SHUNT ACTIVE POWER FILTER BASED ON PARTICLE SWARM OPTIMIZATION-WAVELET TRANSFORM AND ZERO CROSSING CONTROLLER

EKHLAS MHAWI THAJEEL

Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Electrical Engineering.

____

(Supervisor's Signature)

Full Name : ASSOC. PROF. DR. HAMDAN BIN DANIYAL

Position : SENIOR LECTURER

Date : JUNE 2018

____

(Co-supervisor's Signature)

Full Name : ASSOC. PROF. DR. MOHD HERWAN SULAIMAN

Position : SENIOR LECTURER

Date : JUNE 2018

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : EKHLAS MHAWI THAJEEL

ID Number : PEE14001

Date : JUNE 2018

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ABSTRAK

Salah satu masalah serius dengan beban elektrik moden adalah harmonik, yang dihasilkan daripada beban bukan linear. Harmonik boleh menyebabkan haba yang berlebihan dan bunyi bising dalam beban dan menghasilkan banyak kerugian tenaga sama ada dalam sistem penghantaran atau sistem pengedaran elektrik. Pampasan harmonik ini meningkatkan faktor kuasa dan mengurangkan jumlah penyelewengan indeks harmonik (THD) dengan ketara. Ini secara langsung memungkinkan satu sistem mampu memindahkan kuasa aktif dengan lebih banyak tanpa perlu meningkatkan kapasiti. Secara tradisional, penapis pasif telah digunakan untuk menghilangkan harmonik. Namun, oleh kerana beberapa kekurangan instrinsik, penapis pasif telah digantikan oleh penapis kuasa aktif (APF). APF mempunyai ciri penapisan yang unggul dan tindak balas dinamik yang lebih baik berbanding dengan pasif. Sejak beberapa dekad ini, terdapat peningkatan yang ketara dalam penyelidikan APF dan kaedah pengawalannya. Terdapat tiga faktor yang mendorong penyelidikan dalam tesis ini; (1) walaupun banyak kajian telah membuktikan bahawa maklumat persimpangan sifar adalah penting dalam banyak isyarat kawalan, belum wujud percubaan untuk menggabungkan pengawal persimpangan sifar (ZCC) dalam kawalan voltan DC APF, (2) pengoptimuman gerombolan partikel (PSO) telah digunapakai untuk kawalan voltan DC di APF, tetapi penyelidikan prestasi dinamik untuk teknik sedemikian tidak diterbitkan, dan (3) Bingkai Rujukan Segerak (SRF) telah digunakan secara meluas untuk pengekstrakan harmonik dalam APF, walaupun telah dikenalpasti mempunyai respons yang perlahan. Manakala, Transformasi Wavelet Diskrit (DWT) adalah calon yang baik untuk pengekstrakan harmonik, namun tidak mendapat perhatian dalam penyelidikan sebelum ini kerana sifatnya yang lebih kompleks. Kajian tesis ini cuba mengatasi tiga ruang penambahbaikan ini dengan memperkenalkan ZCC, PSO dan DWT sebagai gabungan pengawal baharu untuk APF. Pengawal baru dibangunkan dengan teliti dalam perisian MATLAB-Simulink. Sumber harmonik yang digunakan ialah beban tak linear 5.5 kW yang mirip beban sebenar dari satu kajian praktikal. Ujian kes adalah dari keadaan mantap, pelbagai beban, beban dinamik dan voltan tidak seimbang. Keputusan menunjukkan bahawa DWT mengatasi SRF dalam semua ujian kes dengan purata peningkatan prestasi sebanayak 53%. Didapati juga bahawa kombinasi PSO dan DWT menampakkan hasil yang lebih baik secara umum. Ia adalah pengawal yang lebih unggul berbanding pengawal tradisi Integral Proportional yang ditala dengan kaedah Zeigler-Nichols (PI-ZN) dan Pengawal Logik Kabur (FLC). Walau bagaimanapun, ZCC-DWT secara konsisten menghasilkan prestasi yang lebih baik daripada semua pengawal lain dalam salah satu ujian kes; voltan tidak seimbang. Sebagai kesimpulan, DWT adalah calon yang lebih baik untuk pengekstrakan harmonik dalam APF, berbanding dengan SRF. Bersama dengan DWT, PSO dan ZCC adalah gabungan pengawal yang sangat baik dalam ujian kes yang berbeza. Gabungan baru pengawal ini adalah calon yang baik untuk diterima secara meluas sebagai pengawal baru dalam APF moden.

