Faculty of Electrical Engineering

FUTURE DISTRIBUTION NETWORK PLANNING WITH DEMAND RESPONSE APPLICATIONS

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DECLARATION

I declare that this thesis entitled “FUTURE DISTRIBUTION NETWORK PLANNING WITH DEMAND RESPONSE APPLICATIONS” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

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Name : ASSOC. PROF. DR. GAN CHIN KIM

Date : ....

DEDICATION

This thesis is dedicated to my lovely family.

ABSTRACT

The philosophy in distribution network planning is continuously evolving to ensure an efficient, reliable and cost-effective network design. This is particularly important with the increasing presence of Distributed Generation (DG) and Demand Response (DR) integration at the distribution network. Thus, there is a need to develop distribution network modelling tool so that the associated impacts and benefits of such integration can be properly assessed and quantified. In light of this, this thesis presents a fractal-based approach to generate a large number of consumer settlements for low voltage distribution networks. Subsequently, branching rate and minimum spanning tree concepts have been applied to connect the load points and create the network for low voltage and medium voltage, respectively. The Particle Swarm Optimization (PSO) technique was then utilized to determine the optimum rating and placement of transformers, DG and capacitors. The developed simulation tool allows the modelling and planning of distribution network to be carried out in a systematic way. In addition, a total of 10,000 network case studies have been performed to assess the network performance under the influence of demand response and solar PV penetration levels. Three different demand response strategies have been considered in this work, namely, consumer response to their own demand profile, consumer response to PV generation profile and the consumer optimized demand response facilitated by smart grid application. Methodology for generating optimum DR pattern for 2,000 individual consumers have also been proposed and implemented with the aim to improve network load factor. These comprehensive analysis of the benefits of DR would enable a more meaningful and robust conclusion to be made. The findings show that DR application at consumer level can greatly facilitate the integration of solar PV systems. The DR benefits include reduced network losses and increased network asset utilization levels. Last but not least, this research work has filed a patent for the invention of Internet-of-Things based remote demand response and energy monitoring system that could be used as an enabler for demand response application in the actual environment.

ABSTRAK

Falsafah dalam perancangan rangkaian pengedaran terus berkembang untuk memastikan reka bentuk rangkaian yang cekap, boleh dipercayai, dan kos yang efektif. Hal ini secara khususnya penting kerana peningkatan kehadiran Distributed Generation (DG) dan Demand Response (DR) di rangkaian pengedaran. Oleh itu, menjadi satu keperluan untuk membangunkan alat pemodelan rangkaian pengedaran supaya kesan yang berkaitan dan manfaat integrasi tersebut boleh dinilai dan diukur dengan betul. Sehubungan dengan itu, tesis ini membentangkan pendekatan berasaskan fraktal-asas untuk menjana sejumlah besar penempatan pengguna untuk rangkaian pengagihan voltan rendah. Selepas itu, kadar cawangan dan konsep merangkumi pokok yang minimum telah digunakan untuk menyambung titik beban dan mewujudkan rangkaian untuk voltan rendah dan voltan sederhana. Kemudiannya, teknik Particle Swarm Optimization (PSO) telah digunakan untuk menentukan penarafan optimum dan penempatan transformer, DG dan kapasitor. Alat simulasi yang dibina membolehkan pemodelan dan perancangan rangkaian pengedaran yang akan dijalankan dengan cara yang sistematik. Di samping itu, sejumlah 10,000 kajian kes rangkaian telah dijalankan untuk menilai prestasi rangkaian di bawah pengaruh respon permintaan dan tahap penembusan PV solar. Tiga strategi tindak balas permintaan yang berbeza telah dipertimbangkan dalam kerja-kerja ini, iaitu, respon pengguna ke profil permintaan mereka sendiri, respon pengguna ke profil generasi PV dan tindak balas pengguna dioptimumkan atas permintaan yang difaslitasi oleh grid pintar. Kaedah untuk menjana bentuk DR optimum untuk 2,000 pengguna individu juga telah dicadangkan dan dilaksanakan dengan tujuan untuk meningkatkan rangkaian faktor beban. Analisis komprehensif DR ini akan membuatkan kesimpulan yang lebih bermakna dan mantap. Hasil kajian menunjukkan bahawa aplikasi DR di peringkat pengguna boleh memudahkan integrasi sistem PV solar. Manfaat DR termasuk mengurangkan kehilangan rangkaian dan meningkatkan tahap rangkaian penggunaan aset. Akhir sekali, hasil kajian ini telah memfailkan paten untuk ciptaan Internet-of-Things berdasarkan kawalan respon permintaan dan sistem pemantauan tenaga yang boleh digunakan sebagai pemangkin untuk aplikasi permohonan respon dalam persekitaran sebenar.

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LIST OF ABREVIATIONS

AC	Alternating Current
ACO	Ant Colony Optimization
AVR	Automatic Voltage Regulator
ABC	Aerial Bundled Cable
AI	Artificial Intelligence
ADMD	After Diversity Maximum Demand
BDRAS	Building Demand Response Automated System
BR	Branching Rate
BESS	Battery Energy Storage System
CLs	controllable loads
CPP	Critical-Peak Pricing
CREST	Centre for Renewable Energy Systems Technology
DC	Direct Current
DR	Demand Response
DG	Distributed Generation
DSOs	Distribution System Operators
DRMS	Demand Response Management System
DERs	Distributed Energy Resources
DMS	Demand Management System
DSM	Demand Side Management

DSO	Distribution System Operator
DLC	Direct Load Control
DNMS	Distribution Network Modelling Software Tool
EMS	Energy Management System
FiT	Feed-in Tariff
GA	Genetic Algorithm
GIS	Geographical Information System
HIT	Heterojunction with Intrinsic Thin-layer
IEEE	Institute of Electrical and Electronic Engineering
IoT	Internet of Things
HIS	Improved Harmony Search
ILC	Interruptible Load Contract
ITMBS	Intelligent Trading/Metering/Billing System
LV	Low Voltage
MST	Minimum Spanning Tree
MV	Medium Voltage
MD	Maximum demand
MGO	Micro-Grid Operator
MG	Micro-Grid
NFE	Number of Function Evaluation
OpenDSS	Open Source Distribution System Simulation
PSO	Particle Swarm Optimization
PV	Photovoltaic
PVC	Ploy Vinyl Chloride
PILC	Paper Insulated Lead Covered

PDF	Probability Distribution Function
PMCB	Power Management Controller Box
RNM	Reference Network Model
RTP	Real-Time Pricing
SA	Simulated Annealing
SEDA	Sustainable Energy Development Authority of Malaysia
TNB	Malaysian utility service (Tenaga Nasional Berhad)
TS	Tabu Search
TOU	Time-Of-use
UKGDS	UK Generic Distribution System
XLPE	Cross-Linked Polyethylene

LIST OF SYMBOLS

OF	Objective Function
NLF	New load factor
DLF	Desired load factor
P_{losses}	Total power losses in *kWh* per day
$nV_{violated}$	Number of buses that violate the statutory voltage
NLP	New load factor
LP	Load profile for a day
α	Load factor coefficient
β	Total power losses coefficient
γ	Voltages violation coefficient
npc	Number of the non-participating consumers in the DR program
pc	Number of participating consumers in the DR program
LF	Load Factor
LP^t_j	Load profile before DR participation for consumer *j*
LPt+1j	Load profile after DR participation for consumer *j*
Cu	Copper
Al	Aluminium
kWp	Kilo watt
ktoe	kilotonne of oil equivalent
CL	Total losses cost for a study year