

# Contents

|  |            |
|--|------------|
| <b>Abstract</b>  | <b>iii</b> |
| <b>List of Tables</b>  | <b>xii</b> |
| <b>List of Figures</b>   | <b>xiv</b> |
| <b>1 Introduction</b>  | <b>1</b>   |
| 1.1 Distribution Systems and its Basic Structure . . . . .               | 1          |
| 1.2 Problems of Distribution Systems . . . . .                           | 2          |
| 1.3 Problem of Feeder Unbalance: Phenomenon and Causes . . . . .         | 3          |
| 1.4 Methods of Achieving Feeder Balancing . . . . .                      | 4          |
| 1.5 Feeder Load Balancing using Re-phasing of Loads . . . . .            | 7          |
| 1.6 Feeder Load Balancing using Re-phasing of Single Phase DGs . . . . . | 9          |
| 1.7 Motivation and Objective of the thesis . . . . .                     | 10         |
| 1.8 Outline of the thesis . . . . .                                      | 10         |
| <b>2 Current Injection Based Power Flow</b>                              | <b>13</b>  |
| 2.1 Introduction . . . . .   | 13         |
| 2.2 Three-Phase Current Injection Power flow . . . . .                   | 17         |
| 2.2.1 Modelling of PQ buses . . . . .                                    | 17         |
| 2.2.2 Modelling of PV buses for balanced cases . . . . .                 | 19         |
| 2.3 Results and Discussion . . . . .                                     | 22         |
| 2.3.1 Size of Jacobian Matrix (Number of System Variable) . . . . .      | 23         |
| 2.3.2 Convergence Property . . . . .                                     | 23         |
| 2.3.3 Ill-conditioned Systems with Different Load Condition . . . . .    | 24         |

|          |  |           |
|----------|--|-----------|
| 2.3.4    | Ill-conditioned Systems with Large $R/X$ Ratios Condition . . . . .                  | 27        |
| 2.3.5    | Comparison of Computation Time with CNR and FDBX . . . . .                           | 28        |
| 2.4      | Conclusion . . . . .   | 29        |
| <b>3</b> | <b>Global Optimization Techniques</b>  | <b>30</b> |
| 3.1      | What is the Optimization ? . . . . .   | 30        |
| 3.1.1    | Global Optimization . . . . .  | 32        |
| 3.1.2    | Types of Optimization . . . . .  | 33        |
| 3.1.3    | Optimization Problem used in this Work . . . . .                                     | 35        |
| 3.2      | Particle Swarm Optimization . . . . .  | 35        |
| 3.2.1    | Swarm Intelligence . . . . .   | 35        |
| 3.2.2    | Particle Swarm Optimization . . . . .  | 36        |
| 3.2.3    | PSO terminology . . . . .  | 38        |
| 3.2.4    | A Newtonian Mechanical Model . . . . .   | 39        |
| 3.3      | Butterfly Optimizer . . . . .  | 40        |
| 3.3.1    | Dual population of BO . . . . .  | 40        |
| 3.3.2    | Initialization . . . . .   | 42        |
| 3.3.3    | Perching . . . . .   | 42        |
| 3.3.4    | Patrolling . . . . .   | 43        |
| 3.4      | Performance Analysis of PSO and BO . . . . .   | 44        |
| 3.4.1    | Exploitation Behavior Analysis . . . . .   | 44        |
| 3.4.2    | Exploration Behavior Analysis . . . . .  | 47        |
| 3.4.3    | Local Optimum Avoidance . . . . .  | 50        |
| 3.5      | Conclusion . . . . .   | 52        |
| <b>4</b> | <b>Feeder Load Balancing using Re-phasing of Loads</b>                               | <b>53</b> |
| 4.1      | Introduction . . . . .   | 53        |
| 4.2      | Problem Formulation . . . . .  | 57        |
| 4.2.1    | Three-phase load change-over at distribution transformers . .                        | 57        |
| 4.2.2    | Inclusion of voltage dependency of loads in 3-phase distribution load flow . . . . . | 58        |
| 4.2.3    | Particle Swarm based phase load balancing . . . . .                                  | 61        |

|                            |   |            |
|----------------------------|---|------------|
| 4.3                        | Test System and Studies performed . . . . .                       | 64         |
| 4.4                        | Results and Discussions . . . . .                                 | 66         |
| 4.4.1                      | Case 1: Re-phasing using constant-power load model . . . . .      | 68         |
| 4.4.2                      | Case 2: Re-phasing using voltage-dependent load model . . . . .   | 69         |
| 4.4.3                      | Case 3: Effect of error in load model . . . . .                   | 74         |
| 4.4.4                      | Summary of Results . . . . .                                      | 75         |
| 4.4.5                      | Validation and Comparative Studies . . . . .                      | 77         |
| 4.5                        | Conclusion . . . . .  | 78         |
| <b>5</b>                   | <b>Feeder Load-Balancing using Re-phasing of Single Phase DGs</b> | <b>93</b>  |
| 5.1                        | Introduction . . . . .  | 93         |
| 5.2                        | Problem Formulation . . . . .                                     | 95         |
| 5.2.1                      | Mathematical representation of DG-Switch . . . . .                | 95         |
| 5.2.2                      | Inclusion of DGs in 3-phase distribution load flow . . . . .      | 95         |
| 5.3                        | Result and Discussion . . . . .                                   | 96         |
| 5.3.1                      | Test system . . . . .   | 96         |
| 5.3.2                      | Parameter Settings for BO . . . . .                               | 96         |
| 5.3.3                      | Studies Performed . . . . .                                       | 97         |
| 5.4                        | Conclusion . . . . .  | 117        |
| <b>6</b>                   | <b>Conclusions and Future Scopes</b>                              | <b>119</b> |
| 6.1                        | Conclusions . . . . .   | 119        |
| 6.2                        | Future Scopes . . . . .   | 122        |
| <b>7</b>                   |   | <b>123</b> |
| 7.1                        | VVVF Controller System Generator Model . . . . .                  | 123        |
| 7.2                        | DTC Simulink Model . . . . .                                      | 124        |
| 7.3                        | DTC System Generator Model . . . . .                              | 124        |
| <b>References</b>          |   | <b>125</b> |
| <b>List of Publication</b> |   | <b>134</b> |