

**OPTIMAL PLACEMENT, SIZING AND DISPATCH OF  
BATTERY ENERGY STORAGE SYSTEM  
INTEGRATED DISTRIBUTED GENERATION**

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Degree of Master of Science by Research

Department of Electrical Engineering

University of Moratuwa

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## DECLARATION

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## ABSTRACT

Distributed Generation (DG) has become a key component in modern power industry due its significant advantages over the traditional power generation methods. Nevertheless, it is required to integrate them for distribution networks in such a way that their best expected outcomes can be achieved as inappropriate allocation may impose power system stability, protection and quality issues. This thesis presents novel analytical approaches for optimizing the DG location, size and power dispatch. Analytical methodologies based on formulating objective functions using loss and voltage sensitivities are presented for optimizing the DG location and size. An alternative method for determining the optimal DG sizes which is solved by Lagrange Multiplier Method (LMM) is also presented for better comparison. Moreover, the values obtained for optimal DG sizes from the novel analytical methods are compared with the results obtained by Genetic Algorithm (GA). A novel approach for determining the Battery Energy Storage System (BESS) capacities is presented as a part of developing an optimal power dispatch schedule for BESS units. The time varying nature of loads and DG output are also taken into consideration in this approach. Raw data obtained from a Solar Photovoltaic (SPV) farm in Hambantota area and typical three load profile data (i.e. mix load, residential load and commercial load) obtained from Long Term Generation Expansion Plan (LTGEP) of Ceylon Electricity Board (CEB) are used for modelling the SPV generation and load patterns respectively. The BESS capacities are determined in terms of Load Proportionality Factor (LPF), State of Charge limits (SOC) of battery storages and proportion of off-peak solar period energy consumption expected to be served by each BESS unit. An optimal BESS dispatch algorithm is also presented in this thesis for minimizing the energy losses and voltage deviations. The applicability of the proposed methodologies are tested using standard IEEE-6 and IEEE-33 test bus systems. Simulation results obtained for active power loss variations, voltage profile variations, SOC variations of BESS units and charging/discharging rates of BESS units suggest the acceptability and the appropriateness of the proposed methodologies.

**Keywords-** *Distributed generation, optimal DG allocation, loss sensitivity index (LSI), voltage sensitivity index (VSI), loss-voltage sensitivity index (LVSI), load proportionality factor (LPF), loss minimization, voltage deviations,*

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## TABLE OF CONTENTS

DECLARATION .....	i
ABSTRACT .....	ii
ACKNOWLEDGEMENT .....	iii
LIST OF FIGURES .....	viii
LIST OF TABLES .....	xi
LIST OF ABBREVIATIONS .....	xii
INTRODUCTION .....	1
1.1. Background of the Study.....	2
1.1.1. Problem Statement .....	2
1.1.2. Research Objectives .....	3
1.1.3. Scope of Work .....	3
1.2. Thesis Structure.....	3
1.3. Summary .....	4
LITERATURE REVIEW AND BACKGROUND STUDIES .....	5
2.1. Distributed Generation in Power Systems.....	5
2.1.1. Importance of Distributed Generation.....	5
2.1.2. Classification of DG.....	5
2.1.3. DG Allocation and its Impact on Network .....	6
Power Quality Issues .....	6
Protection Issues .....	7
Stability Issues .....	7
2.1.4. Significance of Optimizing DG Allocation .....	7
2.2. Taxonomy of Optimization Methods Used for DG Allocation .....	8
2.2.1. Problem Formulation.....	8
2.2.2. Constraints .....	8
2.2.3. DG Technology.....	9
2.2.4. Load Profile .....	9
2.2.5. Optimization Techniques Used in DG Allocation .....	9
Exact Optimization.....	10
Linear Programming .....	10
Non-Linear Programming .....	10
Sequential Quadratic Programming .....	11
Dynamic Programming .....	12
Ordinal Programming .....	12
Gradient Search Method .....	12

