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Two-step algorithm for the optimization of vehicle fleet in electricity distribution company

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ABSTRACT

The work of an electricity distribution company is impossible without the extensive use of different types of vehicles (including conventional and electric vehicles) for various purposes. New imperatives set by the market-related economy dictate the rational use of all resources, including the vehicle fleet, subject to constraints on the acquisition, deployment and operation of the fleet in a very uncertain environment. In this paper, a two-step multi-criteria algorithm for the optimization of distribution companies vehicle fleets under uncertainty is proposed. In the first step, fuzzy sets for the preferred vehicle fleet size using queuing theory are composed. In the second step, a multi-criteria fuzzy decision making technique is proposed for the determination of the optimal combination of different types of vehicles. Optimization is carried out for several divisions of one distribution company with different terrain properties. Thanks to the flexible approach of the proposed model, a fair and balanced distribution of vehicles has been achieved between the company's divisions.

Introduction

Together with the proper choice of telecommunication systems, the optimal number and combination of different types of vehicles is a key element of the infrastructure of a distribution utility, in order to enable useful maintenance of a distribution network, rapid response to failures, and the fulfillment of all relevant activities, from both a technical and economic perspective. With the appearance of electric (EV) and plug-in hybrid electric vehicles (PHEV) as a key for achieving energy security and reduced greenhouse gas emission, the optimal composition of number and type of both conventional and electric vehicles becomes more and more important. Furthermore, as the light vehicle fleet moves to electric drive an opportunity opens for "vehicle-to-grid (V2G)"power. The societal advantages of developing V2G include an additional revenue stream for cleaner vehicles, increased stability and reliability of the electric grid, lower electric system costs, and eventually, inexpensive storage and backup for renewable electricity. For the distribution company as the car owner, it is possible to exactly evaluate revenue and costs for these vehicles to supply electricity to three electric markets (peak power, spinning reserves, and regulation) [1,2].

Over the past several decades, electricity distribution companies have had a consistent focus on managing their assets through many approaches and technology solutions focused on asset management [3–6], with the special emphasis on multi-criteria decision support framework risk analysis [7,8]. Although the planning of the optimal fleet mix represents an important component of the overall distribution assets strategy, this aspect has not attracted much attention from researchers. Generally, a fleet mix plan states what kind of assets, and how many, are included in the mix, and when each asset is acquired or retired. A comprehensive review of methods and algorithms used for the fleet composition is given in Ref. [9]. In Ref. [10], the decision support system based on a stochastic programming model for the generation of minimal discounted cost plans covering the purchase, replacement, sale, and/or rental of the vehicles necessary to deal with a seasonal stochastic demand is presented. Besides the costs, the critical aspect of the vehicle size optimization in any utility company is the commercial quality, reflected to the waiting time to the service, due to the possibility that the crews with their vehicles are all busy. Markov chains are extensively used for the modeling of stochastic processes concerning vehicle usage. Optimal scheduling for emergency vehicles based on Markov chain models is given in Refs. [11–16].

Queuing models are an abstraction of Markov chain models and queuing theory provides good approximations of the system behavior where the objective is to minimize operating costs subject to several constraints, including a maximum waiting time for customers [17–19]. However, new requirements concerning

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economical, societal and environmental issues demanded the introduction of multi-criteria analysis approach. In Ref. [20], a multi-criteria decision model to assist service providers in optimizing sustainment activities by minimizing cost and maximizing equipment availability is introduced. The service logistics network by considering the increment of fleet size due to the market expansion has been modeled and optimized. In Refs. [21,22], the non-dominated sorting genetic algorithm to perform a multi-objective optimization of the stochastic fleet estimation model is presented. Solutions are evaluated using three objectives, with a goal of maximizing flexibility in accomplishing each task within its closure time, and minimizing fleet cost and total task duration. Finally, in Ref. [23] an integrated multi-criteria decision making approach to design an optimal resource management based on fuzzy analytic hierarchy process (AHP) is formulated. In this approach, the ant colony optimization is used to obtain optimal solutions satisfying some path planning criteria and to select the best set of vehicles. In strategic fleet management decision all relevant revenues and costs related to the acquisition and operation of the fleet should be modeled as detailed as possible, taking possible long-term contracts and spot markets into consideration, including the use of EVs.

As far as the usage of EVs in utilities is concerned, the analysis has been reduced to the problem of their impact to the distribution network. In Ref. [24], an environmentally and economically sustainable integration of EVs into power systems is developed under the framework of a robust optimization planning model with the constraints of both the power system and the transport sector taken into consideration.