ABSTRACT

One of the serious problems with modern electrical loads is harmonics, which is generated from nonlinear loads. Harmonics can lead to excessive heat and noise in the loads and create large amount of energy losses either in transmission systems or distribution systems. Compensation of these harmonics substantially improves the power factor and reduces the total harmonic distortion index (THD). This means that the system can transfer more active power without having to increase the capacity. Traditionally, passive filters have been used to remove harmonics but for their intrinsic downsides, they have been replaced by active power filter (APF). APF has superior filtering characteristics and dynamic response compared to passive filters. Over the past decades, there has been a significant increase in interest of APFs and its control methods. There are three factors that drives the research in this thesis; (1) although many studies has proven that zero crossing information is crucial in many control signal, there have been no attempt on incorporating zero crossing controller (ZCC) in APF DC link voltage regulation, (2) Particle swarm optimization (PSO) has been adapted for DC link voltage regulation in APF, but there is lack of evidences of dynamic performance investigation for such techniques, and (3) Synchronous Reference Frame (SRF) has been widely adopted for harmonics extraction in APF, although it has been found out to have a slow response. Discrete Wavelet Transform (DWT) on the other hand, is a good candidate for harmonics extraction, but have not received enough attention in the literature due to its relatively high complexity. This study attempts to tackle these gaps by introducing ZCC, PSO and DWT as a new fusion of controller for APF. The new controller is thoroughly developed and rigorously simulated in MATLAB-Simulink environment. The harmonics source is a 5.5 kW nonlinear load mimicking a real-life load from previous practical studies. The test cases ranges from steady state, various loads, dynamic loads and unbalance voltage. The results show that DWT outperforms SRF in all test cases with average 53% improvement. It is also found out that the combination of PSO and DWT yield better results in general. It is a superior controller as compared to traditional Zeigler-Nichols tuned Proportional Integral (PI-ZN) controller and Fuzzy Logic Controller (FLC). However, ZCC-DWT consistently yields better performance than all other controller in one of the test case; the unbalance voltage. As conclusion, DWT is a better candidate for harmonics extraction in APF, as compared with SRF. Together with DWT, PSO and ZCC perform very well in different test cases. This new combination of controller is a good candidate to be widely accepted as a new controller in modern APF.

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LIST OF SYMBOLS

E_{SS}	Steady state error
f_1	Fundamental frequency
f_S	Sampling frequency
f_{sw}	Switching frequency
I_1	Fundamental current component
I_a^*, I_b^*, I_c^*	current reference signal in a-b-c phase
i_d, i_q	Direct and quadrature current
I_f	Filter current
I^*_f	Final reference current signal
I_L	Load current component
I^*_{L1}	The fundamental component of load current
I_{max}	The peak value of reference current
I^*_S	Sinusoidal reference source current
I_α,I_β	Alpha and Beta axis voltage component
K_I	Integral gain of current controller
K_P	Proportional gain of current controller
L_S, L_L, L_f	Source, Load and Filter inductances
P	Active power
Q	Reactive power
R_S, R_L, R_f,	Source, Load and Filter resistances
S	Apparent power
T	Time period of the current
T_S	Settling time
u_{si}	Unit current vectors
V_1	Fundamental voltage component
V_{dc}	DC voltage
V^*_{dc}	Reference voltage
V_f	Filter voltage
V_d , V_q	Direct and quadrature voltage
V_α, V_β	Alpha and Beta axis current component
ω	System frequency
ω_1	System fundamental frequency
ω_n	System n order harmonic frequency
δ	Phase shift relative to the ac source

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANN	Artificial Neural Network
APF	Active Power Filter
BJTs	Bipolar Junction Transistors
CSAPF	Current Source Active Power Filters
CSI	Current Source Inverter
CWT	Continuous Wavelet Transform
DCC	Direct Current Control
DF	Distortion Factor
DPF	Displacement Power Factor
DSP	Digital Signal Processor
DWT	Discrete Wavelet Transform
FFT	Fast Fourier Transform
FLC	Fuzzy Logic Controller
GA	Genetic Algorithm
GTOs	Gate Turn-Off Thyristors
HAPF	Hybrid Active Power Filters
HBCC	Hysteresis Band Current Controller
HPFs	High-Pass Filters
HV	High voltage
HVDC	High Voltage Direct Current
IAE	Integral of Absolute Error
ICC	Indirect Current Control
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBTs	Insulated Gate Bipolar Transistors
IRPT	Instantaneous Reactive Power Theory
ISE	Integral of Squared Error
ITAE	Integral of Time Multiplied by Absolute Error
ITSE	Integral of Time Multiplied by Squared Error
LPFs	Low Pass Filters

LV	Low voltage
MRA	Multi Resolution Analysis
M.F's	Membership Functions
MOSFETs	Metal–Oxide–Semiconductor Field-Effect Transistors
NL	Nonlinear Load
OF	Objective Function
OS	Overshoot
PCC	Point of Common Coupling
PE	Power Electronic
PI	Proportional-Integral Controller
PLL	Phase Lock Loop
PQ	Power Quality
p–q theory	Instantaneous active and reactive power theory
PSO	Particle Swarm Optimization
PWM	Pulse Width Modulation
RMS	Root Mean Square
SAPF	Shunt Active Power Filter
SPWM	Sinusoidal Pulse Width Modulation
SRF	Synchronous Reference Frame
STATCOM	Static Compensator
SVPWM	Space Vector Pulse Width Modulation
THD	Total Harmonic Distortion
TDD	Total Demand Distortion
UPSs	Uninterruptible Power Supplies
US	Undershoot
VSI	Voltage Source Inverter
VSAPF	Voltage Source Active Power Filters
WT	Wavelet Transform
DWT	Discrete Wavelet Transform

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