Advanced Control for Smart Microgrids in Vietnam

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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.

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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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LIST OF SYMBOLS

C	Filter Capacitance [µf]
L	Line Inductance [Mh]
R	Line Resistance [Ω]
S_i	Switching State of Phase i (i= a, b, c) Leg of the IGBT Bridges [0,1]
V_d, V_q	d-Axis and q-Axis Output Voltages of Grid-Connected Inverter in Rotating d-q Reference Frame [V]
V_d*/$V_{d,Ref}$, V_q*/$V_{q,Ref}$	Reference Value Of V_d, V_q [V]
i_d, i_q	d-Axis and q-Axis Currents in Rotating d-q Reference Frame [A]
i_d*/$i_{d,ref}$, i_q*/$i_{q,ref}$	Reference Value of i_d, i_q [A]
$V_{out,a}$, $V_{out,b}$, $V_{out,c}$	Output Voltages Of Grid-Connected Inverter Leg [V]
i_a, i_b, i_c	Inverter-Side Inductor Currents of Phase a, b, c [A]
V_α, V_β	Voltage in α-β Reference Frame [V]
i_α, i_β	Current in α-β Reference Frame [A]
f	Source Voltage Frequency [Hz]
I_{pv}	Photovoltaic Current [A]
N	Coincidence Point
N_s	Number of Cells
p	Number of Pole Pairs
R_s, R_p	Equivalent Series and Parallel Resistance of PV [Ω]

P, Q	Active and Reactive Power Transfer/Receive from the Grid [W]
T_s	Sampling Period [ms]
δ	Power Angle [rad]
ψ_a, ψ_b, ψ_c	Flux Linkage of Phase *a,b,c* [Wb]
ψ_d, ψ_q	*d*-axis and *q*-axis flux Linkage [Wb]
ψ_{pm}	Permanent Magnet Flux Linkage [Wb]

LIST OF ABBREVIATIONS

AMI	Advanced Metering Infrastructure
CHP	Combined Heat and Power Stations
CDMA	Code-Division Multiple-Access
DFIG	Doubly-Fed Induction Generator
DG	Distributed Generation
DPC	Direct Power Control
DSP	Digital Signal Processor
DTC	Direct Torque Control
DSL	Digital Subscriber Lines
ESS	Energy Storage System
EVN	Vietnam Electrical
GPS	Global Positioning System
HAN	Home Area Network
IGBT	Insulated Gate Bipolar Transistor
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial Scientific and Medical
MPC	Model Predictive Control
MPP	Maximum Power Point
MPPT	Maximum Power Tracking Point
MS	Master-Slave
NIST	National Institute Of Standard And Technology
OQPSK	Offset Quadrature Phase-Shift Keying
PC	Personal Computer

PI	Proportional-Integral
PLC	Powerline Communication
PMSG	Permanent Magnet Synchronous Generator
PV	Photovoltaic
PWM	Pulse Width Modulation
Sine-PWM	Sine-Coded Pulse Width Modulation
SCADA	Supervisory Control and Data Acquisition
SCIG	Squirrel Gage Induction Generator
SEP	Smart Energy Profile
SOC	State Of Charge
STATCOM	Static Synchronous Compensator
SVM	Space Vector Modulation
THD	Total Harmonic Distortion
TOE	Tons of Oil Equivalent
TSR	Tip Speed Ratio
UMTS	Universal Mobile Telecommunications System
UPS	Uninterruptible Power Supply
VOC	Voltage-Oriented Control
VSC	Voltage Source Converter
VSI	Voltage Source Inverter
WCDMA	Wideband Code-Division Multiple-Access
WLANs	Wireless Local Area Networks
WiMAX	Worldwide Interoperability for Microwave Access