The aggregation for regulation services has been proposed and explored in Refs. [25–27], with an optimal charging sequence for EVs providing combined regulation and reserve. In Ref. [28], stochastic nature of EV transportation patterns has been considered, while in Ref. [29] the problem formulation takes into account unplanned EV departures during the contract periods and compensates accordingly, with each hour of EV availability with an associated unplanned departure probability. In Ref. [30], a smart load management approach for coordinating multiple plug-in EVs chargers in distribution systems is proposed, with the objectives of shaving peak demand, improving voltage profile and minimizing power losses, as well as the impact of EVs charging stations and typical daily residential loading patterns considered as constraints. A minimized cost model for determining the locations and capacities of charging stations for regional EVs is developed in Ref. [31] with the weights of candidate locations determined by the well-established analytic hierarchy process (AHP). In Ref. [32], an optimal charging and discharging schedule model is proposed minimizing the total operational costs and emissions with network capabilities and driver patterns considered in order to generate the Pareto optimal solution. The attempt to integrate economic, social and environmental criteria in determining the optimal number of EVs in a distribution company is given in Ref. [33].

However, in all approaches mentioned above, the problem of assets optimization or vehicle scheduling has been treated with the aim of aggregator revenues maximization. The car owner perspective, concerning the availability of vehicles is quite different. While the aggregator prefers the EV population to remain in the scheduled modes of aggregated operation for the entirety of each scheduled period of the optimization horizon, the car owner has to balance between the service quality and the revenues from ancillary services offered by EVs.

In this paper, a new practical multi-criteria decision making methodology for the fleet mix determination based on two step algorithm is proposed. In the first step, using the queuing theory, the preferred fleet size is determined. In the second step, a multi-criteria fuzzy decision making technique is used for the determination of the optimal combination of different vehicle types. The preference of individual criteria is determined with the AHP technique.

The innovative contributions of the proposed method are highlighted as follows:

- The methodology allows the integrative approach of the fleet size and composition optimization in a distribution company including conventional and EVs.
- The optimization of the EV fleet size has been performed from the car owner, and not only from the aggregator perspective.
- Multiple criteria are taken into account in this model, including the costs of commercial quality and preferred consumer's area indicators.
- Uncertainties concerning service requests and costs are handled by the usage of fuzzy sets.
- Balanced allocation of vehicles has been achieved between the company's divisions.

The paper is organized in the following way. After the introduction and literature review, in Section 'Fleet mix problem' we explain details about the model parameters together with the fuzzy multi-criteria decision making technique. Section 'Fleet costs estimation' presents the model of vehicle usage in distribution company. In Section 'Service time costs determination', for the sake of illustration, the model is applied to the problem of fleet mix composition for a distribution company in Southern Serbia. Finally, conclusions are brought about the possibilities of model application and further research directions.

Fleet mix problem

Vehicle fleet planning is a generic and broad class of practical decision making problems, including the optimal fleet mix problem. Fleet mix planning involves the determination of a combination of assets (e.g. vehicles) that is expected to maximally fulfill the fleet's mission objectives subject to constraints on the acquisition, deployment and operation of the fleet.

In Ref. [34] the fleet mix is defined as:

$$F = \{(\alpha_i, n_i) : \alpha_i \in A\} \tag{1}$$

where n_i is the number of assets of type α_i.

If F_η is one such set corresponding to a particular time period η, then the fleet mix in period η is written as:

$$F(\eta) = (F_n, \eta) \tag{2}$$

Fleet mix plan is a statement, over a planning horizon, of the fleet mix at various time periods in the planning horizon. Thus, if H is the set of time periods in the planning horizon, and if F_n is the fleet mix during the time period η, a fleet mix plan P for the horizon H is defined as:

$$P = \{F(\eta) : \eta \in H\} \tag{3}$$

Although the number and the structure of vehicle types are very diverse, the two most common types in an electricity distribution company have the dominating position: the light passenger vehicle, and the medium-light terrain vehicle. Moreover, almost 80% of all distribution activities are effectuated using these two types of vehicles. The terrain vehicle is used for activities such the maintenance of substations, underground and overhead network, the repair of minor faults and the inspection of network and other objects on regular and nonscheduled basis. Regardless of the applied technology (gas – powered, EV or PHEV), the light passenger vehicle is used for minor interventions on the network as well. However, unlike terrain vehicles, their use is mainly focused on