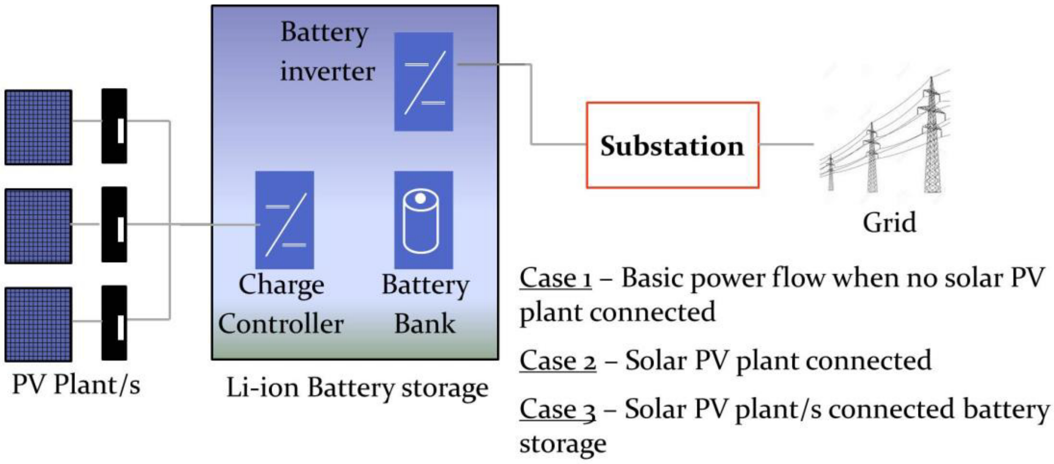

Figure 4.2 : Overview of self-sufficient grid substations with battery sourced distributed PV generation

1. Case 1:

Basic power flow study of the distribution network when there is no SPVP is connected to the network

2. Case 2:

Power flow study of the distribution network when only a large scale SPVP is connected to the network

3. Case 3:

Power flow study of the distribution network when a B-SPVP is connected to the network

Figure 4.2 provides an overview of the three cases detailed above.

As this chapter progresses, how the standard IEEE 33 bus network and practical MV feeder of Hambanthota GSS modelled, development of power flow equations and load profile, calculation of power losses and bus voltages and finally, the formulation of optimizing function with its network constraints are explained. The Figure 4.3 encapsulates the modelling done with the use of MATLAB in the research.

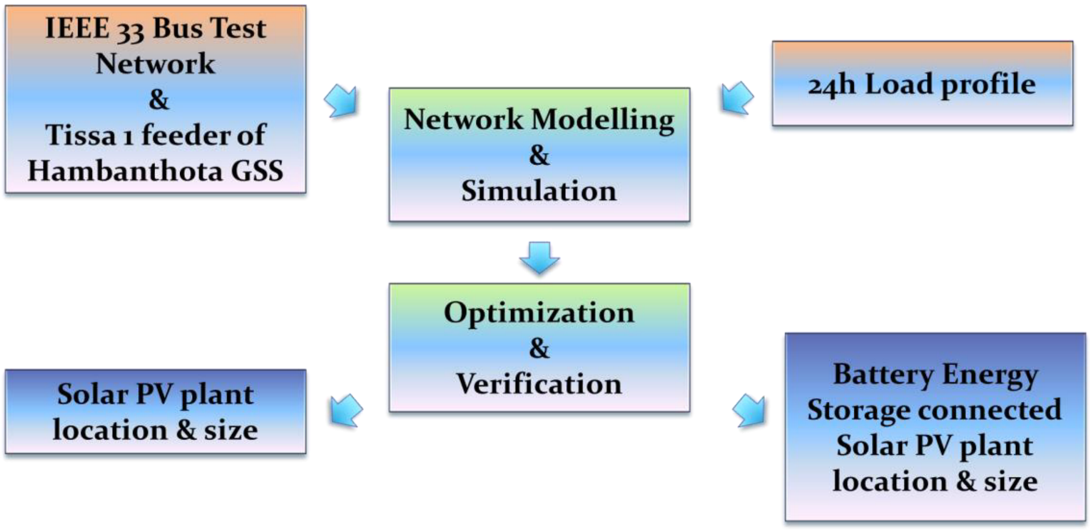

Figure 4.3 : Summary of works carried out using MATLAB software

4.2 Formulation of optimizing function for SPVP and B-SPVP connected cases

Once the solar PV module output was modelled and obtained the solar curve for one day as described in Chapter 3, it was used as an input when developing the optimizing model. During the optimization, SPVP size was varied as a percentage of total connected loads of the distribution network considered. Once the SPVP size was determined, time varying SPVP output was generated. Then the SPVP was connected to each bus except the slack bus of the distribution network and, in order to find the bus voltages and power losses across the branches, the Backward-Forward Sweep Flow (BFSF) load flow was developed carried out for both distribution networks; the standard IEEE 33 Bus RTS and Tissa 1 feeder of Hambanthota GSS in Sri Lanka. This process was done for each hour and calculated Total Energy Loss Index (TELI). TELI is the ratio between total energy loss over a day for SPVP connected only & B-SPVP connected cases to the total energy loss without SPVP & B-SPVP.

$$f = TELI = \frac{\sum_{t=1}^{24} Real(P^{DG}{}_{\text{loss\_Total\_Day}})}{\sum_{t=1}^{24}(P_{\text{loss\_Total\_Day}})}$$

Equation 4.1 : Total Energy Loss Index

$P^{DG}{}_{\text{loss\_Total\_Day}}$ in the Equation 4.1 is the total power loss of the network when SPVP or B-SPVP connected cases.

In consideration of testing the technical viability of the models developed, calculation and minimization of TELI, variation of both SPVP (or B-SPVP) connected bus and SPVP size and the power demand of the network during each hour was required. As a result of that, necessity to optimize the models developed for both SPVP and B-SPVP scenarios emerged. When progressing with optimization problem, following network constraints were considered.

1. SPVP capacity

$$0 < SPVP\ Capacity \leq x \times Total\ connected\ load\ of\ the\ distribution\ network$$

The value of ‘x’ depends on the distribution network and determined as the simulations run. It was evaluated as 200% for IEEE RTS 33 Bus network whereas ‘x’ was resulted as 300% for Tissa 1 feeder of Hambanthota GSS.

2. BESS Capacity

$$0 < BESS\ Capacity \leq x \times SPVP\ Capacity$$

The value of ‘x’ depends on the distribution network and determined as the simulations run. It was evaluated as 200% for IEEE Reliability Test System (RTS) 33 Bus network whereas ‘x’ was resulted as 300% for Tissa 1 feeder of Hambanthota GSS.

3. Hourly Optimum energy levels (OE)

$$0 < OpE \leq 100\% \times Hourly\ Total\ Load$$

4. Load Level (LL) to charge/discharge BESS

$$0 < LL \leq 100\% \times Peak\ Load$$

5. Network Power Balance

$$P_{GSS}(t) + P^{DG}(t) = P^{D}{}_{Total}(t) + P_{loss_{Total}}(t)$$

$$Q_{GSS}(t) + Q^{DG}(t) = Q^{D}{}_{Total}(t) + Q_{loss_{Total}}(t)$$

Equation 4.2 Network power balance equations

where $P_{GSS}(t)$ & $Q_{GSS}(t)$ are active and reactive power supplies from GSS to the distribution network during time t, respectively.

6. SPVP or B-SPVP Placement (Connected Bus)

$$2 \leq DG_{Connected_{Bus_{Number}}} \leq Maximum\ of\ number\ of\ buses$$

where Bus no. 1 is considered as the 'Slack Bus'.

7. Bus Voltage Limits

$$V_{min} \leq Bus\ Voltage \leq V_{max}$$

where V_{max} and V_{min} were kept at 1.0 and 0.95 respectively for optimizing cases.

Initially the optimization model was developed using inbuilt MATLAB GA parameters employing default parameters. In MIGA, the algorithm generates a set of possible solutions which move forward with the best solutions and again check for fitness randomly and test with the fitness function, i.e. the TELI in this study in each iteration. Finally after cross over and mutating, the possible best solutions found by generating, the fitness function is evaluated again to come to conclusion whereas the final best evaluated solution is the optimum solution.

In order to verify the optimal result obtained using MIGA, PSO method which employs a contrasting algorithm compared to MIGA to determine the optimum result, was used to verify the results. PSO optimizes a problem by iteratively trying to improve a solution resulted from previous iteration with regard to a given measure of quality. It solves a problem by having a population of solutions, which are manipulated in the search-space individually according to simple mathematical formulae and guided towards the best population solution, like a flock of birds reaches a destination.

Once the optimal solution is accomplished, reduction in energy loss for each case was analysed and evaluated in terms of reduction in energy loss with respective to the base case load flow energy loss as a percentage as depicted in the Equation 4.3.

$$Reduction\ in\ energy\ loss = \frac{\sum_{t=1}^{24} Real(P^{DG}{}_{\text{loss\_Total\_Day}})}{\sum_{t=1}^{24}(P_{\text{loss\_Total\_Day}})} \times 100\%$$

Equation 4.3 : Reduction in energy loss

After getting the optimal solution, the prime objective of this study, i.e. determination of self-sufficiency level in terms of energy penetration under each case was analysed and evaluated as a percentage of the ratio between energy delivered after installing SPVP or B-SPVP to the energy delivered when there is neither SPVP nor B-SPVP is connected to the distribution as shown in the Equation 4.4.

$$Self - sufficiency\ level\ in\ terms\ of\ energy\ penetration = \frac{\sum_{t=1}^{24} P^{DG}}{\sum_{t=1}^{24} P_D)} \times 100\%$$

Equation 4.4 : Self-sufficiency level in terms of energy penetration

P^{DG} is the hourly active power delivered when SPVP or B-SPVP connected to the distribution network whereas P_D being the hourly active power delivered when neither SPVP nor B-SPVP is connected to the distribution network

In the subsequent sections, detailed descriptions on the two distribution networks utilized for this study, generation of 24-h load profile, the equations used to calculate power loss across branch under each scenario and the BESS control logic for charge/discharge the BESS are presented.

4.2.1 Distribution networks under study

The standard IEEE 33 Bus RTS which has been used repeatedly in modelling and optimizing was used for developing the distribution network of the basic model. In order to find the bus voltages and power losses across the branches, BFSF load flow equations were developed. The model was made out in MATLAB in such a way that it is capable of accepting load and line data of any given power network. The IEEE 33 Bus network arrangement, line and load data are provided as ANNEXURE I.

Once the compiling, troubleshooting and modelling was done for the IEEE RTS standard 33 Bus network, the analysis was carried for a practical MV network connected to Hambanthota GSS in Sri Lanka. The main reason of selecting Hambanthota GSS is because it resides in the country where ample and high tense solar irradiance available. Besides modelling the whole GSS, Tissa 1 feeder was modelled, analyzed and interpreted as the distribution feeders of a GSS can be represented as one feeder connected to GSS. Moreover, the available literature suggested that it is prudent to analyze GSS feeder wise since it brings out feasible results than performing the analysis by modeling all the GSS feeders. Tissa 1 feeder arrangement, line and load data are enclosed herewith as ANNEXURE II.

4.2.2 24-h Load profile

In order to address hourly variability of load over a day, a 24-hour load profile was incorporated during the construction of concrete model. The hourly load variation of the connected loads of the network for both active power and reactive power was based on [53] for Hambanthota GSS is as shown in the Figure 4.4.

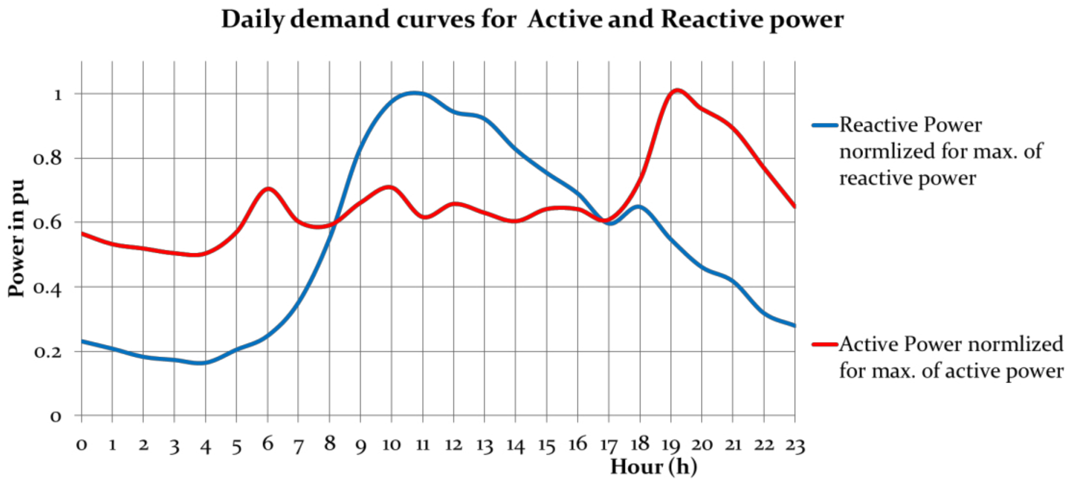

Figure 4.4 : Daily demand curve for Active and Reactive power for Hambanthota GSS

4.2.3 Power Loss across Branches

Equations that were considered during modelling BFSF in MATLAB related to power loss of ith branch that lies between kth and k+1th nodes during tth hour are described with the following notations.

- $P_{D,k+1}$– Active power demand of k+1th node
- $Q_{D,k+1}$ – Reactive power demand of k+1th node
- P^{SPVP}(t),k+1 – Active power demand during tth hour when connected to k+1th node at case 2
- Q^{SPVP}(t),k+1– Reactive power demand during tth hour when connected to k+1th node at case 2

- $P^{B\text{-}SPVP}(t),k+1$ – Active power demand during t^th hour when connected to k+1^th node at case 3
- $Q^{B\text{-}SPVP}(t),k+1$ – Reactive power demand during t^th hour when connected to k+1^th node at case 3

4.2.3.1 Case 1: Power loss when there is no large scale solar power plants connected to the network

1. Active power loss across i^{th} branch; $P_{loss(i)}$

$$P_{loss(i)} = R_{(i)} \times \frac{{P_{D,k+1}}^2 + {Q_{D,k+1}}^2}{|V_{k+1}|^2}$$

Equation 4.5: Active power loss across i^{th} branch; $P_{loss(i)}$ for Case 1

2. Reactive power loss across i^{th} branch; $Q_{loss(i)}$

$$Q_{loss(i)} = X_{(i)} \times \frac{{P_{k+1}}^2 + {Q_{k+1}}^2}{|V_{k+1}|^2}$$

Equation 4.6 : Reactive power loss across i^{th} branch; $Q_{loss(i)}$ for Case 1

3. Total power loss during a day; $P_{loss\_Total\_Day}$

$$P_{loss\_Total\_Day} = \sum_{i=1}^{No.of\ branches} P_{loss(i)} + jQ_{loss(i)}$$

Equation 4.7 : Total power loss during a day; $P_{loss\_Total\_Day}$ for Case 1

4.2.3.2 Case 2: Power loss when only a large scale solar power plant is connected to $k+1^{th}$ node of the network

1. Active power during t^{th} hour; $P_{(i)}(t)$

$$P_{(i)}(t) = P_{D(k+1)}(t) - {P^{SPV}}_{(k+1)}(t) + P_{loss(i)}(t)$$

Equation 4.8 : Active power during t^{th} hour; $P_{(i)}(t)$ for Case 2

2. Reactive power during t^{th} hour; $Q_{(i)}(t)$

$$Q_{(i)}(t) = Q_{D(k+1)}(t) - {Q^{SPV}}_{(k+1)}(t) + Q_{loss(i)}(t)$$

Equation 4.9 : Reactive power during t^{th} hour; $Q_{(i)}(t)$ for Case 2

Since the inverter is assumed to be unity power factor, ${Q^{SPVP}}_{(k+1)}(t)$ is zero.

3. Active power loss across i^{th} branch; $P^{SPVP}{}_{loss(i)}$

$$P^{SPV}{}_{loss(i)} = R_{(i)} \times \frac{\left(P_{D,k+1} - P^{SPV}{}_{(k+1)}\right)^2 + \left(Q_{D,k+1} - Q^{SPV}{}_{(k+1)}\right)^2}{|V_{k+1}|^2}$$

Equation 4.10 : Active power loss across i^{th} branch; $P^{SPVP}{}_{loss(i)}$ for Case 2

4. Reactive power loss across i^{th} branch; $Q^{SPVP}{}_{loss(i)}$

$$Q^{SPV}{}_{loss(i)} = X_{(i)} \times \frac{\left(P_{D,k+1} - P^{SPV}{}_{(k+1)}\right)^2 + \left(Q_{D,k+1} - Q^{SPV}{}_{(k+1)}\right)^2}{|V_{k+1}|^2}$$

Equation 4.11 : Reactive power loss across i^{th} branch; $Q^{SPVP}{}_{loss(i)}$ for Case 2

5. Total power loss during a day; $P^{SPVP}{}_{loss\_Total\_Day}$

$$P^{SPV}{}_{loss\_Total\_Day} = \sum_{i=1}^{no.\ of\ branches} P^{SPV}{}_{loss(i)} + jQ^{SPV}{}_{loss(i)}$$

Equation 4.12 : Total power loss during a day; $P^{SPVP}{}_{loss\_Total\_Day}$ for Case 2

4.2.3.3 Case 3: Power loss when Battery Connected large scale solar power plant is connected to the network

1. Active power during t^{th} hour; $P_{(i)}(t)$

$$P_{(i)}(t) = P_{D(k+1)}(t) - P^{B-SPV}{}_{(k+1)}(t) + P_{loss(i)}(t)$$

Equation 4.13 : Active power during t^{th} hour; $P_{(i)}(t)$ for Case 3

2. Reactive power during t^{th} hour; $Q_{(i)}(t)$

$$Q_{(i)}(t) = Q_{D(k+1)}(t) - Q^{B-SPV}{}_{(k+1)}(t) + Q_{loss(i)}(t)$$

Equation 4.14 : Reactive power during t^{th} hour; $Q_{(i)}(t)$ for Case 3

Since the inverter is assumed to be unity power factor, $Q^{B-SPVP}{}_{(k+1)}(t)$ is zero.

3. Active power loss across i^{th} branch; $P^{B-SPVP}{}_{loss(i)}$

$$P^{B-SPV}{}_{loss(i)} = R_{(i)} \times \frac{\left(P_{D,k+1} - P^{B-SPV}{}_{(k+1)}\right)^2 + \left(Q_{D,k+1} - Q^{B-SPV}{}_{(k+1)}\right)^2}{|V_{k+1}|^2}$$

Equation 4.15 : Active power loss across i^{th} branch; $P^{B-SPVP}{}_{loss(i)}$ for Case 3

4. Reactive power loss across i^{th} branch; $Q^{B-SPVP}{}_{loss(i)}$

$$Q^{B-SPV}{}_{loss(i)} = X_{(i)} \times \frac{\left(P_{D,k+1} - P^{B-SPV}{}_{(k+1)}\right)^2 + \left(Q_{D,k+1} - Q^{B-SPV}{}_{(k+1)}\right)^2}{|V_{k+1}|^2}$$

Equation 4.16 : Reactive power loss across i^{th} branch; $Q^{B-SPVP}{}_{loss(i)}$ for Case 3

5. Total power loss during a day; $P^{B\text{-}SPVP}{}_{loss\_Total\_Day}$

$$P^{B-SPV}{}_{loss\_Total\_Day} = \sum_{i=1}^{no.\,of\,branches} P^{B-SPV}{}_{loss(i)} + jQ^{B-SPV}{}_{loss(i)}$$

Equation 4.17 : Total power loss during a day; $P^{B\text{-}SPVP}{}_{loss\_Total\_Day}$ for Case 3

4.2.4 BESS Control logic

The distribution networks were analysed when a B-SPVP is connected from a bus in the network. In order to charge and discharge batteries, a control logic was required. By modifying the BESS control logic provided in [2] to match with Sri Lankan context, BESS control logic for this study was developed.

The BESS was charged from the output from SPVP. The floor and ceiling levels either to charge or discharge batteries were decided by defining two parameters, Load Level and Optimum Energy level respectfully. Both the charge and discharge efficiencies were assumed to be 95%. The prime concept of the developed BESS control logic is to utilize power from the B-SPVP to cater the total hourly demand of the network drawing minimum amount of power from the main grid whenever possible accommodating technical benefits to the network. The ANNEXURE III is the BESS control logic diagram that was used in the research study.

4.3 Summary

In the Chapter 4, a comprehensive presentation of the research work flow was described including main components that were modelled, how systems were developed by problem formulation and optimization bounded to network constraints using MATLAB software inbuilt MIGA and PSO tools.

5 OPTIMAL SPVP AND B-SPVP INTEGRATION FOR IEEE 33 BUS TEST NETWORK

This chapter outlines the results obtained from the simulations and are followed by descriptive conclusions made based on each result for Standard IEEE 33 Bus Test Network.

5.1 IEEE 33 Bus Test Network

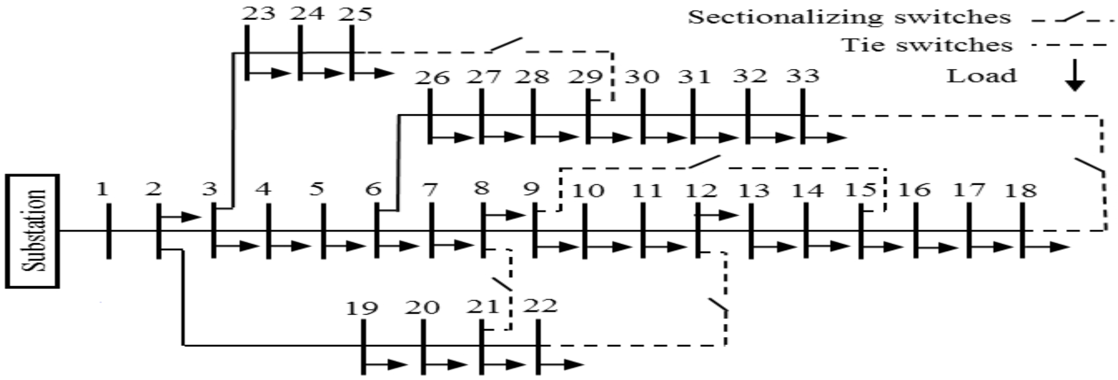

Figure 5.1 : IEEE 33 Bus Test Network Single Line Diagram

The single line diagram of IEEE 33 Bus Test Network is shown in Figure 5.1. The respective loads connected to each bus and the network physical parameters are explicated in ANNEXURE I.

5.2 Basic power flow results without concerning hourly load variation

Results attained from the basic power flow model for backward forward sweep load flow of the IEEE RTS 33 Bus Distribution Network are tabulated in the Table 5.1.

Table 5.1 : Basic power flow results without concerning hourly load variation for IEEE 33 Bus Distribution Network

Total load	: Total connected active power - 3.715MW : Total connected reactive power - 2.3MVar
Maximum voltage	: 1 pu
Minimum Voltage	: 0.882pu @ Bus no. 18
Total real energy loss	: 211 kWh
Slack bus	: Bus no. 1

In the subsequent sections of this chapter, outcomes gained while advancing the models for optimized allocation of SPVP and B-SPVP for IEEE RTS 33 Bus Distribution Network are described in detail.

5.3 Variation of total energy loss under different solar PV penetration levels in each bus (as a % of Total load)

The distribution network was analysed for total energy loss variation in each bus for different penetration levels expressed as a % of total connected active load and best bus; the bus at which SPVP is connected in such a way that total energy loss is minimum over a day, was found to connect the SPVP, by changing both the bus to connect SPVP and the size of SPVP (set as a % of total connected load).

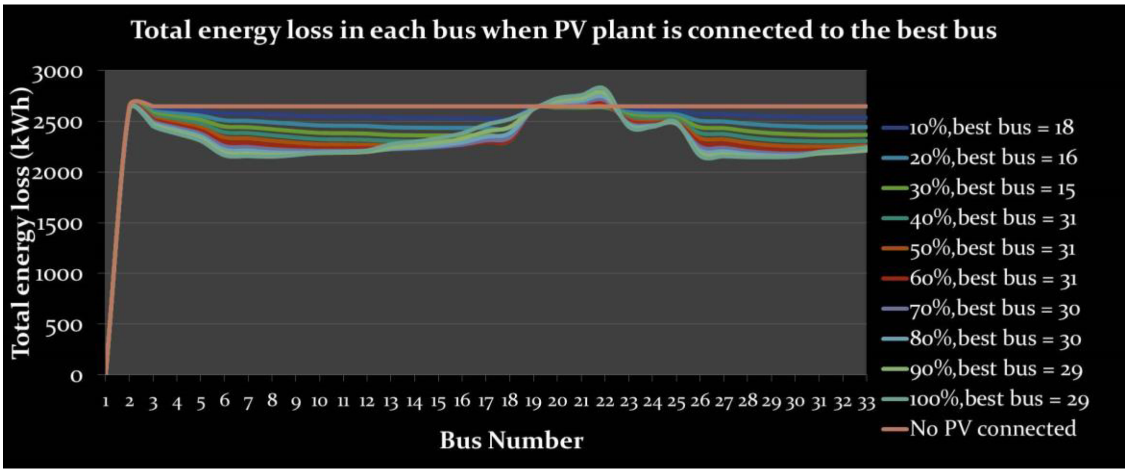

Figure 5.2 : Total energy loss in each bus for different Solar PV penetration levels (as a % of Total load)

The bus-wise total energy loss for different Solar PV penetration levels are plotted and the graph is as in Figure 5.2. From the Figure 5.2, it was observed that for different Solar PV penetration levels, not only the total energy loss over a day is varying but also the best location for SPVP also differs. For a solar penetration of 10%, 50%, 70% and 100% of total load, the best location to connect SPVP are varying as Bus no. 10, 31, 30 and 29, accordingly. Therefore it is obvious there is an essentiality to identify not only the location but also the penetration level to achieve the goal of minimizing total network loss during a day. In other words, for different solar PV penetration levels, both the total energy loss over a day and the best location for SPVP to connect differ and the bus from which SPVP of a given capacity is connected to the network determines the minimization of total energy loss over a day

5.4 Variation of hourly energy loss for different solar PV penetration levels (% of Total load)

To analyse how the network responses when solar or basically a negative load is added to a particular location was examined by studying the impact on hourly energy loss for different Solar PV penetration levels (% of Total load).

