

**POWER MANAGEMENT OF PMSG BASED MICRO
HYDRO SYSTEM INTEGRATED WITH BATTERY
AND PV BASED SOLAR SYSTEM**

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**DEPARTMENT OF ELECTRICAL ENGINEERING
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by

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DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

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CERTIFICATE

It is certified that the thesis entitled “**Power Management of PMSG Based Micro Hydro System Integrated with Battery and PV Based Solar System**” being submitted by **Mr. Vineet P Chandran** 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 him under my supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

Dated: SEP, 2022

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ABSTRACT

Hydropower systems are classified as large, medium, small, mini, micro and pico according to their installed power generation capacity. Micro-hydropower systems are relatively small power sources that are appropriate in most cases for individual users or groups of users, who are independent of the electricity supply grid. This research work attempts to provide simulation, implementation of hardware prototypes for different topologies suitable for off-grid and grid interactive microgrid (MG) systems using a permanent magnet synchronous generator (PMSG) based micro hydro and their integration with other energy source like solar PV array. PMSGs with numerous advantages such as simplified control, high efficiency, less maintenance and robust construction are proven to be better than conventional synchronous generators. For its simplicity, robustness and small size per generated kW, this generator is favoured for micro hydro power plant. The widespread use of these machines, helps in harnessing maximum micro hydro power potential available in mountainous region and also to provide reliable electricity to people residing in those areas, where providing electricity through conventional grid is difficult due to tough geographical and harsh climatic conditions. This work investigates on the use of a PMSG for off-grid and on-grid hydro power generation integrated to renewable energy sources (RESs) and battery energy storage (BES). One of the main highlight of this thesis work, is to provide a derating loop control at MPPT that can de-rate the PV system and protects the BES from overcharging. This work also presents a comprehensive study of different modes of PMSG using RESs for power generation realizing the off-grid or grid interactive MGs feeding a combination of practical loads with viable and successful controllers to ensure desired quality power across loads.

Analysis, design, control and implementation of various isolated and grid interactive configurations of microgrids based on PV array, hydro and BES are carried out in this thesis

work. A total of 14 hybrid system configurations operating in an IM and in the grid connected mode are presented in this study. MATLAB SIMULINK environment is used to simulate all these 14 configurations and for validation of these simulated results and laboratory prototypes are developed to validate the design, control, and mode of them. The foremost objective of this work is to facilitate quality power for loads at consumer end, consisting of nonlinear loads without effecting the performance of micro hydro generator. In order to maintain continuity in the supply, various configurations based on solar PV array and hydro generators are given in the presented work, which are categorised on the basis of system configuration, i.e. number of power stages (in case of solar photovoltaic -single-stage or two-stage) and load connections (three-wire and four-wire). The VSC with appropriate control algorithm, takes care of power quality and reactive compensation of the system. The VSC also ensures the control of frequency and voltages in these configurations. In varying circumstances, the hydro generator voltages and currents satisfy the requirements of the IEEE 519 standard. In multifunctional system, the grid connected VSC, apart from transferring power from RESs to the grid, it also provides multiple objectives such as harmonics reduction, compensating the reactive power and eliminating neutral current. In this work, the synchronization method is also incorporated for efficient operation. The system is made to operate in an islanded and the grid connected modes by re-closure mechanism. The multimode controlled is used to achieve synchronization operation of these systems and to provide different functionalities at the same time. These methods are incorporated to provide uninterrupted power to loads despite availability of the grid. These systems satisfy at the disconnection from the grid and reconnection to the grid as given by the IEEE 1547 standard.

