Advanced Control for Smart Microgrids in Vietnam

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DOCTOR OF PHILOSOPHY

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STATEMENT OF ORIGINAL AUTHORSHIP

This thesis is the result of a research candidature conducted jointly with another University as part of a collaborative Doctoral degree. I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:

Date: September 2017
ACKNOWLEDGEMENTS

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SUMMARY OF THE THESIS

In recent years, researchers all over the world have been focusing on renewable energy more than ever. Vietnam is a tropical country, where there is not only a high potential of renewable energy but also a challenging electrical demand in years to come. This thesis will offer a solution to help the Vietnamese power scheme with a new smart micro grid concept. This new smart microgrid also brings some control challenges to researchers such as power quality and reliability control, power sharing control, system stability, and power flow management, etc. Among the power flow management control, model predictive control has also drawn strong attention among recent control strategies. This thesis will describe the control of grid-connected inverter with model predictive control to obtain the desired real and reactive powers that transfer between the microgrid and utility grid. Numerical simulation and experimental test results will be presented in this thesis also.

The literature review in Chapter Two draws the whole background of the picture. It presents the current state of the power scheme in Vietnam, the smart grid and its characteristics along with the control techniques used in a smart microgrid. To understand the smart microgrid, a detailed microgrid is described with distributed generations (DGs), loads, and power converters. The term “smart” used in “smart microgrid” is defined in this chapter also. The state of art of the microgrid control technique is revealed afterwards. Moreover, several control methods and strategies for microgrids are presented in the last part of this chapter.
With all the demand in the upcoming years from Vietnamese power scenario and its renewable energy potential, the Vietnamese Government is trying to develop the national electrical system in both stability and capacity to ensure the supply throughout the country. Chapter Three offers a whole new structure of the smart micro grid with a major part of the energy coming from renewable sources. This chapter also presents several study cases about different scenario of various power scales in Vietnam. This not only helps to solve the problem of being blackouts that both individual and industrial customers will have to face with years to come but also can take advantage of the great amount of renewable energy sources that are plentiful in Vietnam.

To specify the structure of the microgrid, Chapter Four designs a detail smart microgrid which consists of a hybrid AC-DC bus, with its renewable energy sources as photovoltaics and wind turbines, energy storage, and AC and DC loads. The whole smart micro grid system that fits into the rural areas of Vietnam in the next 10 to 15 years not only benefits the end-user customer but also helps the main grid in case the Vietnamese Government have a change in the energy policy in the near future to encourage people extract more and more green energy. This chapter also describes the several operation options of either cost or energy efficiency of the smart microgrid.

To connect the smart microgrid with the main grid, a grid-interfaced inverter is used in this thesis to control the power flow between the microgrid and utility grid. In Chapter Five, several control methods and strategies to control real and reactive power have been applied. Firstly, the system is transformed into the \( d-q \) rotating frame; therefore the active and reactive power can be controlled separately by controlling the \( d \) and \( q \) axis current components, \( id \) and \( iq \). The first method uses the traditional PI control with feedforward to improve the control performance.
In Chapter Six, the other control method known as model predictive control is also used to control the active and reactive power flows based on the $d-q$ rotating frame. Recently, the direct power control and model predictive control of real and reactive power flows has also been applied widely in the power electronic converter control. These new control techniques appear very attractive with several advantages in comparison with classical modulation methods, especially its excellent dynamic response, simple concept and easy implementation. In the model predictive control, a model is used to predict the future behaviour of the controlled variables. This information is then used in a cost function as the criterion to select the optimal switching state for the system. The control objectives can vary with different cost functions.

In this thesis, a new smart micro grid is designed with its special features along with the model predictive control technique for the grid-connected inverter control. The results have been numerically simulated by both MATLAB Simulink and PSIM software. A protocol has been tested for the grid-connected inverter control. Important conclusions based on the research findings through the thesis project are drawn, and possible future work for further development of the technology are suggested in the last chapter.
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3.3.2. A small town/village