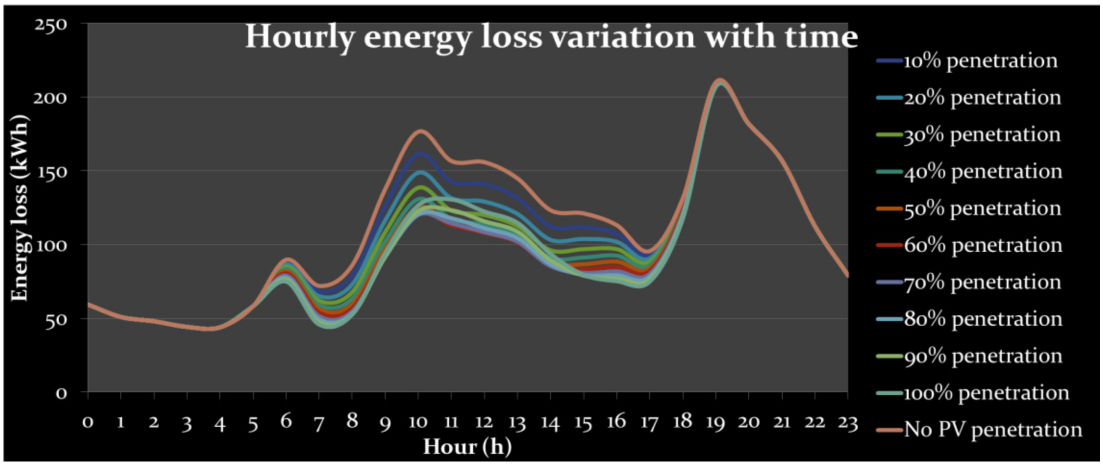

Figure 5.3 : Hourly Energy loss for different Solar PV penetration levels (% of Total load)

As seen from the Figure 5.3, with the increment of SPVP size (as a % of total load), total energy losses reduces but there is a penetration level beyond which the losses again showed an increment in total energy losses, was noted. There for the necessity of identifying the best penetration level in each hour was also recognized. Thus it can be concluded that there is a requirement of determining OE level beyond which total energy loss is increased again as the solar energy penetration advances.

5.5 Variation of Bus voltage under different Solar PV penetration levels (% of Total load)

Further, the distribution network response was inspected in terms of bus voltage profile improvement with the addition of solar energy (indicated as a % of total connected load).

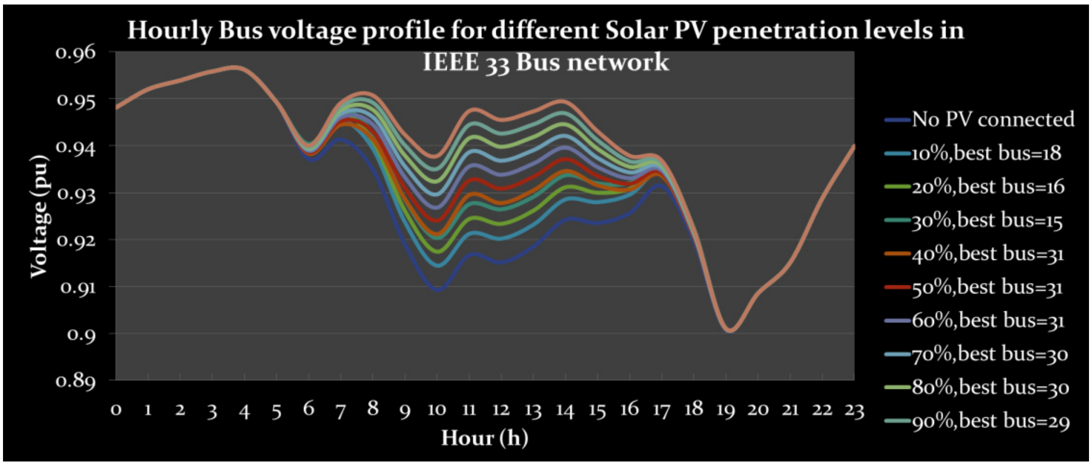

Figure 5.4 : Hourly SPVP Connected Bus voltage profile for different Solar PV penetration levels (% of Total load)

The minimum bus voltage without the installation of the DG unit in IEEE 33 Bus distribution network was 0.904 pu at Bus no. 18. However, with the increase of SPV size, the minimum bus voltage during a day is varied as depicted in the Figure 5.4 for different solar energy penetration levels. Here, the best bus means the bus to which the DG unit is connected such that the total power loss at that particular hour is the lowest.

Having noticing these observations, optimizing models for TELI subjected to the network constraints listed in the Section 4.2, were developed in MATLAB environment using MIGA and verified the results by PSO whose outcomes are detailed below in the sub sections.

5.6 Optimization results for SPVP connected scenario

From the considerations discussed above, it was necessitated to optimize the distribution network for total energy loss subjected to voltage constraint to determine the best location to connect SPVP with the optimum size.

5.6.1 Optimization by MIGA and PSO

Figure 5.5 shows the optimized workspace results using MIGA (Right hand side) and by PSO (Left hand side). The outcomes of the two optimizing methods resulted identical values, as evident from the Figure 5.5.

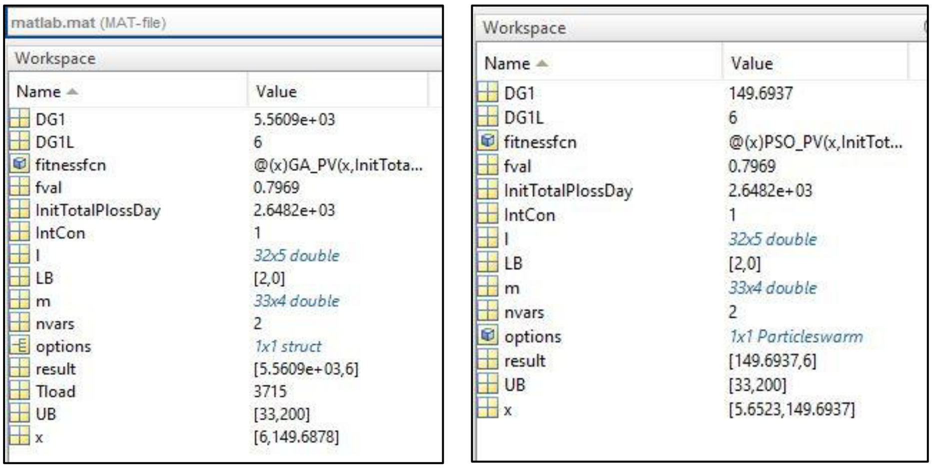

Figure 5.5 : Optimized workspace results obtained from MIGA (Left) & PSO (Right) for IEEE 33 Bus distribution network for SPVP

MATLAB has the feature of viewing how fast the optimization is reaching a final value as the simulation runs and Figure 5.6 shows the simulation outputs generated once the simulation run was over for the two optimizing methods; using MIGA (Right hand side) and by PSO (Left hand side). It is clear from the Figure 5.6 that use of PSO is faster to accomplish the optimized value than the use of MIGA in this problem.

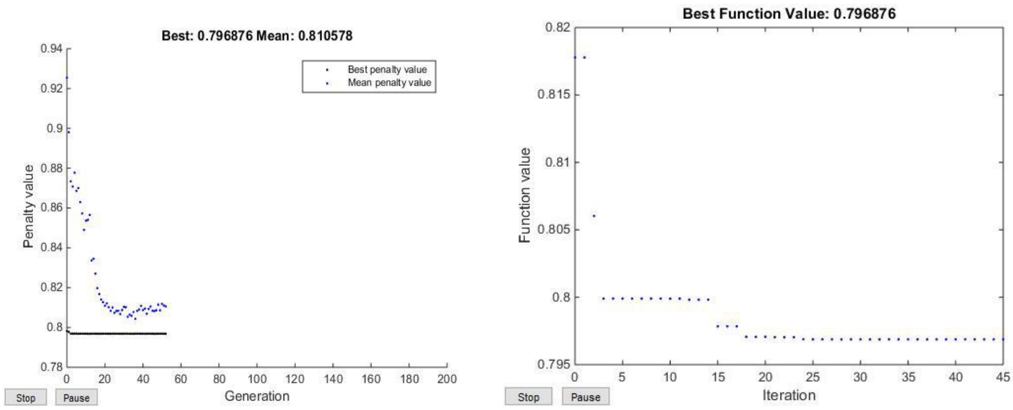

Figure 5.6 : Simulation output obtained from MIGA (Left) & PSO (Right) for IEEE 33 Bus distribution network

5.6.2 Network power balance preservation check for optimized results

The Table 5.2 summarizes the preservation of power balances for the cases before and after connecting the SPVP to the distribution network. As can be seen from Table 5.2, the network power balance before and after connecting SPVP is preserved.

Table 5.2 : Network power balance preservation check for Case 1 & 2 for IEEE 33 Bus distribution network

<table>
<tr><td colspan="4">P_DG</td><td colspan="3">16,668.24 kWh</td></tr>
<tr><td colspan="4">P_DGLoss</td><td colspan="3">2,123.5 kWh</td></tr>
<tr><td colspan="4">P_LT</td><td colspan="3">58,845.6 kWh</td></tr>
<tr><td colspan="4">Initial Total energy loss</td><td colspan="3">2,648.23 kWh</td></tr>
<tr><td colspan="4">P_SubSol=P_LT-P_DG+P_DGLoss</td><td colspan="3">44,287.86 kWh</td></tr>
<tr><td colspan="4">P_SubInitial=P_LT+Initial Total energy loss</td><td colspan="3">61,493.83 kWh</td></tr>
<tr><td colspan="7">$P_{Substation}(t) + P_{DG}(t) = P_{LT}(t) + P_{Loss-Total}(t)$</td></tr>
<tr><td>Case</td><td>P-Sub</td><td>P-DG</td><td>P-Sub+P-DG</td><td>P-Load</td><td>P-Loss</td><td>P-Load+P-Loss</td></tr>
<tr><td>Initial</td><td>61,493.83</td><td>0</td><td>61,493.83</td><td>58,845.6</td><td>2,648.23</td><td>61,493.83</td></tr>
<tr><td>SPVP</td><td>44,287.86</td><td>16,681.24</td><td>60,969.1</td><td>58,845.6</td><td>2,123.5</td><td>60,969.1</td></tr>
</table>

5.6.3 Summary of Optimization Results for SPVP

5.6.3.1 Total size, Reduction of power loss, Energy penetration and lowest bus voltage

Table 5.3 : Summary of Optimization Results for SPVP

Total load (MW)	3.715
PV size (MW) @ Bus No.	5.56 @ 6
Reduction in Energy loss	20.31%
DG penetration in terms of energy (Self-sufficiency level)	28.35%
Lowest bus voltage pu @ Bus no.	0.901 @ 18

Table 5.3 presents a summary of the interested optimized values for SPVP size, location to install, self-sufficiency level of the distribution network expressed as a percentage of DG penetration in terms of energy and lowest bus voltage improvement after connecting the SPVP.

In order to minimize total energy loss over a day for IEEE 33 bus distribution network, it is required to install a SPVP of 5.56MW capacity to the Bus No. 6 where larger portion of the total connected loads that have dispersed in branches starting from Bus no.6, thus suggesting that SPVP is best located near the loads. Once the optimum capacity SPVP is installed, it would result in a 20.31% reduction of energy loss and the lowest bus voltage is improved to 0.901pu from its original value of 0.882pu at the Bus no. 18. The prime determinant; i.e. the self-sufficiency level of the IEEE 33 Bus network is 28.35% of the total energy requirement of the network. This means, with the installation of SPVP of 5.56MW optimum capacity, the network is capable of catering 28.35% of its total energy requirement itself, without drawing that amount of energy from the main grid.

5.6.3.2 Active power injection from different sources

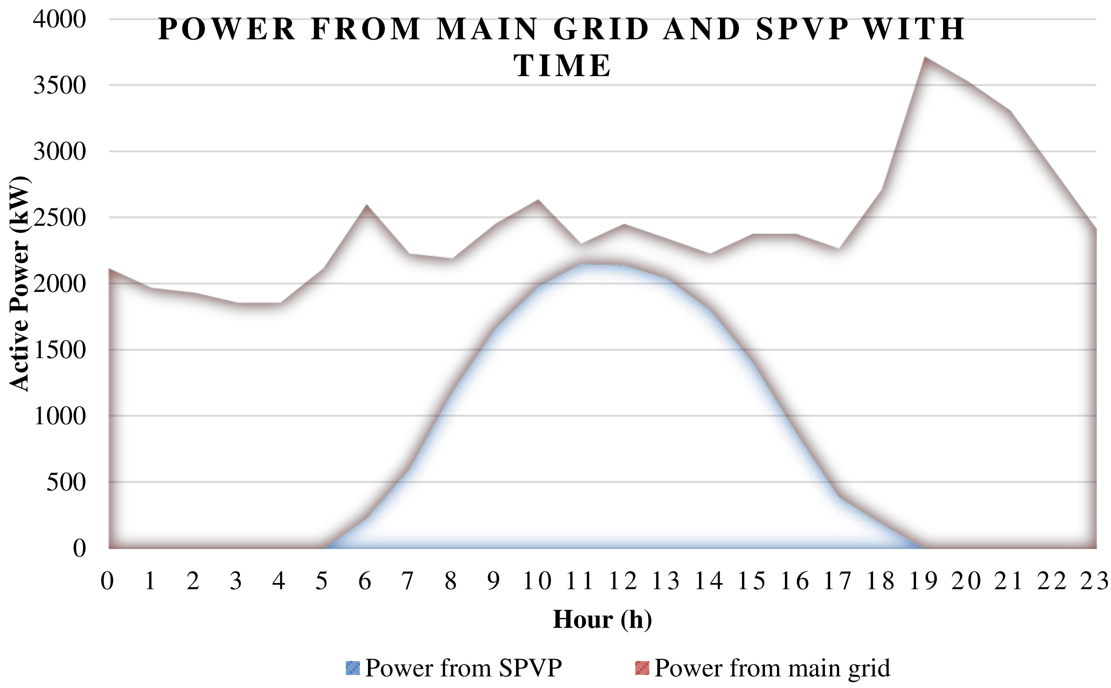

Figure 5.7: Power from main grid and SPVP with time

The proportions of power drawn from main grid when power from SPVP is not sufficient is indicated in red colour while power from SPVP when solar energy presents is indicated in blue colour in the Figure 5.7.

5.7 Optimization results for B-SPVP scenario

It was also necessitated to optimize the distribution network for total energy loss subjected to voltage constraint to determine the best location to connect B-SPVP with the optimum size.

5.7.1 Hourly Optimum energy levels (OE)

As a requirement of determining hourly OE level beyond which total energy loss is increased again as the solar energy penetration advances, was identified, a MATLAB model was developed to determine OE of each hour by varying the distributed resource size expressed as a percentage of hourly total load while keeping the bus to be connected as the same as the optimized location resulted from optimization of SPVP. In this study it was the bus no. 6. Therefore OEs for each hour were found and tabulated in the Table 5.4.

Table 5.4 : Hourly Optimum energy levels (OE) for IEEE 33 Bus distribution network

Hour	OE (As a % of Total hourly load)	Hour	OE (As a % of Total hourly load)
0	38.42%	12	46.68%
1	35.66%	13	44.49%
2	34.93%	14	42.03%
3	33.56%	15	44.53%
4	33.55%	16	44.33%
5	38.38%	17	41.97%
6	47.41%	18	50.49%
7	40.69%	19	69.23%
8	40.45%	20	65.39%
9	46.23%	21	61.04%
10	50.38%	22	52.40%
11	44.14%	23	44.01%

Once OEs for each hour was found, the network was optimized for B-SPVP scenario subjected to the battery control logic depicted in ANNEXURE III and the results are described in the successive subsections.

5.7.2 Optimization by MIGA and PSO

Figure 5.8 shows the optimized workspace results using MIGA (Right hand side) and by PSO (Left hand side). The outcomes of the two optimizing methods resulted identical values, as evident from the Figure 5.8.

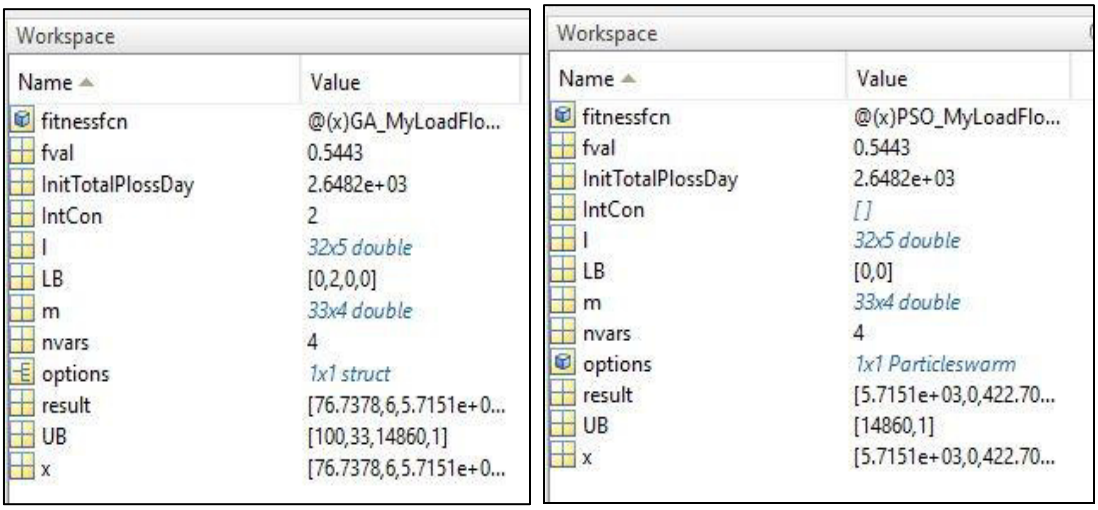

Figure 5.8 : Optimized workspace results obtained from MIGA (Left) & PSO (Right) for IEEE 33 Bus distribution network for B-SPVP

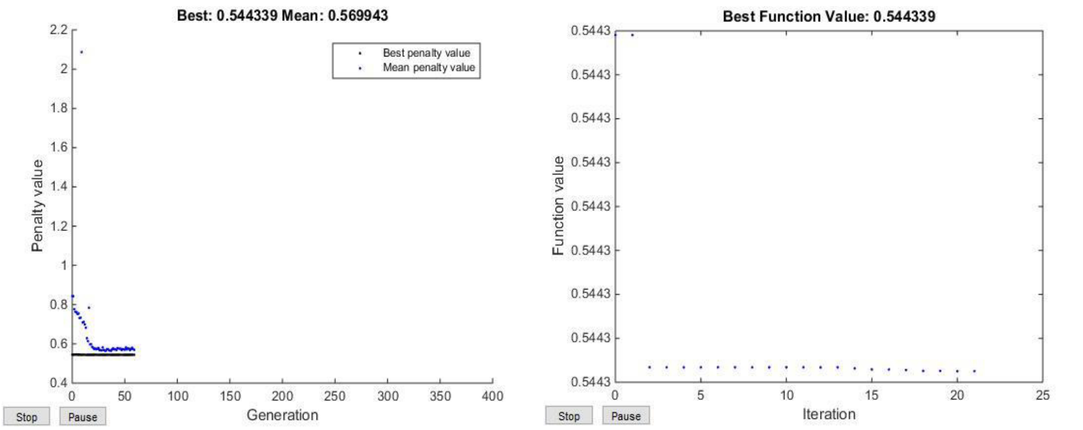

Figure 5.9 : Simulation output obtained from MIGA (Left) & PSO (Right) for IEEE 33 Bus distribution network

Figure 5.9 shows the simulation outputs produced once the simulation run was completed for MIGA (Right hand side) and PSO (Left hand side) optimization techniques. Figure 5.9 also emphasizes that use of PSO is faster to reach the optimized value than using MIGA in this problem.

5.7.3 Network power balance preservation check for optimized results

The Table 5.5 summarizes the preservation of power balances for the cases before and after connecting the B-SPVP to the distribution network. It is noteworthy that the network power balance is preserved even for the scenario of with and without connecting the B-SPVP to the distribution network.

Table 5.5 : Network power balance preservation check for Case 1, 2 & 3 for IEEE 33 Bus distribution network

P_DG				25,994.77 kWh		
P_DGLoss				1,441.53 kWh		
P_LT				58,845.6 kWh		
Initial Total energy loss				2,648.23 kWh		
P_SubSol&Bat=P_LT-P_DG+P_DGLoss				34,292.36 kWh		
P_SubInitial=P_LT+Initial Total energy loss				61,493.83 kWh		
$P_{Substation}(t) + P_{DG}(t) = P_{LT}(t) + P_{Loss-Total}(t)$						
Case	P-Sub	P-DG	**P-Sub+P-DG**	P-Load	P-Loss	**P-Load+P-Loss**
Initial	61,493.83	0	**61,493.83**	5,8845.6	2,648.23	**6,1493.83**
SPVP	44,287.86	16,681.24	**60,969.1**	5,8845.6	2,123.5	**6,0969.1**
B-SPVP	34,292.36	25,994.77	**60,287.13**	5,8845.6	1,441.53	**6,0287.13**

5.7.4 Summary of Optimization Results for B-SPVP

5.7.4.1 Total SPVP & BESS size, Reduction of power loss, Energy penetration and lowest bus voltage

Table 5.6 : Summary of Optimization Results for B-SPVP

Total load (MW)	3.715
PV size (MW) @ Bus No.	2.85 @ 6
Total BESS size (MWh)	5.715
Reduction in Energy loss	45.57%
DG penetration in terms of energy (Self-sufficiency level)	44.17%
Lowest bus voltage pu @ Bus no.	0.948 @ 18

An abstract of interested optimized values for B-SPVP size &BESS size to install, self-sufficiency level of the distribution network expressed as a percentage of DG penetration in terms of energy and lowest bus voltage improvement after connecting the B-SPVP are presented in the Table 5.6.

To minimize total energy loss over a day for IEEE 33 bus distribution network, it is required to install a B-SPVP comprised of a SPVP with 2.85MW capacity and BESS of a size 5.715MWh to the Bus No. 6. Once the optimum capacity B-SPVP is installed, it would result in a 45.57% reduction of energy loss which is further reduces an energy loss reduction of a value 20.31% that existed for optimized SPVP. The size of SPVP in optimized B-SPVP is now has decreased to 2.85MW from its capacity of 5.56MW for optimizing only with SPVP. The lowest bus voltage has now improved to 0.948pu from 0.901pu that was there for optimized only with SPVP and from its original value of 0.882pu for the base case load flow. The key element of interest; i.e. the self-sufficiency level of the IEEE 33 Bus network for B-SPVP is 44.17% of the total energy requirement of the network. This means, with the installation of B-SPVP with a 2.85MW SPVP together with a BESS of 5.715MWh optimum capacity, the network is capable of catering 44.17% of its total energy requirement itself, without absorbing that amount of energy from the main grid.

5.7.4.2 BESS Charge/Discharge with time

By incorporating the battery control logic presented in the ANNEXURE III, how the BESS is charged and discharged over the day is as in the following Figure 5.10.

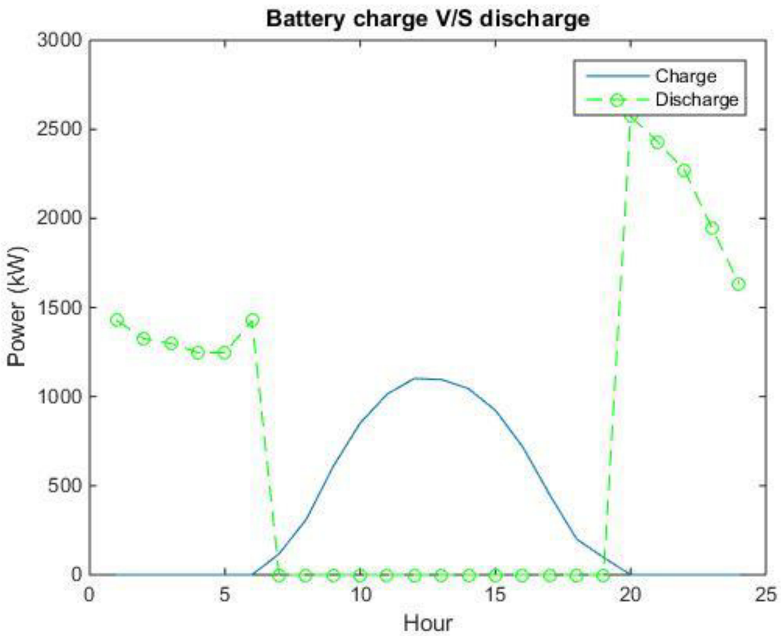

Figure 5.10: BESS Charge/Discharge with time

5.7.4.3 Active power injection from different sources

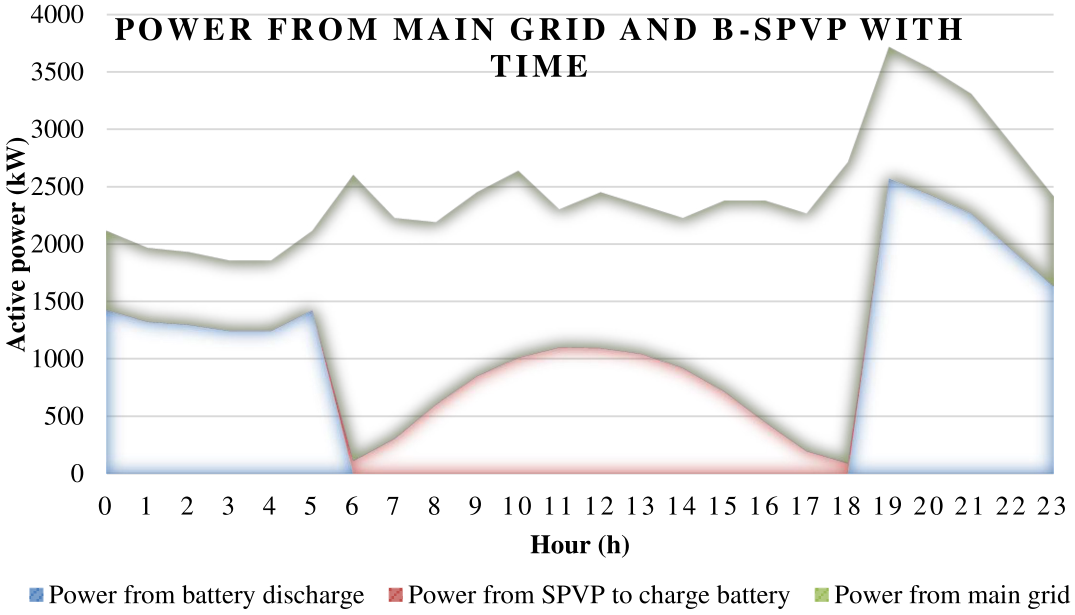

Figure 5.11 : Power from main grid and B-SPVP with time

The proportions of power drawn from main grid when power from B-SPVP is not sufficient is indicated in green colour while power from SPVP to charge the BESS in the presence of solar energy and discharge the stored energy up to OE are indicated in red and blue colours respectively in the Figure 5.11.

