

**MAXIMIZING SOLAR PV INTEGRATION BY
ENHANCING HOSTING CAPACITY OF LV
NETWORKS USING SMART INVERTERS AND
BATTERY ENERGY STORAGE SYSTEMS:
A CASE STUDY**

Dissanayake Mudiyanseelage Krishan Chathuranga Dissanayake

(208671X)

Degree of Master of Science in Electrical Installations

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

July 2025

**MAXIMIZING SOLAR PV INTEGRATION BY
ENHANCING HOSTING CAPACITY OF LV
NETWORKS USING SMART INVERTERS AND
BATTERY ENERGY STORAGE SYSTEMS:
A CASE STUDY**

Dissanayake Mudiyansele Krishan Chathuranga Dissanayake

(208671X)

Thesis/Dissertation submitted in partial fulfillment of the requirements for the
Degree Master of Science in Electrical Installations

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

July 2025

DECLARATION OF THE CANDIDATE & SUPERVISOR

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

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date: 27.07.2025

(DMKC Dissanayake)

The above candidate has carried out research for the Masters Dissertation under our supervision.

Signature of the supervisor:

Date: 28.07.2025

(Prof. W.D.A.S. Wijayapala)

Abstract

The integration of rooftop solar photovoltaic (PV) systems in Sri Lanka, particularly within buildings governed by provincial councils, has been increasing in response to national renewable energy goals. However, the rapid increase of solar PV integration in low-voltage (LV) distribution networks presents considerable technical challenges, notably voltage rise exceeding maximum allowable limits, feeder capacity limitations and transformer capacity limitations. These issues are further compounded by high grid augmentation costs, rendering conventional methods such as feeder upgrades and transformer upgrades economically unfeasible, especially for small to medium-scale PV systems under 42 kVA. As a result, utility providers have imposed restrictions on new PV connections, hindering the full realization of solar energy potential in the region.

This study investigates a cost-effective and technically viable alternative to enhance PV hosting capacity by integrating smart inverters and battery energy storage systems (BESS). A detailed case study was conducted on a 160 kVA transformer located in a solar-rich area in Kotte, where data from actual consumer loads and solar installations were used to model real-world conditions. A series of simulations were developed using MATLAB, exploring different configurations of solar PV system placement, power factor control strategies (Volt-Var and Watt control), and BESS deployment at various feeder locations.

The results indicate that while smart inverters alone can provide limited improvements in voltage regulation, the combined use of smart inverters with BESS—particularly when strategically located at points of maximum voltage—significantly reduces voltage rise and current surges. This facilitates the integration of an additional solar PV without breaching operational voltage limits. Moreover, cost-benefit analysis reveals that the proposed solution offers substantial economic advantages over conventional grid augmentation, with net savings and an acceptable return on investment.

The study concludes that integrating BESS with smart inverter control is a scalable, technically robust, and economically feasible strategy to increase solar PV penetration in

LV distribution networks, thereby supporting the broader transition toward sustainable energy systems in Sri Lanka.

Keywords: Solar PV penetration, Voltage regulation, Grid augmentation, Power factor correction, Battery Energy Storage Systems (BESS), Feeder hosting capacity, Transformer hosting capacity, Smart inverter controls

Acknowledgement

I would like to express my deepest gratitude to Professor W.D.A.S. Wijayapala, my supervisor at the Department of Electrical Engineering, University of Moratuwa, for his invaluable guidance, insightful feedback, and continuous support throughout the duration of this research. His expertise and encouragement were vital from the early stages of conceptualization through to the final completion of the project.

I am also sincerely thankful to the academic staff of the Department of Electrical Engineering for their thoughtful suggestions and technical input, which greatly contributed to the quality and direction of this study.

My heartfelt appreciation goes to my family, whose unwavering support, patience, and encouragement sustained me throughout my academic journey. Their belief in my abilities motivated me to persevere through challenges and remain focused on my goals.

Finally, I would like to acknowledge my friends and colleagues for their interest in my research and for offering helpful ideas and perspectives that enriched the study.

D.M.K.C Dissanayake

(208671X)

Table of Contents

DECLARATION OF THE CANDIDATE & SUPERVISOR	i
Abstract	ii
Acknowledgement.....	iv
Table of Contents	v
List of Figures	ix
List of Tables.....	x
List of Abbreviations.....	xi
CHAPTER 1	1
1 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Project Objectives and Scope	3
1.3.1 Objectives.....	3
1.3.2 Scope	4
1.4 Thesis Outline.....	5
CHAPTER 2	6
2 LITERATURE REVIEW	6
2.1 Introduction to PV Hosting Capacity and Grid Integration Challenges.....	6
2.2 Smart Inverters for Voltage and Power Control.....	7
2.3 Volt–Var Control.....	7
2.4 Volt–Watt Control	8
2.5 Integration of Battery Energy Storage Systems (BESS)	8
2.6 BESS with Volt–Var Control	8

