

INVESTIGATIONS ON WIND BASED MICROGRID WITH SEAMLESS TRANSITION BETWEEN GRID TIED AND ISLANDING MODES

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INDIAN INSTITUTE OF TECHNOLOGY DELHI
SEPTEMBER 2017**

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by

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DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

In fulfillment of requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

SEPTEMBER 2017

CERTIFICATE

It is certified that the thesis entitled “**Investigations on Wind based Microgrid with Seamless Transition Between Grid Tied and Islanding Modes,**” being submitted by **Mrs. Geeta Pathak** for award of the degree of **Doctor of Philosophy** in the Department of Electrical Engineering, Indian Institute of Technology Delhi is a record of the student work carried out by her under our supervision and guidance. The matter embodied in this thesis has not been submitted for award of any other degree or diploma.

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ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and indebtedness to **Prof. Bhim Singh** and **Prof. B. K. Panigrahi** for providing me an opportunity to carry out the Ph.D. work under their supervision. Their keenness and vision have played an important role in guiding me throughout this study. Determination, dedication, innovativeness, resourcefulness and discipline of **Prof. Bhim Singh** and **B. K. Panigrahi** have been the inspiration for me to complete this work. Working under them has been a wonderful experience, which has provided a deep insight to the world of research. Their consistent encouragement, continuous monitoring and commitments for excellence have always motivated me to improve my work and use best of my capabilities.

My sincere thanks and deep gratitude to all advisory committee members **Prof. T. S. Bhatti**, **Prof. Sukumar Mishra**, **Dr. Nilanjan Senroy**, for their valuable advice and guidance during my research period. My grateful to **Prof. G. Bhuvaneswari**, **Dr. Amit Jain** and **Prof. B. P. Singh** and other faculty members in Electrical Engg. Deptt. for their selfless and sincere advice and guidance throughout the work. My thanks are due to Mr. Yatindar Tripathi, Mr. Satish Saha, Mrs. Sunita Verma, Ms. Moni and other Electrical Engg. Deptt. Staff for their contribution to smooth running of my financial and educational matters. My gratitude to Mr. Srichand, Mr. Puran Singh of PG M/c Lab for providing me the facilities and assistance to carry out experimental work.

My especial thanks to Mr. Ikhlq Hussain for his consistent support and motivation. I am also very thankful to Dr. Sabharaj Arya, Dr. Ram Niwas, Dr. Ujjwal Kalla, Dr. Madishetti Sandeep, Dr. N. K. Swami Naidu, Dr. Vashist Bist, Dr. Arun Kumar Verma, and Dr. Chinmay Jain, Mr. Rajan Kumar, Mr. Sachin Devassy, Mr. Nishant, Mr. Aniket Anand, Mr. Saurav Shukla, Mr. Anshul Varshney, Mr. Shadab, Mr. Shailendra Dwivedi, Mr. Anjanee Kumar Mishra, Mr.

Utkarsh Sharma, and Mr. Piyush Kant for their valuable aid and co-operation and informal support during this period. I am thankful to all female scholars Ms. Jincy Philip, Mrs. Nidhi Mishra, Ms. Yashi Singh, Ms. Swati Narula, Ms. Nupur Saxena, Ms. Seema Kewat, Ms. Radha Kushwaha, Mrs. Vandana Jain, Ms. Subarni for their support and cooperation during my research period. My thanks to all other Ph.D. and M. Tech students who directly or indirectly participate and contribute to accomplish this work.

I wish to convey my sincere thanks to Dr. H. C. Sharma, Dean C.T. (G.B.P.U.A.T), Dr. Sudha Arora Head EED, C.T. (G.B.P.U.A.T) for allowing me to pursue Ph.D. from IIT Delhi. I also cannot forget the support of my friends and colleagues Prof. A.K. Swami, Mr. Abhishek Yadav, Dr. Ajay Srivastava, Mrs. Rita Verma of C.T. (G.B.P.U.A.T) for their inspiration, support and discussion of my research work.