Heuristic Optimization.....	13
Genetic Algorithm .....	13
Particle Swarm Optimization .....	15
Ant-Colony Optimization.....	15
Artificial Bee Colony Optimization.....	16
Monte Carlo Simulation.....	16
Tabu Search.....	16
Simulated Annealing.....	17
Differential Evolution .....	17
Analytical Methods .....	17
Sensitivity Based Methods .....	18
2.3. Summary .....	20
OPTIMIZATION OF DG LOCATION .....	22
3.1. Mathematical Background .....	22
3.1.1. Jacobian Matrix.....	22
3.1.2. Exact Loss Formula.....	23
3.1.3. Loss Sensitivity Index .....	24
3.1.4. Voltage Sensitivity Index .....	25
3.2. Optimal DG Location Based on Loss & Voltage Sensitivity Analysis.....	25
3.2.1. Novel Objective Function.....	25
3.2.2. Constraints.....	26
3.2.3. Computational Procedure .....	27
3.3. Verification of the Proposed Methodology .....	27
3.3.1. Case I : Verification using IEEE-6 Bus System .....	28
Case I(A): Fixed DG Capacity-Active Power Loss.....	30
Case I(B): Fixed DG Capacity-Network Voltage Profile .....	30
Case II: Variable DG Capacity.....	31
3.3.2. Case II: Verification using IEEE-33 Bus System .....	34
3.4. Summary .....	38
NOVEL METHODOLOGIES FOR OPTIMIZING DG SIZES .....	39
4.1. Optimization of DG Sizes Using Loss and Voltage Sensitivity Analysis.....	39
4.1.1. Formulation of Objective function.....	39
4.1.2. Computational Procedure .....	41
4.1.3. Verification using IEEE-33 Bus System .....	41
4.2. Optimization of DG Sizes Using Lagrange Multiplier Method .....	44
4.2.1. Problem Formulation.....	44

Total Active Power Loss.....	44
Voltage Drop Between Two Busbars .....	45
Exact Loss Formula .....	45
4.2.2.    Formulation of Objective Function.....	45
4.2.3.    Constraints.....	46
4.2.4.    Solution Method.....	47
4.2.5.    Computational Procedure .....	48
4.2.6.    Verification using IEEE-6 & IEEE-33 Bus Systems .....	49
4.3.    Summary .....	53
BESS CAPACITY CALCULATION METHODOLOGY .....	54
5.1.    Modelling of Solar PV Output .....	55
5.1.1.    Calculation of PV Output .....	56
5.1.2.    Mapping Procedure of SPV Generation .....	60
5.2.    Modelling of Load Curves .....	61
5.2.1.    Mapping Procedure of Load Curves .....	61
5.3.    Analytical Method for PV & BESS Sizing .....	63
5.3.1.    Sample Calculation .....	67
5.4.    Verification of Results for PV Sizes (with BESS).....	71
5.5.    Summary .....	73
OPTIMAL POWER DISPATCH SCHEDULE .....	74
6.1.    Mathematical Background .....	74
6.2.    BESS Dispatch Algorithm .....	75
6.3.    Simulation Results .....	77
6.3.1.    Charge/Discharge Rate of BESS.....	77
6.3.2.    SOC Variation of BESS Units .....	79
6.3.3.    Active Power Loss Variation.....	81
6.3.4.    Voltage Profile Variation .....	85
Variation of Busbar Voltages for the Mix Daily Load Profile .....	85
Variation of Busbar Voltages for the Residential Daily Load Profile .....	87
Variation of Busbar Voltages for the Commercial Daily Load Profile .....	89
6.4.    Summary .....	90
CONCLUSIONS AND FUTURE WORK.....	92
7.1.    Conclusions .....	92
7.2.    Future Work .....	93
REFERENCES .....	95
APPENDIX – A – DERIVATION OF JACOBIAN MATRIX.....	102