सार

यह शोध कार्य एक स्थायी चुंबक तुल्यकालिक जनरेटर पी एम एस जी आधारित छोटे हाइड्रो और अन्य ऊर्जा स्रोतों के साथ उनके एकीकरण का उपयोग करके ऑफ ग्रिड और माइक्रोग्रिड प्रणालियों का (एमजी) ग्रिड -लिए एकीकृत ऑफ एक व्यापक अध्ययन प्रस्तुत करता है। यह आरईएस और बैटरी ऊर्जा भंडारण के ग्रिड हाइड्रो पावर उत्पादन के लिए एक पीएमएसजी के उपयोग पर जांच करता-और ऑन है। पीएमएसजी, उनके कई फायदे जैसे सरलीकृत नियंत्रण, उच्च दक्षता, कम रखरखाव और मजबूत निर्माण पारंपरिक तुल्यकालिक जनरेटर से बेहतर साबित होते हैं। इसकी सादगी, मजबूती और उत्पन्न प्रति किलोवाट के छोटे आकार के लिए, ये जनरेटर छोटे पनबिजली संयंत्रों के पक्षधर हो सकते हैं। इन मशीनों के व्यापक उपयोग से पर्वतीय क्षेत्र में उपलब्ध अधिकतम छोटी पनबिजली क्षमता का दोहन करने में मदद मिल सकती है और इन क्षेत्रों में रहने वाले लोगों को विश्वसनीय बिजली प्रदान करने में मदद मिलती है, जहाँ कठिन भौगोलिक और कठोर जलवायु परिस्थितियों के कारण पारंपरिक ग्रिड के माध्यम से बिजली प्रदान करना मुश्किल है। इस प्रकार, यह अध्ययन बिजली उत्पादन के लिए आरईएस का उपयोग करके पीएमएसजी के विभिन्न तरीकों की एक व्यापक समीक्षा प्रस्तुत करता है, जो ऑफ ग्रिड या एमजी को साकार करने के लिए व्यवहारिक भार के साथ व्यावहारिक भार का संयोजन करता है और लोड पर वांछित गुणवत्ता की शक्ति सुनिश्चित करने के लिए सफल नियंत्रक होता है।

यह अध्ययन पीवी सरणी, हाइड्रो और बैटरी ऊर्जा भंडारण (बीईएस) पर आधारित विभिन्न पृथक और ग्रिड इंटरैक्टिव कॉन्फिगरेशन के विश्लेषण, डिजाइन, नियंत्रण और कार्यान्वयन के उद्देश्य से है। पृथक मोड और ग्रिड से जुड़े मोड में काम करने वाले कुल सोलह प्रणाली इस अध्ययन में प्रस्तुत किए गए हैं। सभी प्रणाली कॉन्फिगरेशन MATLAB सिमुलिक वातावरण में अनुकरण हैं और अनुकरण परिणामों के सत्यापन के लिए प्रयोगशाला नमूने विकसित किए गए हैं। इस काम का मुख्य उद्देश्य हाइड्रो जनरेटरों के प्रदर्शन को प्रभावित किए बिना नॉनलाइनर लोड से मिलकर उपभोक्ता भार को गुणवत्ता की शक्ति प्रदान करना है। आपूर्ति में निरंतरता बनाए रखने के लिए, सौर पीवी, हाइड्रो और पीवी सिस्टम पर आधारित विभिन्न विन्यास इस काम में प्रस्तावित हैं, जिन्हें सिस्टम कॉन्फिगरेशन के आधार पर वर्गीकृत किया गया है, अर्थात बिजली के चरणों की संख्या स्टेज) सौर पीवी) और-स्टेज या टू-(सिंगललोड कनेक्शन तार)। उचित -तार और चार-(तीन नियंत्रण एल्गोरिदम के साथ पी एस सी प्रणाली की बिजली की गुणवत्ता और प्रतिक्रियाशील मुआवजे का ख्याल रखते हैं। VSC भी कई विन्यास में आवृत्ति, शक्ति और वोल्टेज के नियंत्रण को सुनिश्चित करता है। किसी भी परिस्थिति में हाइड्रो जनरेटर वोल्टेज और धाराएं (आई ई ई ई-519) मानक की आवश्यकताओं को पूरा करती हैं। बहुक्रियाशील प्रणाली में ग्रिड कनेक्टेड वीएससी, आरईएस से ग्रिड में बिजली स्थानांतरित करने के अलावा, यह हार्मोनिक शमन, प्रतिक्रियाशील बिजली मुआवजा जैसे कई उद्देश्य भी प्रदान करता है। इस काम को आगे बढ़ाकर कुशल तुल्यकालिक विधि, आइलैंडिंग डिटेक्शन और पुनरावृत्ति तंत्र को शामिल किया गया है, जिसके इस्तेमाल से मल्टीमॉडल कंट्रोलर कई कार्यशीलता प्रदान करने के लिए मोड्स के बीच स्विच करता है, साथ ही ग्रिड की उपलब्धता के बावजूद लोड के बिना निर्बाध आपूर्ति सुनिश्चित करने, कनेक्शन को संतुष्ट करता है और आई ई ई ई- मानक 1547 में निर्धारित वियोग मापदंड में है।

