HARMONIC IMPACT OF INVERTER BASED DISTRIBUTED GENERATION AND OPTIMAL HARMONIC CONTROL USING IMPROVED GRAVITATIONAL SEARCH ALGORITHM

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KESAN HARMONIK BAGI PENJANA TERAGIH BERASASKAN PENYONGSANG DAN KAWALAN OPTIMA HARMONIK MENGGUNAKAN ALGORITMA CARIAN GRAVITI DIPERBAIKI

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DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

Presence of distributed generation (DG) in the distribution system may lead to several advantages such as voltage support, loss reduction, deferment of new transmission and distribution infrastructure and improved system reliability. However, when inverter based DG is connected to a distribution system, it may contribute to power quality problem such as harmonic distortion and resonance. The effect of harmonic not only presents a severe power quality problem but it can also trip protection devices and cause damage to sensitive equipment. In this research, the first objective is to investigate the harmonic impact of different types of DG. For this purpose, a comprehensive study is made to compare the harmonic distortion produced by the different types and number of DG units in a low voltage distribution system. Here, three types of DG units are considered, namely, a mini hydro power, wind turbine doubly fed induction generator and photovoltaic system. The second objective is to determine the maximum allowable penetration level of inverter based DG by considering the harmonic resonance phenomena and harmonic distortion limits. Simulations were carried using the MATLAB/SimPowerSystems software to investigate the impact of DG at different penetration depths. To control harmonic propagation in a distribution system with DG units, an appropriate planning of DG units is considered by determining optimal placement, sizing and voltage control of DG units. Thus, the third objective of this research is to develop an effective heuristic optimisation technique such as improved gravitational search algorithm (IGSA) technique for determining the optimal placement, sizing and voltage control of DG units in a radial distribution system. A multi-objective function is formulated to minimise total power losses, voltage total harmonic distortion (THD_v) and voltage deviation in a distribution system. The loadflow algorithm from MATPOWER and harmonic loadflow are integrated in the MATLAB environment to solve the multi-objective optimisation problem. The proposed IGSA technique is compared with other optimisation techniques, namely, particle swarm optimisation (PSO) and gravitational search algorithm (GSA). Test results on the harmonic impact of inverter based DG show the presence of resonance phenomena and harmonic distortion due to the interaction of the inverter based DG and grid impedance. Moreover, the results also indicate that the maximum permissible penetration level of inverter based DG in the test distribution system is found as 50% of total connected load. Four case studies on an IEEE 13 bus and 69 bus distribution system have been conducted to validate the effectiveness of IGSA. The optimisation results shown that IGSA gives the best fitness value and the fastest average elapsed time compared to PSO and GSA.

ABSTRAK

Kewujudan penjana teragih (PT) dalam sistem pengagihan kuasa mungkin menyumbangkan beberapa kebaikan seperti sokongan voltan, pengurangan kehilangan kuasa, penangguhan pembinaan infrastruktur baru bagi sistem penghantaran dan pengagihan serta peningkatan keboleharapan sistem. Walaubagaimanapun, apabila PT berasaskan penyongsang disambungkan ke sistem pengagihan, ia mungkin menyumbangkan kepada masalah kualiti kuasa seperti herotan harmonik dan salunan. Kesan harmonik bukan sahaja menyebabkan masalah kualiti kuasa yang teruk, bahkan ia juga menyebabkan peranti perlindungan dan memusnahkan peralatan yang peka. Di dalam penyelidikan ini, objektif pertama ialah untuk mengkaji kesan harmonik daripada pelbagai jenis PT berasaskan penyongsang. Bagi tujuan ini, kajian menyeluruh telah dilakukan untuk membandingkan herotan harmonik yang dihasilkan oleh pelbagai jenis dan bilangan unit PT di dalam sistem pengagihan voltan rendah. Dengan ini, tiga jenis unit PT dipertimbangkan, iaitu, penjana kuasa mini hidro, turbin angin penjana aruhan dua suapan dan sistem fotovolta. Objektif kedua ialah menentukan aras penembusan maksima yang dibenarkan bagi PT berasaskan penyongsang dengan mengambilkira fenomena harmonik salunan dan had herotan harmonik. Simulasi menggunakan perisian MATLAB/SimPowerSystems dilaksanakan bagi mengkaji kesan kedalaman penembusan PT. Untuk mengawal perambatan harmonik di dalam sistem pengagihan, perancangan yang sesuai bagi unit PT perlu dipertimbangkan dengan menentukan kedudukan, saiz dan kawalan voltan optima bagi PT. Justeru, objektif ketiga penyelidikan adalah untuk membangunkan teknik pengoptimuman heuristik yang berkesan seperti teknik algoritma carian graviti diperbaiki (ACGD) untuk menentukan kedudukan, saiz dan kawalan voltan yang optimum bagi PT di dalam sistem jejari pengagihan kuasa. Satu fungsi pelbagai-objektif dirumuskan untuk meminimumkan jumlah kehilangan kuasa, purata jumlah herotan harmonik voltan (JHH_v) dan sisihan voltan di dalam sistem pengagihan. Algoritma aliran beban dari MATPOWER dan aliran beban harmonik telah disepadukan di dalam persekitaran MATLAB bagi menyelesaikan masalah pengoptimuman pelbagai-objektif. Teknik ACGD yang dicadangkan telah dibandingkan dengan teknik pengoptimuman yang lain seperti pengoptimuman kuruman zarah (PKZ) dan algoritma carian graviti (ACG). Hasil ujian ke atas kesan harmonik bagi PT berasaskan penyongsang menunjukkan kewujudan fenomena salunan dan herotan harmonik disebabkan interaksi di antara PT berasaskan penyongsang dengan galangan grid. Selain itu, hasil kajian turut menunjukkan bahawa aras maksimum penembusan yang dibenarkan bagi PT berasaskan penyongsang di dalam sistem ujian pengagihan adalah 50% daripada jumlah keseluruhan beban tersambung. Empat kajian kes telah dilakukan ke atas sistem pengagihan Institut Elektrik dan Elektronik Antarabangsa (IEEA) 13 bas dan 69 bas untuk mengesahkan keberkesanan ACGD. Hasil kajian pengoptimuman menunjukkan bahawa ACGD memberikan nilai fungsi objektif terbaik dan purata masa berlalu terpantas berbanding dengan PKZ dan ACG.

