

TABLE OF CONTENTS

| | |
|--|----|
| 1.0.INTRODUCTION..... | 1 |
| 1.1 Background on wind power..... | 2 |
| 1.2 Worldwide growth in wind power..... | 3 |
| 1.3 Wind resources available in Sri Lanka..... | 3 |
| 1.4 Types of wind turbine..... | 8 |
| 1.5 Objective of the Research..... | 10 |
| 2.0.VERTICAL AXIS WIND TURBINE..... | 11 |
| 2.1.Darrieus lift-based VAWT..... | 11 |
| 2.2 Savonius-dragbased VAWT..... | 12 |
| 3.0 AERODYNAMICS AND PERFORMANCE MODELS..... | 14 |
| 3.1 Aerodynamics theory and performance characteristics..... | 14 |
| 3.1.1 Lift force..... | 15 |
| 3.1.2 Drag force..... | 15 |
| 3.1.3 Reynolds number..... | 17 |
| 3.1.4 Blade solidity | 17 |
| 3.1.5 Tip speed ratio..... | 17 |
| 3.1.6 Bezt number..... | 18 |
| 3.1.7 Blade element theory | 20 |
| 3.1.8 CFD models..... | 23 |
| 3.2 Rotor performance parameters..... | 23 |
| 4.0 DESIGN OF NEW TURBINE..... | 25 |
| 4.1 Design of a new turbine..... | 25 |
| 4.2 CFD Simulation method..... | 26 |
| 5.0 DESIGN OF NEW TURBINE BLADE PROFILE..... | 33 |

| | |
|--|----|
| 5.1 Shape of the profile..... | 33 |
| 5.2 Each section of the profile..... | 34 |
| 5.3 Considered variable range..... | 35 |
| 5.4 Methodology of the designing process of the profile shape..... | 37 |
| 5.4.1 Selecting a suitable of variable d | 38 |
| 5.4.2 Selecting a suitable of variable b | 40 |
| 5.4.3 Selecting a suitable of variable a | 42 |
| 5.4.4 Selecting a suitable of variable | 44 |
| 5.4.5 Selecting a suitable of variable e | 45 |
| 5.4.6 Selecting a suitable of variable f | 46 |
| 5.5 Design of deflectors..... | 48 |
| 5.5.1 Selection of a deflector for region one | 49 |
| 5.5.2 Selection of a deflector for region two..... | 52 |
| 5.5.3 Selection of a deflector for region three..... | 55 |
| 6.0 EVALUATION OF THE PERFORMANCES OF THE WIND TURBINE..... | 58 |
| 6.1 CFD simulation method..... | 58 |
| 6.1.1 Computational procedure..... | 58 |
| 6.1.2 Case file generation and simulation..... | 59 |
| 6.2. Experiential method..... | 61 |
| 6.2.1 Open loop wind tunnel..... | 62 |
| 6.2.2 Design and fabrication of a wind tunnel..... | 66 |
| 6.2.3 Wind tunnel test arrangement..... | 70 |
| 6.2.4 Results and observation..... | 72 |
| 6.2.5 Model test at <i>Galle Fort</i> | 75 |
| 6.2.6 Prototype test at <i>Galle Fort</i> | 77 |
| 6.3 Comparison of Numerical and Experimental data..... | 83 |

| | |
|---|----|
| 6.4 Comparison of NACA 4518 blade profile and proposed blade profile..... | 84 |
| 7.0 CONCLUSIONS..... | 85 |
| REFERENCES..... | 87 |
| APPENDIX | 90 |