APPENDIX – B – PARAMETERS OF IEEE-6 BUS SYSTEM .....	104
APPENDIX – C – PARAMETERS OF IEEE-33 BUS SYSTEM .....	105

## LIST OF FIGURES

Figure 3.1: IEEE-6 bus test system.....	28
Figure 3.2: LVSI for different DG locations for IEEE-6 bus network.....	29
Figure 3.3: Active power loss comparison for Case I & II.....	32
Figure 3.4: Busbar voltages for different locations of 4-MW DG unit.....	32
Figure 3.5: Combined active power loss reduction and bus voltage enhancement for different locations of 4-MW DG unit.....	34
Figure 3.6: IEEE-33 bus test system.....	34
Figure 3.7: Combined active power loss reduction and bus voltage enhancement for multiple DG locations of 0.2-MW DG units.....	38
Figure 4.1: Active power loss comparison (IEEE-33 bus system) .....	42
Figure 4.2: Voltage profile comparison (IEEE-33 bus system) .....	43
Figure 4.3: Typical configuration of a radial or meshed network.....	44
Figure 4.4: Active power loss comparison.....	51
Figure 4.5: Voltage profile comparison for IEEE-6 bus network.....	51
Figure 4.6: Voltage profile comparison for IEEE-33 bus network.....	52
Figure 4.7: Comparison of combined loss reduction and bus voltage enhancement for Case I and Case II.....	53
Figure 5.1(a): Expected PV output @ 7 a.m. (For Hambantota PV farm) .....	59
Figure 5.1(b): Expected PV output @ 9 a.m. (For Hambantota PV farm) .....	59
Figure 5.1(c): Expected PV output @ 12 noon (For Hambantota PV farm).....	59
Figure 5.1(d): Expected PV output @ 3 p.m. (For Hambantota PV farm) .....	59
Figure 5.1(e): Expected PV output @ 5 p.m. (For Hambantota PV farm) .....	59
Figure 5.1(f): Expected PV output @ 8 p.m. (For Hambantota PV farm) .....	59
Figure 5.2: Aggregated daily SPV output curve (For Hambantota PV farm).....	60
Figure 5.3: Total daily SPV output curves of the PV units (with No BESS) in the IEEE-33 network.....	61
Figure 5.4: Normalized mix daily load profile.....	62
Figure 5.5: Normalized residential load profile.....	62
Figure 5.6: Normalized commercial load profile.....	63

Figure 5.7: Illustration of the definitions of peak solar period and off-peak solar Period.....	64
Figure 5.8: Load areas of the IEEE-33 test bus system.....	65
Figure 6.1 BESS dispatch algorithm.....	76
Figure 6.2: Charge/Discharge rates of BESS units (For mix daily load profile).....	78
Figure 6.3: Charge/Discharge rates of BESS units (For residential daily load profile) .....	78
Figure 6.4: Charge/Discharge rates of BESS units (For commercial daily load profile) .....	79
Figure 6.5: SOC variation of BESS units (For mix daily load profile) .....	80
Figure 6.6: SOC variation of BESS units (For residential daily load profile) .....	80
Figure 6.7: SOC variation of BESS units (For commercial daily load profile) .....	81
Figure 6.8: Active power loss variation (For mix daily load profile) .....	82
Figure 6.9: Active power loss variation (For residential daily load profile) .....	82
Figure 6.10: Active power loss variation (For commercial daily load profile).....	83
Figure 6.11(a): Variation of busbar voltages @ 4 a.m. (For mix daily load profile) .....	85
Figure 6.11(b): Variation of busbar voltages @ 3 p.m. (For mix daily load profile) .....	85
Figure 6.11(c): Variation of busbar voltages @ 8 p.m. (For mix daily load profile) .....	86
Figure 6.12(a): Variation of busbar voltages @ 4 a.m. (For residential daily load profile).....	87
Figure 6.12(b): Variation of busbar voltages @ 3 p.m. (For residential daily load profile).....	87
Figure 6.12(c): Variation of busbar voltages @ 8 p.m. (For residential daily load profile).....	88
Figure 6.13(a): Variation of busbar voltages @ 4 a.m. (For commercial daily load profile).....	89
Figure 6.13(b): Variation of busbar voltages @ 3 p.m. (For commercial daily load	

profile).....	89
Figure 6.13(c): Variation of busbar voltages @ 8 p.m. (For commercial daily load profile).....	90