The completion of this work was not possible without the blessings of my father, Late Shri B. S. Negi who left this world when my work was at the verge of completion and is not with us to share this joy. The unconditional support and love of my mother, Mrs. Shanti Devi helped me at every stage of my academic and personal life to see this achievement come true. I must appreciate my husband Mr. K. K. Pathak for handling all responsibilities during my research at IIT Delhi. My especial thanks to my daughter Sejal without her cooperation this work cannot reach to such success. My thanks to my brothers and their families, my in-laws for their support and blessings.

Above all, I owe it all to Almighty God for granting me the wisdom, health and strength to undertake this research task and enabling me to its completion.

Dated:

Geeta Pathak

ABSTRACT

High living standards and dependency on electrical gadgets and appliances have increased the world wide electricity consumption. This energy demand is met out by utilizing the conventional resources (coal, diesel, petrol etc.) as well as renewable resources such as solar, wind, tidal, bio-gas etc. The energy demand for each and every area is not fulfilled by the existing power grid due to the remoteness of the places. Moreover, sometimes the power cuts lasting from few minutes to several hours occur in metropolitan cities during peak hours. The microgrid can be a good alternative to support the local demand and to fill this energy gap. The microgrid consists of various small scale distributed generations based on renewables (wind, solar, hydro etc.) and sometimes conventional resources (fossil fuel, gas etc.) and energy storage devices (battery banks, superconducting capacitors, electric vehicles etc.) to feed the local loads. It is capable of connecting or disconnecting from the utility grid to operate in grid connected or in isolated mode of operations.

This research work deals with the supplying power to the loads under such scenarios of far distant places where the grid is not feasible and the other scenario when the system is suffering from energy crisis due to the grid outages. The microgrid topologies (wind-diesel, wind-hydro and wind-solar) are proposed to feed the local loads in isolated mode for rural electrification. Various control algorithms are implemented for satisfactory performance of these microgrids under steady state and dynamic conditions. These algorithms provide voltage control, harmonics elimination, reactive power compensation and power balancing. The brushless generators such as, squirrel cage induction generator (SCIG), permanent magnet synchronous generator (PMSG), synchronous reluctance generator (SyRG) and permanent magnet brushless DC generator (PMBLDCG) are used for power generation in remote areas as they are maintenance free. For

the variable speed wind generation and solar power generation, the maximum power tracking (MPPT) is realized using perturb and observe (P&O) and incremental conductance (INC) approaches. The BESS (Battery Energy Storage System) is used to provide load leveling during wind fluctuations, solar PV (Photo-Voltaic) insolation changes and load variations. Such microgrids provide power quality solutions and are able to maintain the power balancing.

Another important function of the microgrid is its synchronization and de-synchronization from the utility grid. The grid outage is very common even in advanced cities where electrical power shedings/ cuts persist for few minutes to several hours. During such conditions, the microgrids can serve the system at local level and when the grid is appeared they can be synchronized with the AC mains. If the renewable generation is high, renewable power can be fed to the utility grid and during high demand and lower renewable generation, the grid can feed the loads. The microgrid has to operate in two modes, islanded mode and grid connected mode with the voltage control and current control algorithms. Another control called synchronization control is used for STS (Static Transfer Switch) closing/ opening for smooth transition between two modes. This is in order to make the synchronization and de-synchronization process seamless and transient free. The microgrid configurations with wind and solar PV generators, operation in isolated mode and their synchronization and de-synchronization with the utility grid are investigated in detail. In grid tied operation, the microgrid feeds power to the utility grid during high renewable generation and low demand condition. The grid power can also be utilized by the loads during nights or when the renewable generation is insufficient to feed the loads. In such a way, the load demand is continuously supplied and excess or deficit power generation is managed by the utility grid.

In another synchronization topology, a diesel generator (DG) set is used with these renewables so that during an outage when the renewable generation is not enough to meet the load demand, the DG is synchronized with the PCC (Point of Common Coupling) and starts feeding the local loads. In this way, the economic utilization of the fossil fuel resource is possible. After clearing the outage with a grid appearance, the DG is disconnected and the inverter starts operating in an islanded mode and then synchronized with the utility grid. Now as the renewable power increases the extra power can be fed to the AC mains and it is used to generate revenues.