3.3.3. A factory far from grid

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3.3.5. A rural farm

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<th>Description</th>
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<tr>
<td>$C$</td>
<td>Filter Capacitance [$\mu f$]</td>
</tr>
<tr>
<td>$L$</td>
<td>Line Inductance [Mh]</td>
</tr>
<tr>
<td>$R$</td>
<td>Line Resistance [$\Omega$]</td>
</tr>
<tr>
<td>$S_i$</td>
<td>Switching State of Phase $i$ ($i = a, b, c$) Leg of the IGBT Bridges [0,1]</td>
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<tr>
<td>$V_{d}, V_q$</td>
<td>$d$-Axis and $q$-Axis Output Voltages of Grid-Connected Inverter in Rotating $d$-$q$ Reference Frame [V]</td>
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<td>$V_{d,ref}, V_{q,ref}$</td>
<td>Reference Value Of $V_{d}, V_q$ [V]</td>
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<td>$i_{d}, i_q$</td>
<td>$d$-Axis and $q$-Axis Currents in Rotating $d$-$q$ Reference Frame [A]</td>
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<td>$i_{d,ref}, i_{q,ref}$</td>
<td>Reference Value of $i_{d}, i_q$ [A]</td>
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<tr>
<td>$V_{out,a}, V_{out,b}, V_{out,c}$</td>
<td>Output Voltages Of Grid-Connected Inverter Leg [V]</td>
</tr>
<tr>
<td>$i_a, i_b, i_c$</td>
<td>Inverter-Side Inductor Currents of Phase $a, b, c$ [A]</td>
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<td>$V_{\alpha}, V_{\beta}$</td>
<td>Voltage in $\alpha$-$\beta$ Reference Frame [V]</td>
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<tr>
<td>$i_{\alpha}, i_{\beta}$</td>
<td>Current in $\alpha$-$\beta$ Reference Frame [A]</td>
</tr>
<tr>
<td>$f$</td>
<td>Source Voltage Frequency [Hz]</td>
</tr>
<tr>
<td>$I_{pv}$</td>
<td>Photovoltaic Current [A]</td>
</tr>
<tr>
<td>$N$</td>
<td>Coincidence Point</td>
</tr>
<tr>
<td>$N_s$</td>
<td>Number of Cells</td>
</tr>
<tr>
<td>$p$</td>
<td>Number of Pole Pairs</td>
</tr>
<tr>
<td>$R_s, R_p$</td>
<td>Equivalent Series and Parallel Resistance of PV [$\Omega$]</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
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<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>$P, Q$</td>
<td>Active and Reactive Power Transfer/Receive from the Grid [W]</td>
</tr>
<tr>
<td>$T_s$</td>
<td>Sampling Period [ms]</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Power Angle [rad]</td>
</tr>
<tr>
<td>$\psi_a, \psi_b, \psi_c$</td>
<td>Flux Linkage of Phase $a,b,c$ [Wb]</td>
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<tr>
<td>$\psi_d, \psi_q$</td>
<td>$d$-axis and $q$-axis flux Linkage [Wb]</td>
</tr>
<tr>
<td>$\psi_{pm}$</td>
<td>Permanent Magnet Flux Linkage [Wb]</td>
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AMI</td>
<td>Advanced Metering Infrastructure</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power Stations</td>
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<tr>
<td>CDMA</td>
<td>Code-Division Multiple-Access</td>
</tr>
<tr>
<td>DFIG</td>
<td>Doubly-Fed Induction Generator</td>
</tr>
<tr>
<td>DG</td>
<td>Distributed Generation</td>
</tr>
<tr>
<td>DPC</td>
<td>Direct Power Control</td>
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<tr>
<td>DSP</td>
<td>Digital Signal Processor</td>
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<tr>
<td>DTC</td>
<td>Direct Torque Control</td>
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<tr>
<td>DSL</td>
<td>Digital Subscriber Lines</td>
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<tr>
<td>ESS</td>
<td>Energy Storage System</td>
</tr>
<tr>
<td>EVN</td>
<td>Vietnam Electrical</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HAN</td>
<td>Home Area Network</td>
</tr>
<tr>
<td>IGBT</td>
<td>Insulated Gate Bipolar Transistor</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>ISM</td>
<td>Industrial Scientific and Medical</td>
</tr>
<tr>
<td>MPC</td>
<td>Model Predictive Control</td>
</tr>
<tr>
<td>MPP</td>
<td>Maximum Power Point</td>
</tr>
<tr>
<td>MPPT</td>
<td>Maximum Power Tracking Point</td>
</tr>
<tr>
<td>MS</td>
<td>Master-Slave</td>
</tr>
<tr>
<td>NIST</td>
<td>National Institute Of Standard And Technology</td>
</tr>
<tr>
<td>OQPSK</td>
<td>Offset Quadrature Phase-Shift Keying</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<td>--------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>PI</td>
<td>Proportional-Integral</td>
</tr>
<tr>
<td>PLC</td>
<td>Powerline Communication</td>
</tr>
<tr>
<td>PMSG</td>
<td>Permanent Magnet Synchronous Generator</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>PWM</td>
<td>Pulse Width Modulation</td>
</tr>
<tr>
<td>Sine-PWM</td>
<td>Sine-Coded Pulse Width Modulation</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>SCIG</td>
<td>Squirrel Gage Induction Generator</td>
</tr>
<tr>
<td>SEP</td>
<td>Smart Energy Profile</td>
</tr>
<tr>
<td>SOC</td>
<td>State Of Charge</td>
</tr>
<tr>
<td>STATCOM</td>
<td>Static Synchronous Compensator</td>
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<tr>
<td>SVM</td>
<td>Space Vector Modulation</td>
</tr>
<tr>
<td>THD</td>
<td>Total Harmonic Distortion</td>
</tr>
<tr>
<td>TOE</td>
<td>Tons of Oil Equivalent</td>
</tr>
<tr>
<td>TSR</td>
<td>Tip Speed Ratio</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
</tr>
<tr>
<td>UPS</td>
<td>Uninterruptible Power Supply</td>
</tr>
<tr>
<td>VOC</td>
<td>Voltage-Oriented Control</td>
</tr>
<tr>
<td>VSC</td>
<td>Voltage Source Converter</td>
</tr>
<tr>
<td>VSI</td>
<td>Voltage Source Inverter</td>
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<tr>
<td>WCDMA</td>
<td>Wideband Code-Division Multiple-Access</td>
</tr>
<tr>
<td>WLANs</td>
<td>Wireless Local Area Networks</td>
</tr>
<tr>
<td>WiMAX</td>
<td>Worldwide Interoperability for Microwave Access</td>
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