OPTIMAL DISTRIBUTED GENERATION OUTPUT AND BATTERY SWITCHING STATION PLACEMENT VIA RANKED EVOLUTIONARY PARTICLE SWARM OPTIMIZATION

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ABSTRACT

Improvements in DC electrical motor and battery technologies have stimulated interest in Electrical Vehicle (EV) among industrial and personal users. To support the growth of EV, multiple types of Charging Station (CS) have been introduced. The three available types of CS units are Levels 1, 2 and 3. In the charging process, Levels 1 and 2 use the AC/DC charging approach whereas Level 3 uses the DC/DC. However, there are some drawbacks in these CS types, either in terms of charging time (for Levels 1 and 2) or the impact to the system performance (Level 3). This research used the concept of Battery Switching Station (BSS) to solve these problems and introduced analytical and optimization methods to identify appropriate locations of BSS that would have a significant impact on the distribution network even with the existence of Distributed Generation (DG). Besides that, a new meta-heuristic optimization known as Ranked Evolutionary Particle Swarm Optimization (REPSO) and Multi-Objectives REPSO (MOREPSO) which are superior and simple algorithms were employed to find the optimum results for DG output and BSS placement. The analysis started by validating the REPSO performance with three other existing PSOs to solve the 10 benchmark mathematical functions and find the optimal DG output. REPSO had produced optimal results with faster computing time requiring less iterations. In the optimal BSS placement analysis, REPSO gave the best location and had lower power loss in the system for BSS as compared to the analytical approach and randomization of BSS placement. For further improvement to the distribution network, REPSO was employed to compute the optimal output of DG and BSS placement simultaneously where this technique produced the lowest power loss and flexible locations. Another contribution of this research is performing MOREPSO would achieve balanced results between power losses and line capacity increment that are caused by DG output and BSS placement in the distribution network.

ABSTRAK

Kemajuan dalam teknologi motor elektrik DC dan bateri telah menarik minat pihak industri dan pengguna untuk menceburkan diri dengan kenderaan elektrik (EV). Bagi menyokong perkembangan EV di pasaran, pelbagai jenis stesyen pengecas (CS) telah diperkenalkan. Tiga jenis CS yang telah dibangunkan adalah pengecas Tahap 1, Tahap 2 dan Tahap 3. Namun, setiap jenis CS ini mempunyai kesan terhadap penggunaanya samada dari segi tempoh mengecas (bagi Tahap 1 dan Tahap 2) mahupun kesan terhadap prestasi sistem pengagihan (Tahap 3). Konsep Stesyen Penukaran Bateri (BSS) digunakan dalam kajian ini bagi mengatasi masalah-masalah tersebut dan turut memperkenalkan kaedah analisis dan pengoptimuman untuk mengenalpasti lokasi BSS yang boleh menyebabkan impak yang ketara pada system talian, walaupun dengan adanya penjana pengagihan (DG). Selain itu, meta-heuristik yang baru iaitu *Ranked Evolutionary Particle Swarm Optimization* (REPSO) dan *Multi-Objectives* REPSO (MOREPSO) digunakan dalam kajian ini kerana keringkasan dan kehebatannya dalam mencari keluaran DG dan lokasi BSS yang optimum. Analsisi dimulakan dengan membandingkan prestasi REPSO bersama tiga jenis PSO yang lain dalam menyelesaikan sepuluh fungsi matematik serta mencari nilai optimum bagi keluaran DG. REPSO telah memberi nilai optima menerusi tempoh pengkomputeran yang pantas dan jumlah lelaran yang kecil. Dalam analisis pengoptimuman lokasi BSS, REPSO memberi lokasi yang terbaik berbanding kaedah analitikal dan kaedah BSS yang diletakkan secara rawak. Bagi penambahbaikan ke atas prestasi sistem pengagihan, REPSO digunakan untuk mencari nilai optimum bagi pengeluaran DG dan lokasi BSS secara serentak, dimana teknik ini berjaya memberikan nilai kehilangan kuasa yang paling rendah serta lokasi BSS yang fleksibel. Penemuan lain yang diperolehi dari kajian ini adalah dalam penggunaan MOREPSO yang mengimbangkan di antara nilai kehilangan kuasa dan kemeningkatan kapasiti talian yang berlaku disebabkan oleh keluaran DG dan penempatan BSS dalam sistem pengagihan.

