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Multistage distribution network expansion planning under smart grids environment

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ABSTRACT

This paper presents a novel model for multistage smart distribution network expansion planning (MSDNEP) in the presence of vehicle to grid (V2G) and fault passage indicator (FPI) in a multi-objective optimization framework. Distribution networks should be expanded in order to serve load growth in the best manner possible. The two objectives considered are: minimization of total cost during the planning horizon and maximization of reliability index. The proposed model determines the sitting and sizing of parking lot as well as conventional alternatives for expansion, such as, optimal size, location and time in which the new lines must be added, replaced or removed. Moreover, the impacts of using FPIs in a distribution network on reliability and the investment cost are in the scope of this study. Due to its good handling of mixed integer nonlinear problem, a non-dominated sorting genetic algorithm (NSGA-II) is utilized for optimization such a complex problem. The effectiveness of the proposed model is demonstrated by applying to a distribution test system and results show a significant improvement in the area of distribution network planning.

Introduction

Future distribution networks will be much complicated; incorporating renewable resources that their availability and productivity are inherently fluctuating, changes the natural behavior of power systems. On the other hand, any problem in distribution level can immediately impress the customers and most of the customer reliability problems are originated from the electric power distribution systems [1,2]. Hence, the present structure and methodology for planning of the power system should be revised. Energy storage will be required for efficiency covering the incompatibility between the renewable energy sources generation and the energy demands. Due to smart distribution networks (SDN) can accommodate all kinds of dispersed generations (DGs) and distribution storage like V2Gs, some major of power system stakeholders, such as governments are becoming encouraged to reengineering the distribution power system according to the smart grid paradigm [3].

The necessity of a smooth transition from today (via progress achieved plan) toward an optimal smart energy system is authenticated in [4]. Therefore, it is necessary to consider this initiative plan as a roadmap for construction of the new distribution networks or expanding the existing networks, while this paper focuses on the expanding manner.

The main goal of the distribution network expansion planning (DNEP) is to determine a configuration that supplies the load demands all over the planning horizon. In conventional DNEP, there are some major alternatives for planners such as where, when and what type of lines and substations should be added (or probably removed/replaced) to reach the optimal configuration. Over the years, DNEP has achieved much attention in the literature. In some researches, the impacts of DGs as well as reliability issues on distribution system planning are well developed [5,6]. A method for distribution system planning, considering DGs is developed in [7] to investigate investment cost of DGs and loss reduction, while in [8], the authors present a multistage DNEP considering DGs and their effects on reliability improvement. In [9] a multistage DNEP has been developed considering the uncertainties of load demand and power supplied by DGs. Load bus voltage stability improvement using DG planning is proposed in [10], while sitting and sizing of DGs to improve loss reduction of a distribution power system is addressed in [11,12]. From the electricity market point