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LIST OF ABBREVIATIONS

RES	Renewable Energy Sources
PV	Photo Voltaic
BES	Battery Energy Storage
MPPT	Maximum Power Point Tracking
P & O	Perturb and Observe
MP& O	Modified Perturb and Observe
INC	Incremental Conductance
DC	Direct Current
AC	Alternating Current
PCC	Point of common coupling
DSTATCOM	Distribution Static Compensator
IGBT	Insulated Gate Bipolar Transistor
VSC	Voltage Source Converter
PMSG	Permanent Magnet Synchronous Generator
PLL	Phase Locked Loop
FLL	Frequency Locked Loop
STS	Static Transfer Switch
DSP	Digital Signal Processor
ADC	Analog to Digital Converter
PI	Proportional Integrator
MAF-EPLL	Moving Average Filter Enhanced Phase Locked Loop
IM	Isolated Mode
GCM	Grid Connected Mode
SOGI	Second Order Generalized Integrator
TOGI	Third Order Generalized Integrator

FOGI	Fourth Order Generalized Integrator
S&H	Sample and Hold
TOSI	Third Order Sinusoidal Integrated
MSOGI	Multi-layer Second Order Generalized Integrated
ISOGI	Improved Second Order Generalized Integrated
MG	Micro Grid
DGS	Distributed Generated Systems
CF-FLL	Comb- filter Frequency Locked Loop
DSOGI	Dual Second Order Generalized Integrated
FC	Fundamental Component
SO-CCF	Second Order Complex Coefficient Filter
BDC	Bi- Directional Convertor
NF	Notch Filter
BPF	Band Pass Filter
LPF	Low Pass Filter
HPF	High Pass Filter
THD	Total Harmonic Distortion
CBF	Complex Band Pass Filter

LIST OF SYMBOLS

$v_{sab}, v_{sbc}, v_{sca}$	PMSG generator line voltages
i_{sa}, i_{sb}, i_{sc}	PMSG generator line currents
v_{sa}, v_{sb}, v_{sc}	PMSG generator phase voltages
i_{La}, i_{Lb}, i_{Lc}	Nonlinear load currents
i_{ca}, i_{cb}, i_{cc}	Voltage source converter currents
i_{sn}, i_{Ln} and i_{cn}	Source neutral current, load neutral current and 4th leg converter current.
V_{pv}, I_{pv} and V_{dc}	PV array voltage, current and DC- link voltage
i_{sa} THD, i_{sb} THD, i_{sc} THD,	The source current THDs
v_{sab} THD, v_{sbc} THD, v_{sca} THD	The source voltage THDs
i_{La} THD, i_{Lb} THD, i_{Lc} THD	The load current THDs
P_g, Q_g	Generator powers
V_s THD	THD of source voltage
i_{La}, i_{Lb}, i_{Lc}	Load currents
P_L, Q_L	Load powers
i_L THD	Harmonic spectrum of load current
i_{ca}, i_{cb}, i_{cc}	VSC currents
P_c, Q_c	Converter powers
D	Duty ratio
I_{Loss}	Active loss component
I_{qq}	Reactive voltage component
$I_{pLTotal}$	Amplitude of active component
$i_{qLTotal}$	Amplitude of reactive component
V_{batt} and I_{batt}	BES voltage and BES current
L_f	Interfacing inductor

R_f and C_f	Ripple filter resistance and inductance
P_{PV}	PV array power
I_{PV}	PV array current
V_{PV}	PV array voltage
V_{mpp}	MPP voltage
I_{mpp}	MPP current
V_{oc}	Open circuit PV voltage
I_{sc}	Short circuit PV current
V_{PVref}	Reference PV array voltage
V_{Labc}	Load voltage
i_{Labc}	Load current
w_{ap} and w_{aq}	Inphase and quadrature unit templates
i_α and i_β	Orthogonal voltages
V_t	RMS value of terminal Voltage of PCC
V_t^*	Reference RMS value of terminal Voltage of PCC
V_{te}	Error in RMS value of terminal Voltage of PCC
i_{Cabc}	VSC current
f_g and f_s	Grid and hydro generator frequency
θ_g and θ_s	Grid and hydro generator angles
m_a	Modulation index
a	Over loading factor
V_{sm}	Estimated amplitude of the grid voltage
f_{sw}	Switching frequency
P_w	Wind power
$i_{L\alpha}$ and $i_{L\beta}$	Orthogonal component of load current
I_{ds} and I_{qs}	d-axis and q-axis component of PMSG source current
K_1, K_2, K_3	Gains of the generalized integrators

K_{pv} , k_{iv} , k_{if} and k_{pf} Integral and proportional gain of voltage and frequency PI controllers