If the same graph is represented as a line graph, the graph would be as in the Figure 5.12 below in which all the power levels are visible clearly.

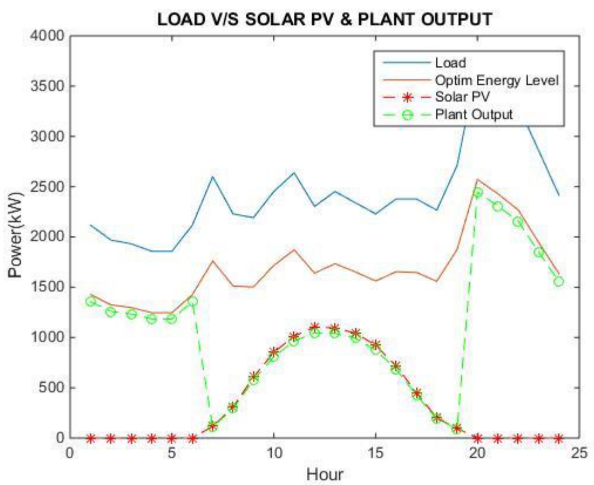

Figure 5.12: Power from main grid and B-SPVP with time

5.8 Comparison of total energy loss variation of optimized results over a day for IEEE RTS 33 Bus Distribution Network

The hourly energy loss resulted from each three cases considered; i.e. energy loss having neither SPVP nor a B-SPVP connected to the distribution network, energy loss having only a SPVP and energy loss having only a B-SPVP connected to the distribution network were plotted against each hour and the obtained graph is the Figure 5.13 below.

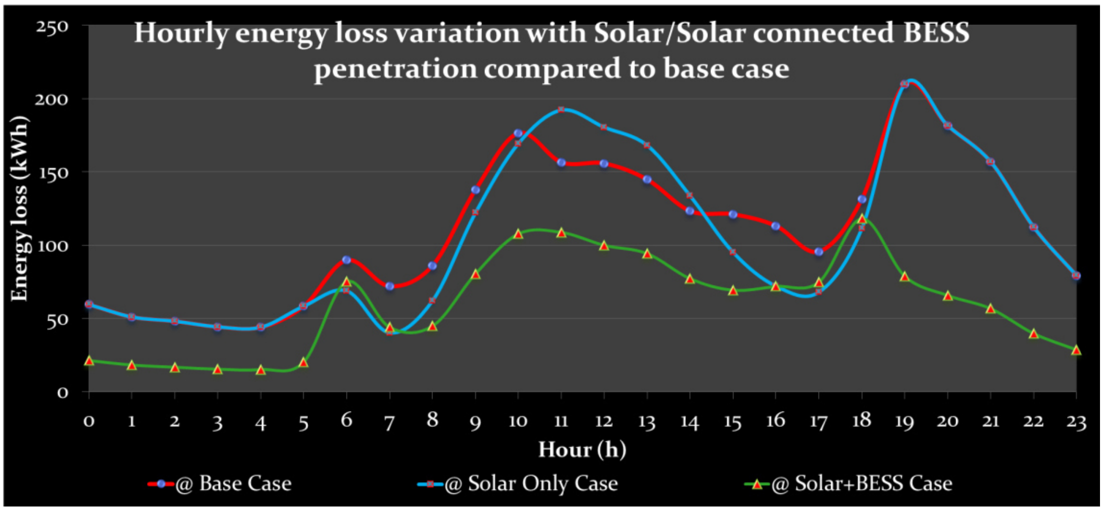

Figure 5.13 : Hourly energy loss variation with Solar/Solar connected BES penetration compared to base case

At a glance, it is clear from the graph that the energy loss variation with time when only the optimized B-SPVP connected to the distribution network, almost always lies below the curves of the energy loss variation with time than that of the other cases considered. The highest losses in each of the three cases occur during the peak hour, i.e. during the 19th hour. Since the SPVP and B-SPVP are connected in the proximity of network loads, reduced power losses have occurred when compared with the base case which draws all the required energy from the main grid. With only SPVP connected case, the energy loss occur during extremely sunny hours (from 11th to 14th hour) has gone beyond the base case energy losses owing to the uncontrollability of solar power entered to the network, i.e. the energy from SPVP is larger than the OE during highly sunny hours. When there is no presence of solar energy (from 0th to 5th hour & from 17th to 23rd hour), loss variation curve of only SPVP connected case follows the same curve of the base case loss variation whereas the energy loss curve of only B-SPVP case during the non-existence of solar hours lies below the other two cases because BESS discharges its potential energy that has been charged from its connected SPVP, without bringing down all the required energy all the way from main grid, thus resulted in reduced I^2Z loss of the network.

5.9 Comparison of voltage profile improvement with optimized results over a day for IEEE RTS 33 Bus Distribution Network

In order to analyse how minimum voltage of each bus is modified with the addition of optimized SVPV and B-SPVP to the IEEE 33 bus distribution network, minimum voltages of each bus in each case were mapped out against each bus and the resulted graph is the Figure 5.14 below.

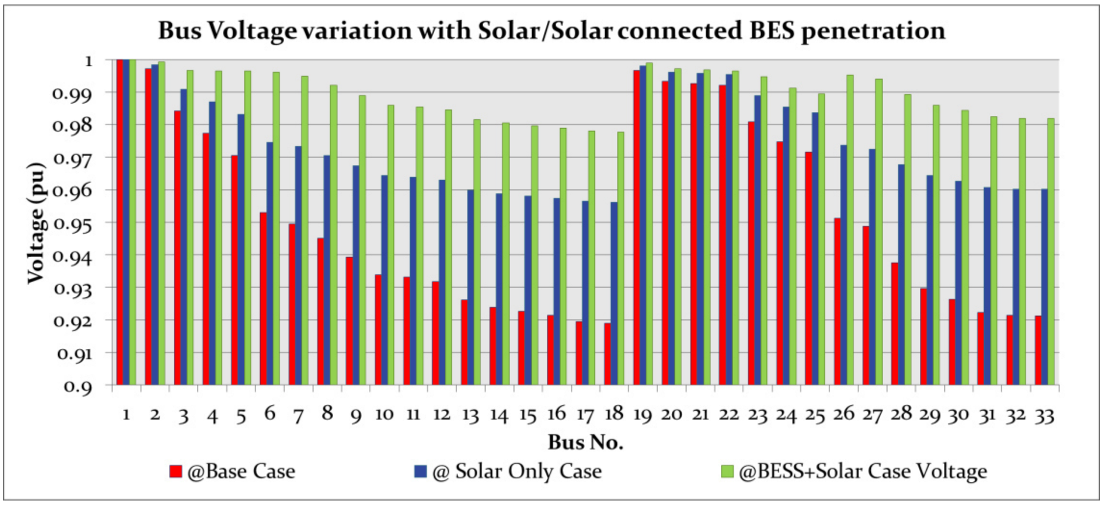

Figure 5.14 : Bus voltage variation with Solar/Solar connected BES penetration with time

As is illustrated from the Figure 5.14, when one case result is concerned, voltage levels decreases as the buses locate away from the slack bus and thus it is entirely dependent on the network configuration. Minimum voltages of each bus are shown in red colour for base case results whereas blue and green colour bars represent resultant values for optimized SPVP and optimized B-SPVP cases. As seen from the Figure 5.14, the minimum bus voltages have increased with the addition of SPVP which further escalated with the addition of B-SPVP, within the acceptable voltage range. Thus the voltage constraint is preserved in both SPVP case and B-SPVP case.

6 OPTIMAL SPVP AND B-SPVP INTEGRATION FOR TISSA 1 FEEDER

In conjunction of the Chapter 3 and 4, the developed models were used to optimize Tissa 1 feeder of Hambanthota GSS and the results are presented in the Chapter 6.

6.1 Tissa 1 feeder of Hambanthota GSS

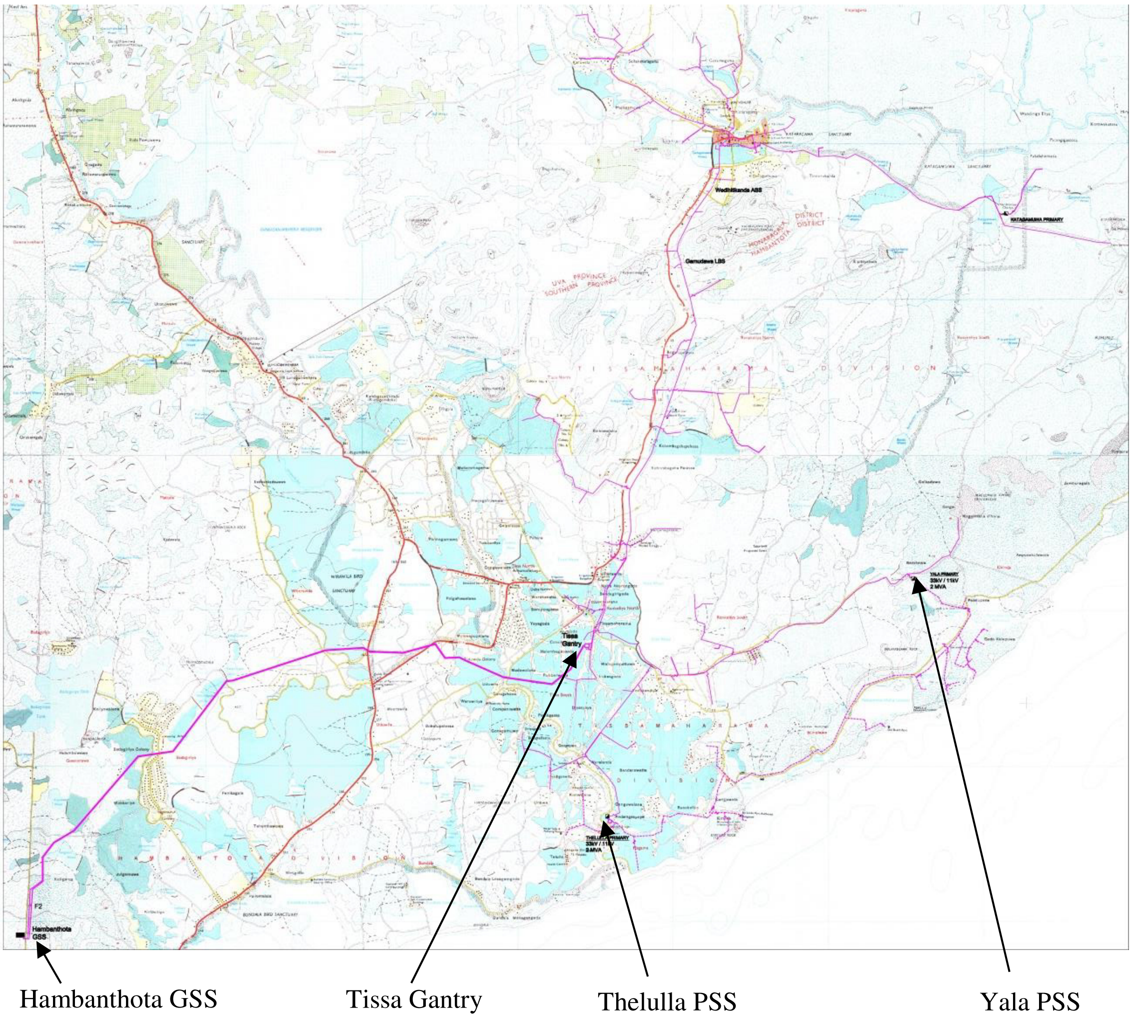

Figure 6.1 : Tissa 1 feeder of Hambanthota GSS

Physical layout of Tissa 1 feeder connected to Hambanthota GSS is shown in Magenta colour in the Figure 6.1. The respective loads connected to each bus and the network physical parameters are given in details in ANNEXURE II.

6.2 Basic power flow results without concerning hourly load variation

The basic power flow model for backward forward sweep load flow of the Tissa 1 feeder of Hambanthota GSS was developed in MATLAB and results attained are as in the Table 6.1. It was assumed that the feeder is balanced.

Table 6.1 : Basic power flow results without concerning hourly load variation for Tissa 1 feeder of Hambanthota GSS

Total load	: Total connected active power - 6.598MW : Total connected reactive power - 2.33MVar
Maximum voltage	: 1 pu
Minimum Voltage	: 0.899pu @ Bus no. 373
Total real energy loss	: 462 kWh
Slack bus	: Bus no. 1
Feeder length	: 167.69 km

6.3 Optimization results for SPVP connected scenario

Outcomes of the optimizing models that have been developed in MATLAB using MIGA and verified by PSO are described below in the sub sections.

6.3.1 Optimization by MIGA and PSO

Figure 6.2 shows the optimized workspace results using MIGA (Right hand side) and which are verified by PSO (Left hand side). The outcomes of the two optimizing methods resulted identical values, as evident from the Figure 6.2.

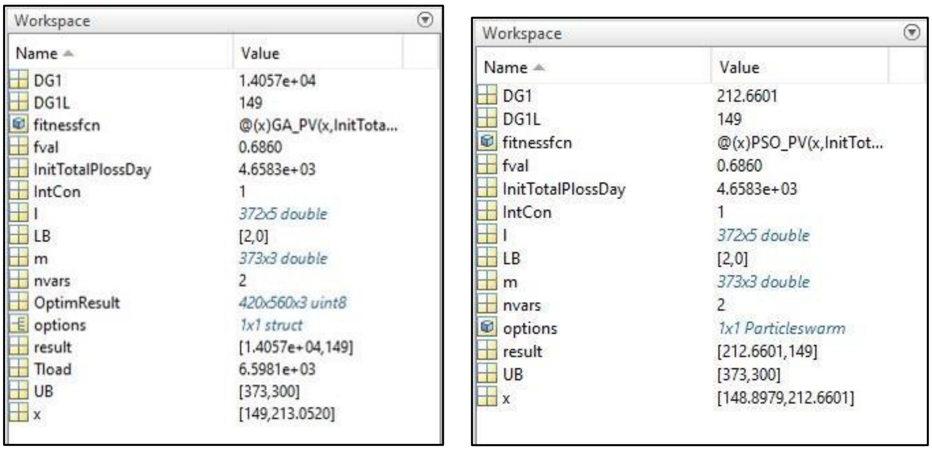

Figure 6.2 : Optimized workspace results obtained from MIGA (Left) & PSO (Right) for Tissa 1 feeder for SPVP

How the two optimizing methods reached the final optimized values is shown in the Figure 6.3. Even from these results it is clear that use of PSO is faster to attain the optimized value than the use of MIGA.

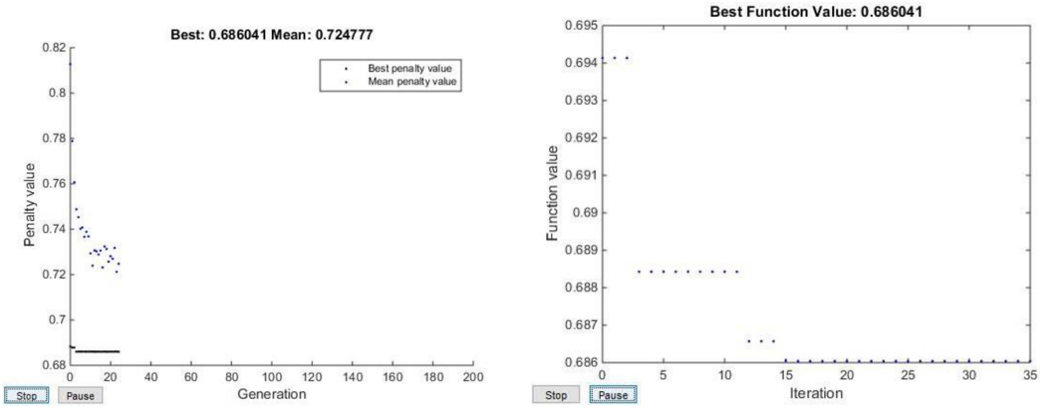

Figure 6.3 : Simulation output obtained from optimization with MIGA (Left) & PSO (Right) for Tissa 1 feeder

6.3.2 Network power balance preservation check for optimized results

The Table 6.2 summarizes the preservation of power balances for the cases before and after connecting the SPVP to the distribution network. As can be seen from Table 6.2, the network power balance before and after connecting SPVP is preserved for Tissa 1 feeder as well.

Table 6.2 : Network power balance preservation check for Case 1 & 2 for Tissa 1 feeder

P_DG				42,048.9 kWh		
P_DGLoss				3,195.8Wh		
P_LT				104,513.7 kWh		
Initial Total energy loss				4,658.3 kWh		
P_SubSol=P_LT-P_DG+P_DGLoss				65,660.6 kWh		
P_SubInitial=P_LT+Initial Total energy loss				109,172 kWh		
$P_{Substation}(t) + P_{DG}(t) = P_{LT}(t) + P_{Loss-Total}(t)$						
Case	P-Sub	P-DG	**P-Sub+P-DG**	P-Load	P-Loss	**P-Load+P-Loss**
Initial	109,172	0	**109,172**	104,513.7	4,658.3	**109,172**
SPVP	65,660.6	42,048.9	**107,709.5**	104,513.7	3,195.8	**107,709.5**

6.3.3 Summary of Optimization Results for SPVP

6.3.3.1 Total size, Reduction of power loss, Energy penetration and lowest bus voltage

Table 6.3 : Summary of Optimization Results for SPVP

Total load (MW)	6.598
PV size (MW) @ Bus No.	14.057 @ 149
Reduction in Energy loss	31.4%
DG penetration in terms of energy (Self-sufficiency level)	40.23%
Lowest bus voltage pu @ Bus no.	0.963 @ 373

Table 6.3 presents the summarized optimized values for SPVP size, location to install, self-sufficiency level of the distribution network expressed as a percentage of DG penetration in terms of energy and lowest bus voltage improvement after connecting the SPVP.

In order to minimize total energy loss over a day for Tissa 1 feeder, it is required to install a SPVP of 14.057MW capacity to the Bus No. 149. Once the SPVP of optimum capacity is installed, it would result in a 31.4% reduction of energy loss and the lowest bus voltage is improved to 0.963pu from its original value of 0.899pu at the Bus no. 373. The self-sufficiency level of the Tissa 1 feeder is 40.23% of the total energy requirement of the feeder. This means, with the installation of a large scale SPVP of 14.057MW optimum capacity, the feeder is capable of catering 40.23% of its total energy requirement itself, without drawing that amount of energy from the main grid.

6.3.3.2 Active power injection from different sources

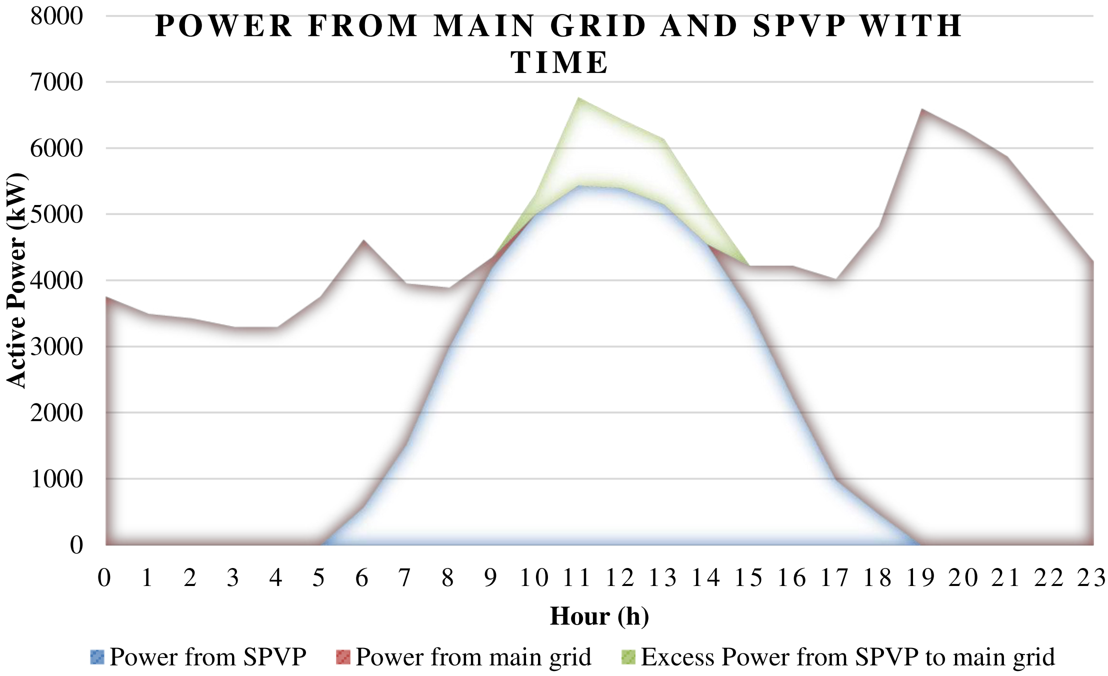

Figure 6.4: Power from main grid and SPVP with time

The proportions of power drawn from main grid when power from SPVP is not sufficient is indicated in red colour while power from SPVP when solar energy presents is indicated in blue colour in the Figure 6.4. For Tissa 1 feeder, the excess energy transition from SPVP to main grid is during 10th, 11th, 12th, 13th and 14th hours is indicated in green colour.

6.4 Optimization results for B-SPVP scenario

6.4.1 Hourly Optimum energy levels (OE)

The OEs of each hour were determined by varying the distributed resource size expressed as a percentage of hourly total load while keeping the bus to be connected as the same as the optimized location resulted from optimization of SPVP. For Tissa 1 feeder it was the bus no. 149. Therefore OEs for each hour were found and provided in the Table 6.4.

Table 6.4 : Hourly Optimum energy levels (OE) for Tissa 1 feeder

Hour	OE (As a % of Total hourly load)	Hour	OE (As a % of Total hourly load)
0	56.09%	12	65.92790849
1	52.12%	13	62.9%
2	51.12%	14	59.74%
3	49.13%	15	63.6%
4	49.13%	16	63.51%
5	56.08%	17	60.40%
6	69%	18	72.42%
7	59.15%	19	100%
8	58.36%	20	94.17%
9	65.72%	21	88.11%
10	71%	22	76.03%
11	62.06%	23	64.06%

These OEs were used to optimize the B-SPVP model subjected to the battery control logic depicted in ANNEXURE III and the results are described in the successive subsections.

6.4.2 Optimization by MIGA and PSO

Figure 6.5 presents the optimized workspace results attained using MIGA (Right hand side) and which are verified by PSO (Left hand side). The outputs from the two optimizing methods resulted equal values, as apparent from the Figure 6.5.

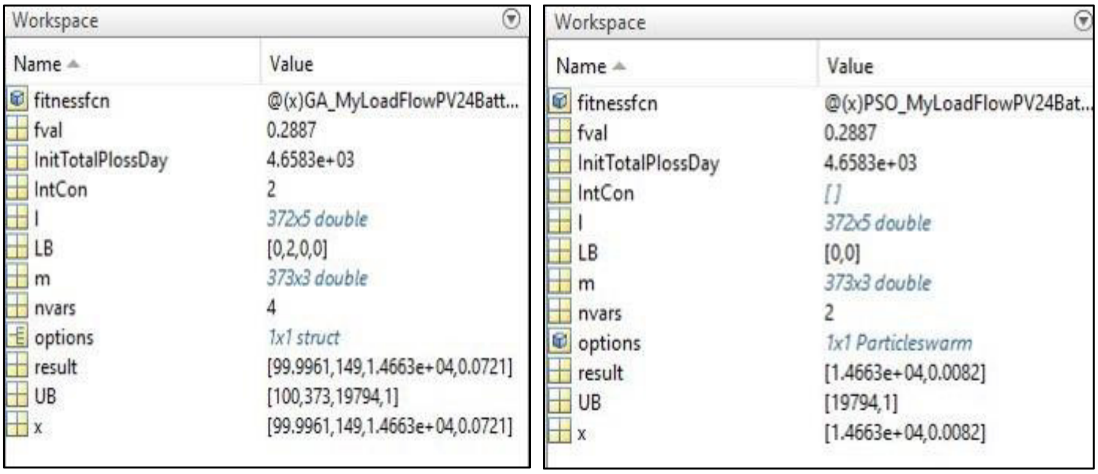

Figure 6.5 : Optimized workspace results obtained from MIGA (Left) & PSO (Right) for Tissa 1 feeder

Figure 6.6 shows the simulation outputs produced for MIGA (Right hand side) and PSO (Left hand side) optimization techniques for Tissa 1 feeder. Figure 6.6 also emphasizes again that use of PSO is faster to reach the optimized value than using MIGA.

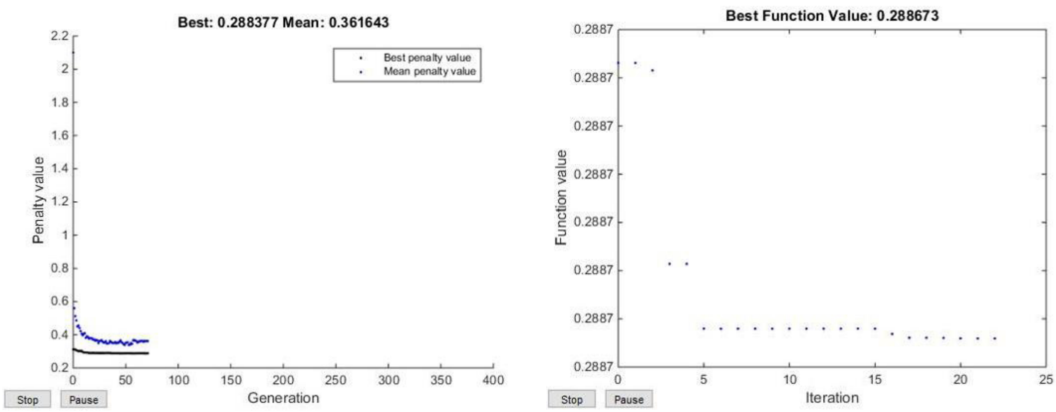

Figure 6.6 : Simulation output for Tissa 1 feeder using MIGA

6.4.3 Network power balance preservation check for optimized results

The Table 6.5 depicts how preservation of power balances for the cases is maintained before and after connecting the B-SPVP to the Tissa 1 feeder. As can be seen from Table 6.5, the network power balance before and after connecting B-SPVP is ensured.