These microgrids are capable of supplying power to the remote places as well as to the cities during outage or emergencies. Their controls are robust and are used to achieve power quality solutions and to provide power management. The satisfactory performances of these microgrids are demonstrated with simulation results obtained using developed models in MATLAB/Simulink and their validation is done with experimental results on the developed prototypes in the laboratory.

सारांश

यह अनुसन्धान दूरस्थ तथा दुर्गम स्थानों जहाँ पर ग्रिड द्वारा बिजली नहीं पहुंचाई जा सकती या जो क्षेत्र विकसित होने पर भी बिजली की अनुपलब्धता या बिजली के बाधित होने से प्रभावित हो रहे हैं, उन परिस्थितियों पर पर केंद्रित है। इस में एकाकी (आइसलैंडेड) माइक्रोग्रिड टोपोलोजिज़ जैसे विंड-डीजल , विंड-हाइड्रो, विंड-सोलर प्रस्तुत के गई हैं। ये माइक्रोग्रिडस स्थानीय लोड्स को बिजली आपूर्ति पहुंचाने के लिए विकसित की गई हैं। इनमें कई नियंत्रण तकनीकों का उपयोग हुआ है। जो माइक्रोग्रिड की सामान्य तथा परिवर्तनशील अवस्थाओं में कुशल सञ्चालन को दर्शाता है । ये तकनीकें वोल्टेज नियमन, हार्मोनिक्स निर्मूलन, रिएक्टिव ऊर्जा क्षतिपूरण और ऊर्जा संतुलन बनाये रखने में सफल हुई हैं । ब्रुशलेस जनरेटर से दुर्गम स्थानों पर ऊर्जा उत्तपादन व आपूर्ति के लिए प्रयोग हुए हैं। ताकि रखरखाव की आवश्यकता न्यूनतम रहे। गति परिवर्तनशील वायु ऊर्जा और सौर ऊर्जा से अधिकतम ऊर्जा निष्कर्षण (मैक्सिमम पावर ट्रैकिंग) के लिए पी. ऐन. ओ. और आई. ऐन.सी . तकनीकों का प्रयोग किया गया है। वायु या सौर ऊर्जा की अनियमितता के समय वैद्युत ऊर्जा समतलन के लिए बैटरी बैंक को उपयोग में लाया गया है । ये माइक्रोग्रिड बिजली की गुणवत्ता बढ़ने व ऊर्जा संतुलन में सफल हुई है।

माइक्रोग्रिड का दूसरा मुख्य पहलू ग्रिड के साथ सिंक्रोनाइज होना और और डीसिंक्रोनाइज होना है। आजकल विकसित शहरों में ग्रिड का चलेजाना बहुत साधारण बात है।

यह बिजली की कटौति कुछ मिनट से कई घंटों की हो सकती है। इन परिस्थितियों से निपटने के लिए मइक्रोग्रिड को स्थानीय लोड्स को ऊर्जा प्रदान करनी चाहिए। और ग्रिड के साथ सिंक्रोनाइज होने की सुविधा होनी चाहिए। जब रिन्यूएबल पावर उत्पादन बहुतायत में हो तो उस ऊर्जा को ग्रिड के संभरण की व्यवस्था हो और जब ऊर्जा खपत अधिक हो या रिन्यूएबल पावर उत्पादन काम हो तो ऊर्जा ग्रिड से लेने की सुविधा हो। इन सभी कृत्यों की पूर्ति के लिए मइक्रोग्रिड एकाकी तथा ग्रिड संगत प्रणाली में क्रमशः विभव (वोल्टेज) नियंत्रण तथा धारा (करंट) नियंत्रण तकनीकों के साथ काम करती है। एक अन्यत्र सिंक्रोनस नियंत्रण प्रणाली जो कि एस. टी. एस. के परिपथ में जोड़े जाने और परिपथ से अलग होने की प्रक्रिया में काम आती है। ट्रांसिएंट रहित सञ्चालन के लिए काम में आती है।

