



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electrical Power and Machines Engineering

# Optimal Management of Distribution Networks Regarding Reactive Power Generation

A Thesis submitted in partial fulfilment of the requirements of the degree  
of

Master of Science in Electrical Engineering

(Electrical Power and Machines Engineering)

by

**Ahmed Selim Abdelwahab Sayed**

Bachelor of Science in Electrical Engineering

(Electrical Power and Machines Engineering)

Faculty of Engineering, Ain Shams University, 2015

Supervised By

**Prof. Dr. Soliman Mohamed Eldebeiky**

**Prof. Dr. Mohamed Abdelatif Badr**

**Dr. Amr Magdy Abdeen**

Cairo - (2020)



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electrical Power and Machines Engineering

# Optimal Management of Distribution Networks Regarding Reactive Power Generation

by

**Ahmed Selim Abdelwahab Sayed**

Bachelor of Science in Electrical Engineering

(Electrical Power and Machines Engineering)

Faculty of Engineering, Ain Shams University, 2015

**Examiners' Committee**

**Name and Affiliation**

**Prof.Dr. Soliman Mohamed Eldebeiky**

Electrical Power and Machines Dept.

Faculty of Engineering

Ain Shams University

**Prof. Dr. Almoataz Youssef Abdelaziz**

Electrical Power and Machines Dept.

Faculty of Engineering

Ain Shams University

**Prof. Dr. Loai S. Nasert**

Electrical Power and Machines Dept.

Faculty of Engineering

Ain Shams University

**Signature**

.....

.....

.....

Date:23 August 2020

# Statement

This thesis is submitted as a partial fulfilment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

**Student name:**

**Ahmed Selim Abdelwahab Sayed**

Signature

.....

Date:23 August 2020

# Researcher Data

Name : Ahmed Selim Abdelwahab sayed  
Date of birth : 20/6/1992  
Place of birth : Elminia, Egypt  
Last academic degree : Bachelor of Science  
Field of specialization : Electrical Engineering  
University issued the degree : Ain Shams University  
Date of issued degree : 2015  
Current job : Testing and Commissioning Engineer

## ACKNOWLEDGEMENTS

First of all, I would like to thank **GOD ALMIGHTY** for having made everything possible by giving me strength and courage to finish this work. I would like to express my deep gratitude and sincere feelings to **Prof. Dr. Abdelatif Badr** God bless him and his residence is spacious in his paradise. I wish to express my sincere gratitude and deep appreciation to **Prof. Dr. Soliman Eldebeiky** for his continued support and invaluable assistance, helpful suggestions, support and encouragement. I would like also to thank **Dr. Amr Magdy** for his interest in my research and technical discussions during the course of this research.

*Ahmed Selim*

2020

# Abstract

In traditional power system network, power flows through three stages: generation, transmission, and distribution. The power flows in one direction from generation until reaching final user in distribution network. In this configuration, the generation process has total authority of the electrical power system; this configuration is defined as a centralized electrical power system. Many problems appear in this configuration such as increasing loss in transmission power lines due to flow of power for large distance. Therefore, the smart grid was developed to improve the power system efficiency and reliability and overcome the issue of power losses in transmission lines. This is achieved through using advanced techniques in metering devices, bidirectional information, networking, and advanced control technology.

Distributed generators (DGs) are considered a main feature of a smart grid. DGs are defined as small units connected directly to a distribution network and can be based on Renewable Energy Sources (RES), such as wind and solar, or on traditional energy sources, such as diesel generators. On the other hand, many microgrids are developed through connecting many DGs together to supply a defined load in a rural region with the required power which is difficult to connect with the distribution network. These microgrids depend on RES; therefore, generation power from these sources is random as it depends on atmospheric condition, as well, the load is random depending on the load condition. Therefore an energy management system is necessary to be developed to balance between the active and reactive generation with the required active and reactive power under the operation conditions to achieve the optimal management.

Reactive power is very important in an electrical power system; it supports the transfer of the active power, supplies loads with the required

reactive power and security operation of electrical power system since it can affect the voltage level. As reactive power is produced from generation units, the cost is no longer free and must be estimated. Therefore, an operation cost function for each generation unit must depend on active and reactive power cost. This study introduces an optimization operation cost for distributed generators (DGs) in microgrid depending on active and reactive power cost instead of active power cost only. This study achieves reaching optimal management and verifying the required active and reactive power with minimum cost to save stability of the system. The main contribution in this thesis is illustrated with the new technique which is presented as the Teaching-Learning-Based Optimization (TLBO) technique. The TLBO is used for solving the economic dispatch problem to obtain optimal management with the minimum cost.