Table 6.5 : Network power balance preservation check for Case 1, 2 & 3 for Tissa 1 feeder

<table>
<tr><td colspan="4">P_DG</td><td colspan="3">64,892.5 kWh</td></tr>
<tr><td colspan="4">P_DGLoss</td><td colspan="3">1,344.77 kWh</td></tr>
<tr><td colspan="4">P_LT</td><td colspan="3">104,513.7 kWh</td></tr>
<tr><td colspan="4">Initial Total energy loss</td><td colspan="3">4,658.3 kWh</td></tr>
<tr><td colspan="4">P_SubSol&Bat=P_LT-P_DG+P_DGLoss</td><td colspan="3">40,965.97 kWh</td></tr>
<tr><td colspan="4">P_SubInitial=P_LT+Initial Total energy loss</td><td colspan="3">109,172 kWh</td></tr>
<tr><td colspan="7">$P_{Substation}(t) + P_{DG}(t) = P_{LT}(t) + P_{Loss-Total}(t)$</td></tr>
<tr><td>Case</td><td>P-Sub</td><td>P-DG</td><td>P-Sub+P-DG</td><td>P-Load</td><td>P-Loss</td><td>P-Load+P-Loss</td></tr>
<tr><td>Initial</td><td>109,172</td><td>0</td><td>109,172</td><td>104,513.7</td><td>4,658.3</td><td>109,172</td></tr>
</table>

SPVP	65,660.6	42,048.9	**107,709.5**	104,513.7	3,195.8	**107,709.5**
B-SPVP	40,965.97	64,892.5	**105,858.48**	104,513.7	1,344.77	**105,858.48**

6.4.4 Summary of Optimization Results for B-SPVP

6.4.4.1 Total SPVP & BESS size, Reduction of power loss, Energy penetration and lowest bus voltage

Table 6.6 : Summary of Optimization Results for B-SPVP

Total load (MW)	6.598
PV size (MW) @ Bus No.	6.598 @ 149
Total BESS size (MWh)	14.663
Reduction in Energy loss	71.13%
DG penetration in terms of energy (Self-sufficiency level)	62.09%
Lowest bus voltage pu @ Bus no.	0.983 @ 373

An abstract of interested optimized values for B-SPVP size &BESS size to install, self-sufficiency level of the distribution network expressed as a percentage of DG penetration in terms of energy and lowest bus voltage improvement after connecting the B-SPVP for Tissa 1 feeder are presented in the Table 6.6.

To minimize total energy loss over a day for Tissa 1 feeder, it is required to install a B-SPVP comprised of a SPVP with 6.598MW capacity and BESS of a size 14.663MWh to the Bus No. 373. Once the optimum capacity B-SPVP is installed, it would result in a 71.13% reduction of energy loss which is further reduces an energy loss reduction of a value 40.23% that existed for optimized SPVP. The size of SPVP in optimized B-SPVP is now has decreased to 6.598MW from its capacity of 14.06MW for optimizing only with SPVP. The lowest bus voltage has now improved to 0.983pu from 0.963pu that was there for optimized only with SPVP and from its original value of 0.899pu for the base case load flow. The self-sufficiency level of the Tissa 1 feeder for B-SPVP is 62.09% of the total energy requirement of the feeder. This means, with the installation of B-SPVP with a 6.598MW SPVP together with a BESS of 14.663MWh optimum capacity, the feeder is capable of catering

62.09% of its total energy requirement itself, without absorbing that amount of energy from the main grid.

6.4.4.2 BESS Charge/Discharge with time

By incorporating the battery control logic presented in the ANNEXURE III, how the BESS is charged and discharged over the day for Tissa 1 feeder is as in the following Figure 6.7.

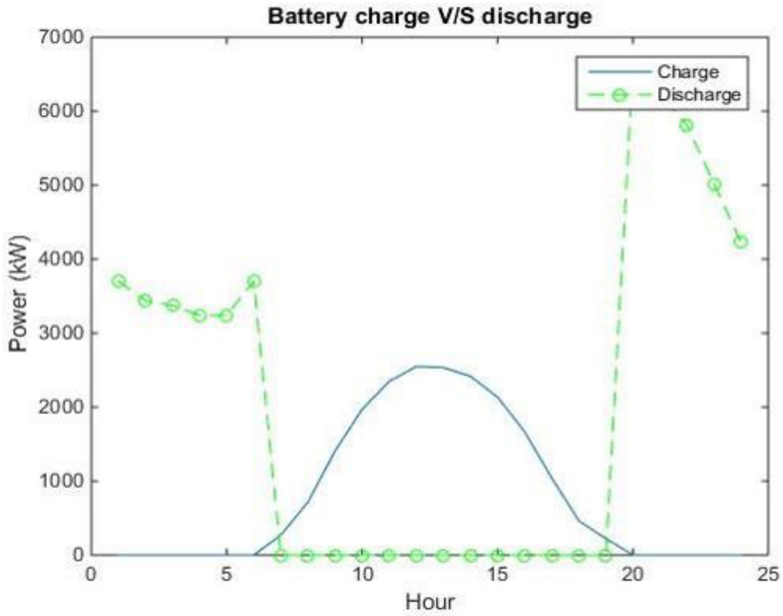

Figure 6.7: BESS Charge/Discharge with time

6.4.4.3 Active Power Injection from different sources

The proportions of power drawn from main grid when power from B-SPVP is not sufficient is indicated in green colour while power from SPVP to charge the BESS in the presence of solar energy and discharge the stored energy up to OE are indicated in red and blue colours in the Figure 6.8, respectively.

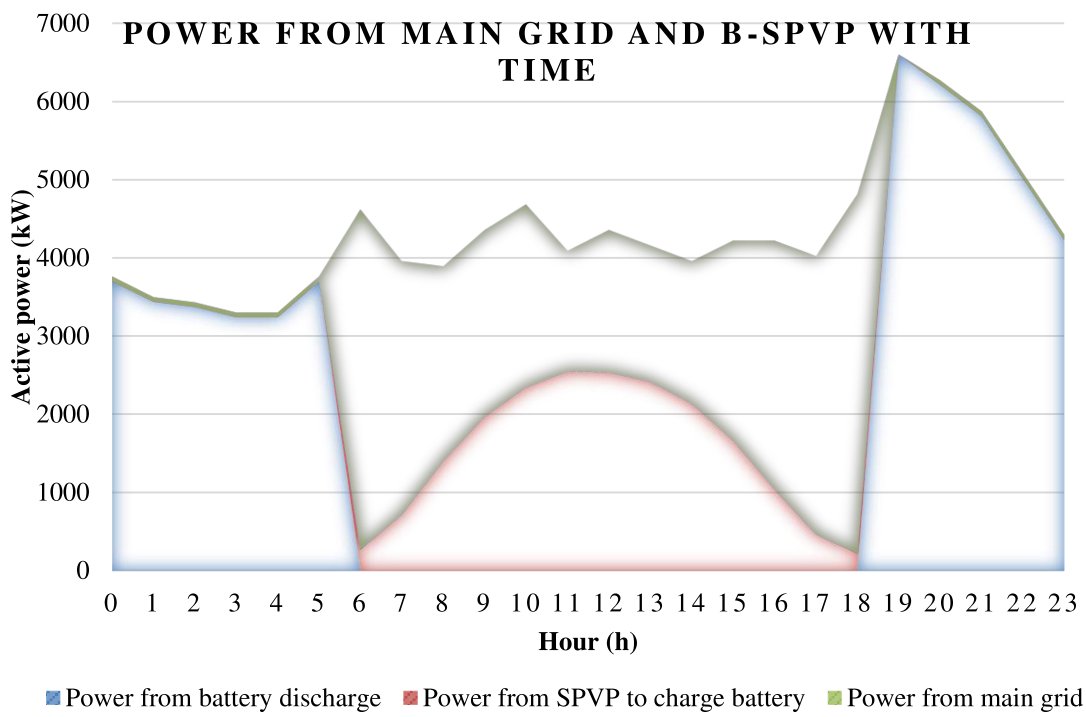

Figure 6.8 : Power from main grid and B-SPVP with time

If the same graph is represented as a line graph, the graph would be as in the Figure 6.9 below in which all the power levels are visible clearly.

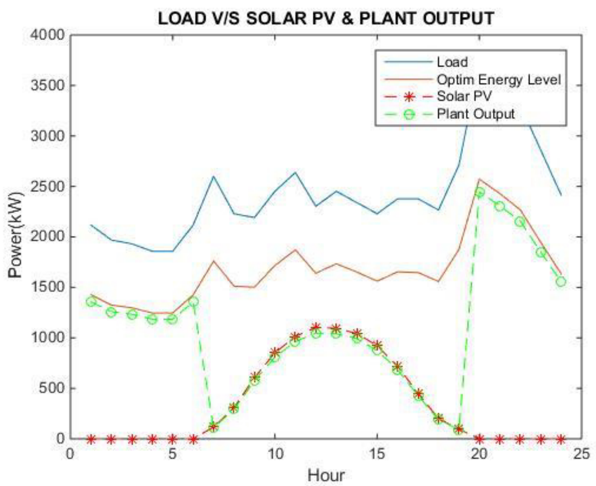

Figure 6.9: Power from main grid and B-SPVP with time

6.4.5 Comparison of total energy loss variation of optimized results over a day for Tissa 1 feeder

The hourly energy loss resulted from each three cases considered; i.e. energy loss having neither SPVP nor a B-SPVP connected to the Tissa 1 feeder, energy loss having only a SPVP and energy loss having only a B-SPVP connected to the feeder were plotted against each hour and the graph obtained is the Figure 6.10 below.

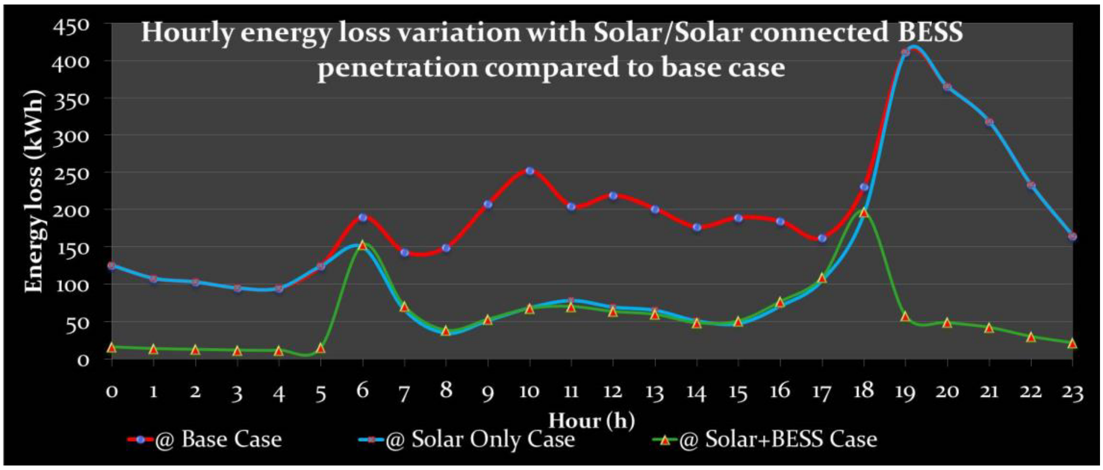

Figure 6.10 : Hourly energy loss variation with Solar/Solar connected BES penetration compared to base case

It is clear from the Figure 6.10, that the energy loss variation with time when only the optimized B-SPVP connected to the distribution network, almost always lies below the curves of the energy loss variation with time than that of the other cases considered because BESS discharges its potential energy that has been charged from its connected SPVP, without bringing down all the required energy all the way from main grid, thus resulted in reduced I^2Z loss of the network. As the same as for IEEE 33 bus network, the highest losses in each of the three cases occur during the peak hour, i.e. during the 19th hour for Tissa 1 feeder as well. Since the SPVP and B-SPVP are connected in the proximity of network loads i.e. at the Bus no. 149, reduced power losses have occurred when compared with the base case which draws all the required energy from the main grid. During sunny hours, from 5th to 17th hour, loss variation curve of B-SPVP connected case follows the same curve of the SPVP loss variation is observed. Therefore as far as only the losses during the 5th to 17th hours are concerned, installing either only the SPVP or B-SPVP has no significant effect on reducing network losses, for Tissa 1 feeder.

6.4.6 Comparison of voltage profile improvement with optimized results over a day for Tissa 1 feeder

In order to analyse how minimum voltage of each bus is modified with the addition of optimized SVPV and B-SPVP to Tissa 1 feeder of Hambanthota GSS, minimum voltages of each bus in each case were mapped out against each bus and the resulted scatter graph is presented in the Figure 6.11 to Figure 6.15.

As is illustrated from Figure 6.11 to Figure 6.15, when result of one case is concerned, voltage levels decreases as the buses locate away from the slack bus and thus it is entirely dependent on the network configuration. Minimum voltages of each bus are shown in red colour for base case results whereas blue and green colour bars represents resultant values for optimized SPVP and optimized B-SPVP cases, respectively. As seen from the Figure 6.11 to Figure 6.15, the minimum bus voltages have increased with the addition of SPVP which further escalated with the addition of B-SPVP, within the acceptable voltage range. Thus the voltage constraint is preserved in both SPVP case and B-SPVP case in Tissa 1 feeder as well.

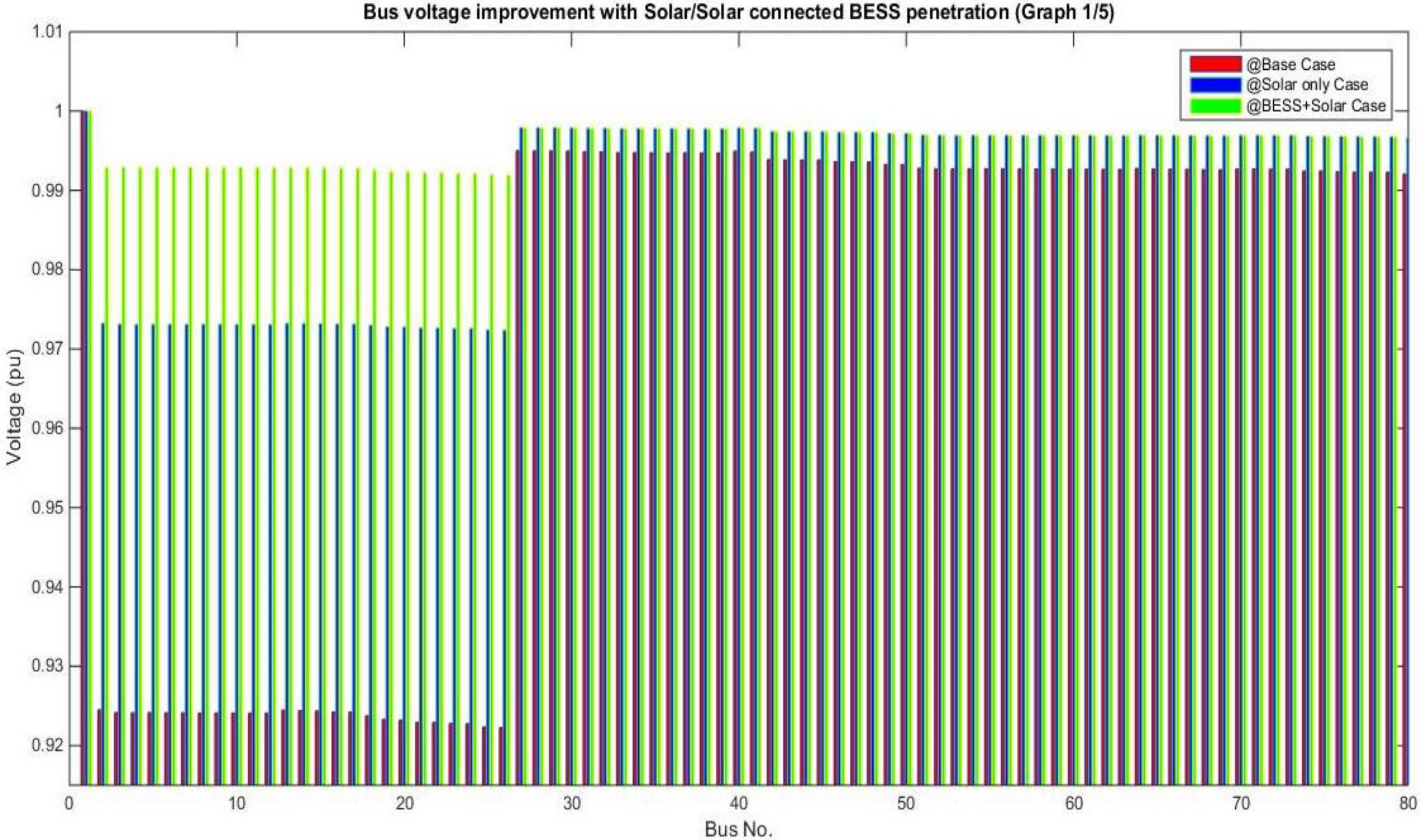

Figure 6.11 : Voltage profile improvement with optimized results over a day for Tissa 1 feeder (Graph 1/5)

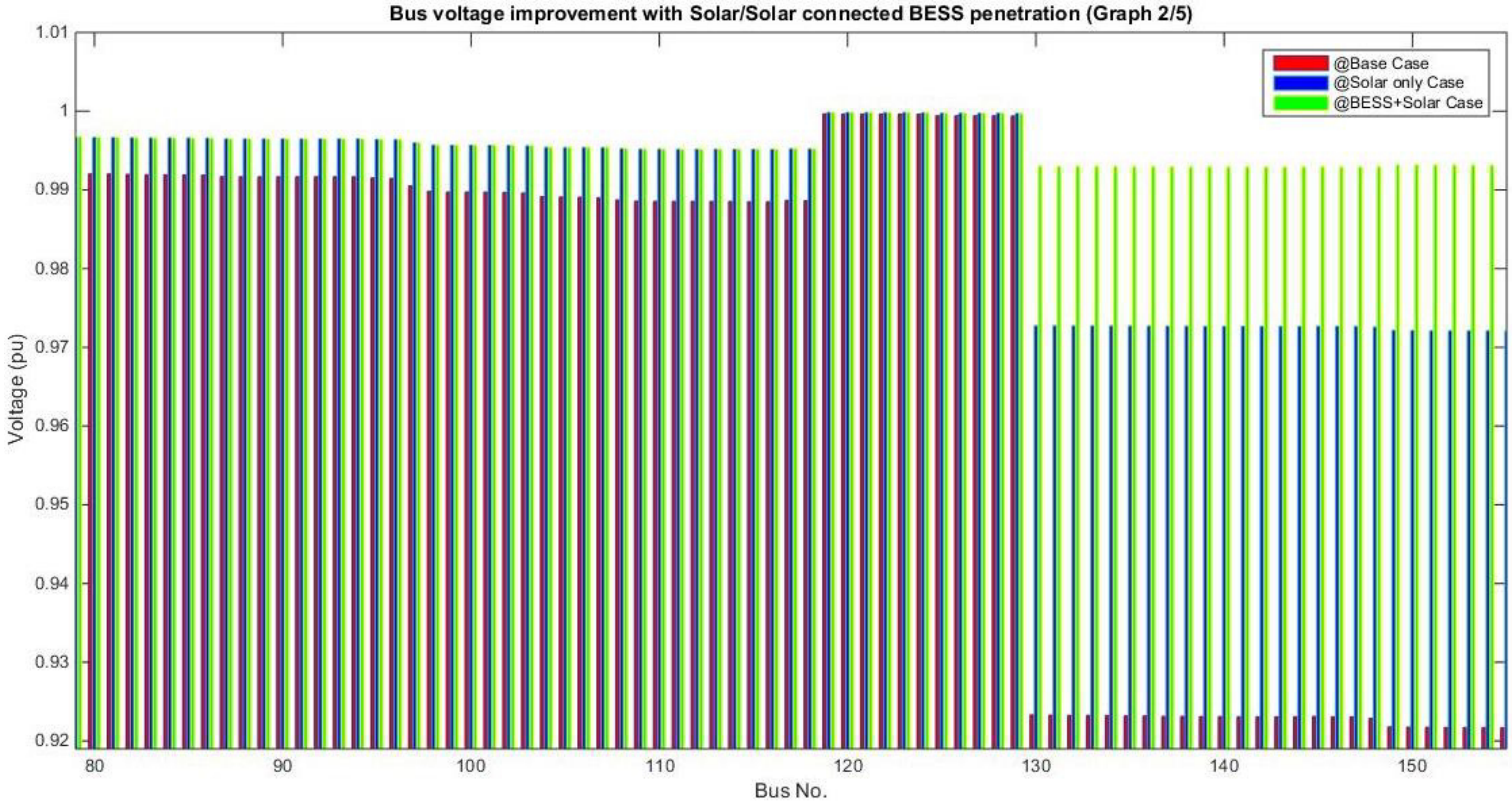

Figure 6.12 : Voltage profile improvement with optimized results over a day for Tissa 1 feeder (Graph 2/5)

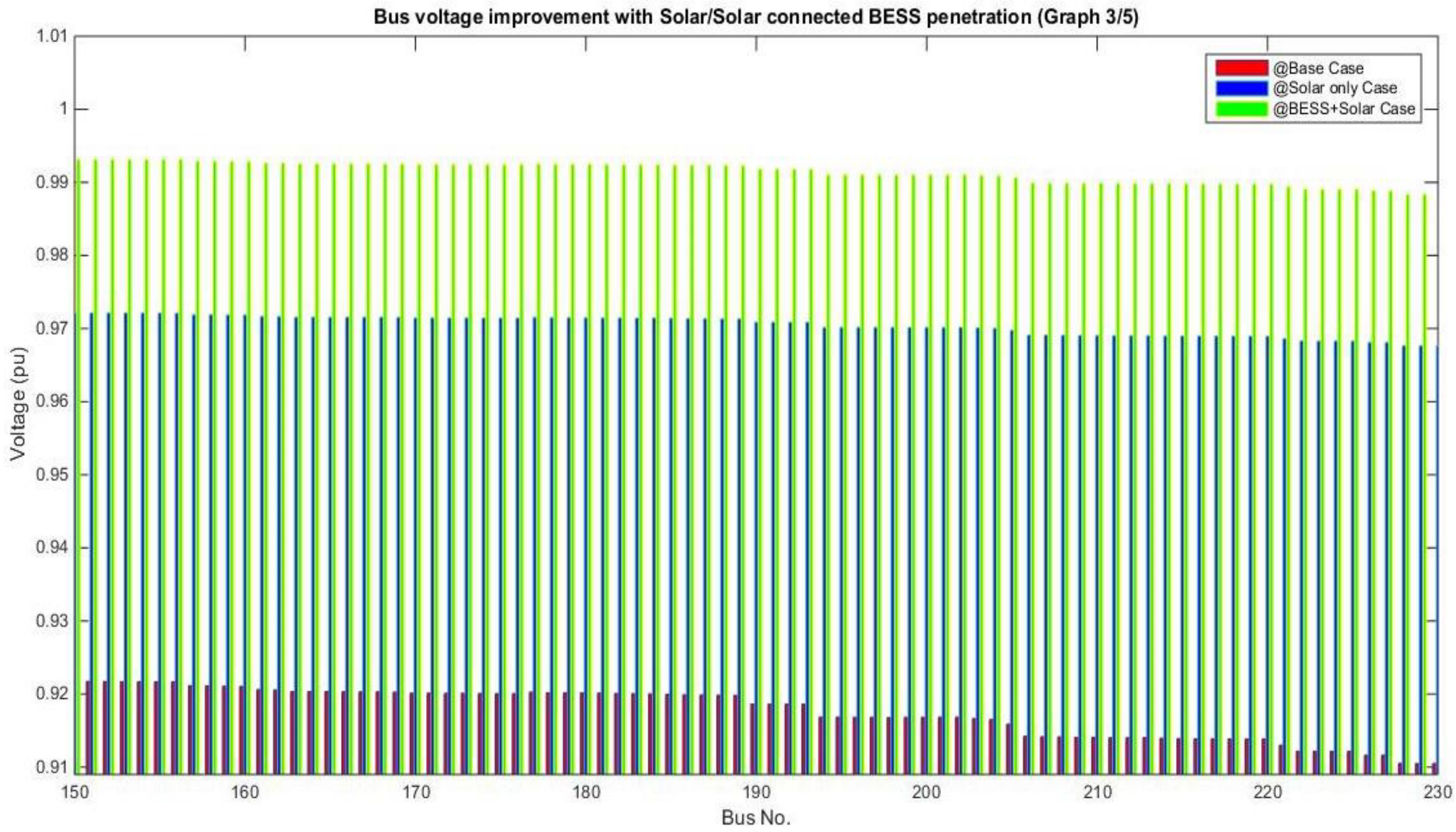

Figure 6.13 : Voltage profile improvement with optimized results over a day for Tissa 1 feeder (Graph 3/5)

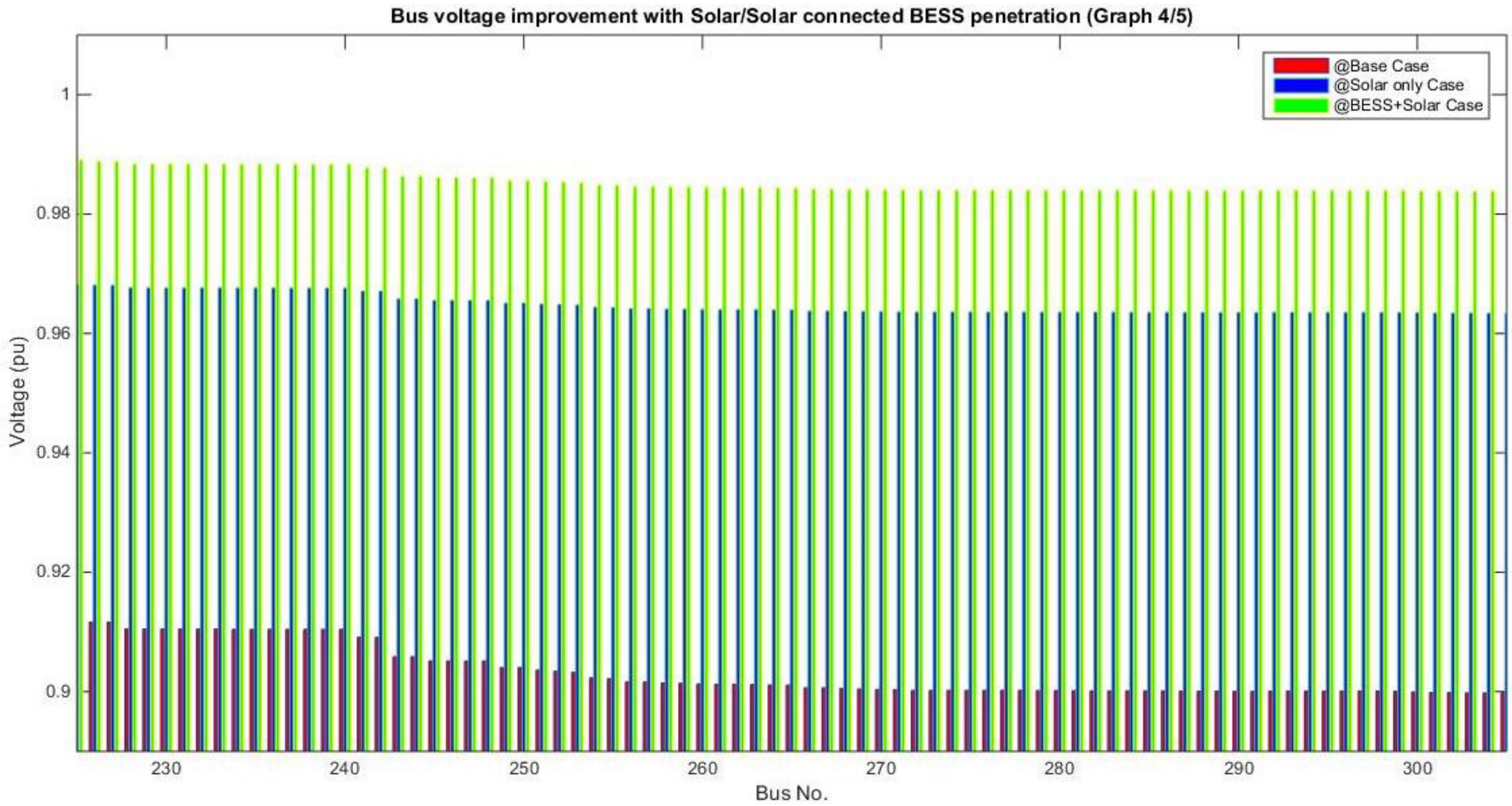

Figure 6.14 : Voltage profile improvement with optimized results over a day for Tissa 1 feeder (Graph 4/5)