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LIST OF SYMBOLS

c_1	-	Acceleration Cognitive Coefficient (PSO Parameter)
c_2	-	Acceleration Social Coefficient (PSO Parameter)
D	-	BSS Existence Coefficient
d	-	Dimensions (PSO Parameter)
D	-	Max Dimensions (PSO Parameter)
D	-	Distance (MO Parameter)
E	-	Supply Voltage
G_{best}	-	Global Best Value (PSO Parameter)
I	-	Line Current
i	-	Line Number
i	-	Particles' Number (PSO Parameter)
I_{best}	-	Random P_{best} Value (PSO Parameter)
j	-	Sending Bus
k	-	Receiving Bus
k	-	Current Iteration (PSO Parameter)
L	-	Number Of Bus In The System
loc	-	Location
N	-	Number Of Particle (PSO Parameter)
n	-	Number Of Non-Dominated Solution (MO Parameter)
n-bus	-	Maximum Number Of Bus In The System
n-line	-	Maximum Number Of Line In The System
P	-	Active Power
P_{best}	-	Local Best Value (PSO Parameter)
Q	-	Reactive Power
R	-	Resistance
r_1, r_2	-	Random Number (PSO Parameter)

S	-	Apparent Power
T	-	Number Of Objective Functions (MO Parameter)
V	-	Bus Voltage
v	-	Velocity (PSO Parameter)
w	-	Weight Value (PSO Parameter)
X	-	Impedance
x	-	Particle (PSO Parameter)
α	-	Active Power Component
β	-	Reactive Power Component
δ	-	Voltage Angle
ε	-	Relative Error (PSO Parameter)

LIST OF ABBREVIATIONS

ABC	-	Artificial Bees Colony
ACO	-	Ant Colony Optimization
AIS	-	Artificial Immune System
AMPSO	-	Adaptive Mutation -Particle Swarm Optimization
BFT	-	Bacteria Foraging Technique
BSS	-	Battery Switching Station
CLONALG	-	Clonal Selection Algorithm
CPSO	-	Classical Particle Swarm Optimization
CS	-	Charging Station
C-VSI	-	Combined-Voltage Stability Index
DC	-	Direct Current
DCCS	-	DC Charging Slot
DE	-	Differential Evolution
DE-PSO	-	Differential Evolution - Particle Swarm Optimization
DER	-	Distributed Energy Resources
DG	-	Distributed Generation
DSM	-	Demand Side Management
ENA	-	Energy Network Association
EP	-	Evolutionary Programming
EV	-	Electric Vehicle
FVSI	-	Fast Voltage Stability Index
GA	-	Genetic Algorithm
GA-PSO	-	Hybrid Genetic Algorithm - Particle Swarm Optimization
GV	-	Gasoline Vehicle
HV	-	High Voltage
IPSO	-	Iteration PSO

IWPSO	-	Inertia Weight PSO
LCI	-	Line Capacity Increment
LV	-	Low Voltage
M	-	Multi-modal
MO	-	Multi-Objective
MOPSO	-	Multi-Objective Particle Swarm Optimization
MOREPSO	-	Multi-Objective Rank Evolutionary Particle Swarm Optimization
MV	-	Medium Voltage
N	-	Non-separable
PF	-	Power Factor
PL	-	Power Loss
PQ	-	Constant Power Operating
PSO	-	Particle Swarm Optimization
PV	-	Constant Voltage Operating
REPSO	-	Rank Evolutionary Particle Swarm Optimization
S	-	Separable
SAE	-	Society of Automotive Engineers
SD	-	Standard Deviation
SDOA	-	Sensory-Deprived Optimization Algorithm
SoC	-	State of Charging
SVC	-	Static VAR Compensator
THD	-	Total Harmonic Distortion
U	-	Uni-modal
VSI	-	Voltage Stability Index
WT	-	Wind Turbine

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CHAPTER 1

INTRODUCTION

1.1 Overview of Modern Distribution Network

Traditional power system consists of three main components in managing electric power for consumer usage. Starting from “Generation” component, the generated power is delivered through the “Transmission” component and dispensed via “Distribution” component. In this scheme, the power is flowing in one direction, which is from the generation side to the distribution side. There is no other power resource, either at transmission or distribution sides. Among these three components, distribution system has the highest power loss, due to the lower X/R ratio, lower voltage level and radial configuration. Studies have shown that more than 70% of power losses in the power system network occurs in distribution system [1].