In this thesis, it is considered that considering DGs operate as PQ type which have a known power factor for each DG. The model used is a smart microgrid containing three DGs (Diesel, Solar, and Wind) and, a capacitor bank to supply the load with the required active and reactive power. The model is applied on IEEE 33 Standard Test System. This study is divided to two parts; the first part objective is to clarify the efficiency of two optimization techniques in optimizing operation cost for the system depending on active and reactive power cost instead of active power cost only. The second part objective is to select the optimal sizing and siting of the capacitor bank to achieve minimum operation cost and improve the voltage level at all buses.

# Table of Contents

|  |           |
|--|-----------|
| ABSTRACT.....  | I         |
| TABLE OF CONTENTS.....   | III       |
| LIST OF FIGURES.....   | V         |
| LIST OF TABLES .....   | VII       |
| <b>1.1. GENERAL OVERVIEW .....</b>   | <b>1</b>  |
| <b>1.2. Motivation .....</b>   | <b>1</b>  |
| <b>1.3. Thesis Objective .....</b>   | <b>2</b>  |
| <b>1.4. Thesis Outlines .....</b>  | <b>4</b>  |
| <b>CHAPTER 2. LITERATURE REVIEW.....</b>                                   | <b>5</b>  |
| <b>2.1. Introduction .....</b>   | <b>5</b>  |
| <b>2.2. Electricity Production in the World.....</b>                       | <b>5</b>  |
| <b>2.3. Smart Grid.....</b>  | <b>7</b>  |
| 2.3.1 Advantages of Smart Grid.....  | 9         |
| 2.3.2 Disadvantages of Smart Grid .....                                    | 10        |
| <b>2.4. Distributed Generator .....</b>                                    | <b>10</b> |
| 2.4.1 Benefits of DGs .....  | 12        |
| 2.4.2 Problems Facing DGs .....  | 12        |
| 2.4.3 DGs Operation Modes .....  | 14        |
| <b>2.5. Microgrid .....</b>  | <b>14</b> |
| 2.5.1. Advantages of Microgrid .....                                       | 15        |
| 2.5.2. Disadvantages and Drawbacks of Microgrid .....                      | 14        |
| 2.5.3. Three Operation Modes for Microgrid.....                            | 17        |
| <b>2.6. Distribution Network.....</b>                                      | <b>19</b> |
| 2.6.1 Distribution Network without DGs.....                                | 20        |
| 2.6.2 Distribution Network with DGs .....                                  | 20        |
| <b>2.7. Management System in Distribution Network .....</b>                | <b>20</b> |
| 2.7.1 Energy Management System.....  | 21        |
| 2.7.2 Economic Dispatch .....  | 21        |
| <b>2.8. Reactive Power Compensation .....</b>                              | <b>23</b> |
| <b>2.9. Microgrid Model Survey .....</b>                                   | <b>24</b> |
| <b>2.10. Teaching-Learning-Based Optimization (TLBO) Survey .....</b>      | <b>29</b> |
| <b>2.11. Harmony Search (HS) Algorithm Survey.....</b>                     | <b>31</b> |
| <b>CHAPTER 3. MODEL AND COST FUNCTION FOR DISTRIBUTED GENERATORS .....</b> | <b>34</b> |
| <b>3.1. Introduction .....</b>   | <b>34</b> |
| <b>3.2. Model .....</b>  | <b>34</b> |
| <b>3.3. problem Formulation.....</b>                                       | <b>35</b> |
| <b>3.4. Objective Function .....</b>                                       | <b>36</b> |
| <b>3.5. Teaching-Learning-Based Optimization (TLBO) Technique.....</b>     | <b>36</b> |
| <b>3.6. Harmony Search (HS) Technique .....</b>                            | <b>41</b> |
| <b>3.7. Evaluating Cost Function for DGs .....</b>                         | <b>44</b> |
| <b>3.8. Power losses Reduction .....</b>                                   | <b>47</b> |
| <b>CHAPTER 4. DISTRIBUTED GENERATORS DATA AND RESULTS .....</b>            | <b>49</b> |
| <b>4.1. Introduction .....</b>   | <b>49</b> |
| <b>4.2. Solving Economic Dispatch Problem Procedures, Part 1 .....</b>     | <b>50</b> |
| <b>4.3. DGs Data, Part 1 .....</b>   | <b>51</b> |