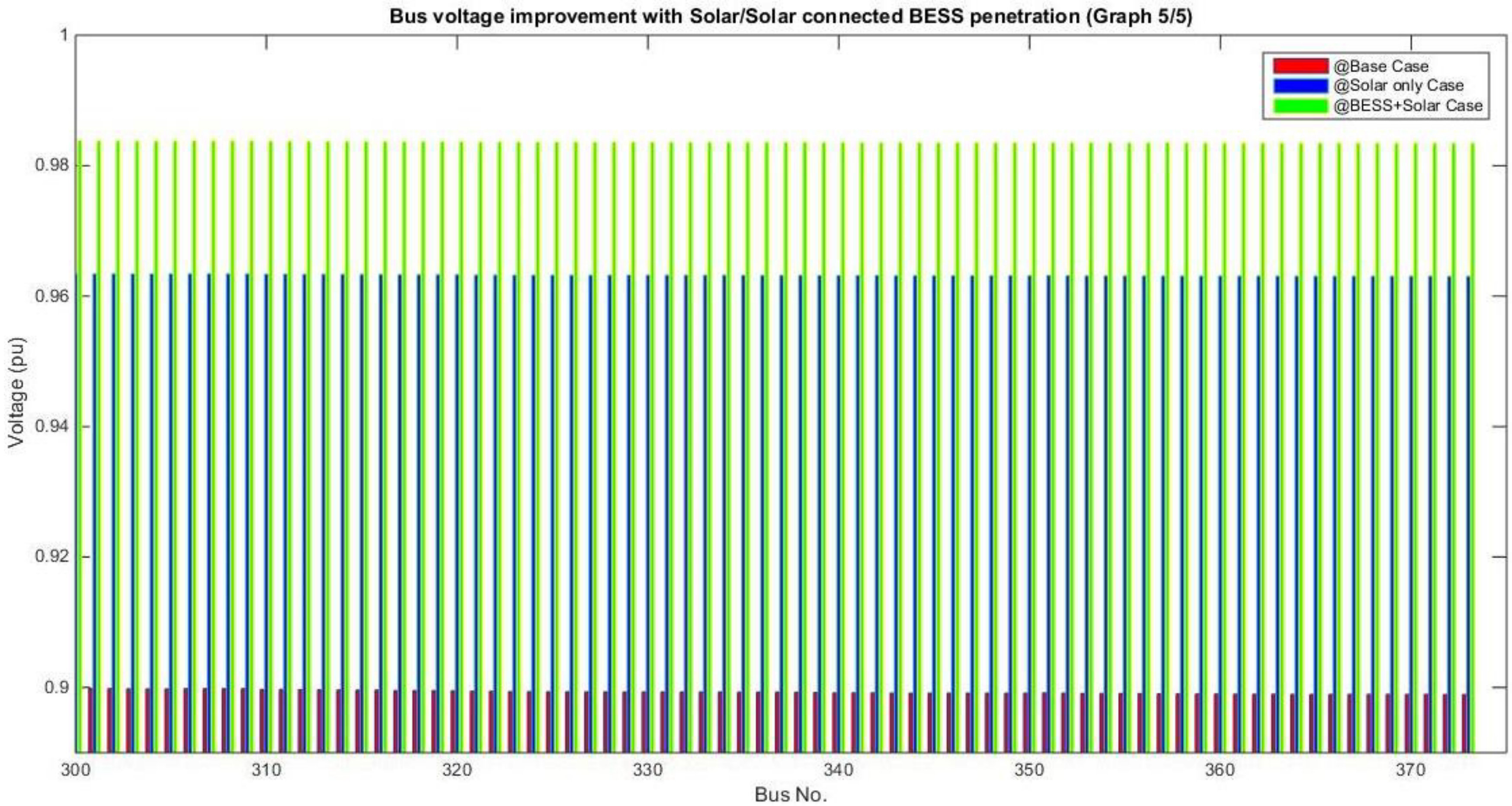

Figure 6.15 : Voltage profile improvement with optimized results over a day for Tissa 1 feeder (Graph 5/5)

6.5 Financial Evaluation

With the intention of determining financial viability of implementing the SPVP and B-SPVP with the optimized capacities, a financial evaluation was carried out in three scenarios in terms of Simple Payback Period (SPP) and Levelized Cost of Energy (LCOE) considering the economic life of the plants being 20 years with the costs incurred in the construction, operation and maintenance for 20 years. To determine the SPP for the three cases, variable costs of each generating units that were in operation on 03rd August 2018 [54] and given in the Table 6.7, were taken into account together with their generated energy hourly. Total energy from each generator unit during each hour was then commensurate to match the total energy demanded from Tissa 1 feeder in each hour. Since there is no variable cost of unit generated related to hydro power plants and SPVPs due to the availability of their energy sources at no cost, variable costs of them was set to zero.

Table 6.7 : Variable cost (Rs./MWh) for generating units of Sri Lanka on 03rd August 2018

Generator unit	Variable cost (Rs./MWh)	Generator unit	Variable cost (Rs./MWh)
Kelanitissa Gas Turbine 01	45,000.00	ACE Embilipitiya	24,740.00
Kelanitissa Gas Turbine 02	45,000.00	Nothern Power	23,420.00
Kelanitissa Gas Turbine 03	45,000.00	West Coast Gas Turbine 01	23,260.00
Kelanitissa Gas Turbine 04	45,000.00	West Coast Gas Turbine 02	23,260.00
Kelanitissa Gas Turbine 05	45,000.00	West Coast Steam Turbine	23,260.00
Kelanitissa Gas Turbine 06	45,000.00	Sapugaskanda Unit 01	22,580.00
Kelanitissa Steam Turbine 01	37,050.00	Sapugaskanda Unit 02	22,580.00
Kelanitissa Steam Turbine 02	37,050.00	Sapugaskanda Unit 03	22,580.00
Gas Turbine 07	37,050.00	Sapugaskanda Unit 04	22,580.00
Kelanitissa Jebic (GT08)	37,050.00	Sapugaskanda Unit 05	22,580.00
Kelanitissa JBIC (STEAM)	37,050.00	Sapugaskanda Unit 06	22,580.00
Lakdanavi	37,050.00	Sapugaskanda Unit 07	22,580.00
AES-Kelanitissa	31,440.00	Sapugaskanda Unit 08	22,580.00
Aggreko-Hambanthota	25,990.00	Sapugaskanda Unit 09	22,580.00
Aggreko- Pallekele	25,990.00	Sapugaskanda Unit 10	22,580.00
Aggreko- Galle	25,990.00	Sapugaskanda Unit 11	22,580.00
Aggreko-Kurunegala	25,990.00	Sapugaskanda Unit 12	22,580.00
Asia Power	25,840.00	Puttalam Coal Unit 01	8,070.00

ACE Horana	25,050.00	Puttalam Coal Unit 02	8,070.00
ACE Matara	24,830.00	Puttalam Coal Unit 03	8,070.00

With references made to [45, 49, 50, 54], using the specific values mentioned in the Table 6.8, financial evaluations were made assuming a project Internal Rate of Return (IRR) of minimum 10%.

The three cases studied are as follows.

1. Case A: When the optimized SPVP is connected to the Tissa 1 feeder

   In this Case A, financial evaluations were carried out to determine SPP and LCOE of the optimized SPVP when connected to the Tissa 1 feeder of Hambanthota GSS. The complete evaluation sheets are annexed as ANNEXURE IV & ANNEXURE V.

2. Case B: When the optimized B-SPVP is connected to the Tissa 1 feeder

   Under Case B, financial evaluation was carried out to determine LCOE and SPP for the optimized B-SPVP when connected to the Tissa 1 feeder of Hambanthota GSS by incorporating the related unit costs as it is nowadays. The complete evaluation sheets are annexed as ANNEXURE VI & ANNEXURE VII.

3. Case C: Determination of the Capital Cost of BESS (in USD/kWh) of B-SPVP to compete with small GT in Kelanitissa, at the optimum solution

   As Case C, unit cost of a BESS was found by keeping the LCOE of optimized B-SPVP to Rs. 45.00 subjected to the minimum of 10% IRR. This is because, in order to consider energy unit from B-SPVP to compete with power plants that are already in the Sri Lankan power system, the unit cost of energy generates from B-SPVP should be less than or equal to highest unit cost power plant in the system, i.e. small Gas Turbine (GT) units in Kelanitissa power plant whose specific cost of generation unit is Rs. 45.00 on average. The SPP was also worked out for this case as well. The complete evaluation sheets are annexed as ANNEXURE VIII & ANNEXURE IX.

Table 6.8 : Specific values used for financial evaluation

Parameters	Case A	Case B	Case C
Capital Cost for PV plant (USD/kW)	1,000	1,000	1,000
Capital Cost for BESS (USD/kWh)	-	2,000	-
Capital Cost for inverter (USD/kW)	-	270	270
Loan/Equity (% / %)	70/30	70/30	70/30
Project IRR (%)	10.71	10.14	10.87

Summary of the financial evaluation for the three cases are tabulated in the following Table 6.9.

Table 6.9 : Summary of financial evaluation for optimized Tissa 1 feeder SPVP and B-SPVP

Parameters	Case A	Case B	Case C
Solar Plant Capacity (MW)	14.06	6.60	6.60
Total BESS size (MWh)	-	14.663	14.663
Capital Cost for PV plant (USD/kW)	1,000	1,000	1,000
Capital Cost for BESS (USD/kWh)	-	2,000	**135**
Capital Cost for inverter (USD/kW)	-	270	270
Levelised Tariff (LKR/kWh)	**22.00**	**175.00**	**45.00**
Loan/Equity (% / %)	70/30	70/30	70/30
Project IRR (%)	10.71	10.14	10.87
Simple payback period (Years)	**16**	**156**	**26**
NPV (USD mil)	**14**	**110**	**28**

When a SPVP of optimum capacity of 14.06MW connected to the bus no. 149, in order to have a project IRR of 10%, an energy unit generated from SPVP should be at least Rs. 22 per kWh and its NPV will be 14 USD million. Based on the energy benefit gain from SPVP, the capital cost can be recovered within 16 years. For the B-SPVP project IRR to be 10%, in prevailing costs nowadays, an energy unit generated from B-SPVP is Rs. 175 per kWh which is why it is far too prohibitive to consider BESS units in the LCLTGEP in Sri Lanka. In order to be considering for base case of

LCLGEP in Sri Lanka, an energy unit generated from a B-SPVP should be Rs. 45 per kWh on average. If one day the capital cost of a BESS unit goes down to a value of USD 135 per kWh from its today's value of USD 2,000 per kWh, then Tissa 1 feeder can be made 62.09% self-sufficient in terms of energy while its NPV being 28 USD million. It is twice the NPV of a SPVP with optimum capacity, but it can make Tissa 1 feeder self-sufficient for 40.23% in terms of energy. Depending on the energy benefit gain from B-SPVP under Case C, the capital cost can be recovered within 26 years.

7 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Integration of DGs that use RES is boosting in the distribution networks due to their proven technical and economic rewards. However, imbalances at the time of demand for electricity and power generation in the distribution network have retarded the proliferation of non dispatchable DGs, such as SPVPs. The study has shown that the problems associated with the integration of DG into the distribution network can be eliminated with proper use of BESSs. In this research, the planning of SPVP and B-SPVP in the distribution networks has been demonstrated. The optimal planning of SPVP and B-SPVP subject to voltage and network power balance constraints has been accomplished.

7.1 Conclusions

1. Development of generalized models applicable to any distribution network for sizing and placement of SPVP and B-SPVP using MIGA and PSO

In the study, models have been developed for deciding the optimum size and place of SPVP and B-SPVP to reduce the amount of energy losses in the distribution network considered. In addition to minimizing of energy losses, the effect of the size and location of the SPVP and B-SPVP on the bus voltage deviation has also been examined using MIGA software. The results obtained from MIGA have been verified by comparison with the optimization done with the use of PSO which uses an algorithm to reach the optimum value, and attained the same results. The optimizing function was assessed as the TELI which is the ratio between the total energy losses when SPVP or B-SPVP to the total energy loss when neither SPVP nor B-SPVP is installed in the distribution network considered. Initially the building up of general model was tested with the standard IEEE 33 bus network. Subsequently data of Tissa 1 feeder of Hambanthota GSS was used to assess the optimum size and location to place SPVP and B-SPVP in the feeder to minimize energy loss drawing least power from main grid. The prime objective of finding out the self-sufficiency of the distribution networks is summarized in the following Table 7.1. The outcomes of this study can be an eye-opener highlighting potential importance in planning for integration of SPVP and B-SPVP at distribution networks.

Table 7.1 : Self-sufficiency level in terms of energy for Tissa 1 feeder and IEEE RTS 33 bus network under optimized condition for SPVP and B-SPVP

	Tissa 1 feeder	**IEEE 33 Bus Test network**
SPVP (% of Total energy)	40.23%	28.35%
B-SPVP (% of Total active energy)	62.09%	44.17%

2. Condition for optimum penetration levels for Solar connected BES for minimum total energy losses

In this study, a condition has been derived for optimum penetration levels for either SPVP or B-SPVP for minimum total energy losses and presented as an hourly optimum energy level expressed as a percentage of hourly total load. Beyond these specified penetration levels, total energy losses increases.

3. Solar power plant and BESS sizes of SPVP and B-SPVP

The sizes of solar power plant and BESS of SPVP and B-SPVP for standard IEEE 33 bus network and Tissa 1 feeder have been derived in this research and depicted in the Table 7.2. It can be concluded that the sizes of SPVP and B-SPVP are dependent on the distribution network under study.

Table 7.2 : Optimal Solar power plant and BESS sizes of SPVP and B-SPVP

	Tissa 1 feeder	**IEEE 33 Bus Test network**
SPVP size (% of Total connected load)	212%	150%
B-SPVP (% of Total connected load)	99%	76%

Moreover it has been affirmed that the Solar PV plant/Solar connected BES are capable of accepting only a fraction of peak rather than the peak load, by scrutinizing the optimized outcomes of the two networks.

4. Reduction in total power losses & voltage profile improvement in Tissa 1 feeder

It encapsulated that the addition of SPVP can reduce power losses in the network while improving the voltage profile at the same time. Moreover, it has been found out that the losses can be further reduced and voltage profile can be further developed by co-locating BESS with SPVP.
The reduction of the total power loss and the voltage profile improvement of the lowest bus voltage with the addition of SPVP and B-SPVP are tabulated in the Table 7.3, for Tissa 1 feeder.

Table 7.3 : Reduction in total power losses & voltage profile improvement in Tissa 1 feeder

	Base case	**With SPVP only**	**With B-SPVP**
Voltage profile improvement	0.899 pu	0.963 pu	0.983 pu
Total power loss reduction (%)	-	31.4%	71.13%

5. Consideration of solar intermittency for the output of PV modules

During the study, solar intermittency has been taken into account for prediction of output from solar PV modules with time-varying weather data when developing models for optimal sizing and placement of SPVP and B-SPVP.

6. Declivity of prices of solar PV plants and utility scale batteries with the Economies of unit scale

Based on a study report on Use of Battery Energy Storage Systems published by PUCSL, it has been revealed during the research that the battery cost would come down significantly to an affordable limit by the end of year 2020 and based on [47] by the year 2015. In addition, the study has conveyed the message that rejecting a technology focusing only on its current cost rather than its future potential creates an artificial barrier for the technology, by figuring out the viable unit cost of BESS.

7.2 Recommendations for further studies

The realization of this research study was done narrowing down the study into the following limitations.

- Consideration of solar energy as the RES
- Consideration of utility scale BESS as the energy storage option
- Optimization of the distribution network in terms of energy loss bounded by voltage constraint whereas the self-sufficiency is expressed in terms of energy penetration of either output energy from large scale SPVP or B-SPVP
- Analysis by installing single generator units than considering installation of multiple units coupled to single BESS
- Development of a battery control logic in order to maximize the output power from SPVP and B-SPVP

At the closure of this study, it is proposed to put forward following suggestions which are constrained in this study, as future works.

1. Analysis for the penetration of large scale wind farms

Most of the time not only solar, but wind power is also considered non-dispatchable. But with the utilization of BESS coupled with wind power, even the wind power plants can also be treated as dispatchable. Further, there is also an equation that can quantify wind speed that then can be used to calculate output power from a wind turbine presented as in [48] using historical wind data with Weibull probability density function.

2. Analysis of network behaviour by taking the reactive power component

The study illustrated in this thesis was narrowed down to active power component only. Therefore it is proposed to extend the research works by incorporating the reactive power component in the study as well.

3. Development of a battery control logic proposing an optimum Time-of-Use tariff model

The control logic proposed in this study for determining the optimum levels of energy requirements for scheduling the charging and discharging of the battery storage considered utilization of solar power as much as possible without concerning any financial aspect when sizing BESS since there is no Time-of-Use tariff prevail in Sri Lanka in the energy market. But if one day if it is to be implemented when purchasing power from power plants, it is suggested to develop a battery control logic that incorporate Time-of-Use tariff proposing tariffs for each time interval, as a future work.

4. Analysis for different load characteristics

In this research, the load was considered to be independent on voltage since Sri Lankan demand is mainly comprises of residential loads. For a highly industrialized power system, there can be electrical networks where load is voltage dependent and therefore the DG placement can also be influenced by the load characteristics too. For that reason it is recommended to extend the research works of this study by developing a model that is capable of catering the electrical networks with voltage dependent loads as well.

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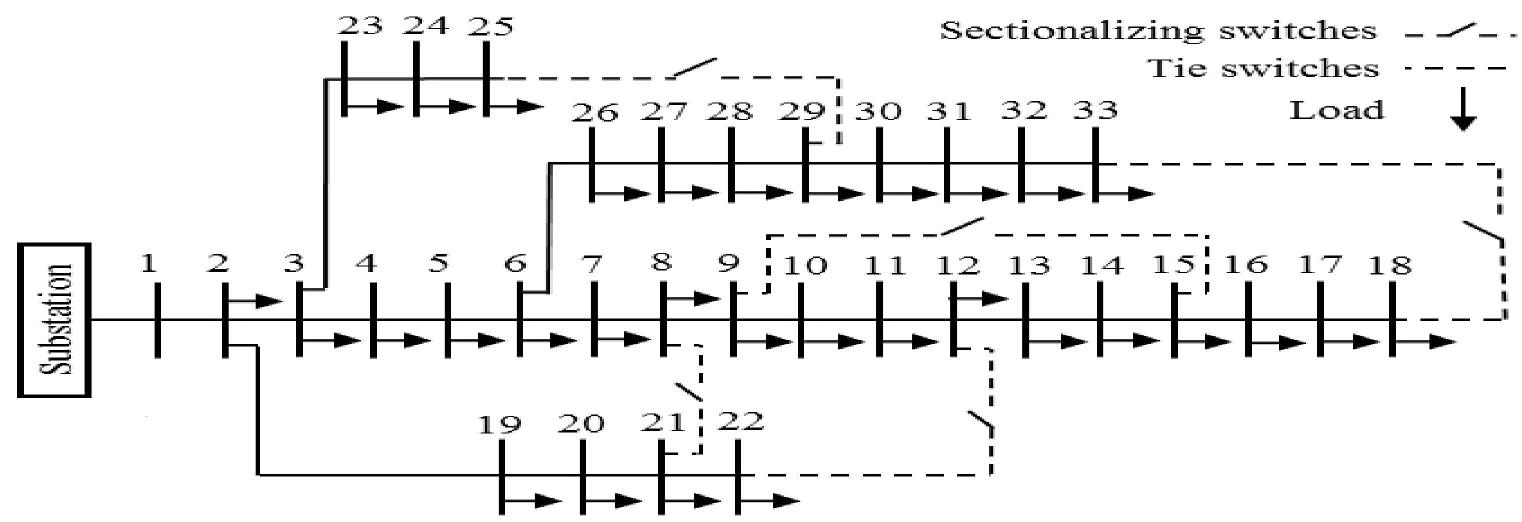
ANNEXURE I

IEEE Reliability Test System (RTS) 33 Bus standard network details

IEEE Reliability Test System (RTS) 33 Bus standard network details

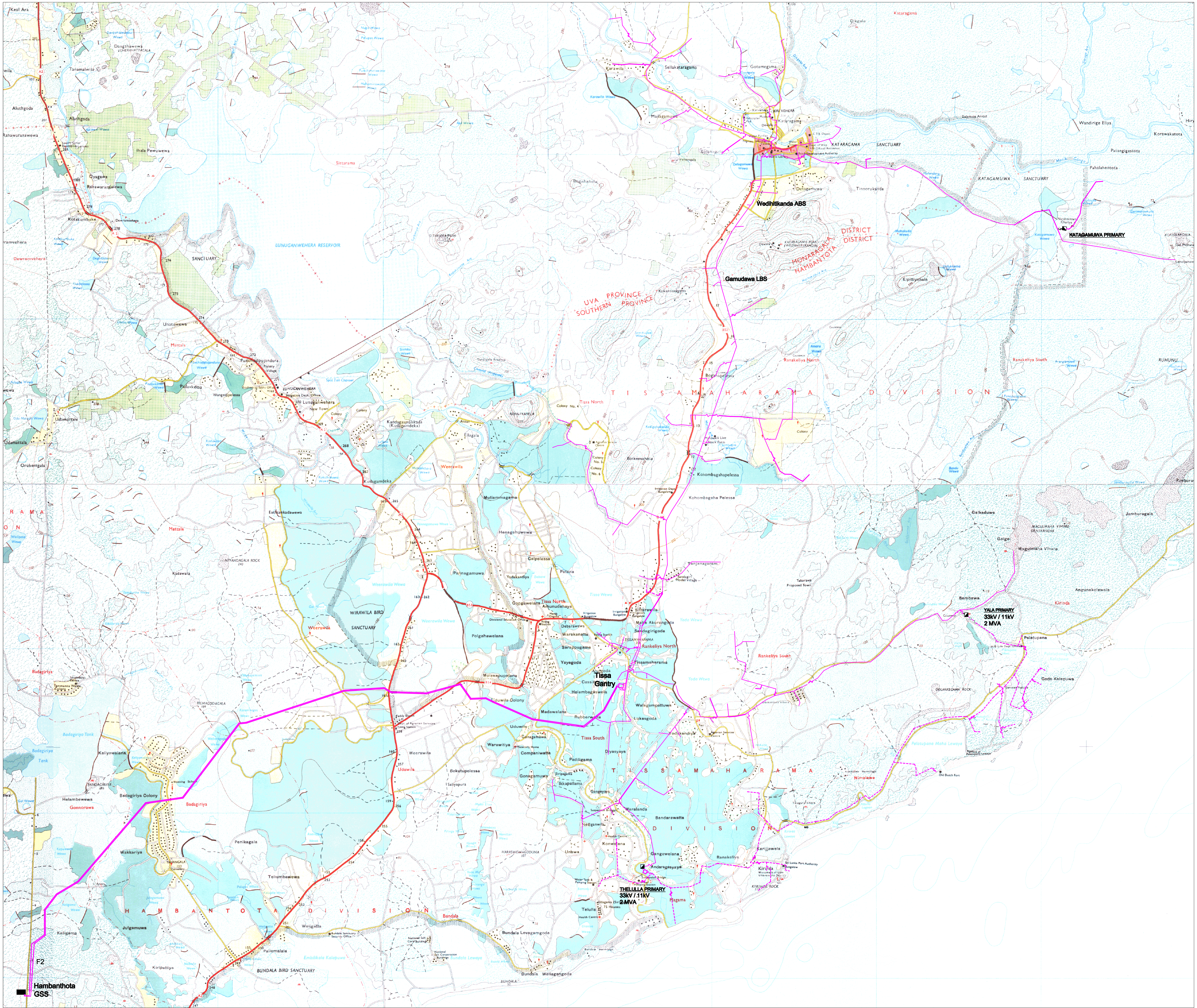


Single Line Diagram

Loads Connected to each bus				S_Base = 100MVA			
Bus Number	Nominal load			V_Base = 33kV			
	P (kW)	Q (kVar)		From	To	Resistance and Reactance (Ohms)	
						R (Ohms)	X (Ohms)
1	0	0					
2	100	60		1	2	0.0922	0.0470
3	90	40		2	3	0.4930	0.2511
4	120	80		3	4	0.3660	0.1864
5	60	30		4	5	0.3811	0.1941
6	60	20		5	6	0.8190	0.7070
7	200	100		6	7	0.1872	0.6188
8	200	100		7	8	0.7114	0.2351
9	60	20		8	9	1.0300	0.7400
10	60	20		9	10	1.0440	0.7400
11	45	30		10	11	0.1966	0.0650
12	60	35		11	12	0.3744	0.1298
13	60	35		12	13	1.4680	1.1550
14	120	80		13	14	0.5416	0.7129
15	60	10		14	15	0.5910	0.5260
16	60	20		15	16	0.7463	0.5450
17	60	20		16	17	1.2890	1.7210
18	90	40		17	18	0.7320	0.5740
19	90	40		2	19	0.1640	0.1565
20	90	40		19	20	1.5042	1.3554
21	90	40		20	21	0.4095	0.4784
22	90	40		21	22	0.7089	0.9373
23	90	50		3	23	0.4512	0.3083
24	420	200		23	24	0.8980	0.7091
25	420	200		24	25	0.8960	0.7011
26	60	25		6	26	0.2030	0.1034
27	60	25		26	27	0.2842	0.1447
28	60	20		27	28	1.0590	0.9337
29	120	70		28	29	0.8042	0.7006
30	200	600		29	30	0.5075	0.2585
31	150	70		30	31	0.9744	0.9630
32	210	100		31	32	0.3105	0.3619
33	60	40		32	33	0.3410	0.5302