## LIST OF TABLES

Table 2.1: Comparison of DG technologies.....	5
Table 2.2: Optimization techniques used in DG allocation.....	9
Table 2.3: Summary of literature review and background studies.....	20
Table 3.1: VSI and LSI values at base case scenario (IEEE-6 network) .....	28
Table 3.2: Comparison of active power loss for Case I and Case II.....	31
Table 3.3: %TNVI values for different busbar locations.....	32
Table 3.4: Calculation of $\Delta P_{loss,i} \times TNVI$ values for Case I (IEEE-6 bus system) .....	33
Table 3.5: VSI and LSI values at base case scenario (IEEE-33 network) .....	35
Table 3.6: Calculation of $\Delta P_{loss,i} \times TNVI$ values (IEEE-33 bus system.....	37
Table 4.1: Comparison of DG sizes (IEEE-33 bus system) .....	42
Table 4.2: Summary of results for optimal DG sizes.....	50
Table 5.1: Summary of SPV parameters and calculations.....	58
Table 5.2: Case I ( $\eta=20\%$ , Mix daily load profile) .....	69
Table 5.3: Case II ( $\eta=25\%$ , Mix daily load profile) .....	69
Table 5.4: Case III ( $\eta=30\%$ , Mix daily load profile) .....	70
Table 5.5: Case IV ( $\eta=20\%$ , Residential load profile) .....	70
Table 5.6: Case IV ( $\eta=20\%$ , Commercial load profile) .....	71
Table 5.7: Comparison of PV sizes (with BESS).....	71
Table 6.1: Daily energy loss comparison for different load profiles.....	84

## LIST OF ABBREVIATIONS

ABCO	:	Artificial Bee Colony Optimization
ACO	:	Ant Colony Optimization
BESS	:	Battery Energy Storage System
BPDF	:	Beta Probability Density Function
CEB	:	Ceylon electricity Board
CSP	:	Concentrated Solar Power
DE	:	Differential Evolution
DER	:	Distributed Energy Resources
DG	:	Distributed Generation
DNO	:	Distribution Network Operator
DP	:	Dynamic Programming
DSO	:	Distribution System Operator
ELF	:	Exact Loss Formula
EV	:	Electric Vehicles
FF	:	Fill Factor
GA	:	Genetic Algorithm
GHG	:	Green House Gases
IA	:	Improved Analytical
IPP	:	Independent Power Producers
LMM	:	Lagrange Multiplier Method
LP	:	Linear Programming
LPF	:	Load Proportionality Factor
LSF	:	Loss Sensitivity Factor
LTGEP	:	Long Term Generation Expansion Plan
MCS	:	Monte Carlo Simulation
MINLP	:	Mixed Integer Non-Linear Programming
MIP	:	Mixed Integer Programming
MPPT	:	Maximum Power Point Tracking
NLP	:	Non-Linear Programming
OP	:	Ordinal Programming
OPF	:	Optimal Power Flow

PSO	:	Particle Swarm Optimization
RES	:	Renewable Energy Sources
SA	:	Simulated Annealing
SBM	:	Sensitivity Based Methods
SCL	:	Short Circuit Level
SOC	:	State of Charge
SPV	:	Solar Photo-Voltaic
SQP	:	Sequential Quadratic Programming
TS	:	Tabu Search
VI	:	Voltage Index
VPP	:	Virtual Power Plant