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ω	Turbine speed
ψ	Flux linkage
ρ	The air density
ϕ	The chaotic value
ρ	A control parameter with a real value in the range of 0 and 4
ω_o	Base Angular Frequency
ω_{ref}	The reference speed
$\lvert V_i \rvert$	The root mean square (RMS) value of the i^{th} bus voltage
ΔI_L	Maximum ripple current
A	Swept area
A_t	Turbine gain
$B(h)$	The ratio of the h^{th} harmonic to the fundamental current
$best(t)$	Minimum fitness
c_1, c_2	The acceleration constants
C_f	The filter capacitance
C_p	The aerodynamic efficiency of the turbine blade
D	Air density
D_m	Mechanical Friction and Windage
d^{th}	The dimension
E_d	The real part of grid side voltage
E_f	The output field voltage
E_{f0}	The output field voltage to the machine during the initialisation period
e_g	The band-gap energy of solar cell material
e_g	Band gap energy
E_q	The imaginary part of grid side voltage
F	The total force
f_{base}	Base Frequency
$fitness_i(t)$	The fitness value of the agent i at time t
f_{line}	Line frequency

F_{min}	The fitness function
f_p	Penstock Head Loss Coefficient
f_s	Switching frequency
G	Solar radiation
$G(t)$	The value of the gravitational constant at time t
G_0	The value of the gravitational constant at the first cosmic quantum-interval of time t_0
$Gbest^k$	The global best position in the entire swarm
G_{max}	Maximum Gate Position
G_{min}	Minimum Gate Position
G_R	Reference solar radiation
H_e	Effective head
H	Inertia Constant
h	The harmonic order
i^{th}	The particle
I_c	Capacitive current
I_d	Diode current
I_d	The real part of output inverter current
I_d^*	The reference current of I_d
I_{dc}	DC current
I_g	Grid current
I_{gd}	The real part of grid current
I_i	Inverter output current
I_i^1	The fundamental current at bus i
I_{id}	The real part of inverter output current
I_i^h	The h^{th} harmonic current at bus i
I_{iq}	The imaginary part of inverter output current
I_L	Rated RMS Line Current
I_o	Dark current
I_{oR}	The dark current at the reference temperature
I_p	Parallel current
I_q	The imaginary part of output inverter current

I_q^*	The reference current of I_q
I_{satR}	Sat. current at ref. conditions / cell
I_{sc}	Photo current
I_{scR}	The short circuit current at the G_R
I_{SCR}	Short circuit current at ref. conditions / cell
k	Boltzman constant
K_A	Regulator Gain
K_D	Demagnetizing term
K_i	The integral gains of the PI controller
K_p	The proportional gains of the PI controller
L_g	The grid side inductance
L_i	The inverter side inductance
Loc	The location of the DG
M	Mass
m	The number of buses
MX_{GTCR}	Maximum Gate Closing Rate
MX_{GTOR}	Maximum Gate Opening Rate
n	Diode ideality factor
N_1/N_2	The ratio of inductance filter
$Pbest_i^k$	The best position ever visited by a particle i at the k^{th} iteration
P_{loss}	The total power loss
$P_{loss\_basecase}$	The base case power loss
$P_{loss\_optimisation}$	The power loss after DG placement
$P_{loss\_reduction}$	The reduction in power loss
P_m	Turbine power
P_r	Turbine's power rating
Q	Servo gain
q	Electron charge
R	Resistance
r	The radius of turbine blade
r_1, r_2	Two random numbers in the range of 0 and 1
$rand_j$	A random number in the interval between 0 and 1