ANNEXURE II

Details of Tissa 1 feeder of Hambanthota GSS



Wedihitikanda ABS
KATAGAMUWA PRIMARY
Gamudawa LBS
YALA PRIMARY
33kV / 11kV
2 MVA
Tissa
Gantry
THELULLA PRIMARY
33kV / 11kV
2 MVA
F2
Hambanthota
GSS
LUNUGANWEHERA RESERVOIR
UVA PROVINCE
SOUTHERN PROVINCE
MONARAGALA DISTRICT
HAMBANTOTA DISTRICT
T I S S A M A H A R A M A D I V I S I O N
H A M B A N T O T A D I V I S I O N
KATARAGAMA
WIRAWILA BIRD SANCTUARY
BUNDALA BIRD SANCTUARY

Loads connected at each bus of Tissa 1 feeder

Loads Connected to each bus		
Bus Number	Nominal load	
	P (kW)	Q (kVar)
1	0.00	0.00
2	0.00	0.00
3	0.00	0.00
4	66.60	22.94
5	0.00	0.00
6	0.00	0.00
7	0.00	0.00
8	0.00	0.00
9	0.00	0.00
10	17.14	5.90
11	0.00	0.00
12	39.94	13.76
13	0.00	0.00
14	0.00	0.00
15	0.00	0.00
16	0.00	0.00
17	52.86	18.21
18	0.00	0.00
19	0.00	0.00
20	0.00	0.00
21	0.00	0.00
22	20.40	7.03
23	0.00	0.00
24	17.92	6.17
25	45.33	15.62
26	0.00	0.00
27	0.00	0.00
28	0.00	0.00
29	25.50	8.79
30	0.00	0.00
31	0.00	0.00
32	65.40	22.53
33	0.00	0.00
34	0.00	0.00
35	0.00	0.00
36	50.09	17.25
37	0.00	0.00
38	0.00	0.00
39	87.19	30.04
40	47.64	16.41

Loads Connected to each bus		
Bus Number	Nominal load	
	P (kW)	Q (kVar)
41	0.00	0.00
42	0.00	0.00
43	0.00	0.00
44	148.13	51.03
45	0.00	0.00
46	0.00	0.00
47	0.00	0.00
48	41.85	14.42
49	0.00	0.00
50	63.08	21.73
51	0.00	0.00
52	0.00	0.00
53	0.00	0.00
54	58.94	20.30
55	0.00	0.00
56	0.00	0.00
57	27.13	9.35
58	0.00	0.00
59	44.37	15.29
60	0.00	0.00
61	106.91	36.83
62	0.00	0.00
63	58.96	20.31
64	0.00	0.00
65	73.24	25.23
66	0.00	0.00
67	0.00	0.00
68	0.00	0.00
69	51.52	17.75
70	56.70	18.60
71	0.00	0.00
72	0.00	0.00
73	14.81	5.10
74	0.00	0.00
75	148.39	51.12
76	0.00	0.00
77	0.00	0.00
78	0.00	0.00
79	29.10	9.60
80	0.00	0.00

Loads Connected to each bus		
Bus Number	Nominal load	
	P (kW)	Q (kVar)
81	93.23	32.12
82	46.73	16.10
83	0.00	0.00
84	0.00	0.00
85	41.21	14.20
86	0.00	0.00
87	0.00	0.00
88	0.00	0.00
89	0.00	0.00
90	4.28	1.48
91	0.00	0.00
92	17.54	6.04
93	0.00	0.00
94	2.88	0.99
95	0.00	0.00
96	0.77	6.73
97	0.00	0.00
98	0.00	0.00
99	0.00	0.00
100	0.00	0.00
101	1.16	0.40
102	0.00	0.00
103	0.00	0.00
104	0.00	0.00
105	0.00	0.00
106	20.13	-2.02
107	0.00	0.00
108	0.00	0.00
109	0.00	0.00
110	0.00	0.00
111	0.00	0.00
112	0.00	0.00
113	108.50	35.64
114	0.00	0.00
115	0.00	0.00
116	100.98	33.26
117	0.00	0.00
118	0.00	0.00
119	13.86	4.36
120	0.00	0.00
121	0.00	0.00
122	0.00	0.00
Loads Connected to each bus		

Loads Connected to each bus		
Bus Number	Nominal load	
	P (kW)	Q (kVar)
123	8.32	2.77
124	0.00	0.00
125	0.00	0.00
126	0.00	0.00
127	85.93	28.12
128	0.00	0.00
129	249.48	81.97
130	0.00	0.00
131	0.00	0.00
132	0.00	0.00
133	123.23	42.45
134	0.00	0.00
135	0.00	0.00
136	68.99	23.77
137	0.00	0.00
138	143.49	49.43
139	0.00	0.00
140	36.00	11.70
141	0.00	0.00
142	0.00	0.00
143	0.90	0.30
144	151.61	52.23
145	0.00	0.00
146	0.00	0.00
147	129.31	44.55
148	0.00	0.00
149	0.00	0.00
150	0.00	0.00
151	0.00	0.00
152	0.00	0.00
153	0.00	0.00
154	84.60	27.90
155	0.00	0.00
156	39.10	13.47
157	0.00	0.00
158	0.00	0.00
159	0.00	0.00
160	104.70	36.07
161	0.00	0.00
162	0.00	0.00
163	0.00	0.00
164	0.00	0.00
Loads Connected to each bus		

Bus Number	Nominal load	
	P (kW)	Q (kVar)
165	27.30	9.40
166	0.00	0.00
167	81.25	27.99
168	0.00	0.00
169	0.00	0.00
170	0.00	0.00
171	0.00	0.00
172	0.00	0.00
173	55.80	19.22
174	110.43	38.04
175	0.00	0.00
176	56.70	19.53
177	0.00	0.00
178	0.00	0.00
179	68.83	23.71
180	0.00	0.00
181	0.00	0.00
182	0.00	0.00
183	43.50	14.10
184	99.05	34.12
185	0.00	0.00
186	0.00	0.00
187	9.00	3.00
188	0.00	0.00
189	207.28	71.41
190	0.00	0.00
191	49.03	16.89
192	30.60	10.20
193	7.80	2.40
194	0.00	0.00
195	0.00	0.00
197	0.00	0.00
198	95.10	31.20
199	0.00	0.00
200	21.00	6.90
201	0.00	0.00
202	12.53	4.32
203	0.00	0.00
204	0.00	0.00
205	0.00	0.00
206	0.00	0.00
207	0.00	0.00
Loads Connected to each bus		
Bus	Nominal load	

Bus Number	Nominal load	
	P (kW)	Q (kVar)
208	77.12	26.57
209	0.00	0.00
210	34.71	11.96
211	0.00	0.00
212	0.00	0.00
213	8.10	2.70
214	41.34	14.24
215	0.00	0.00
216	72.92	25.12
217	0.00	0.00
218	0.00	0.00
219	0.00	0.00
220	54.36	18.73
221	0.00	0.00
222	0.00	0.00
223	51.84	17.86
224	0.00	0.00
225	8.40	2.70
226	0.00	0.00
227	7.80	2.70
228	0.00	0.00
229	0.00	0.00
230	26.20	9.02
231	0.00	0.00
232	0.30	0.15
233	1.20	0.30
234	0.00	0.00
235	48.65	16.76
236	0.00	0.00
237	0.00	0.00
238	20.86	7.19
239	0.00	0.00
240	3.32	1.14
241	0.00	0.00
242	45.52	15.68
243	0.00	0.00
244	70.39	24.25
245	0.00	0.00
246	0.00	0.00
247	0.00	0.00
248	8.29	2.86
249	0.00	0.00
Loads Connected to each bus		
Bus	Nominal load	

Number	P (kW)	Q (kVar)
250	56.38	19.42
251	0.00	0.00
252	0.00	0.00
253	0.00	0.00
254	0.00	0.00
255	29.76	10.25
256	0.00	0.00
257	4.23	1.46
258	0.00	0.00
259	80.89	27.87
260	0.00	0.00
261	0.00	0.00
262	93.00	30.60
263	0.00	0.00
264	17.40	5.70
265	9.81	85.39
266	0.00	0.00
267	4.50	1.50
268	0.00	0.00
269	130.79	45.05
270	0.00	0.00
271	0.00	0.00
272	0.00	0.00
273	0.00	0.00
274	0.00	0.00
275	29.98	10.33
276	0.00	0.00
277	64.42	22.19
278	0.00	0.00
279	0.00	0.00
280	131.70	43.20
281	0.00	0.00
282	35.18	12.12
283	35.10	12.09
284	0.00	0.00
285	0.00	0.00
286	0.00	0.00
287	0.00	0.00
288	0.00	0.00
289	31.37	10.81
290	0.00	0.00
291	60.44	20.82
Loads Connected to each bus		
Bus Number	Nominal load	
	P (kW)	Q (kVar)

Number	P (kW)	Q (kVar)
292	0.00	0.00
293	42.61	14.68
294	0.00	0.00
295	0.00	0.00
296	14.28	4.92
297	0.00	0.00
298	6.32	2.18
299	0.00	0.00
300	0.00	0.00
301	0.00	0.00
302	5.10	1.50
303	0.00	0.00
304	35.10	11.40
305	51.82	17.85
306	0.00	0.00
307	36.31	12.51
308	2.10	0.60
309	0.00	0.00
310	0.00	0.00
311	63.54	21.89
312	0.00	0.00
313	15.60	5.10
314	0.00	0.00
315	50.90	17.54
316	31.93	11.00
317	0.00	0.00
318	0.00	0.00
319	0.00	0.00
320	20.10	6.92
321	0.00	0.00
322	32.64	11.25
323	0.00	0.00
324	29.00	9.99
325	0.00	0.00
326	0.00	0.00
327	0.00	0.00
328	24.96	8.60
329	0.00	0.00
330	153.18	52.77
331	11.44	3.94
332	19.64	6.76
333	0.00	0.00
Loads Connected to each bus		
Bus Number	Nominal load	
	P (kW)	Q (kVar)

334	1.50	0.60
335	0.00	0.00
336	0.00	0.00
337	20.09	6.92
338	0.00	0.00
339	0.90	0.30
340	0.00	0.00
341	0.00	0.00
342	70.38	24.24
343	0.00	0.00
344	0.00	0.00
345	48.95	16.86
346	0.00	0.00
347	13.35	4.60
348	4.20	1.50
349	25.80	8.40
350	0.90	0.30
351	0.00	0.00
352	0.00	0.00
353	0.00	0.00

354	0.00	0.00
355	76.05	26.20
356	0.00	0.00
357	0.00	0.00
358	7.20	2.40
359	0.00	0.00
360	45.40	15.64
361	0.00	0.00
362	0.00	0.00
363	0.00	0.00
364	0.00	0.00
365	0.00	0.00
366	0.00	0.00
367	0.00	0.00
368	0.00	0.00
369	0.00	0.00
370	0.00	0.00
371	5.00	1.72
372	0.00	0.00
373	16.05	5.53

Network physical parameters of Tissa 1 feeder

S_Base = 100MVA			
V_Base = 33kV			
From	**To**	**R (Ohms)**	**X (Ohms)**
1	2	7.796	16.252
2	3	0.066	0.065
3	4	0.187	0.185
3	5	0.149	0.148
5	6	0.039	0.039
6	7	0.144	0.143
7	8	0.541	0.536
8	9	0.150	0.149
8	10	0.023	0.023
10	11	0.212	0.210
11	12	0.043	0.043
2	13	0.017	0.037
13	14	0.022	0.048
14	15	0.014	0.030
15	16	0.042	0.090
16	17	0.016	0.036
16	18	0.161	0.348
18	19	0.151	0.327
19	20	0.096	0.086
20	21	0.213	0.190
21	22	0.105	0.093
21	23	0.132	0.117
23	24	0.057	0.051
23	25	0.337	0.299
25	26	0.081	0.072
26	27	0.417	0.370
26	28	0.454	0.403
28	29	0.072	0.064
27	30	0.162	0.061
30	31	0.416	0.156
31	32	0.034	0.030
31	33	0.727	0.272
33	34	0.030	0.026
34	35	0.579	0.515
35	36	0.051	0.045
33	37	0.323	0.121
37	38	0.187	0.070
38	39	0.099	0.037
27	40	0.036	0.032
40	41	0.154	0.137
41	42	1.030	0.916
42	43	0.050	0.044

From	**To**	**R (Ohms)**	**X (Ohms)**
43	44	0.058	0.051
44	45	0.098	0.087
43	46	0.311	0.276
46	47	0.372	0.331
47	48	0.065	0.058
46	49	0.547	0.486
49	50	0.035	0.031
49	51	0.807	0.717
51	52	0.167	0.148
52	53	0.056	0.049
53	54	0.020	0.018
53	55	0.060	0.053
55	56	0.082	0.073
56	57	0.020	0.018
52	58	0.058	0.052
58	59	0.017	0.015
59	60	0.105	0.093
60	61	0.024	0.021
61	62	0.206	0.183
62	63	0.031	0.028
51	64	0.102	0.090
64	65	0.245	0.218
65	66	0.420	0.157
66	67	0.352	0.132
67	68	1.067	0.400
68	69	0.185	0.069
65	70	0.125	0.111
70	71	0.025	0.022
71	72	0.030	0.027
72	73	0.034	0.031
19	74	0.203	0.180
74	75	0.039	0.035
74	76	0.080	0.071
76	77	0.077	0.068
77	78	0.131	0.116
78	79	0.084	0.075
77	80	0.271	0.241
80	81	0.042	0.037
80	82	0.076	0.067
82	83	0.061	0.054
83	84	0.443	0.394
84	85	0.032	0.029

From	To	R (Ohms)	X (Ohms)
83	86	0.080	0.071
86	87	0.264	0.235
87	88	0.072	0.064
88	89	0.209	0.186
89	90	0.076	0.067
89	91	0.222	0.198
91	92	0.046	0.041
92	93	0.444	0.395
93	94	0.099	0.088
87	95	0.224	0.199
95	96	0.101	0.090
96	97	1.379	1.225
97	98	1.018	0.905
98	99	0.122	0.108
99	100	0.571	0.507
100	101	0.056	0.050
99	102	0.050	0.045
102	103	0.106	0.095
103	104	0.674	0.599
104	105	0.069	0.061
105	106	0.022	0.019
106	107	0.092	0.082
107	108	0.468	0.416
108	109	0.441	0.392
109	110	0.159	0.141
110	111	0.031	0.028
111	112	0.146	0.130
111	113	0.079	0.071
111	114	0.050	0.044
114	115	0.293	0.261
115	116	0.086	0.076
108	117	0.066	0.058
117	118	0.123	0.109
118	119	0.031	0.028
119	120	0.059	0.052
118	121	0.500	0.444
121	122	0.210	0.187
122	123	0.063	0.056
120	124	0.033	0.030
124	125	0.468	0.416
125	126	0.028	0.025
126	127	0.059	0.052
125	128	0.038	0.034
128	129	0.068	0.060
3	130	0.165	0.163
130	131	0.039	0.035
131	132	0.020	0.018
132	133	0.010	0.009
132	134	0.053	0.047
134	135	0.075	0.066
135	136	0.024	0.022
135	137	0.098	0.087
137	138	0.032	0.029
138	139	0.078	0.069
139	140	0.029	0.026
139	141	0.062	0.055
141	142	0.004	0.004
142	143	0.038	0.033
142	144	0.056	0.050
137	145	0.052	0.046
145	146	0.261	0.232
146	147	0.096	0.086
130	148	0.044	0.039
148	149	0.243	0.241
149	150	0.034	0.030
150	151	0.031	0.027
151	152	0.040	0.036
152	153	0.074	0.066
153	154	0.081	0.072
153	155	0.384	0.341
155	156	0.033	0.030
151	157	0.577	0.513
157	158	0.026	0.023
158	159	0.043	0.038
159	160	0.018	0.016
160	161	0.509	0.452
161	162	0.163	0.061
162	163	1.981	0.742
163	164	0.070	0.062
164	165	0.031	0.028
164	166	0.198	0.074
166	167	0.036	0.032
161	168	0.395	0.351
168	169	0.139	0.052
169	170	0.643	0.241
170	171	0.004	0.004
171	172	0.354	0.314
172	173	0.030	0.027
170	174	0.241	0.090
174	175	0.413	0.367
175	176	0.039	0.035
168	177	0.100	0.089

From	To	R (Ohms)	X (Ohms)
177	178	0.155	0.138
178	179	0.032	0.029
179	180	0.093	0.082
179	181	0.107	0.095
181	182	0.109	0.041
182	183	0.083	0.031
183	184	0.066	0.025
184	185	0.196	0.073
185	186	0.330	0.123
186	187	0.216	0.081
186	188	0.277	0.104
188	189	0.085	0.032
149	190	0.361	0.357
190	191	0.010	0.009
191	192	0.015	0.013
192	193	0.035	0.031
190	194	0.563	0.558
194	195	0.045	0.044
195	196	0.036	0.036
196	197	0.041	0.041
197	198	0.131	0.130
197	199	0.206	0.204
199	200	0.068	0.067
194	201	0.569	0.564
201	202	0.057	0.056
194	203	0.070	0.069
203	204	0.048	0.048
204	205	0.216	0.214
205	206	0.575	0.570
206	207	0.121	0.108
207	208	0.043	0.038
208	209	0.296	0.263
209	210	0.020	0.018
210	211	0.241	0.214
211	212	0.130	0.115
212	213	0.075	0.067
211	214	0.333	0.296
214	215	0.404	0.359
215	216	0.068	0.060
216	217	0.097	0.086
217	218	0.415	0.369
218	219	0.108	0.096
219	220	0.036	0.032
206	221	0.471	0.466
221	222	0.328	0.325
222	223	0.106	0.105

From	To	R (Ohms)	X (Ohms)
222	224	0.227	0.225
224	225	0.085	0.085
222	226	0.207	0.205
226	227	0.220	0.196
226	228	0.463	0.458
228	229	0.220	0.218
229	230	0.025	0.025
229	231	0.414	0.410
231	232	0.059	0.058
231	233	0.079	0.079
228	234	0.711	0.632
234	235	0.085	0.076
235	236	0.588	0.522
235	237	0.270	0.239
237	238	0.061	0.054
238	239	0.416	0.369
239	240	0.056	0.050
228	241	0.567	0.562
241	242	0.078	0.078
241	243	1.417	1.404
243	244	0.037	0.033
243	245	0.320	0.317
245	246	0.042	0.038
246	247	0.037	0.033
247	248	0.096	0.086
245	249	0.499	0.494
249	250	0.043	0.038
249	251	0.204	0.202
251	252	0.080	0.079
252	253	0.084	0.083
253	254	0.440	0.436
254	255	0.067	0.067
255	256	0.260	0.257
256	257	0.035	0.031
256	258	0.075	0.075
258	259	0.028	0.028
259	260	0.056	0.056
260	261	0.028	0.028
261	262	0.044	0.043
261	263	0.023	0.023
263	264	0.047	0.047
264	265	0.042	0.042
264	266	0.269	0.266
266	267	0.138	0.137
266	268	0.061	0.061
268	269	0.066	0.066

From	To	R (Ohms)	X (Ohms)
269	270	0.063	0.062
270	271	0.019	0.019
271	272	0.095	0.094
272	273	0.003	0.003
273	274	0.000	0.000
274	275	0.008	0.008
274	276	0.011	0.011
272	277	0.008	0.008
272	278	0.012	0.010
278	279	0.054	0.048
279	280	0.022	0.019
279	281	0.141	0.139
281	282	0.057	0.056
282	283	0.019	0.019
283	284	0.021	0.019
284	285	0.032	0.029
285	286	0.041	0.036
286	287	0.411	0.365
287	288	0.128	0.114
288	289	0.026	0.023
288	290	0.309	0.275
290	291	0.017	0.015
286	292	0.234	0.208
292	293	0.031	0.027
293	294	0.307	0.273
294	295	0.201	0.179
295	296	0.040	0.035
294	297	0.394	0.350
297	298	0.069	0.061
272	299	0.041	0.037
299	300	0.165	0.147
300	301	0.142	0.126
301	302	0.098	0.087
302	303	0.449	0.399
303	304	0.094	0.084
304	305	0.033	0.029
301	306	0.027	0.024
306	307	0.063	0.056
307	308	0.013	0.012
307	309	0.012	0.010
306	310	0.246	0.218
310	311	0.015	0.013
310	312	0.072	0.064
312	313	0.048	0.042
313	314	0.041	0.037
314	315	0.027	0.024

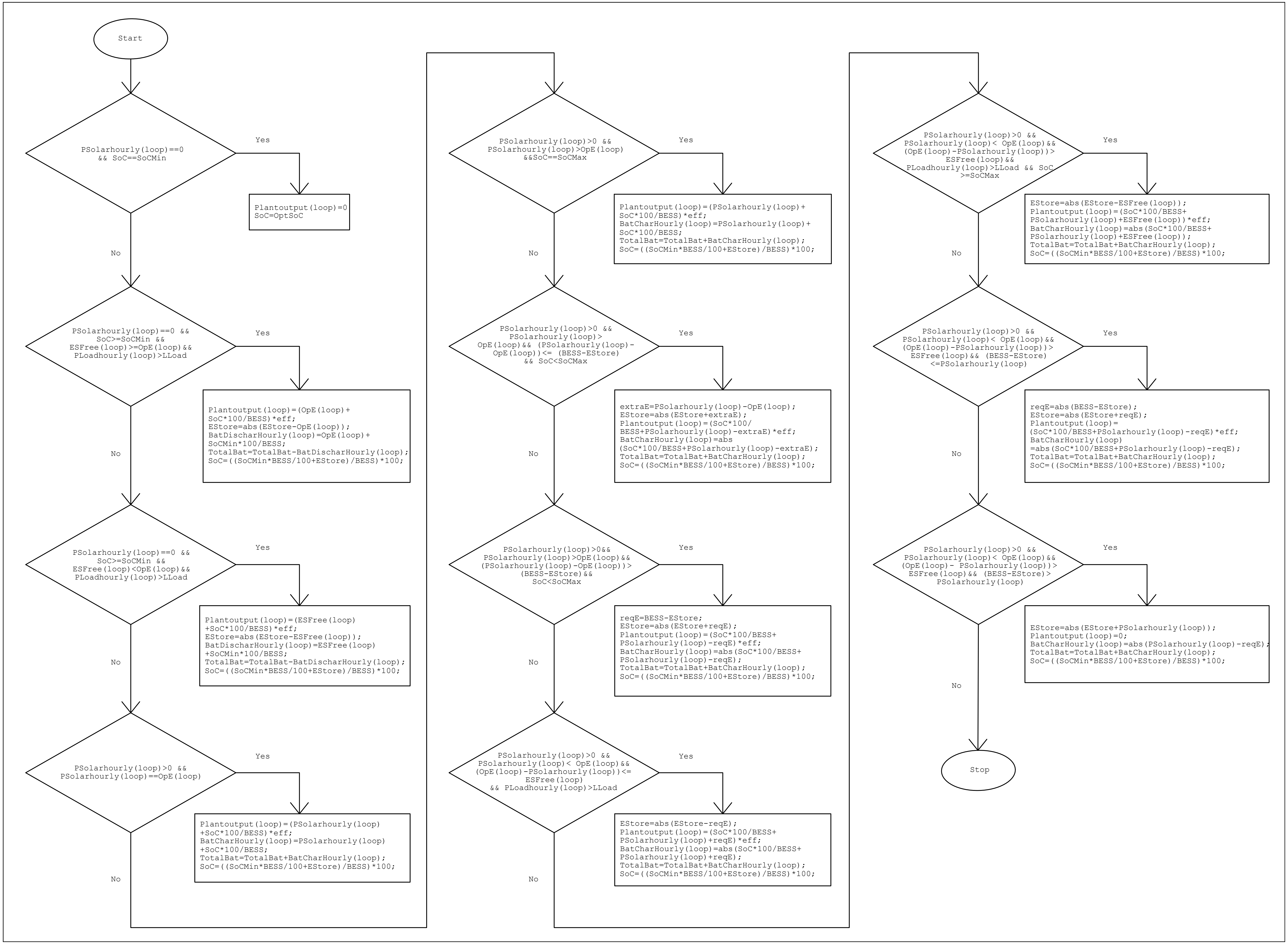
From	To	R (Ohms)	X (Ohms)
315	316	0.047	0.042
316	317	0.207	0.184
317	318	0.238	0.211
318	319	0.100	0.089
319	320	0.055	0.049
317	321	0.317	0.282
321	322	0.027	0.024
321	323	0.165	0.147
323	324	0.026	0.024
323	325	0.075	0.067
325	326	0.027	0.024
326	327	0.173	0.154
327	328	0.017	0.015
325	329	0.079	0.070
329	330	0.051	0.046
330	331	0.049	0.044
330	332	0.114	0.101
332	333	0.216	0.192
333	334	0.121	0.107
332	335	0.270	0.240
335	336	0.348	0.309
336	337	0.050	0.044
268	338	0.048	0.042
338	339	0.105	0.094
339	340	0.115	0.102
340	341	0.049	0.043
340	342	0.019	0.017
342	343	0.254	0.225
343	344	0.144	0.128
344	345	0.019	0.017
344	346	0.056	0.050
346	347	0.032	0.029
347	348	0.091	0.080
348	349	0.085	0.076
349	350	0.077	0.069
340	351	0.059	0.052
351	352	0.301	0.267
352	353	0.225	0.200
353	354	0.075	0.066
354	355	0.032	0.028
355	356	0.037	0.033
356	357	0.411	0.365
357	358	0.106	0.095
357	359	0.275	0.245
359	360	0.025	0.023
360	361	0.855	0.760

From	To	R (Ohms)	X (Ohms)
361	362	0.180	0.160
362	363	0.030	0.026
363	364	1.622	1.441
364	365	0.045	0.040
365	366	0.077	0.069
366	367	0.433	0.385
361	362	0.180	0.160
362	363	0.030	0.026
363	364	1.622	1.441