LIST OF FIGURES

| | |
|---|----|
| Figure 1.1: Wind resource map of Sri Lanka | 5 |
| Figure 1.2: Wind turbine types | 9 |
| Figure 2.1: Darrieus wind turbine | 12 |
| Figure 2.2: Savonius rotor | 13 |
| Figure 3.1: VAWT model in both three and two-dimensional orientations | 15 |
| Figure 3.2: Local forces on a blade | 16 |
| Figure 3.3: Airflow around an airfoil | 16 |
| Figure 3.4: Rotor efficiency vs. Downstream/Upstream Wind speed ratio | 19 |
| Figure 3.5: Plan view of actuator cylinder to analyze VAWTs | 21 |
| Figure 3.6: Lift and drag force on VAWT | 21 |
| Figure 3.7: Velocities at the rotor plane | 21 |
| Figure 3.8: Schematic of blade elements | 22 |
| Figure 3.9: Component of local angle of attack | 22 |
| Figure 3.10: Rotor efficiency vs. tip speed ratio | 24 |
| Figure 4.1: Mesh file generation | 27 |
| Figure 4.2: Simulation in <i>Fluent 6.28</i> | 28 |
| Figure 4.3: Wind pattern variation around the rotor | 28 |
| Figure 4.4: Pressure variation around the rotor | 29 |
| Figure 4.5: Angular positions of the blades | 29 |
| Figure 4.6: Torque variation of the three blades with rotor angular positions | 30 |
| Figure 4.7: Torque variation of the three blades at same angular position | 30 |
| Figure 4.8: Straight-bladed vertical axial wind turbine | 31 |
| Figure 4.9: Comparison of results | 32 |
| Figure 5.1: VAWT NACA blade profiles | 33 |
| Figure 5.2: Main features of the profile | 34 |
| Figure 5.3: Four sectors of the blade profile in x-y coordinate system | 35 |
| Figure 5.4: Coordinate system with reference to center of the turbine | 35 |
| Figure 5.5: Major points of the profile | 36 |
| Figure 5.6: Performances of the CN 455332 Profile | 38 |
| Figure 5.7: Variation of profile Shapes for different values of d | 39 |
| Figure 5.8: Power coefficient variation in different values of d | 40 |
| Figure 5.9: wind pattern variation of profile <i>CN-455332</i> | 40 |
| Figure 5.10: Variation of profile Shapes for different values of b | 41 |
| Figure 5.11: Power coefficient variation for different values of b | 41 |

| | |
|--|----|
| Figure 5.12: wind pattern and pressure variation of profile <i>CN-445332</i> | 42 |
| Figure 5.13: Variation of profile Shapes for different values of <i>a</i> | 43 |
| Figure 5.14: Power coefficient variation in deferent values of <i>a</i> | 43 |
| Figure 5.15: Variation of profile Shapes for different values of <i>c</i> | 44 |
| Figure 5.16: Power coefficient variation in different values of <i>c</i> | 45 |
| Figure 5.17: Wind pattern and pressure variation of Profile <i>CN-455332</i> | 45 |
| Figure 5.18: Power coefficient variation in deferent values of <i>e</i> | 46 |
| Figure 5.19: Power coefficient variation in deferent values of <i>f</i> | 47 |
| Figure 5.20: Typical shape of the profile | 47 |
| Figure 5.21: Define four regions for the deflectors design process | 48 |
| Figure 5.22: Deflector shapes a, b and c | 49 |
| Figure 5.23: Considered different four angular positions for deflector 1 | 49 |
| Figure 5.24: All deflector angles considered at region 1 | 49 |
| Figure 5.25: Deflector shape <i>a</i> - Angle 30-Position optimizing process at region one | 50 |
| Figure 5.26: Power coefficient variation for different position at region one | 50 |
| Figure 5.27: Selected deflector shape for optimizing angle at region one | 51 |
| Figure 5.28: Power coefficient variation for different deflector angles at region one | 51 |
| Figure 5.29: Power coefficient variation for different deflector shapes at region one | 52 |
| Figure 5.30: considered shapes for deflector two | 52 |
| Figure 5.31: Four deferent angles considered for region two | 53 |
| Figure 5.32: Power coefficient variation for different positions at region two | 53 |
| Figure 5.33: A considered case on optimizing process at region two | 54 |
| Figure 5.34: Power coefficient variation for different deflector Angles at region two | 54 |
| Figure 5.35: Power coefficient variation for different deflector shapes at region two | 55 |
| Figure 5.36: Power coefficient variation for different deflector shapes at region two | 56 |
| Figure 5.37: Initially Obtained deflectors in related regions | 56 |
| Figure 5.38: The plan view of the blades with deflectors | 57 |
| Figure 6.1: velocity variation around the wind turbine | 59 |
| Figure 6.2: Variation of power coefficient with different tip speed ratios | 60 |
| Figure 6.3: Power output variation with wind speed | 61 |
| Figure 6.4: Axial flow fan | 63 |
| Figure 6.5: A centrifugal blower | 63 |
| Figure 6.6: Wind tunnel arrangement | 66 |
| Figure 6.7: Fan connecting to the motor | 67 |

