POWER SHARING AND VOLTAGE COMPENSATION MODELING USING ADAPTIVE VIRTUAL IMPEDANCE-BASED PREDICTIVE CONTROL IN ISLANDED MICROGRID

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To my beloved Parents, Wife, Daughters (Hareem Fatima and Hamnah Fatima), Brothers and Sister.

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ABSTRACT

In microgrid's islanded mode of operation, the precise power sharing is an immensely critical challenge when there is a difference in line impedance of the DG inverters connected in parallel. The existing control strategies in parallel connected inverter-based microgrid power sharing issues, voltage compensation at point of common coupling (PCC) and circulating current among connected inverters in mismatched feeder impedance case need to be addressed. This project aimed to develop decentralised power sharing and voltage compensation modelling using the predictive control scheme for an islanded microgrid structure with two Voltage Source Converters (VSCs). This mismatched impedance was nullified by using the adaptive virtual impedance (AVI) control. The finite control set–model predictive control (FCS-MPC) strategy was used to replace the pulse-width modulation (PWM) strategy in order to have fast response, which had the benefit of power sharing among the VSCs, while compensating for the rated voltage at the PCC due to load changing. The AVI was used to generate the reference voltage, which responded to the values of the impedance mismatch by utilising the derivative terms for the FCS-MPC for faster tracking response and minimum tracking error when the load changed rapidly. The AVI-based predictive control scheme was compared with the conventional and static virtual impedance (SVI) methods based on the simulation results obtained through MATLAB/Simulink software. From the results, the power sharing accuracy for the connected loads for the proposed AVI-based predictive control scheme improved by 99%. The voltage error for the compensation at PCC was 0.01% under the AVI-based predictive control scheme, 1.92 % under the SVI-based control scheme and 0.72 % under the conventional control scheme. The circulating current was suppressed up to 0.047 A under the AVI-based predictive control scheme with the condition of mismatched line impedances. The AVI-based predictive control scheme was able to enhance power sharing performance and simultaneously maintain the voltage magnitude at the PCC effectively when the loads changed.

ABSTRAK

Dalam mod operasi pulau mikrogrid, perkongsian kuasa yang tepat adalah cabaran yang sangat kritikal apabila terdapat perbezaan dalam galangan talian penyongsang DG yang disambungkan secara selari. Strategi kawalan sedia ada dalam isu perkongsian kuasa mikrogrid berasaskan penyongsang bersambung selari, pampasan voltan pada titik gandingan sepunya (PCC) dan arus edaran antara penyongsang yang disambungkan dalam kes galangan penyuap yang tidak sepadan perlu ditangani. Projek ini bertujuan untuk membangunkan perkongsian kuasa terdesentralisasi dan pampasan voltan menggunakan skema kawalan ramalan untuk struktur mikrogrid pulau dengan dua Penukar Sumber Voltan (VSC). Impedans yang tidak sepadan ini telah dibatalkan dengan menggunakan kawalan impedans maya suai (AVI). Strategi kawalan ramalan model set kawalan terhingga (FCS-MPC) digunakan untuk menggantikan strategi modulasi lebar nadi (PWM) untuk mendapat tindak balas pantas, yang mempunyai faedah perkongsian kuasa di kalangan VSC, sambil mengimbangi penarafan. voltan pada PCC akibat perubahan beban. AVI digunakan untuk menjana voltan rujukan, yang bertindak balas kepada nilai ketidakpadanan impedans dengan menggunakan istilah terbitan untuk FCS-MPC untuk tindak balas penjejakan yang lebih pantas dan ralat penjejakan minimum apabila beban berubah dengan cepat. Skim kawalan ramalan berasaskan AVI dibandingkan dengan kaedah impedans maya (SVI) konvensional dan statik berdasarkan keputusan simulasi yang diperolehi melalui perisian MATLAB/Simulink. Daripada keputusan, ketepatan perkongsian kuasa untuk beban yang disambungkan untuk skim kawalan ramalan berasaskan AVI yang dicadangkan bertambah baik sebanyak 99%. Ralat voltan untuk pampasan di PCC ialah 0.01% di bawah skim kawalan ramalan berasaskan AVI, 1.92 % di bawah skim kawalan berasaskan SVI dan 0.72 % di bawah skim kawalan konvensional. Arus edaran ditekan sehingga 0.047 A di bawah skim kawalan ramalan berasaskan AVI dengan keadaan galangan talian yang tidak sepadan. Skim kawalan ramalan berasaskan AVI dapat meningkatkan prestasi perkongsian kuasa dan pada