मइक्रोग्रिड की ग्रिड से जुड़ने व अलग होने की प्रणाली का प्रयोग वायु, वायु तथा सौर ऊर्जा उत्पादक मइक्रोग्रिड विन्यास (कॉन्फ़िगरेशन) के साथ प्रयोग में लाया गया है। एक भिन्न प्रकार का विन्यास ग्रिड या डीजल जनरेटर के साथ सिंक्रोनाइज व डीसिंक्रोनाइज होने के सन्दर्भ में लिया गया है। ताकि जब ग्रिड प्रस्तुत न हो और रिन्यूएबल ऊर्जा का उत्पादन भी काम हो तो डी.जी. विसंबंध कर मइक्रोग्रिड के एकाकी प्रणाली में लाते हैं और पुनः ग्रिड के साथ सिंक्रोनाइज कर ऊर्जा प्रवाह को व्यवस्थित कर देते हैं। ताकि अधिक उत्पादित ऊर्जा (बिजली) से आय प्राप्त की जा सके।

दूरस्थ स्थानों जहां ग्रिड पहुंचना संभव नहीं है तथा उन शहरों जहां बिजली की

कटौति अक्सर होती है इस प्रकार की मइक्रोग्रिड एक अच्छा बिजली उत्तपादन का माध्यम हो सकती हैं। इनकी नियंत्रण तकनीक बहुत पुख्ता, वैद्युत ऊर्जा की गुणवत्ता के बढ़ने वाली व ऊर्जा संतुलन स्थापित करने वाली है। इन मइक्रोग्रिड्स की कार्य संपादन क्षमता सिमुलेशन परिणामों के साथ मातलब/सिमलिनक सॉफ्टवेर तथा प्रयोगात्मक परिणाम लघु प्रतिकृति (प्रोटोटाइप) बना कर सिद्ध की गई है।

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LIST OF ABBREVIATIONS

ADC	Analog to Digital Channel
BESS	Battery Energy Storage System
BPFF	Back Propagation Feed Forward
CERTS	The Consortium for Electric Reliability Technology Solutions
CIGRE	The International Council on Large Electric Systems (French: Conseil International des Grands Réseaux Électriques)
CCA	Current Control Algorithm
DBR	Diode Bridge Rectifier
DFIG	Doubly Fed Induction Generator
DSO	Digital storage Oscillator
DSTATCOM	Distributed Static Compensator
EPLL	Enhanced Phase Lock Loop
GW	Giga Watts
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
INC	Incremental Conductance
kWh	Kilo Watt Hour
LMS	Least Mean Square
LMLS	Least Mean Logarithmic Square
LPF	Low Pass Filter
MG	Microgrid
MPPT	Maximum Power Point Tracking
NN	Neural Network
NSLMF	Normalized Sign Least Mean Fourth
PCB	Printed Circuit Board
PCC	Point of Common Coupling
PI	Proportional and Integral
PLL	Phase Lock Loop
PQ	Power Quality
PSO	Particle Swarm Optimization

PWM	Pulse Width Modulation
PMSG	Permanente Magnet Synchronous Generator
P&O	Perturb and Observe
RZALMS	Reweighted Zero Attractor Least Mean Square
RMS	Root Mean Square
RC filter	Ripple Filter
SA	Sign Algorithm
SCIG	Squirrel Cage Induction Generator
SHC	Sample and Hold Circuit
SRF	Synchronous Reference Frame
STS	Static Transfer Switch
SyRG	Synchronous Reluctance Generator
THD	Total Harmonic Distortion
USD	United State Dollar
VCA	Voltage Control Algorithm
VSC	Voltage Source Converter
WECS	Wind Energy Conversion System
ZCD	Zero Crossing Detector