| | |
|---|----|
| Figure 6.8: Designed diffuser | 67 |
| Figure 6.9: Fan housing | 68 |
| Figure 6.10: Motor connecting to the fan | 68 |
| Figure 6.11: Designed setting chamber | 69 |
| Figure 6.12: fabricated blades | 70 |
| Figure 6.13: built model rotor with deflectors | 70 |
| Figure 6.14: Tunnel test arrangement | 71 |
| Figure 6.15: Break load applying to the rotor | 71 |
| Figure 6.16: Torque measuring arrangement of the shaft. | 72 |
| Figure 6.17: Speed measurement | 72 |
| Figure 6.18: Experimental power coefficient variation (wind tunnel test) | 74 |
| Figure 6.19: Model test at <i>Galle Fort</i> | 75 |
| Figure 6.20: Experimental Power Coefficient Variation (Model Test) | 77 |
| Figure 6.21: Main parts of the turbine | 78 |
| Figure 6.22: Fabrication details of the wind blades | 79 |
| Figure 6.23: Main Structure | 79 |
| Figure 6.24: Radial arm | 80 |
| Figure 6.25: Prototype turbine | 80 |
| Figure 6.26: Experimental Power Coefficient Variation (Prototype Test) | 82 |
| Figure 6.27: Performances variation of Numerical and Experimental analysis | 83 |
| Figure 6.28: Experimental performances of <i>NACA 4518</i> Profile and Proposed profile | 84 |

LIST OF TABLES

| | |
|--|----|
| Table 1.1: Good-to-Excellent wind resources in Sri Lanka | 6 |
| Table 1.2: NREL wind resource classes | 6 |
| Table 1.3: Wind condition variation of Sri Lanka | 8 |
| Table 4.1: Torque variation of the blades with respect to the angular position | 29 |
| Table 5.1: Expressions selected for the four sections | 34 |
| Table 5.2: Major points of the profile | 36 |
| Table 5.3: Selected independent variable ranges | 36 |
| Table 5.4: Considered Profiles for different values of d | 39 |
| Table 5.5: Considered Profiles for different values of b | 41 |
| Table 5.6: Considered Profiles for different values of a | 42 |
| Table 5.7: Considered Profiles for different values of c | 44 |
| Table 5.8: Considered Profiles for different values of e | 46 |
| Table 5.9: Considered Profiles for different values of f | 47 |
| Table 5.10: Selected Deflector details | 56 |
| Table 5.11: Obtained Deflectors details | 57 |
| Table 6.1: Turbine unit without deflectors-Wind tunnel test | 72 |
| Table 6.2: Turbine unit with deflectors-Wind Tunnel test | 73 |
| Table 6.3: Turbine unit without deflectors-Wind tunnel test (Tabulated Data) | 73 |
| Table 6.4: Turbine unit with deflectors-Wind tunnel test (Tabulated Data) | 74 |
| Table 6.5: Turbine Unit with deflectors - Model test | 76 |
| Table 6.6: Turbine Unit without deflectors –Model test | 76 |
| Table 6.7: Turbine unit with deflectors- Model test (Tabulated data) | 76 |
| Table 6.8: Turbine unit without deflectors Model test (Tabulated data) | 77 |
| Table 6.9: Turbine unit without deflectors–Prototype test | 81 |
| Table 6.10: Turbine unit without deflectors–Prototype test (Tabulated data) | 82 |