|  |            |
|--|------------|
| 4.4. Operation Cost with/without Optimization .....                              | 53         |
| 4.5. Optimizing Operation Cost for five cases .....                              | 55         |
| 4.6. Optimization Output Analysis for Five Cases .....                           | 65         |
| 4.7. Total Cost Analysis for Five Cases .....                                    | 71         |
| 4.8. Optimal Siting and sizing for Capacitor Bank.....                           | 75         |
| 4.9. Procedures for Selecting optimal Siting and sizing for Capacitor Bank ..... | 75         |
| 4.10. DGs Data, Part 2 .....   | 76         |
| 4.11. Three Operation Modes.....   | 78         |
| 4.12. Active and Reactive Power Output from DGs and Capacitor Bank, Part 2.....  | 79         |
| 4.13. Total Operation Cost for Three Modes .....                                 | 85         |
| 4.14. Voltage Profile.....   | 86         |
| 4.15. Analysis and Conclusion for Three Operation Modes .....                    | 87         |
| <b>CHAPTER 5. CONCLUSIONS AND FUTURE WORK .....</b>                              | <b>89</b>  |
| 6.1. Conclusions .....   | 89         |
| 6.2. Future Work.....  | 92         |
| <b>REFERENCE .....</b>   | <b>93</b>  |
| <b>APPENDICES .....</b>  | <b>97</b>  |
| <b>PUBLICATION .....</b>   | <b>100</b> |

# List of Figures

|   |    |
|---|----|
| FIG 2.1. ELECTRICITY PRODUCTION IN THE WORLD, END OF 2017 [2].....  | 5  |
| FIG 2.2. TOTAL INVESTMENT IN ELECTRICITY IN THE WORLD, END OF 2017 [2].....   | 6  |
| FIG 2.3. RENEWABLE POWER CAPACITY IN THE WORLD FROM 2007 TO 2017 [2]. .....   | 6  |
| FIG 2.4. ELECTRICAL POWER SYSTEM. ....  | 8  |
| FIG 2.5. DGS CONNECTED TO DISTRIBUTION NETWORK. ....  | 10 |
| FIG 2.6. SIMULATED SMART MICROGRID. ....  | 18 |
| FIG 2.7. DISTRIBUTED GENERATORS.. ....  | 21 |
| FIG 2.8. REACTIVE POWER COMPENSATION.....   | 24 |
| FIG 2.9. WIND SYSTEM OUTPUT POWER CURVE. ....   | 25 |
| FIG 2.10. PV SOLAR SYSTEM STRUCTURE. ....   | 26 |
| FIG 2.11. POWER OUTPUT FROM PV SYSTEM.....  | 28 |
| FIG 2.12. LOCAL AND GLOBAL OPTIMIZATION. ....   | 30 |
| FIG 2.13. MUSIC IMPROVISATION VS OPTIMIZATION PROCESS.....  | 31 |
| FIG 3.1. SIMULATED MICROGRID MODEL.....   | 34 |
| FIG 3.2. IEEE 33 STANDARD TEST SYSTEM.....  | 35 |
| FIG 3.3. TEACHING-LEARNING-BASED OPTIMIZATION FLOWCHART. ....   | 39 |
| FIG 3.4. IMPROVISE A NEW HARMONY VECTOR. ....   | 43 |
| FIG 3.5. HARMONY SEARCH FLOW CHART.....   | 43 |
| FIG 3.6. LINE DIAGRAM BETWEEN TWO BUSES IN DISTRIBUTION SYSTEM. ....  | 47 |
| FIG 4.1. TOTAL OPERATION COST (\$).....   | 54 |
| FIG 4.2. TOTAL OPERATION COST FOR FIRST CASE (TLBO & HS).....   | 57 |
| FIG 4.3. TOTAL OPERATION COST FOR SECOND CASE (TLBO & HS). ....   | 59 |
| FIG 4.4. TOTAL OPERATION COST FOR THIRD CASE (TLBO & HS). ....  | 61 |
| FIG 4.5. TOTAL OPERATION COST FOR FOURTH CASE (TLBO & HS). ....   | 63 |
| FIG 4.6. TOTAL OPERATION COST FOR FIFTH CASE (TLBO & HS). ....  | 65 |
| FIG 4.7. ACTIVE POWER OUTPUT FROM DG1 (DIESEL) IN FIVE CASES WITH USING TWO<br>OPTIMIZATION TECHNIQUES (TLBO & HS )...... | 66 |
| FIG 4.8. ACTIVE POWER OUTPUT FROM DG2 (SOLAR) IN FIVE CASES WITH USING TWO<br>OPTIMIZATION TECHNIQUES (TLBO & HS )......  | 66 |
| FIG 4.9. ACTIVE POWER OUTPUT FROM DG3 (WIND) IN FIVE CASES WITH USING TWO<br>OPTIMIZATION TECHNIQUES (TLBO & HS )......   | 67 |