LIST OF SYMBOLS

C_b	Parallel capacitance of BESS
$\hat{e}_{I_L}$	peak to peak current ripple of boost converter
e_{pa}	Error between actual and desired outputs
$f_s \& f_{ss}$	Switching frequency
i_a, i_b, i_c	Three phase instantaneous currents
i_a^*, i_b^*, i_c^*	Three phase source reference currents for phase a, b and c
i_{ca}, i_{cb}, i_{cc}	Three phase compensating currents
$i_{cca}, i_{ccb}, i_{ccc}$	Three phase excitation currents of the capacitor bank
I_{bt}	Charging current
i_{cn}, i_{Ln}, i_n	Compensating neutral current of VSC, load neutral current and system neutral current
I_{fp}	Fundamental active power component of the reference source current
I_{fq}	Fundamental reactive power components of reference three phase source currents
$I_{gt/gd}$	Reference grid current active component
i_{ga}, i_{gb}, i_{gc}	Sensed grid/ generator three phase currents
$i_{ga}^*, i_{gb}^*, \text{ and } i_{gc}^*$	Reference grid/generator currents
i_{La}, i_{Lb}, i_{Lc}	Three phase load currents
$i_{La}^*, i_{Lb}^*, i_{Lc}^*$	Reference load currents
I_{Ld}	Active component of load current
i_{Lfa}	Fundamental load current component for phase $\tilde{a}$
I_{Lpb}	Aggregation function of input layer for active power component of load current
I_o	Wind active component after boosting
I_{pf}	Reference active power component
i_{pa}, i_{pb}, i_{pc}	Three phase active power components of load currents
I_{pavg}	Equivalent per phase of load active power component
I_{pbl}	Aggregation function for active component of hidden layer
i_{pa}^*	Active reactive component of reference source current
$i_{PMBLDCG}$	PMBLDC generator current for phase $\tilde{a}$
I_{pv}	Solar panel current
i_{qa}, i_{qb}, i_{qc}	Three phase reactive power components of load currents
I_{qavg}	Equivalent per phase reactive power component of load current
i_{qa}^*	Reactive component of reference source current

I_{qbl}	Aggregation function for reactive component of hidden layer
I_{rip}	Current ripple of interfacing inductor
I_v	Current component coming from the PI controller
I_w & I_{wind}	Current component of Wind
i_{wa}, i_{wb}, i_{wc}	Wind turbine generated currents of phase $\tilde{a}, b, c\tilde{o}$
k_i	Integral gain
k_p	Proportional gain
L_f	Interfacing inductance
L_o	Boost inductor
m	Modulation index
$-$	Shifting operator
$-_i$	Adaptive weighted step size
N_{θ}	Reference frequency
P_{bt}	Battery Power
P_g	Grid/Generator Power
P_{hy}	Hydro power
P_L	Load demand
P_{La}, P_{Lb}, P_{Lc}	Single phase load powers
P_{pv}	Solar power
P_{RT}	Total renewable power
P_s	Source power
P_{VSC}	VSC Power
P_w & P_{wind}	Wind power
R_b	Parallel resistance of BESS
R_s	Series connected internal resistance of BESS
Q_{cc}	Reactive power of capacitor bank
$\tilde{u}$ and ℓ	Constants
S_1 to S_6	Gating signals
$''_{sa}, ''_g$ & $''_{dg}$	Grid and load voltage angles
u_{pa}, u_{pb}, u_{pc}	In-phase unit voltage templates
u_{qa}, u_{qb}, u_{qc}	Quadrature phase unit voltage templates
v_a, v_b, v_c	Three phase instantaneous voltages at PCC
v_{ab}	Line voltage
v_{abc}	Voltages of three phases
V_o	DC link voltage
V_{err}	Voltage error

V_{gt}	Grid Voltage
V_{gabc}	Three phase grid voltage
V_L	Line voltage
V_{La}, V_{Lb}, V_{Lc}	Load voltages
$V_{La}^*, V_{Lb}^*, V_{Lc}^*$	Reference load voltages
V_p^*	Peak reference voltage magnitude
V_{pv}	Solar panel output voltage
V_w	Wind speed
V_t	Terminal Voltage
V_t^*	Reference terminal voltage
$w_{pal}, w_{pbl}, w_{pcl}$	Three phase active power components of load currents
$w_{qal}, w_{qbl}, w_{qcl}$	Three phase reactive power components of load currents
X_{pb}	Active component of output of input layer neuron
X_{qb}	Reactive component of output of input layer neuron