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Nomenclature

IC_{sub}	investment cost for a substation ($)
IC_{l_a}	investment cost for a line (type a) ($/km)
IC_{fpi}	investment cost for a FPI ($)
OC_{sub}	substation annual operation cost ($/kVA)
MC_{sub}	substation annual maintenance cost ($/kVA)
MC_{fpi}	FPI annual maintenance cost ($)
MC_l	line annual maintenance cost ($/km)
FC_{v2g}	fixed cost for construction of parking lot ($)
C_{access}	cost of accessories of parking lot like converter and plug ($/MVA)
C_{loss}	cost per unit of energy lost ($/kW h)
C_d	degradation cost of V2G ($)
C_m	parking lot annual maintenance cost ($/kVA)
r	interest rate
L_l	length of line l (km)
P_{v2g}	capacity of each V2G dedicated to grid connection (kW)
Prb_{v2g}	plug-in probability of a vehicle (%)
P_{L_l}	active power loss in line l (kW)
P_{lp_n}	active power of load point n (kW)
P_{rep}	load points not supplied during fault repair
P_{loc}	load points not supplied during fault location
$S_{G2V,\max}$	maximum power drawn by parking from the grid (kW)
S_s	apparent power of substation (kVA)
S_f	apparent power of feeder (kVA)
P_{g_i}, Q_{g_i}	active and reactive power generation at bus i respectively
P_{l_i}, Q_{l_i}	active and reactive load at bus i respectively
P_{ij}, Q_{ij}	active and reactive power flow at element $i-j$ respectively
$V_{\min}, V_{\max}$	minimum and maximum allowed operation voltage
γ_l	Failure rate of line (fail/km year)
γ_s	Failure rate of substation (fail/year)
η_{charge}	charging efficiency (%)
t_{locs}	duration of fault location for a substation (h)
t_{reps}	duration of fault repair for a substation (h)
t_{loc}	duration of fault location for a line (h)
t_{rep}	duration of fault repair for a line (h)
T	time horizon of planning
t_{disp}	total time that V2Gs are dispatched (h)
t_{sc}	stage of construction of parking lot
N_{af}	number of affected load points by the fault
N_{ltype}	number of line types
N_{sb}	number of substations
N_l	number of lines
N_{lp}	number of load points
N_F	number of objective functions
N_{repo}	number of solutions in the repository
N_{loc}	number of load points isolated during fault location
N_{v2g}	number of V2Gs
N_p	number of parking lots
N_{rep}	number of load points isolated during fault repair
N_{ls}	Number of load points isolated during substation failure
Pr_{pur}	purchased energy cost
Pr_p	market price at the peak time
Int_{prb}	interruption probability
Ω_{sb}	the set of distribution substations
Ω_{le}	the set of existing lines
Ω_{lf}	the set of candidate lines
Ω_i	the set of elements connected to bus i
Ω_f	the set of feeders
N_{stage}	number of stages of planning

of view, the roles of wholesaler and retailer on distribution system planning have been studied in [13]. A multi-objective DNEP is developed in [14], where two objectives are total cost as well as risk factor minimization.

On the other hand, DNEP is a complex optimization problem, since it is inherently a mixed integer, nonlinear and non-convex problem. In literature, different kinds of classical optimization methods have been used such as dynamic and pseudo dynamic programming [15,16], mixed integer linear programming [17] and non-linear programming [18,19]. Heuristic and meta-heuristic methods, for instance, genetic algorithm (GA) [20,21] and ant colony [22] are also employed for solving such a crucial optimization problem.

Most of planning models and methodologies in literature do not pay attention to the capability of SDN. This paper presents a new multi-objective and multi-stage model considering parking lot in the DNEP, while the impacts of adding FPIs to distribution network are considered. Using FPIs may improve fault location process and enhances reliability indices, however, it may impose some costs [23–27]. Due to reliability concern, it is necessary to evaluate reliability in every model. Therefore, one of the objectives of the proposed model is reliability enhancement. Thus, the total cost and reliability are treated as competing objective functions.

The conflicting objectives of MSDNEP obligate a well-organized multi-objective optimization method to well deal with them. There are several scalarization methods reported in the literature such as weighted sum approach [21,28] and weighted sum ε constraint [29]. Although these approaches are simple and easy to implement, there are some weakness associated with them, such as: these approaches require high prior knowledge of problem and multiple runs, not applicable for non-convex problems, there is only one solution for a given set of weights and the decision maker cannot have a good set of trade-off solutions among the objectives [30,31]. In priori methods, a relative preference vector is used to scalarize multiple objectives without any knowledge of possible consequences and trade-offs between objectives. The optimal solution obtained by these methods is highly subjective to the particular decision maker. In contrast to the priori methods, in posterior methods, first the set of Pareto optimal solutions will be found [32,33] and obtaining a final solution is left to the decision maker with its own preferences. Whenever reaching the Pareto optimal set, it follows implementing a decision making method in final optimal solution exploitation. Due to the imprecise nature of decision making, it is necessary to find a mathematical expression to represent human judgment. The capability of fuzzy approach to represent human thoughts is shown in [6,31]. There are several optimization methods effectively solve the multi-objective problem using non-dominancy concept with regard to all objective functions. Among these methods, NSGA-II has shown its applicability and robustness in handling non-convex and mixed integer problems [34,35]. Therefore, NSGA-II as a strong widely-used optimization method of multi-objective dilemma and fuzzy satisfying method, are employed to cope with MSDNEP.

The rest of the paper is organized as follows: a mathematical model for the reliability-based DNEP considering parking lot is developed in Section 'Problem formulation'. Section 'Optimization