|  |    |
|--|----|
| FIG 4.10. REACTIVE POWER OUTPUT FROM DG1 (DIESEL) IN FIVE CASES WITH USING TWO OPTIMIZATION TECHNIQUES (TLBO & HS ).....   | 68 |
| FIG 4.11. REACTIVE POWER OUTPUT FROM DG2 (SOLAR) IN FIVE CASES WITH USING TWO OPTIMIZATION TECHNIQUES (TLBO & HS ).....    | 68 |
| FIG 4.12. REACTIVE POWER OUTPUT FROM DG3 (WIND) IN FIVE CASES WITH USING TWO OPTIMIZATION TECHNIQUES (TLBO & HS ).....     | 69 |
| FIG 4.13. REACTIVE POWER OUTPUT FROM CAPACITOR BANK IN FIVE CASES WITH USING TWO OPTIMIZATION TECHNIQUES (TLBO & HS )..... | 69 |
| FIG 4.14. ACTIVE POWER LOSSES IN FIVE CASES WITH USING TWO OPTIMIZATION TECHNIQUES (TLBO & HS ).....                       | 70 |
| FIG 4.15. REACTIVE POWER LOSSES IN FIVE CASES WITH USING TWO OPTIMIZATION TECHNIQUES (TLBO & HS ).....                     | 71 |
| FIG 4.16. OPERATION COST ANALYSIS FOR FIVE CASES WITH USING TWO OPTIMIZATION TECHNIQUES (TLBO & HS ).....                  | 71 |
| FIG 4.17. INCREASING PERCENTAGE IN OPERATION COST FOR CASES (2,3,4,5) OVER THAN CASE 1. ....                               | 74 |
| FIG 4.18. ACTIVE AND REACTIVE POWER OUTPUT FOR DG1 (DIESEL) IN THREE MODES. ....   | 79 |
| FIG 4.19. ACTIVE AND REACTIVE POWER OUTPUT FOR DG2 (SOLAR) IN THREE MODES. ....  | 80 |
| FIG 4.20. ACTIVE AND REACTIVE POWER OUTPUT FOR DG3 (WIND) IN THREE MODES. ....   | 81 |
| FIG 4.21. REQUIRED REACTIVE POWER FROM CAPACITOR BANK IN THREE MODES. ....   | 82 |
| FIG 4.22. ACTIVE AND REACTIVE POWER LOSSES IN THREE MODES.....   | 83 |
| FIG 4.23. DGS PERCENTAGE OUTPUT INCREASE IN THREE MODES.....   | 84 |
| FIG 4.24. TOTAL OPERATION COST IN THREE MODES. ....  | 85 |
| FIG 4.25. VOLTAGES PROFILE FOR THREE MODES.....  | 86 |

# List of Tables

|  |    |
|--|----|
| TABLE 2.1. CAPACITY RANGE OF DGS . . . . .   | 12 |
| TABLE 2.2. MUSICAL TERMS VS OPTIMIZATION TERMS. . . . .  | 31 |
| TABLE 3.1. THE PSEUDO CODE FOR HARMONY SEARCH. . . . .   | 40 |
| TABLE 3.2. THE PSEUDO CODE FOR TLBO . . . . .  | 44 |
| TABLE 4.1. OUTPUTS LIMITS FOR DGS, CAPACITOR BANK, AND POWER FACTOR FOR EACH<br>DG (FOR BASE CASE AND FIVE CASES). . . . . | 52 |
| TABLE 4.2. DGS COST FUNCTION COEFFICIENTS (ACTIVE POWER FIRST PART). . . . .   | 52 |
| TABLE 4.3. DGS COST FUNCTION COEFFICIENTS (REACTIVE POWER FIRST PART) . . . . .  | 52 |
| TABLE 4.4. CAPACITOR BANK COST DETAILS, PART 1 . . . . .   | 52 |
| TABLE 4.5. LOAD DATA, PART1 . . . . .  | 53 |
| TABLE 4.6. OPERATION COST WITH/ WITHOUT OPTIMIZATION. . . . .  | 54 |
| TABLE 4.7. DGS AND CAPACITOR BANK OUTPUTS, ACTIVE AND REACTIVE POWER LOSSES<br>FOR CASE 1 . . . . .                        | 56 |
| TABLE 4.8. DGS AND CAPACITOR BANK OUTPUTS, ACTIVE AND REACTIVE POWER LOSSES<br>FOR CASE 2 . . . . .                        | 58 |
| TABLE 4.9. DGS AND CAPACITOR BANK OUTPUTS, ACTIVE AND REACTIVE POWER LOSSES<br>FOR CASE 3 . . . . .                        | 60 |
| TABLE 4.10. DGS AND CAPACITOR BANK OUTPUTS, ACTIVE AND REACTIVE POWER LOSSES<br>FOR CASE 4 . . . . .                       | 62 |
| TABLE 4.11. DGS AND CAPACITOR BANK OUTPUTS, ACTIVE AND REACTIVE POWER LOSSES<br>FOR CASE 5 . . . . .                       | 64 |
| TABLE 4.12. OUTPUTS LIMITS FOR DGS, CAPACITOR BANK, AND POWER FACTOR FOR EACH<br>DG FOR (THREE MODES). . . . .             | 76 |
| TABLE 4.13. DGS COST FUNCTION COEFFICIENTS (ACTIVE POWER, PART 1) . . . . .  | 77 |
| TABLE 4.14. DGS COST FUNCTION COEFFICIENTS (REACTIVE POWER, PART 2). . . . .   | 77 |
| TABLE 4.15. CAPACITOR BANK COST DETAILS, PART 1 . . . . .  | 77 |
| TABLE 4.16. LOAD DATA, PART 2. . . . .   | 77 |