Power loss in the distribution network indirectly represents the financial loss of utility. For example, 1 kWh or power loss is equivalent to RM 0.2121 of loss in Malaysia utility (considered the generation cost only) [2]. Thus, if the average power loss in the system is 203 kW (for 33-bus distribution network), the financial loss faced by utility in one year is RM 427,339.10 (0.2121 RM/kWh x 8760h x 203kW). This non-negligible amount of losses has a direct impact on the profit of the utility companies and also portrays the overall efficiency of the system. Therefore, utility companies will try to ensure their system operate in highest level of efficiency for minimum power loss and maximum profit. In line with this objective, many researchers focusing on improving the performance of distribution network, in order to increase the overall performance of power system.

Many approaches have been introduced in the past to improve the distribution network performance. Capacitor bank allocation [3-7] and reconfiguration [8-11] are some examples of techniques that can be applied to improve the voltage profile and minimize power loss for distribution network. Beside these techniques, Distributed Generation (DG) installation in distribution network would also improve overall efficiency of the system. By locating the DG closed to the consumer side (end load), loads that close to the DG will be supplied by the DG and other loads will receive power from the grid side. This means that the distribution network does not depend only on single power resource (transmission/distribution substation) in order to fulfil load demand. However, it is very important to ensure that the DG output is at optimal value to maximize its benefits. Without the optimal DG output, the DG might cause higher power loss in the distribution network, compared to the initial condition (without DG).

The need of DG in the distribution network nowadays becomes more significant with the rapid development in Electrical Vehicle (EV) technology. Since most of the EV customers are located within the distribution network, the EV charging process will increase the demand for electricity in the distribution network and will indirectly cause an impact to the distribution system performance. Therefore, the investigation on the optimal DG output and suitable placement for charging component of EV is crucially required to ensure the performance of distribution network, such as power loss and stability, can be improved.

1.2 Research Questions

Many well-known automobile companies such as Honda, Toyota and Volkswagen have started to introduce their EV models to consumers. This rapid development in EV was influenced by various incentives offered by the government to the manufacture and customer such as rebate of the price for new EV and tax reduction. Furthermore, increase in the global oil price also contributed to the rapid development of EV technology [12, 13]. As a result, the number of EV user is increasing [14]. In order to support the usage of EV, the Charging Point or Charging Station (CS) is required. Some works have been conducted in countries like the United States to introduce a standard CS type by considering different voltage levels and charging time. Generally, there are three types of CS, which are CS Level 1, Level 2 and Level 3 [15-17]. The Level 1 and 2 CSs have a slow charging characteristic, but less impact to the distribution network performance due to the small amount of reactive power consumption. In contrast, CS Level 3 has a fast charging characteristic with high impact to the distribution system performance.

In order to increase the number of EV usage, the issue on CS should be resolved immediately. Consumers will feel reluctant to use EVs if they have to wait for a long period of time to charge their EV. Although a fast charging process is possible based on Level 3, it is expensive due to penalties imposed by utility for large reactive power consumption. Considering such problems, the use of Battery Switching Station (BSS) with Level 2 CS will be implemented in this work, so that the "waiting time" and the impacts to the system performance can be minimized. Besides, with the existence of DG units in the distribution system, the impacts of BSS to the distribution network can be minimized. The main focus of this research is to propose techniques that able to find an optimal DG output and BSS placement, so that better performance of the distribution network can be achieved.

The research questions highlighted while analysing the impacts of DG and BSS in the distribution network are as below:

i. What is the suitable method that can be used to determine multiple DG units' output, in order to provide the lowest power loss in the system?

ii. Will BSS cause significant impacts when it is located randomly in the system, with or without DG? If yes, where to locate this BSS?

iii. Can harmonization between DG operation and BSS coordination provide positive impacts, even when DG is not operating at optimal output?

iv. Apart from the power loss impact, were DG and BSS can provide significant changes to the other power system performance, such as voltage profile, voltage stability index and line capacity increment?

All the listed problems will be analysed and discussed in detail in this study.

1.3 Problem Statement

The total power loss in the modern distribution network is a great issue as compared with the transmission or generation power loss. Therefore, the increment in the number of EV user gives an indicator that the new demand, which cause the power loss increment, will be existed in the distribution network.

In the recent work, it has shown that the use of uncontrolled EV charging strategy have caused many drawbacks to the distribution network performance, such as power loss increment, component rating exceeded and etc. With the used of BSS unit, the problem caused by uncontrolled EV charging strategy can be reduced. However, the BSS should not be randomly located in the system. This will caused the power loss to increase or might affect the stability of the system. Thus, the strategy for optimal BSS placements is will be proposed. For the system with DG unit, the optimal DG output as well as optimal BSS placement (or both together) can also provide the better solution for power loss and stability of distribution network.