masa yang sama mengekalkan magnitud voltan pada PCC dengan berkesan apabila beban berubah.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Ampere
AC	-	Alternating current
AVI	-	Adaptive Virtual impedance
CC	-	Circulating Current
CF	-	Cost Function
DC	-	Direct current
DG	-	Distributed Generation
FCS-	-	Finite control set Model Predictive Control
f_{nom}	-	Nominal Frequency
GPC	-	Generalized Predictive Control
LPF	-	Low pass filter
LUT	-	Lookup table
Hz	-	Frequency
W	-	Watt
MGs	-	Micro Grid system
PCC	-	Point of common coupling
PI	-	Proportional Integral
PLL	-	Phase Lock Loop
P_{Load}	-	Load active power
PV	-	Photovoltaic
ΔP	-	Microgrid active power deviation
PWM	-	Pulse width Modulation
Q_L	-	Load reactive power
Q_n	-	Inverter reactive power (n=number of inverter)
VI	-	Virtual impedance
L_{vir}	-	Virtual inductance
ΔQ	-	Microgrid Reactive power deviation

R_{vir}	-	Virtual resistance
RMS	-	Root mean square
r	-	Reference signal
s	-	Second
FCS	-	Finite Control Set
MPC	-	Model Predictive Control
RERs	-	renewable energy resources
SVM	-	Space vector modulation
IGBTs	-	Insulated-Gate Bipolar Transistor
V	-	Voltage
V_{dc}	-	DC voltage
V_g	-	Microgrid output voltage
V_o	-	Output voltage
T_s	-	Sampling Time
V_{nom}	-	Nominal Voltage
ω_{nom}	-	Nominal angular frequency
OSS	-	Optimal Switching Sequence
OSV	-	Optimal Switching Vector
EPC	-	Explicit Predictive Control
m_p, n_q	-	Power controller Coefficients
λ_d	-	Weighting Factor

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APPENDIX F

LIST OF PUBLICATIONS

1. **M. H. Khan**, S. A. Zulkifli, N. Zeb, R. Jackson, and E. Garba, "Decentralized Adaptive-Virtual-Impedance-Based Predictive Power for Mismatched Feeders in Islanded Microgrids," vol. 12, no. 2, 2022. doi.org/10.20508/ijrer.v12i2.12772.g8450 (Published IJRER Q2 Scopus,WoS)
2. **M. H. Khan**, S. A. Zulkifli, R. Jackson, G. Elhassan, W. Ahmad, and M. A. Sadiq, "Power Sharing Control and Voltage Compensation Using Virtual Impedance Loop Control for Islanded Microgrid," 3rd IEEE International Virtual Conference on Innovations in Power and Advanced Computing Technologies, i-PACT 2021, pp. 1–6, 2021. (IEEE Xplore). doi: 10.1109/i-PACT 52855. 2021.9696538 (Published)
3. **M. H. Khan** and S. A. Zulkifli, "Resiliency Impact of circulating current suppression for parallel connected inverters in Microgrid. (Published in IEEE Letters)
4. **M. H. Khan**, S. A. Zulkifli, E. Pathan, E. Garba, R. Jackson, and H. Arshad, "Decentralize power sharing control strategy in islanded microgrids," vol. 20, no. 2, pp. 752–760, 2020. doi: 10.11591/ijeecs.v21.i2.pp682-690. (Published in Scopus Q3)
5. G. Elhassan, S. A. Zulkifli, E. Pathan, **M. H. Khan** and R. Jackson "ORIGINAL RESEARCH PAPER A comprehensive review on time-delay compensation techniques for grid-connected inverters," IET Power Generation ,Willy no. January, pp. 1–16, 2020. doi:10.1049/rpg2.12033 (Published in Scopus Q2, WoS).
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APPENDIX G

VITA

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