From	To	R (Ohms)	X (Ohms)
364	365	0.045	0.040
365	366	0.077	0.069
366	367	0.433	0.385
367	368	0.353	0.313
368	369	0.096	0.086
364	370	0.059	0.052
370	371	0.030	0.027
371	372	1.434	1.274
372	373	0.076	0.068

ANNEXURE III

BESS control logic diagram


Start
PSolarhourly(loop)==0 && SoC==SoCMin
Yes
Plantoutput(loop)=0 SoC=OptSoC
No
PSolarhourly(loop)==0 && SoC>=SoCMin && ESFree(loop)>=OpE(loop)&& PLoadhourly(loop)>LLoad
Yes
Plantoutput(loop)=(OpE(loop)+ SoC*100/BESS)*eff; EStore=abs(EStore-OpE(loop)); BatDischarHourly(loop)=OpE(loop)+ SoCMin*100/BESS; TotalBat=TotalBat-BatDischarHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)==0 && SoC>=SoCMin && ESFree(loop)<OpE(loop)&& PLoadhourly(loop)>LLoad
Yes
Plantoutput(loop)=(ESFree(loop) +SoC*100/BESS)*eff; EStore=abs(EStore-ESFree(loop)); BatDischarHourly(loop)=ESFree(loop) +SoCMin*100/BESS; TotalBat=TotalBat-BatDischarHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0 && PSolarhourly(loop)==OpE(loop)
Yes
Plantoutput(loop)=(PSolarhourly(loop) +SoC*100/BESS)*eff; BatCharHourly(loop)=PSolarhourly(loop) +SoC*100/BESS; TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0 && PSolarhourly(loop)>OpE(loop) &&SoC==SoCMax
Yes
Plantoutput(loop)=(PSolarhourly(loop)+ SoC*100/BESS)*eff; BatCharHourly(loop)=PSolarhourly(loop)+ SoC*100/BESS; TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0 && PSolarhourly(loop)> OpE(loop)&& (PSolarhourly(loop)- OpE(loop))<= (BESS-EStore) && SoC<SoCMax
Yes
extraE=PSolarhourly(loop)-OpE(loop); EStore=abs(EStore+extraE); Plantoutput(loop)=(SoC*100/ BESS+PSolarhourly(loop)-extraE)*eff; BatCharHourly(loop)=abs (SoC*100/BESS+PSolarhourly(loop)-extraE); TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0&& PSolarhourly(loop)>OpE(loop)&& (PSolarhourly(loop)-OpE(loop))> (BESS-EStore)&& SoC<SoCMax
Yes
reqE=BESS-EStore; EStore=abs(EStore+reqE); Plantoutput(loop)=(SoC*100/BESS+ PSolarhourly(loop)-reqE)*eff; BatCharHourly(loop)=abs(SoC*100/BESS+ PSolarhourly(loop)-reqE); TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0 && PSolarhourly(loop)< OpE(loop)&& (OpE(loop)-PSolarhourly(loop))<= ESFree(loop) && PLoadhourly(loop)>LLoad
Yes
EStore=abs(EStore-reqE); Plantoutput(loop)=(SoC*100/BESS+ PSolarhourly(loop)+reqE)*eff; BatCharHourly(loop)=abs(SoC*100/BESS+ PSolarhourly(loop)+reqE); TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0 && PSolarhourly(loop)< OpE(loop)&& (OpE(loop)-PSolarhourly(loop))> ESFree(loop)&& PLoadhourly(loop)>LLoad && SoC >=SoCMax
Yes
EStore=abs(EStore-ESFree(loop)); Plantoutput(loop)=(SoC*100/BESS+ PSolarhourly(loop)+ESFree(loop))*eff; BatCharHourly(loop)=abs(SoC*100/BESS+ PSolarhourly(loop)+ESFree(loop)); TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0 && PSolarhourly(loop)< OpE(loop)&& (OpE(loop)-PSolarhourly(loop))> ESFree(loop)&& (BESS-EStore) <=PSolarhourly(loop)
Yes
reqE=abs(BESS-EStore); EStore=abs(EStore+reqE); Plantoutput(loop)= (SoC*100/BESS+PSolarhourly(loop)-reqE)*eff; BatCharHourly(loop) =abs(SoC*100/BESS+PSolarhourly(loop)-reqE); TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
PSolarhourly(loop)>0 && PSolarhourly(loop)< OpE(loop)&& (OpE(loop)- PSolarhourly(loop))> ESFree(loop)&& (BESS-EStore)> PSolarhourly(loop)
Yes
EStore=abs(EStore+PSolarhourly(loop)); Plantoutput(loop)=0; BatCharHourly(loop)=abs(PSolarhourly(loop)-reqE); TotalBat=TotalBat+BatCharHourly(loop); SoC=((SoCMin*BESS/100+EStore)/BESS)*100;
No
Stop

ANNEXURE IV

Levelized Cost of Energy calculation for Case A - When the optimized SPVP is connected to the Tissa 1 feeder

Levelized Cost of Energy calculation for Case A - When the optimized SPVP is connected to the Tissa 1 feeder

Capacity	14.06	MW		
Capital Cost	1000	USD/kW		
Daily Solar generation	42048.9	kWh/Day		
Total Capital Cost	14.057	USD Mil	Interest Rate	
Loan	9.8399	USD Mil		10%
Equity	4.2171	USD Mil		
			O&M Escalation	
Exchange Rate	178	LKR/USD		5%

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Energy Supply	GWh		15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376	15.1376
Levelised Tariff	LKR/kWh		22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
Revenue	LKR mil		333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333
O&M Cost	LKR mil		17.52	18.39	19.31	20.28	21.29	22.35	23.47	24.65	25.88	27.17	28.53	29.96	31.45	33.03	34.68	36.41	38.23	40.14	42.15	44.26
Profit before interest	LKR mil		315.5	314.64	313.72	312.75	311.74	310.67	309.56	308.38	307.15	305.86	304.50	303.07	301.57	300.00	298.35	296.61	294.79	292.88	290.88	288.77
Net Profit	LKR mil		315.51	314.64	313.72	312.75	311.74	310.67	309.56	308.38	307.15	305.86	304.50	303.07	301.57	300.00	298.35	296.61	294.79	292.88	290.88	288.77
Committment fee	LKR mil		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Cash flow	LKR mil	-2502	316	315	314	313	312	311	310	308	307	306	304	303	302	300	298	297	295	293	291	289
		2502	18	18	19	20	21	22	23	25	26	27	29	30	31	33	35	36	38	40	42	44

Project IRR **10.71%**

NPV - USD mil 14

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Loan Repayment	USD mil		0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55		
Interest Payment	USD mil		0.96	0.90	0.85	0.79	0.74	0.68	0.63	0.57	0.52	0.46	0.41	0.36	0.30	0.25	0.19	0.14	0.08	0.03		
Committment fee	USD mil		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Net Profit	USD mil		1.77	1.77	1.76	1.76	1.75	1.75	1.74	1.73	1.73	1.72	1.71	1.70	1.69	1.69	1.68	1.67	1.66	1.65	1.63	1.62
Cash Flow	USD mil	-4.22	0.27	0.32	0.37	0.42	0.47	0.52	0.56	0.61	0.66	0.71	0.75	0.80	0.85	0.89	0.94	0.98	1.03	1.07	1.63	1.62

Equity IRR **12.21%**

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Loan Repayment Schedule																					
Opening Balance (USD mil)	9.8399	9.29	8.75	8.20	7.65	7.11	6.56	6.01	5.47	4.92	4.37	3.83	3.28	2.73	2.19	1.64	1.09	0.55			
Loan Repayment (USD mil)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55			
Closing Balance (USD mil)	9.29	8.75	8.20	7.65	7.11	6.56	6.01	5.47	4.92	4.37	3.83	3.28	2.73	2.19	1.64	1.09	0.55	0.00			
Interest (USD mil)	0.96	0.90	0.85	0.79	0.74	0.68	0.63	0.57	0.52	0.46	0.41	0.36	0.30	0.25	0.19	0.14	0.08	0.03			

ANNEXURE V

Simple payback period calculation for Case A - When the optimized SPVP is connected to the Tissa 1 feeder

Simple payback period calculation for Case A - When the optimized SPVP is connected to the Tissa 1 feeder

Power Plant	**Variable unit cost (Rs/MWh)**	**Hourly Power (MW) 0:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Kps - Gt 01	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 02	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 03	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 04	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 05	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 06	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Steam 01	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Steam 02	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gas Turbine 07	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Jebic (GT08)	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps JBIC (STEAM)	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lakdanavi	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AES-Kps	31,440.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Hamban	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Pallekele	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Galle	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Kurunegala	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Asia Power	25,840.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE - Horana	25,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE-Matara	24,830.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE- Embilipitiya	24,740.00	0.000	0.000	0.000	0.000	0.000	0.097	0.090	0.107	0.104	0.104	0.107	0.089	0.096	0.093	0.089	0.091	0.092	0.101	0.141	0.252	0.243	0.270	0.223	0.123
Nothern Power	23,420.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Coast GT1	23,260.00	0.232	0.211	0.195	0.179	0.196	0.203	0.187	0.222	0.214	0.212	0.216	0.182	0.185	0.185	0.178	0.182	0.181	0.199	0.220	0.243	0.236	0.259	0.256	0.241
West Coast GT2	23,260.00	0.490	0.439	0.420	0.387	0.412	0.414	0.382	0.462	0.446	0.445	0.452	0.379	0.394	0.382	0.371	0.385	0.381	0.414	0.466	0.502	0.481	0.521	0.518	0.502
West Coast Steam	23,260.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sapu 01	22,580.00	0.039	0.026	0.026	0.026	0.025	0.036	0.034	0.040	0.039	0.039	0.039	0.032	0.033	0.032	0.030	0.031	0.031	0.034	0.037	0.040	0.039	0.043	0.042	0.041
Sapu 02	22,580.00	0.043	0.026	0.026	0.026	0.025	0.036	0.034	0.040	0.039	0.039	0.039	0.033	0.035	0.035	0.034	0.034	0.034	0.037	0.041	0.044	0.043	0.047	0.046	0.045
Sapu 03	22,580.00	0.049	0.026	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.037	0.040	0.000	0.017	0.036	0.039	0.042	0.047	0.050	0.048	0.053	0.052	0.051
Sapu 04	22,580.00	0.049	0.026	0.026	0.026	0.025	0.041	0.038	0.045	0.043	0.043	0.044	0.037	0.040	0.039	0.038	0.038	0.039	0.042	0.047	0.050	0.048	0.053	0.052	0.051
Sapu 05	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.022	0.022	0.018	0.019	0.020	0.017	0.017	0.017	0.020	0.023	0.025	0.024	0.026	0.026	0.025
Sapu 06	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 07	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.022	0.022	0.019	0.020	0.020	0.019	0.019	0.019	0.021	0.023	0.025	0.024	0.026	0.026	0.025
Sapu 08	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.006	0.022	0.022	0.022	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 09	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.020	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 10	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.016	0.016	0.015	0.015	0.019	0.021	0.022	0.021	0.025	0.025	0.025
Sapu 11	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.023	0.025	0.025	0.025
Sapu 12	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.022	0.022	0.019	0.018	0.018	0.018	0.018	0.018	0.021	0.023	0.025	0.024	0.026	0.026	0.025
Puttalam Coal01	8,070.00	0.530	0.469	0.473	0.477	0.458	0.454	0.416	0.493	0.477	0.477	0.483	0.411	0.434	0.426	0.409	0.419	0.418	0.045	0.509	0.544	0.528	0.578	0.570	0.556
Puttalam Coal02	8,070.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Puttalam Coal03	8,070.00	0.776	0.676	0.683	0.687	0.661	0.649	0.601	0.709	0.690	0.680	0.698	0.583	0.630	0.628	0.610	0.615	0.618	0.679	0.755	0.798	0.776	0.839	0.834	0.806
Total Hourly P (MW)		3.761	3.497	3.431	3.299	3.299	3.761	4.619	3.959	3.893	4.355	4.685	4.091	4.355	4.157	3.959	4.223	4.223	4.025	4.817	6.598	6.268	5.872	5.081	4.289
Total Hourly P of Tissa 1 (MW)		3.761	3.497	3.431	3.299	3.299	3.761	4.619	3.959	3.893	4.355	4.685	4.091	4.355	4.157	3.959	4.223	4.223	4.025	4.817	6.598	6.268	5.872	5.081	4.289

For Optimized only with SPVP

	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Solar P hourly (MW)	0.000	0.000	0.000	0.000	0.000	0.000	0.576	1.522	2.993	4.199	5.000	5.432	5.400	5.150	4.548	3.548	2.221	0.987	0.474	0.000	0.000	0.000	0.000	0.000
Solar variable cost (Rs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy replaced by SPVP	0.000	0.000	0.000	0.000	0.000	0.000	0.576	1.522	2.993	4.199	5.000	5.432	5.400	5.150	4.548	3.548	2.221	0.987	0.474	0.000	0.000	0.000	0.000	0.000
Cost if not replaced by only solar (Rs.)	35,793.61	28,630.57	27,947.32	25,838.95	26,367.44	30,061.97	29,162.98	35,066.14	34,001.14	33,736.41	35,202.54	29,547.76	31,007.01	29,606.57	28,967.74	30,038.12	30,065.56	29,634.36	37,543.38	42,853.59	41,471.64	45,379.04	43,825.33	40,077.67
Benefit if replaced by solar (Rs.)	0.00	0.00	0.00	0.00	0.00	0.00	13,523.93	28,831.44	34,001.14	33,736.41	35,202.54	29,547.76	31,007.01	29,606.57	28,967.74	30,038.12	30,065.56	22,913.26	11,242.68	0.00	0.00	0.00	0.00	0.00

Total daily cost without SPVP (Rs.)	**801,826.84**
Total daily cost with SPVP (Rs.)	**358,684.17**
Total daily net benefit with SPVP (Rs.)	**443,142.68**
Total Annual benefit only with SPVP (Rs. mil)	**159.53**
Total Annual benefit only with SPVP (USD mil)	**0.90**
Total Capital Cost (USD mil)	**14.057**
	15.68
Simple payback period (Years)	**16**

ANNEXURE VI

Levelized Cost of Energy calculation for Case B - When the optimized B-SPVP is connected to the Tissa 1 feeder

Levelized Cost of Energy calculation for Case B - When the optimized B-SPVP is connected to the Tissa 1 feeder

BES Data

BES Capacity	14.663	MW
Duration	5	Hours
Usable Energy	48.56762	MWh
100% Depth of discharge cycles	1	Nos
Operating Days/Year	300	Days

Solar Power plant Data

Capacity	6.60	MW

Inverter Data

Capacity	17.5956	MW

Capital Structure

Loan	70%	
Cost of debt	8%	
Equity	30%	
Contract Term/Project life	20	years
Depreciation	0%	
BES O&M, Warranty & Augme	43	USD/MWh
Solar O&M, Warranty & Augm	0.7%	
O&M Escalation	5%	
Charging cost	0.033	USD/kWh
Charging cost escalator	0.55%	
Inverter efficiency	95%	
Capital Cost of BESS	2000	USD/kWh
Capital Cost of PV Plant	1000	USD/kW
Capital Cost of Inverter	270	USD/kW
Total Capital Cost	108.4841	USD Mil
Loan Amount	75.93884	USD Mil
Equity Amount	32.54522	USD Mil
Exchange Rate	178	LKR/USD
Annual escalation	3.7%	(The Colombo Consumer Price Index - January 2019)

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Energy Supply	GWh		14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703
Levelised Tariff	LKR/kWh		175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
Revenue	LKR mil		2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550	2,550
Total charging cost	LKR mil		90	91	91	92	92	93	93	94	94	95	95	96	96	97	97	98	98	99	99	100
O&M Cost of BES	LKR mil		112	117	123	129	136	142	149	157	165	173	182	191	200	210	221	232	243	256	268	282
O&M Cost of Solar Plant	LKR mil		8.22	8.28	8.34	8.39	8.45	8.51	8.57	8.63	8.69	8.75	8.82	8.88	8.94	9.00	9.06	9.13	9.19	9.26	9.32	9.39
Total of Costs	LKR mil		210	216	222	229	236	243	251	259	268	276	286	295	305	316	327	339	351	364	377	391
Profit before interest	LKR mil		2,340	2,334	2,327	2,321	2,314	2,306	2,299	2,291	2,282	2,273	2,264	2,254	2,244	2,234	2,223	2,211	2,199	2,186	2,173	2,159
Net Profit	LKR mil		2,340	2,334	2,327	2,321	2,314	2,306	2,299	2,291	2,282	2,273	2,264	2,254	2,244	2,234	2,223	2,211	2,199	2,186	2,173	2,159
Committment fee	LKR mil		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash flow	LKR mil	-19310	2,340	2,334	2,327	2,321	2,314	2,306	2,299	2,291	2,282	2,273	2,264	2,254	2,244	2,234	2,223	2,211	2,199	2,186	2,173	2,159
		19310	210	216	222	229	236	243	251	259	268	276	286	295	305	316	327	339	351	364	377	391

Project IRR **10.14%**

NPV - USD mil **110**

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Loan Repayment	USD mil		4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22		
Interest Payment	USD mil		5.91	5.57	5.23	4.89	4.56	4.22	3.88	3.54	3.21	2.87	2.53	2.19	1.86	1.52	1.18	0.84	0.51	0.17		
Committment fee	USD mil		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Net Profit	USD mil		13.15	13.11	13.08	13.04	13.00	12.96	12.91	12.87	12.82	12.77	12.72	12.67	12.61	12.55	12.49	12.42	12.35	12.28	12.21	12.13
Cash Flow	USD mil	-32.55	3.02	3.32	3.63	3.93	4.22	4.52	4.81	5.11	5.40	5.68	5.97	6.25	6.53	6.81	7.09	7.36	7.63	7.89	12.21	12.13

Equity IRR **13.55%**

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Loan Repayment Schedule																					
Opening Balance (USD mil)		75.9388	71.72	67.50	63.28	59.06	54.84	50.63	46.41	42.19	37.97	33.75	29.53	25.31	21.09	16.88	12.66	8.44	4.22		
Loan Repayment (USD mil)		4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22		
Closing Balance (USD mil)		71.72	67.50	63.28	59.06	54.84	50.63	46.41	42.19	37.97	33.75	29.53	25.31	21.09	16.88	12.66	8.44	4.22	0.00		
Interest (USD mil)		5.91	5.57	5.23	4.89	4.56	4.22	3.88	3.54	3.21	2.87	2.53	2.19	1.86	1.52	1.18	0.84	0.51	0.17		

ANNEXURE VII

Simple payback period calculation for Case B - When the optimized B-SPVP is connected to the Tissa 1 feeder

Simple payback period calculation for Case B - When the optimized B-SPVP is connected to the Tissa 1 feeder

Power Plant	Variable unit cost (Rs/MWh)	Hourly Power (MW) 0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Kps - Gt 01	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 02	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 03	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 04	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 05	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 06	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Steam 01	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Steam 02	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gas Turbine 07	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Jebic (GT08)	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps JBIC (STEAM)	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lakdanavi	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AES-Kps	31,440.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Hamban	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Pallekele	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Galle	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Kurunegala	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Asia Power	25,840.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE - Horana	25,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE-Matara	24,830.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE- Embilipitiya	24,740.00	0.000	0.000	0.000	0.000	0.000	0.097	0.090	0.107	0.104	0.104	0.107	0.089	0.096	0.093	0.089	0.091	0.092	0.101	0.141	0.252	0.243	0.270	0.223	0.123
Nothern Power	23,420.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Coast GT1	23,260.00	0.232	0.211	0.195	0.179	0.196	0.203	0.187	0.222	0.214	0.212	0.216	0.182	0.185	0.185	0.178	0.182	0.181	0.199	0.220	0.243	0.236	0.259	0.256	0.241
West Coast GT2	23,260.00	0.490	0.439	0.420	0.387	0.412	0.414	0.382	0.462	0.446	0.445	0.452	0.379	0.394	0.382	0.371	0.385	0.381	0.414	0.466	0.502	0.481	0.521	0.518	0.502
West Coast Steam	23,260.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sapu 01	22,580.00	0.039	0.026	0.026	0.026	0.025	0.036	0.034	0.040	0.039	0.039	0.039	0.032	0.033	0.032	0.030	0.031	0.031	0.034	0.037	0.040	0.039	0.043	0.042	0.041
Sapu 02	22,580.00	0.043	0.026	0.026	0.026	0.025	0.036	0.034	0.040	0.039	0.039	0.039	0.033	0.035	0.035	0.034	0.034	0.034	0.037	0.041	0.044	0.043	0.047	0.046	0.045
Sapu 03	22,580.00	0.049	0.026	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.037	0.040	0.000	0.017	0.036	0.039	0.042	0.047	0.050	0.048	0.053	0.052	0.051
Sapu 04	22,580.00	0.049	0.026	0.026	0.026	0.025	0.041	0.038	0.045	0.043	0.043	0.044	0.037	0.040	0.039	0.038	0.038	0.039	0.042	0.047	0.050	0.048	0.053	0.052	0.051
Sapu 05	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.022	0.022	0.018	0.019	0.020	0.017	0.017	0.017	0.020	0.023	0.025	0.024	0.026	0.026	0.025
Sapu 06	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 07	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.022	0.022	0.019	0.020	0.020	0.019	0.019	0.019	0.021	0.023	0.025	0.024	0.026	0.026	0.025
Sapu 08	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.006	0.022	0.022	0.022	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 09	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.020	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 10	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.016	0.016	0.015	0.015	0.019	0.021	0.022	0.021	0.025	0.025	0.025
Sapu 11	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.023	0.025	0.025	0.025
Sapu 12	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.022	0.022	0.019	0.018	0.018	0.018	0.018	0.018	0.021	0.023	0.025	0.024	0.026	0.026	0.025
Puttalam Coal01	8,070.00	0.530	0.469	0.473	0.477	0.458	0.454	0.416	0.493	0.477	0.477	0.483	0.411	0.434	0.426	0.409	0.419	0.418	0.045	0.509	0.544	0.528	0.578	0.570	0.556
Puttalam Coal02	8,070.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Puttalam Coal03	8,070.00	0.776	0.676	0.683	0.687	0.661	0.649	0.601	0.709	0.690	0.680	0.698	0.583	0.630	0.628	0.610	0.615	0.618	0.679	0.755	0.798	0.776	0.839	0.834	0.806
Victoria 01	0.00	0.154	0.000	0.000	0.000	0.000	0.113	0.126	0.074	0.145	0.169	0.185	0.156	0.165	0.163	0.157	0.160	0.161	0.176	0.168	0.207	0.200	0.220	0.217	0.093
Victoria 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.126	0.112	0.109	0.130	0.185	0.156	0.165	0.163	0.126	0.160	0.161	0.176	0.155	0.207	0.200	0.220	0.174	0.149
Victoria 03	0.00	0.124	0.000	0.000	0.000	0.000	0.000	0.084	0.074	0.145	0.152	0.185	0.156	0.165	0.163	0.126	0.160	0.161	0.176	0.155	0.207	0.200	0.220	0.174	0.118
Victoria Stage II	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rand - 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.102	0.099	0.099	0.101	0.085	0.090	0.089	0.086	0.088	0.000	0.000	0.000	0.152	0.147	0.161	0.000	0.000
Rand - 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.102	0.099	0.099	0.101	0.083	0.090	0.089	0.086	0.117	0.088	0.096	0.106	0.152	0.147	0.161	0.119	0.000
Rant - 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.037	0.036	0.036	0.037	0.031	0.033	0.033	0.031	0.000	0.000	0.035	0.039	0.064	0.064	0.070	0.000	0.000
Rant - 02	0.00	0.000	0.000	0.000	0.000	0.000	0.034	0.032	0.037	0.036	0.036	0.037	0.031	0.033	0.033	0.031	0.032	0.000	0.035	0.039	0.064	0.064	0.070	0.069	0.000
Kotmale 01	0.00	0.000	0.094	0.064	0.095	0.083	0.098	0.120	0.069	0.072	0.140	0.118	0.087	0.081	0.065	0.063	0.090	0.097	0.070	0.098	0.116	0.085	0.088	0.096	0.000
Kotmale 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000	0.000	0.000
Kotmale 03	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.137	0.074	0.072	0.121	0.138	0.095	0.077	0.065	0.069	0.103	0.107	0.070	0.111	0.091	0.088	0.103	0.000	0.000
Nilambe	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.004	0.004	0.004	0.004	0.005	0.005	0.000
Ukuwela 01	0.00	0.050	0.044	0.044	0.044	0.043	0.000	0.039	0.046	0.045	0.045	0.046	0.038	0.041	0.040	0.039	0.040	0.040	0.043	0.048	0.051	0.049	0.054	0.054	0.052
Ukuwela 02	0.00	0.047	0.041	0.042	0.042	0.040	0.040	0.037	0.043	0.042	0.042	0.043	0.036	0.039	0.038	0.037	0.037	0.038	0.041	0.045	0.048	0.047	0.051	0.051	0.049
Bowatenna	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.058	0.059	0.024	0.025	0.028	0.082	0.089	0.036	0.030	0.101	0.073	0.000	0.000
Upper Kothmale1	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.207	0.200	0.117	0.116	0.112
Upper Kothmale2	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.132	0.087	0.084	0.128	0.161	0.094	0.103	0.207	0.200	0.117	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
New Laxapana 01	0.00	0.157	0.047	0.024	0.024	0.023	0.068	0.122	0.074	0.024	0.140	0.143	0.120	0.128	0.126	0.122	0.124	0.124	0.136	0.150	0.160	0.155	0.170	0.168	0.163
New Laxapana 02	0.00	0.135	0.047	0.024	0.024	0.023	0.068	0.105	0.074	0.024	0.121	0.123	0.104	0.110	0.109	0.105	0.107	0.107	0.117	0.129	0.138	0.133	0.147	0.145	0.140
Polpitiya 01	0.00	0.123	0.102	0.105	0.108	0.105	0.103	0.095	0.113	0.109	0.109	0.108	0.092	0.097	0.090	0.092	0.096	0.095	0.105	0.117	0.125	0.120	0.130	0.131	0.125
Polpitiya 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Olax 01	0.00	0.026	0.023	0.023	0.023	0.022	0.022	0.020	0.024	0.023	0.023	0.024	0.020	0.021	0.021	0.020	0.021	0.021	0.022	0.025	0.027	0.026	0.028	0.028	0.027
Olax 02	0.00	0.026	0.023	0.023	0.023	0.022	0.022	0.020	0.024	0.023	0.023	0.024	0.020	0.021	0.021	0.020	0.021	0.021	0.022	0.025	0.027	0.026	0.028	0.028	0.027
Olax 03	0.00	0.026	0.023	0.023	0.023	0.022	0.022	0.020	0.024	0.023	0.023	0.024	0.020	0.021	0.021	0.020	0.021	0.021	0.022	0.025	0.027	0.026	0.028	0.028	0.027
Olax 04	0.00	0.034	0.029	0.030	0.030	0.029	0.028	0.026	0.031	0.030	0.030	0.031	0.026	0.028	0.027	0.026	0.027	0.027	0.029	0.032	0.035	0.033	0.037	0.036	0.035
Olax 05	0.00	0.030	0.029	0.030	0.030	0.029	0.028	0.026	0.031	0.030	0.030	0.031	0.026	0.028	0.027	0.026	0.027	0.027	0.029	0.032	0.035	0.033	0.032	0.032	0.031
Cany 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.074	0.062	0.055	0.054	0.052	0.053	0.054	0.059	0.065	0.069	0.027	0.000	0.000	0.000
Cany 02	0.00	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.052	0.050	0.051	0.051	0.056	0.062	0.066	0.027	0.029	0.029	0.028
Wps 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.069	0.067	0.000	0.000	0.000
Wps 02	0.00	0.027	0.047	0.024	0.024	0.023	0.057	0.053	0.062	0.024	0.048	0.049	0.041	0.044	0.043	0.042	0.043	0.043	0.047	0.052	0.069	0.067	0.029	0.029	0.028
Broadlands	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Samanalawewa 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.024	0.025	0.021	0.022	0.022	0.021	0.064	0.064	0.023	0.026	0.110	0.107	0.029	0.000	0.000
Samanalawewa 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.107	0.000	0.000	0.000
Samanalawewa03	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.010	0.009	0.009	0.009	0.008	0.009	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.010	0.010	0.010	0.011	0.011	0.010
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Udavalawa	0.00	0.007	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.003	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008
Inginiyagala	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Moragahakanda	0.00	0.010	0.009	0.009	0.009	0.008	0.009	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.010	0.010	0.010	0.011	0.011	0.010
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kol onnawa Generation	0.00	0.000	0.551	0.583	0.544	0.578	0.624	0.870	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kukule 01	0.00	0.000	0.061	0.062	0.062	0.060	0.059	0.079	0.064	0.063	0.063	0.064	0.054	0.057	0.057	0.054	0.056	0.056	0.061	0.067	0.072	0.069	0.110	0.075	0.000
Kukule 02	0.00	0.000	0.061	0.062	0.062	0.060	0.059	0.079	0.064	0.063	0.063	0.064	0.054	0.057	0.057	0.054	0.056	0.056	0.061	0.067	0.072	0.069	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.007	0.000	0.019	0.027	0.027	0.007	0.000	0.000	0.006	0.004	-0.002	-0.008	0.017	0.011	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heladhanavi	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IPP Mini Hydro	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.334	0.323	0.000	0.000	0.000
Kilinochchi Wd 1	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kilinochchi Wd2	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Musalpity WIND	0.00	0.014	0.020	0.020	0.017	0.019	0.018	0.017	0.015	0.005	0.000	0.001	0.013	0.013	0.012	0.013	0.013	0.014	0.013	0.019	0.019	0.016	0.019	0.019	0.013
Wind -Spare	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Welikanda Solar	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.016	0.015	0.020	0.018	0.018	0.012	0.012	0.009	0.005	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Hambantota Solar	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.024	0.066	0.057	0.055	0.059	0.058	0.047	0.041	0.023	0.015	0.002	0.000	0.000	0.000	0.000	0.000
Vauniya Solar	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.006	0.014	0.021	0.018	0.013	0.021	0.008	0.008	0.017	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Dendro 1	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CEB- Barge	0.00	0.163	0.071	0.072	0.072	0.070	0.103	0.095	0.112	0.109	0.109	0.111	0.093	0.099	0.122	0.126	0.128	0.129	0.141	0.156	0.166	0.160	0.177	0.174	0.169
New Chunnakum	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.044	0.047	0.040	0.028	0.029	0.039	0.050	0.055	0.059	0.057	0.062	0.062	0.060
Norechcole Wind	0.00	0.112	0.124	0.135	0.106	0.111	0.112	0.105	0.115	0.087	0.074	0.081	0.084	0.088	0.087	0.089	0.048	0.088	0.082	0.095	0.111	0.111	0.132	0.137	0.132
Seguwanthive / Vidathamuni	0.00	0.032	0.031	0.033	0.031	0.030	0.032	0.027	0.030	0.024	0.027	0.035	0.031	0.033	0.030	0.027	0.030	0.034	0.035	0.034	0.036	0.032	0.032	0.035	0.042
Senok Wind (MAMPURI-1)	0.00	0.023	0.020	0.021	0.016	0.015	0.016	0.016	0.002	0.013	0.010	0.011	0.011	0.012	0.011	0.010	0.010	0.011	0.010	0.014	0.014	0.014	0.019	0.024	0.025
Total Hourly P (MW)		3.761	3.497	3.431	3.299	3.299	3.761	4.619	3.959	3.893	4.355	4.685	4.091	4.355	4.157	3.959	4.223	4.223	4.025	4.817	6.598	6.268	5.872	5.081	4.289
Total Hourly P of Tissa 1 (MW)		3.761	3.497	3.431	3.299	3.299	3.761	4.619	3.959	3.893	4.355	4.685	4.091	4.355	4.157	3.959	4.223	4.223	4.025	4.817	6.598	6.268	5.872	5.081	4.289
For Optimized with B-SPVP																									
B-SPVP P hourly (MW)		3.701	3.439	3.373	3.242	3.242	3.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.598	6.214	5.814	5.017	4.227
B-SPVP variable cost (Rs)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy replaced by B-SPVP		3.701	3.439	3.373	3.242	3.242	3.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.598	6.214	5.814	5.017	4.227
Cost if not replaced by B-SPVP (Rs.)		35,793.61	28,630.57	27,947.32	25,838.95	26,367.44	30,061.97	29,162.98	35,066.14	34,001.14	33,736.41	35,202.54	29,547.76	31,007.01	29,606.57	28,967.74	30,038.12	30,065.56	29,634.36	37,543.38	42,853.59	41,471.64	45,379.04	43,825.33	40,077.67
Benefit if replaced byB-SPVP (Rs.)		35,793.61	28,630.57	27,947.32	25,838.95	26,367.44	30,061.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42,853.59	41,471.64	45,379.04	43,825.33	40,077.67