Therefore, in this research, the concentration will be given to the introduction of new Meta-Heuristic technique, so that the optimal DG output and optimal BSS placement can be obtained.

1.4 Research Objectives

The objectives of this research are:

i. To model the BSS units in the power system analysis.

ii. To develop an analytical approach based on minimizing the power loss increment for the BSS units placement in the distribution network.

iii. To improve the Particle Swarm Optimization (PSO) with Evolutionary Programming (EP) concept for finding the optimal DG output and BSS placement, in order to minimize losses in distribution system.

iv. To develop Multi Objective solution for new meta-heuristic technique, in solving the multiple impacts of DG and BSS. In this work, the impacts of power loss and line capacity increment will be considered.

1.5 Scope of Work

The scopes of work considered in this research are summarized as follow:

i. Only one charging mode, which is constant current mode, is considered in modelling the BSS unit for the simplification purpose.

ii. The Level 2 CS is considered in the BSS units due to the voltage level, which is 230V (similar as Malaysia's voltage level) and the impact to the distribution system is less than Level 3 CS.

iii. The maximum number of BSS unit that is allowed to be located at each bus in the system is two units due to the impracticality in placing many new loads at one location.

iv. The analysis for DG was only considering the optimal DG output for minimizing the power loss; meanwhile the DG locations were fixed.

v. The total DG output in the system must be less than the total demand in the system, in order to avoid reverse current injected to substation.

From the subtasks and limited scope, the importance of optimal DG output and BSS coordination can be clearly seen after the analyses have completed.

1.6 Significance of the Research

The main motivation of this research is to determine the optimal DG output and BSS placement, so that the power loss, voltage stability index as well as line capacity increment of the distribution network can be improved.

With the used of BSS unit, the longer charging time that is faced by EV users can be solved. Not only that, the BSS will also provide less impact, in term of voltage drop and power loss, to the distribution network compared to Level 3 CS (since the BSS will use Level 2 CS). With the two proposed techniques, analytical and meta-heuristic, the BSS placement in the system will give minimum power loss value. For the optimal DG output analysis, the new Ranked Evolutionary Particle Swarm Optimization (REPSO) that is proposed in this study provides the fastest and most consistent result compared to other PSO types. This consistency is important to increase the users' trust to the results, which is given by meta-heuristic technique. Furthermore, the REPSO also capable to give the optimal result as other PSOs did, and sometimes even better. Thus, by using the optimal DG output provided by REPSO, the power loss in the system can be greatly minimized.

The simultaneous DG output and BSS placement analysis provides the best option for the power system planner to select the suitable operation for installing and operating these two components. Compared to sequential analysis (finding optimal

DG output first, followed by optimal BSS placement), the simultaneous DG output and BSS placement analysis provides more possible solution for BSS to be located in the system, with lower power loss. The different result between these two approaches is due to the local optimal trap that is faced by the sequential technique. The REPSO is again beneficial in determining the simultaneous analysis between DG output and BSS coordination in the system.

From the whole analysis, many BSS can be located in the network with optimal DG operation and indirectly, will help the growth of EV industry in the future.

1.7 Thesis Organization

This thesis is organized in seven chapters. The overview on distribution system including the DG and CS, thesis objective and scopes are briefly described in the first chapter. The second chapter addresses the literatures on the existing techniques in determining the DG output and the latest work on charging station for EV. In the third chapter, the impacts of DG operation and uncoordinated BSS positioning to the distribution network performance are discussed in detailed. The modelling for the BSS, the proposed voltage stability index and the proposed analytical formulation for BSS placement are also discussed in this chapter. The introduction of new meta-heuristic method, based on hybridization technique between PSO and EP is described in the fourth chapter.

The fifth chapter details out on the comparison between new meta-heuristic and other three existing techniques in solving the mathematical benchmark function as well as determining the optimal DG output. Performance of the proposed analytical method and new meta-heuristic method in positioning the BSS is presented in the sixth chapter. The advantages of simultaneous analysis between DG output and BSS coordination are also highlighted in this chapter. From the impacts of simultaneous analysis between DG and BSS to the distribution network, the multi-objective (MO) solution approach for the new meta-heuristic technique is introduced in seventh chapter. Last but not least, the seventh chapter provides the thesis conclusion with some suggestions for future works.

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