R_c	Load compensating resistance
R_g	The generator resistance
Rij	Distance between other agents to the particular agents
R_l	The line resistance
R_{loss}	Iron Loss Resistance
Rp	The permanent droop
R_s	Neutral Series Resistance
Rt	Transient droop
$Size$	The DG size
t^{th}	The iteration number
T_a	Armature Time Constant
T_A	Regulator Time Constant
T_B	Lag time constant
T_C	Lead time constant
T_c	Cell temperature
T_{CR}	Reference cell temperature
T_{do}	Unsaturated Transient Time
T_{do}''	Unsaturated Sub-Trans Time
Tg	Main servo time constant
THD_i	The current total harmonic distortion
THD_v	The voltage total harmonic distortion
$THD_{v\max}$	The maximum allowable level at each bus
T_m	Turbine torque
Tp	The pilot valve and servo motor time constant
T_{qo}''	Sub-Trans Time
T_R	Reset time or dashpot time constant
T_W	Water starting time
U	Velocity of water in a penstock
u_d	The real part of PI controller's control rules
U_{NL}	Velocity of water at no load
u_q	The imaginary part of PI controller's control rules
V_ctrl	The controlling voltage

V_{AMAX}	Max. reg. internal voltage
V_{AMIN}	Min. reg. internal voltage
V_c	Capacitive voltage
V_d	The real part of inverter side voltage
$VD_{basecase}$	The base case voltage deviation
V_{dc}	DC voltage
V_{dev}	The voltage deviation
$VD_{improvement}$	The improved voltage deviation
$VD_{optimisation}$	The voltage deviation after DG placement
V_E	Exciter output voltage
V_g	Grid voltage
V_{gd}	The real part of grid voltage
V_{gq}	The imaginary part of grid voltage
V_i	Inverter output voltage
V_{id}	The real part of inverter output voltage
v_i^k	Velocity
V_{iq}	The imaginary part of inverter output voltage
V_{iref}	Reference voltage at bus *i* and
V_{LN}	Rated RMS Line-to-Neutral Voltage
V_m	Rated wind speed
$V_{\max}$	The upper bound of the voltage limits
$V_{\min}$	The lower bound of bus voltage limits
V_q	The imaginary part of inverter side voltage
V_{rated}	Rated voltage
V_{ref}	The voltage reference
V_{ref0}	The initialised value of the reference voltage V_{ref}
V_{RMAX}	Max regulator output
V_{RMIN}	Min. regulator output
v_w	The wind speed
w	The inertia weight
worst(t)	Maximum fitness
X	Reactance

X_c	The capacitive reactance
X_d	Unsaturated reactance
X_d'	Unsaturated transient reactance
X_d''	The generator subtransient reantance
x_i^d	The position of i^{th} agent
X_l	The line inductive reactance
X_p	Potier reactance
X_q	Unsaturated reactance
X_q''	Unsaturated sub-trans. reactance
X_s	Neutral series reactance
Y_h	Admittance matrix at each harmonic
z	The real gate
z_{FL}	The gate at full load
Z_g	The generator impedance
z_i	The initial gate
Z_l,	The line impedance
z_{NL}	The gate at no load
Z_t	The transformer impedance
α	Acceleration factor
α_T	Temperature coefficient of photo current
γ	A decision parameter

LIST OF ABBREVIATIONS

AC	Alternating current
ACO	Ant colony optimization
AGC	Automatic generation control
ASD	Adjustable speed drives
DC	Direct current
DFIG	Doubly fed induction generator
DG	Distributed generation
FFT	Fast Fourier transform
GA	Genetic algorithm
GSA	gravitation search algorithm
IEEE	Institute of Electrical Electronics Engineers
IGSA	Improved gravitational search algorithm
LCL	Inductance, capacitance and inductance passive filter
MHP	Mini hydro power
p.u	Per unit
PCC	Point of common coupling
PFCC	Power factor correction capacitor
PSO	Particle swarm optimization
PV	Photovoltaic
PWM	Pulse width modulation
RMS	Root mean square
THDi	Current total harmonic distortion
THDv	Voltage total harmonic distortion
VSI	Voltage source inverter
WTG	Wind turbine generation

CHAPTER I

INTRODUCTION

1.1 RESEARCH BACKGROUND

Recently, renewable energy generation technologies are increasingly utilised in power distribution networks. The drive for green energy sources, financial opportunities presented for investors, potential benefits for utilities like peak-shaving, congestion alleviation, reduction of losses and better asset utilization are contributing factors to renewable energy development (El-Khattam & Salama 2004). Renewable energy based distributed generation (DG) is seen as a resolution for solving environmental concerns and security of electricity supply to support sustainable growth. From the interfacing approach used to connect to the grid, there are two types of DG units, namely, inverter based DG and non-inverter based DG (Dugan et al. 2000). Examples of inverter based DG include photovoltaic (PV) systems, wind turbine generators, fuel cells, and micro turbines which use power converters as interfacing devices to the grid. The mini hydro power (MHP) and induction generator are considered as non-inverter based DG units.

The integration of DG into a distribution system will have either positive or negative impact depending on the distribution system operating features and the DG characteristics. DG can be valuable if it meets at least the basic requirements of the system operating perspective and feeder design (Begovic 2001). According to Daly & Morrison (2001), the effect of DG on power quality depends on the type of DG, its interface with the utility system, the size of DG unit, the total capacity of the DG