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

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by

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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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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 अनुपल्बधता या बिजली के बाधित होने से प्रभावित होरहे हैं, उन परिस्थितियों पर पर केंद्रित है। इस मे एकाकी (आइस्लेंडेड) माइक्रोग्रिड टोपोलोजिज़ जैसे विंड-डीजल , विंड-हाइड्रो, विंड-सोलर प्रस्तुत के गईं हैं। ये माइक्रोग्रिडस स्थानीय लोड्स को बिजली आपुर्ती पहुंचने के लिए विकसित की गईं हैं। इनमें कई नियंत्रण तकनीकों का उपयोग हुआ है। जो माइक्रोग्रिड की सामान्य तथा परिवर्तनशील अवस्थाओं मे कुशल सञ्चालन को दर्शाता है । ये तकनीकें वोल्टेज नियमन, हॉर्मोनिक्स निर्मूलन, रिएक्टिव ऊर्जा क्षतिपूरण और ऊर्जा संतुलन बनाये रखने मैं सफल हुईं हैं । ब्रुशलेस जनरेटर से दुरगम 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 मे लाया गया है । ये मइक्रोग्रिड बिजली की गुणवत्ता बढ़ने व ऊर्जा संतुलन मे सफल हुई है।

मइक्रोग्रिड का दूसरा मुख्य पहलू ग्रिड के साथ सिंक्रोनाइज होना और और डीसिंक्रोनाइज होना है। आजकल विकसित शहरों मे 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 मे हो तो उस ऊर्जा को ग्रिड के संभरण की व्यवस्था हो और जब ऊर्जा खपत अधिक हो या रिन्यूएबल पावर उत्तपादन काम हो तो ऊर्जा ग्रिड से लेने की सुविधा हो। इन सभी कृत्यों की पूर्ति के लिए मइक्रोग्रिड एकाकी तथा ग्रिड संगत प्रणाली मे 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 मे जोड़े जाने और परिपथ से अलग होने की प्रक्रिया मे काम आती है। ट्रांसिएंट रहित सञ्चालन के लिए काम मे आती है।

मइक्रोग्रिड की ग्रिड से जुड़ने व अलग होने की प्रणाली का प्रयोग वायु, वायु तथा सौर ऊर्जा उत्तपादक मइक्रोग्रिड विन्यास (कॉन्फ़िगरेशन) के साथ प्रयोग मे लाया गया है। एक भिन्न प्रकार का विन्यास ग्रिड या डीजल जनरेटर के साथ सिंक्रोनाइज व डीसिंक्रोनाइज होने के सन्दर्भ मे लिया गया है। ताकि जब ग्रिड प्रस्तुत न हो और रिन्यूएबल ऊर्जा का उत्तपादन भी काम हो तो डी.जी. विसंबंध कर मइक्रोग्रिड के एकाकी प्रणाली मे लाते हैं और पुनः ग्रिड के साथ सिंक्रोनाइज कर ऊर्जा प्रवाह को व्यवस्थित कर देते हैं। ताकि अधिक उतपादित 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
æI_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
$i^*_{ga,}$ $i^*_{gb,,}$ 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 óaô
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 óaô
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 óa, b, cô
k_i	Integral gain
k_p	Proportional gain
L_f	Interfacing inductance
L_o	Boost inductor
m	Modulation index
ε	Shifting operator
ε_i	Adaptive weighted step size
ɤ$_0$	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
ů and ɣ	Constants
S_1 to S_6	Gating signals
ɗ$_{sa,}$ ɗ$_g$ & ɗ$_{dg}$	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