## **List of Abbreviations**

|      |                                      |
|------|--------------------------------------|
| RES  | Renewable Energy Sources             |
| DG   | Distributed Generation               |
| EMS  | Energy Management Systems            |
| PV   | Photovoltaic                         |
| WT   | Wind Turbine                         |
| EC   | Economic Dispatch                    |
| DN   | Distribution Network                 |
| PCC  | Point of Common Coupling             |
| ELD  | Economic Load Dispatch               |
| TLBO | Teaching-Learning-Based Optimization |
| HS   | Harmony Search                       |
| HMS  | Harmony Memory Size                  |
| HMCR | Harmony Memory Consideration Rate    |
| PAR  | Pitch Adjustment Rate                |
| BW   | Band Width                           |
| NI   | Number of Iteration                  |

# **Chapter 1. Introduction**

## **1.1. General Overview**

This chapter gives overview information about the thesis goals, motivation behind choice of thesis research point, and objectives needed to be achieved from this thesis. All chapters are also presented through a brief description of the major outlines in each chapter.

## **1.2. Motivation**

With an increasing interest in renewable energy sources (RES) whether they are variable renewable energy resources such as wind and solar or thermal renewable energy resources, there is a challenge to connect and integrate these RES with the main power system network. Many countries achieved the integration of high units from renewable energy with the main grid successfully, but other countries are still facing this problem. The developed power system can integrate with the rise in RES. This development is achieved by increasing the power system flexibility; at the same time of developing power system, RES is developed also in operation by adding storage unit and control systems to can integrate with main network. This development helps to achieve the coupling between RES and main grid. Power systems have many types of renewable energy resources such as wind, solar, geothermal power, and hydropower.

Energy sources come from two main categories: the first is traditional energy sources (fuel and oil) and the second is RES. Traditional energy resources are the main power sources in the world, but, now with the advanced technology, RES increase gradually to solve the population problem and fuel cost of traditional resources.

## **1.3. Thesis Objective**

By increased use of renewable DGs, in distribution network and in microgrids, the power is generated randomly because renewable DGs are

dependent on the atmospheric condition and, at the same time, demand power is random also due to the changes in loads. Therefore, balance must be made between generation and demand, taking into consideration the operation cost at all times [1]. Management system (MS) is developed to achieve this balance and one of the main components of management system is economic dispatch which balances between demand and generation with minimum cost. Economic dispatch problem is solved by using many optimizing techniques used as software; optimization process repeats every slot of time to obtain optimal management.

Reactive power is very important in electrical power system; it supports transfer active power, supplies loads with required reactive power, and security operation of electrical power system since it can affect the voltage level. As reactive power is produced from generation units, the cost is no longer free and must be estimated. Therefore, operation cost function for each generation unit must depend on active and reactive power cost.

This thesis introduces optimization operation cost for distributed generators (DGs) in microgrid depending on active and reactive power cost instead of active power cost only. This study achieves reaching optimal management and verifying the required active and the reactive power with minimum cost to save stability of the system. The main contribution in this thesis is illustrated with the new techniques, which is presented as the Teaching-Learning-Based-Optimization (TLBO) technique and Harmony Search (HS) techniques.

The study is applied in microgrid model containing three DGs (diesel, solar, and wind) and capacitor bank and this model is applied in IEEE 33 Standard Test System. This study is divided to two parts; the first part objective is to clarify efficiency of two optimization techniques in optimizing operation cost for the system depending on active and reactive