2.7	BESS with Volt–Watt Control	9
2.8	Combined Volt–Var and Volt–Watt Control	9
2.9	Impact of Control Strategies on Hosting Capacity: Deterministic vs. Stochastic Analysis 9	
2.9.1	Deterministic Analysis	10
2.9.2	Stochastic Analysis	10
2.10	Vertical PV Systems.....	10
2.11	Bifacial Vertical Systems	10
2.12	Hybrid Configurations.....	11
2.13	Transformer and Cable Hosting Capacity Considerations	11
2.14	Economic Considerations and Cost-Benefit Analysis.....	11
2.15	Gaps in the Literature and Research Direction.....	12
2.16	Summary	12
	CHAPTER 3	14
3	METHODOLOGY	14
3.1	Introduction	14
3.2	Overview	14
3.3	Data Collection and Transformer Selection	15
3.4	System Modelling.....	19
3.4.1	Modelling of transmission line	19
3.4.2	Modelling of Inverters.....	22
3.5	Simulation Scenarios	25
3.6	Technical Evaluation Metrics.....	27
3.7	Economic Analysis of Optimal Configuration	27
3.7.1	Purpose and Scope	27

3.7.2	Considered Parameters.....	27
3.7.3	Evaluation Metrics	30
3.8	Summary	30
CHAPTER 4		32
4	RESULTS AND ANALYSIS.....	32
4.1	Introduction	32
4.2	Scenario 1: Baseline (Existing System Without Control)	32
4.3	Scenario 2: Additional 40 kW solar PV system (without any Control) integrated to the Feeder 1	33
4.4	Scenario 3: Applying Power Factor Control (PF = 0.95) to Scenario 2.....	34
4.5	Scenario 4: Applying Power Factor Control (PF = 0.9) to Scenario 2.....	35
4.6	Scenario 5: Integration of BESS with Power Factor Control (PF = 0.95) ..	36
4.7	Scenario 6: Improved upon Scenario 5 - Solar PV and BESS Expansion ..	38
4.8	Current and I ² R Loss Analysis	39
CHAPTER 5		43
5	FINANCIAL EVALUATION.....	43
5.1	Introduction	43
5.2	Calculations	43
5.2.1	Battery Sizing and Capital Cost Calculation for First 10 Years	43
5.2.2	Battery Sizing and Capital Cost Estimation for the Second 10-Year Period	46
5.2.3	Operational and Maintenance Cost Calculation.....	47
5.2.4	Energy Export Revenue	48
CHAPTER 6		52
1.	CONCLUSIONS AND RECOMMENDATIONS	52

a.	Conclusions	52
b.	Recommendation for further studies	54
	References.....	55

List of Figures

Figure 1 : Selected Distribution Area.....	15
Figure 2 : GIS Map of Transformer AZ0204.....	18
Figure 3: Details of Aerial Bundled Cables	21
Figure 4 : Residential Loads and Pi-Sections of the Feeder	22
Figure 5 : Power Control Circuit of the Inverter Model	24
Figure 6 : Control Circuit of the Inverter	24
Figure 7: Grid Augmentation Cost received for Quilwaththa Tamil School	28
Figure 8: Grid Augmentation Cost received for Deltagamunupura School.....	28
Figure 9 : Estimated Generation Cost (10th Oct 2024) Published by PUCSL	29
Figure 10 : Time Specific Forecast of Battery Prices	29
Figure 11 : Voltage Variation at Key Locations Along Each Feeder (Scenario 1).....	33
Figure 12 : Voltage Variation at Key Locations of Feeder 1 with 40 kW PV Integrated at Different Points (Scenario 2)	34
Figure 13 : Comparison of Voltage Profiles Between Scenario 2 and Scenario 3	35
Figure 14 : Comparison of Voltage Profiles Between Scenario 2 and Scenario 4	36
Figure 15 : Maximum Recorded Voltages with BESS Installed at Different Locations Along Feeder 1	37
Figure 16: Voltage Profile at Key Locations Along Feeder 1 for Scenario 6.....	38
Figure 17 : Comparison of I ² R Losses Across All Simulation Scenarios.....	41
Figure 18 : Comparison of I ² R Losses in All Scenarios Relative to Scenario 2	41
Figure 19: Power Curve of the 118 kW Solar PV System	44

List of Tables

Table 1 : Transformer Data	16
Table 2 : Consumer details of AZ-0204.....	17
Table 4 : Measured Voltage Profiles at Various Points Along the Three Feeders (Scenario 1).....	32
Table 5 : Measured Voltage Profiles at Key Locations of Feeder 1 with 40 kW PV System Integrated at Different Feeder Points (Scenario 2).....	33
Table 6 : Measured Voltage Profiles at Key Locations of Feeder 1 for Scenario 3	34
Table 7 : Measured Voltage Profiles at Key Locations of Feeder 1 for Scenario 4	35
Table 8 : Measured Voltage Profiles at Key Locations of Feeder 1 for Scenario 5	37
Table 9: Measured Voltage Profiles at Key Locations of Feeder 1 for Scenario 6	38
Table 10 : Measured Feeder Currents at Three Key Locations Along Feeder 1 Across Simulation Scenarios.....	40
Table 11 : Calculated I ² R Losses at Three Key Locations Along Feeder 1 for Each Simulation Scenario	40
Table 12: Capacity and Cost Calculation of BESS for the First 10 Years.....	45
Table 13: Capacity and Cost Calculation of BESS for the Second 10 Years	47
Table 14: Cost Benefit Analysis	49

List of Abbreviations

Abbreviation	Description
PUCSL	Public Utilities Commission of Sri Lanka
LECO	Lanka Electricity Company Private Limited
CEB	Ceylon Electricity Board
LV	Low Voltage
MV	Medium Voltage
BESS	Battery Energy Storage System
PV	Photovoltaic
DoD	Depth of Discharge
ROI	Return on Investment