Total daily cost without SPVP (Rs.)	**801,826.84**
Total daily cost with SPVP (Rs.)	**388,247.12**
Total daily net benefit with SPVP (Rs.)	**413,579.72**
Total Annual benefit only with SPVP (Rs. mil)	**124.07**
Total Annual benefit only with SPVP (USD mil)	**0.70**
Total Capital Cost (USD mil)	**108.48**
	155.63
Simple payback period (Years)	**156**

ANNEXURE VIII

Levelized Cost of Energy calculation for Case C - Determination of the Capital Cost of BESS (in USD/kWh) of B-SPVP to compete with small GT in Kelanitissa, at the optimum solution

Levelized Cost of Energy calculation for Case C - When the Capital Cost of BESS (in USD/kWh) of B-SPVP to compete with small GT in Kelanitissa, at the optimum solution

BES Data

BES Capacity	14.663	MW
Duration	5	Hours
Usable Energy	48.56762	MWh
100% Depth of discharge cycles/Day	1	Nos
Operating Days/Year	300	Days

Solar Power plant Data

Capacity	6.598	MW

Inverter Data

Capacity	17.5956	MW

Capital Structure

Loan	0.7	
Cost of debt	0.08	
Equity	0.3	

Contract Term/Project life	20	years
Depreciation		

BES O&M, Warranty & Augmentation cost	43	USD/MWh
Solar O&M, Warranty & Augmentation cost	0.007	
O&M Escalation	0.05	
Charging cost	0.033	USD/kWh
Charging cost escalator	0.0055	
Inverter efficiency	0.95	

Capital Cost of BESS	135	USD/kWh
Capital Cost of PV Plant	1000	USD/kW
Capital Cost of Inverter	270	USD/kW
Total Capital Cost	17.90544	USD Mil
Loan Amount	12.53381	USD Mil
Equity Amount	5.371632	USD Mil

Exchange Rate	178	LKR/USD
Annual escalation	3.7%	(The Colombo Consumer Price Index - January 2019)

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Energy Supply	GWh		14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703	14.5703
Levelised Tariff	LKR/kWh		45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
Revenue	LKR mil		656	656	656	656	656	656	656	656	656	656	656	656	656	656	656	656	656	656	656	656
Total charging cost	LKR mil		90	91	91	92	92	93	93	94	94	95	95	96	96	97	97	98	98	99	99	100
O&M Cost of BES	LKR mil		112	117	123	129	136	142	149	157	165	173	182	191	200	210	221	232	243	256	268	282
O&M Cost of Solar Plant	LKR mil		8.22	8.28	8.34	8.39	8.45	8.51	8.57	8.63	8.69	8.75	8.82	8.88	8.94	9.00	9.06	9.13	9.19	9.26	9.32	9.39
Total of Costs	LKR mil		210	216	222	229	236	243	251	259	268	276	286	295	305	316	327	339	351	364	377	391
Profit before interest	LKR mil		446	440	433	427	420	412	405	396	388	379	370	360	350	340	329	317	305	292	279	264
Net Profit	LKR mil		446	440	433	427	420	412	405	396	388	379	370	360	350	340	329	317	305	292	279	264
Committment fee	LKR mil		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash flow	LKR mil	-3187	446	440	433	427	420	412	405	396	388	379	370	360	350	340	329	317	305	292	279	264
		3187	210	216	222	229	236	243	251	259	268	276	286	295	305	316	327	339	351	364	377	391

Project IRR	**10.87%**
NPV - USD mil	**28**

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Loan Repayment	USD mil		0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70		
Interest Payment	USD mil		0.97	0.92	0.86	0.81	0.75	0.70	0.64	0.58	0.53	0.47	0.42	0.36	0.31	0.25	0.19	0.14	0.08	0.03		
Committment fee	USD mil		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Net Profit	USD mil		2.50	2.47	2.43	2.40	2.36	2.32	2.27	2.23	2.18	2.13	2.08	2.02	1.97	1.91	1.85	1.78	1.71	1.64	1.56	1.49
Cash Flow	USD mil	-5.37	0.83	0.85	0.87	0.89	0.91	0.92	0.94	0.95	0.95	0.96	0.96	0.97	0.96	0.96	0.95	0.94	0.93	0.92	1.56	1.49

Equity IRR **16.15%**

Loan Repayment Schedule	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Opening Balance (USD mil)		12.5338	11.84	11.14	10.44	9.75	9.05	8.36	7.66	6.96	6.27	5.57	4.87	4.18	3.48	2.79	2.09	1.39	0.70		
Loan Repayment (USD mil)		0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70		
Closing Balance (USD mil)		11.84	11.14	10.44	9.75	9.05	8.36	7.66	6.96	6.27	5.57	4.87	4.18	3.48	2.79	2.09	1.39	0.70	0.00		
Interest (USD mil)		0.97	0.92	0.86	0.81	0.75	0.70	0.64	0.58	0.53	0.47	0.42	0.36	0.31	0.25	0.19	0.14	0.08	0.03		

ANNEXURE IX

Simple payback period calculation Case C - Determination of the Capital Cost of BESS (in USD/kWh) of B-SPVP to compete with small GT in Kelanitissa, at the optimum solution

Simple payback period calculation for Case C - When the Capital Cost of BESS (in USD/kWh) of B-SPVP to compete with small GT in Kelanitissa, at the optimum solution

Power Plant	Variable unit cost (Rs/MWh)	Hourly Power (MW)																							
		0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Kps - Gt 01	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 02	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 03	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 04	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 05	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps - Gt 06	45,000.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Steam 01	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Steam 02	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gas Turbine 07	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps Jebic (GT08)	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kps JBIC (STEAM)	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lakdanavi	37,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AES-Kps	31,440.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Hamban	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Pallekele	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Galle	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aggreko-Kurunegala	25,990.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Asia Power	25,840.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE - Horana	25,050.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE-Matara	24,830.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ACE- Embilipitiya	24,740.00	0.000	0.000	0.000	0.000	0.000	0.097	0.090	0.107	0.104	0.104	0.107	0.089	0.096	0.093	0.089	0.091	0.092	0.101	0.141	0.252	0.243	0.270	0.223	0.123
Nothern Power	23,420.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Coast GT1	23,260.00	0.232	0.211	0.195	0.179	0.196	0.203	0.187	0.222	0.214	0.212	0.216	0.182	0.185	0.185	0.178	0.182	0.181	0.199	0.220	0.243	0.236	0.259	0.256	0.241
West Coast GT2	23,260.00	0.490	0.439	0.420	0.387	0.412	0.414	0.382	0.462	0.446	0.445	0.452	0.379	0.394	0.382	0.371	0.385	0.381	0.414	0.466	0.502	0.481	0.521	0.518	0.502
West Coast Steam	23,260.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sapu 01	22,580.00	0.039	0.026	0.026	0.026	0.025	0.036	0.034	0.040	0.039	0.039	0.039	0.032	0.033	0.032	0.030	0.031	0.031	0.034	0.037	0.040	0.039	0.043	0.042	0.041
Sapu 02	22,580.00	0.043	0.026	0.026	0.026	0.025	0.036	0.034	0.040	0.039	0.039	0.039	0.033	0.035	0.035	0.034	0.034	0.034	0.037	0.041	0.044	0.043	0.047	0.046	0.045
Sapu 03	22,580.00	0.049	0.026	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.037	0.040	0.000	0.017	0.036	0.039	0.042	0.047	0.050	0.048	0.053	0.052	0.051
Sapu 04	22,580.00	0.049	0.026	0.026	0.026	0.025	0.041	0.038	0.045	0.043	0.043	0.044	0.037	0.040	0.039	0.038	0.038	0.039	0.042	0.047	0.050	0.048	0.053	0.052	0.051
Sapu 05	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.022	0.022	0.018	0.019	0.020	0.017	0.017	0.017	0.020	0.023	0.025	0.024	0.026	0.026	0.025
Sapu 06	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 07	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.019	0.022	0.022	0.022	0.022	0.019	0.020	0.020	0.019	0.019	0.019	0.021	0.023	0.025	0.024	0.026	0.026	0.025
Sapu 08	22,580.00	0.024	0.021	0.021	0.017	0.016	0.020	0.006	0.022	0.022	0.022	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 09	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.020	0.022	0.023	0.024	0.026	0.026	0.025
Sapu 10	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.016	0.016	0.015	0.015	0.019	0.021	0.022	0.021	0.025	0.025	0.025
Sapu 11	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.020	0.021	0.017	0.018	0.017	0.017	0.017	0.017	0.019	0.022	0.023	0.023	0.025	0.025	0.025
Sapu 12	22,580.00	0.024	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.022	0.022	0.022	0.019	0.018	0.018	0.018	0.018	0.018	0.021	0.023	0.025	0.024	0.026	0.026	0.025
Puttalam Coal01	8,070.00	0.530	0.469	0.473	0.477	0.458	0.454	0.416	0.493	0.477	0.477	0.483	0.411	0.434	0.426	0.409	0.419	0.418	0.045	0.509	0.544	0.528	0.578	0.570	0.556
Puttalam Coal02	8,070.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Puttalam Coal03	8,070.00	0.776	0.676	0.683	0.687	0.661	0.649	0.601	0.709	0.690	0.680	0.698	0.583	0.630	0.628	0.610	0.615	0.618	0.679	0.755	0.798	0.776	0.839	0.834	0.806
Victoria 01	0.00	0.154	0.000	0.000	0.000	0.000	0.113	0.126	0.074	0.145	0.169	0.185	0.156	0.165	0.163	0.157	0.160	0.161	0.176	0.168	0.207	0.200	0.220	0.217	0.093
Victoria 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.126	0.112	0.109	0.130	0.185	0.156	0.165	0.163	0.126	0.160	0.161	0.176	0.155	0.207	0.200	0.220	0.174	0.149
Victoria 03	0.00	0.124	0.000	0.000	0.000	0.000	0.000	0.084	0.074	0.145	0.152	0.185	0.156	0.165	0.163	0.126	0.160	0.161	0.176	0.155	0.207	0.200	0.220	0.174	0.118
Victoria Stage II	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rand - 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.102	0.099	0.099	0.101	0.085	0.090	0.089	0.086	0.088	0.000	0.000	0.000	0.152	0.147	0.161	0.000	0.000
Rand - 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.102	0.099	0.099	0.101	0.083	0.090	0.089	0.086	0.117	0.088	0.096	0.106	0.152	0.147	0.161	0.119	0.000
Rant - 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.037	0.036	0.036	0.037	0.031	0.033	0.033	0.031	0.000	0.000	0.035	0.039	0.064	0.064	0.070	0.000	0.000
Rant - 02	0.00	0.000	0.000	0.000	0.000	0.000	0.034	0.032	0.037	0.036	0.036	0.037	0.031	0.033	0.033	0.031	0.032	0.000	0.035	0.039	0.064	0.064	0.070	0.069	0.000
Kotmale 01	0.00	0.000	0.094	0.064	0.095	0.083	0.098	0.120	0.069	0.072	0.140	0.118	0.087	0.081	0.065	0.063	0.090	0.097	0.070	0.098	0.116	0.085	0.088	0.096	0.000
Kotmale 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000	0.000	0.000
Kotmale 03	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.137	0.074	0.072	0.121	0.138	0.095	0.077	0.065	0.069	0.103	0.107	0.070	0.111	0.091	0.088	0.103	0.000	0.000
Nilambe	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.004	0.004	0.004	0.004	0.005	0.005	0.000
Ukuwela 01	0.00	0.050	0.044	0.044	0.044	0.043	0.000	0.039	0.046	0.045	0.045	0.046	0.038	0.041	0.040	0.039	0.040	0.040	0.043	0.048	0.051	0.049	0.054	0.054	0.052
Ukuwela 02	0.00	0.047	0.041	0.042	0.042	0.040	0.040	0.037	0.043	0.042	0.042	0.043	0.036	0.039	0.038	0.037	0.037	0.038	0.041	0.045	0.048	0.047	0.051	0.051	0.049
Bowatenna	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.058	0.059	0.024	0.025	0.028	0.082	0.089	0.036	0.030	0.101	0.073	0.000	0.000
Upper Kothmale1	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.207	0.200	0.117	0.116	0.112
Upper Kothmale2	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.132	0.087	0.084	0.128	0.161	0.094	0.103	0.207	0.200	0.117	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
New Laxapana 01	0.00	0.157	0.047	0.024	0.024	0.023	0.068	0.122	0.074	0.024	0.140	0.143	0.120	0.128	0.126	0.122	0.124	0.124	0.136	0.150	0.160	0.155	0.170	0.168	0.163
New Laxapana 02	0.00	0.135	0.047	0.024	0.024	0.023	0.068	0.105	0.074	0.024	0.121	0.123	0.104	0.110	0.109	0.105	0.107	0.107	0.117	0.129	0.138	0.133	0.147	0.145	0.140
Polpitiya 01	0.00	0.123	0.102	0.105	0.108	0.105	0.103	0.095	0.113	0.109	0.109	0.108	0.092	0.097	0.090	0.092	0.096	0.095	0.105	0.117	0.125	0.120	0.130	0.131	0.125
Polpitiya 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Olax 01	0.00	0.026	0.023	0.023	0.023	0.022	0.022	0.020	0.024	0.023	0.023	0.024	0.020	0.021	0.021	0.020	0.021	0.021	0.022	0.025	0.027	0.026	0.028	0.028	0.027
Olax 02	0.00	0.026	0.023	0.023	0.023	0.022	0.022	0.020	0.024	0.023	0.023	0.024	0.020	0.021	0.021	0.020	0.021	0.021	0.022	0.025	0.027	0.026	0.028	0.028	0.027
Olax 03	0.00	0.026	0.023	0.023	0.023	0.022	0.022	0.020	0.024	0.023	0.023	0.024	0.020	0.021	0.021	0.020	0.021	0.021	0.022	0.025	0.027	0.026	0.028	0.028	0.027
Olax 04	0.00	0.034	0.029	0.030	0.030	0.029	0.028	0.026	0.031	0.030	0.030	0.031	0.026	0.028	0.027	0.026	0.027	0.027	0.029	0.032	0.035	0.033	0.037	0.036	0.035
Olax 05	0.00	0.030	0.029	0.030	0.030	0.029	0.028	0.026	0.031	0.030	0.030	0.031	0.026	0.028	0.027	0.026	0.027	0.027	0.029	0.032	0.035	0.033	0.032	0.032	0.031
Cany 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.074	0.062	0.055	0.054	0.052	0.053	0.054	0.059	0.065	0.069	0.027	0.000	0.000	0.000
Cany 02	0.00	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.052	0.050	0.051	0.051	0.056	0.062	0.066	0.027	0.029	0.029	0.028
Wps 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.069	0.067	0.000	0.000	0.000
Wps 02	0.00	0.027	0.047	0.024	0.024	0.023	0.057	0.053	0.062	0.024	0.048	0.049	0.041	0.044	0.043	0.042	0.043	0.043	0.047	0.052	0.069	0.067	0.029	0.029	0.028
Broadlands	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Samanalawewa 01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.024	0.025	0.021	0.022	0.022	0.021	0.064	0.064	0.023	0.026	0.110	0.107	0.029	0.000	0.000
Samanalawewa 02	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.107	0.000	0.000	0.000
Samanalawewa03	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.010	0.009	0.009	0.009	0.008	0.009	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.010	0.010	0.010	0.011	0.011	0.010
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Udavalawa	0.00	0.007	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.003	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008
Inginiyagala	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Moragahakanda	0.00	0.010	0.009	0.009	0.009	0.008	0.009	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.010	0.010	0.010	0.011	0.011	0.010
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kol onnawa Generation	0.00	0.000	0.551	0.583	0.544	0.578	0.624	0.870	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kukule 01	0.00	0.000	0.061	0.062	0.062	0.060	0.059	0.079	0.064	0.063	0.063	0.064	0.054	0.057	0.057	0.054	0.056	0.056	0.061	0.067	0.072	0.069	0.110	0.075	0.000
Kukule 02	0.00	0.000	0.061	0.062	0.062	0.060	0.059	0.079	0.064	0.063	0.063	0.064	0.054	0.057	0.057	0.054	0.056	0.056	0.061	0.067	0.072	0.069	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.007	0.000	0.019	0.027	0.027	0.007	0.000	0.000	0.006	0.004	-0.002	-0.008	0.017	0.011	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heladhanavi	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IPP Mini Hydro	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.334	0.323	0.000	0.000	0.000
Kilinochchi Wd 1	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kilinochchi Wd2	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Musalpity WIND	0.00	0.014	0.020	0.020	0.017	0.019	0.018	0.017	0.015	0.005	0.000	0.001	0.013	0.013	0.012	0.013	0.013	0.014	0.013	0.019	0.019	0.016	0.019	0.019	0.013
Wind -Spare	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Welikanda Solar	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.016	0.015	0.020	0.018	0.018	0.012	0.012	0.009	0.005	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Hambantota Solar	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.024	0.066	0.057	0.055	0.059	0.058	0.047	0.041	0.023	0.015	0.002	0.000	0.000	0.000	0.000	0.000
Vauniya Solar	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.006	0.014	0.021	0.018	0.013	0.021	0.008	0.008	0.017	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Dendro 1	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CEB- Barge	0.00	0.163	0.071	0.072	0.072	0.070	0.103	0.095	0.112	0.109	0.109	0.111	0.093	0.099	0.122	0.126	0.128	0.129	0.141	0.156	0.166	0.160	0.177	0.174	0.169
New Chunnakum	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.044	0.047	0.040	0.028	0.029	0.039	0.050	0.055	0.059	0.057	0.062	0.062	0.060
Norechcole Wind	0.00	0.112	0.124	0.135	0.106	0.111	0.112	0.105	0.115	0.087	0.074	0.081	0.084	0.088	0.087	0.089	0.048	0.088	0.082	0.095	0.111	0.111	0.132	0.137	0.132
Seguwanthive / Vidathamuni	0.00	0.032	0.031	0.033	0.031	0.030	0.032	0.027	0.030	0.024	0.027	0.035	0.031	0.033	0.030	0.027	0.030	0.034	0.035	0.034	0.036	0.032	0.032	0.035	0.042
Senok Wind (MAMPURI-1)	0.00	0.023	0.020	0.021	0.016	0.015	0.016	0.016	0.002	0.013	0.010	0.011	0.011	0.012	0.011	0.010	0.010	0.011	0.010	0.014	0.014	0.014	0.019	0.024	0.025
Total Hourly P (MW)		3.761	3.497	3.431	3.299	3.299	3.761	4.619	3.959	3.893	4.355	4.685	4.091	4.355	4.157	3.959	4.223	4.223	4.025	4.817	6.598	6.268	5.872	5.081	4.289
Total Hourly P of Tissa 1 (MW)		3.761	3.497	3.431	3.299	3.299	3.761	4.619	3.959	3.893	4.355	4.685	4.091	4.355	4.157	3.959	4.223	4.223	4.025	4.817	6.598	6.268	5.872	5.081	4.289
For Optimized with B-SPVP																									
B-SPVP P hourly (MW)		3.701	3.439	3.373	3.242	3.242	3.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.598	6.214	5.814	5.017	4.227
B-SPVP variable cost (Rs)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy replaced by B-SPVP		3.701	3.439	3.373	3.242	3.242	3.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.598	6.214	5.814	5.017	4.227
Cost if not replaced by B-SPVP (Rs.)		35,793.61	28,630.57	27,947.32	25,838.95	26,367.44	30,061.97	29,162.98	35,066.14	34,001.14	33,736.41	35,202.54	29,547.76	31,007.01	29,606.57	28,967.74	30,038.12	30,065.56	29,634.36	37,543.38	42,853.59	41,471.64	45,379.04	43,825.33	40,077.67
Benefit if replaced byB-SPVP (Rs.)		35,793.61	28,630.57	27,947.32	25,838.95	26,367.44	30,061.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42,853.59	41,471.64	45,379.04	43,825.33	40,077.67

Total daily cost without SPVP (Rs.)	**801,826.84**
Total daily cost with SPVP (Rs.)	**388,247.12**
Total daily net benefit with SPVP (Rs.)	**413,579.72**
Total Annual benefit only with SPVP (Rs.)	**124.07**
Total Annual benefit only with SPVP (USD mil)	**0.70**
Total Capital Cost (USD mil)	**17.91**
	25.69
Simple payback period (Years)	**26**