Volume 1, Issue 2, pp. 33-37, 2017.

International Journal of Scientific Engineering and Science

A Survey on Multi-Criteria Based Optimizations in the Routing of Electric Vehicles

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Abstract— *As the part of energy conservation and to reduce the emission of carbon dioxide and greenhouse gases into the environment recently many countries have been promoting the usage of electric vehicles (EVs) into their fleet. Due to the limited battery capacity or the limited driving range it is important to visit recharging or replenishment stations in the midway or mid of the tour. But this will result in a congestion at the recharging station due to the concurrent request for the battery recharge. So this should be considered by the available route planners to improve transportation system efficiency and sustainability. Optimization of electric vehicle routing can be considered with multiple criteria's such as time-window constraints, energy efficiency, distance travelling, battery recharging capacity, congestion at the charging station etc. this will reduce the associated cost of travelling time, charging time and energy consumption along the route of electric vehicles and this will also minimizes the congestion of electric vehicles at the charging stations. This work provides a comparitive study of multiple strategies used for the optimization of electric vehicles routing problem.*

Keywords— *Battery capacity, battery recharge, driving range, electric vehicles, recharging or replenishment station, route planners.*

I. INTRODUCTION

Nowadays, main issues regarding the pollution are the emission of greenhouse gases and carbon dioxide into the environment. Main alternative of this is to use battery electric vehicles. As a result European union and other countries are widely promoting electric vehicles into their fleet to become the part of green vehicles or green logistics. Recently it become the one of the main research area in the automobile sector. The main obstacle that reduces the popularity of electric vehicles are its short driving range and its large recharging time. Even with the available quick recharging technologies a battery recharge will take several minutes and thus it will result in the congestion at the recharging stations.

In order to optimize the routing of electric vehicles based on multiple criteria's following steps should be considered

1. energy consumed by the vehicle along the route or path should be minimum that is energy based optimization
2. taken by the electric vehicle to recharge at the charging station during the tour from the starting point to the stopping point should be minimum and it is the time based optimization.
3. it is important to find the minimum paths for travelling between the origin and destination and this is the distance based optimization
4. finally health of the battery to be taken in to account thus it will help to increase battery life time
5. waiting time at the charging station

II. CLASSIFICATION OF OPTIMIZATION TECHNIQUES FOR ELECTRIC VEHICLE ROUTING

Following are the classification of optimization techniques for the routing of electric vehicles as shown in figure 1.

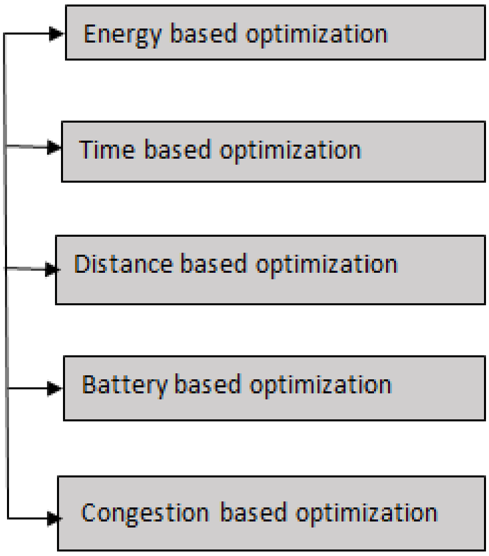

Fig. 1. Classification of optimization techniques for the routing of electric vehicles.

A. Energy Based Optimization

Because of the increasing fossil fuel prices and environmental pollution it is important to look for alternatives such as electric vehicles.it will prevent global warming by the limited emission of the greenhouse gases in to the environment. Electric vehicles can be powered either by conventional or regenerative energy resources.

If we aimed an energy efficient driving of an electric vehicle it will create many challenges to the available navigation system and the route planners. Considering an energy optimal electric vehicle routing simply as an edge cost calculation and applying standard algorithms will does not work [1].

IJSES

International Journal of Scientific Engineering and Science

Volume 1, Issue 2, pp. 33-37, 2017.

The main characteristics of electric vehicle are its i) limited driving range ii) longer charging time and iii) ability to regain energy during deceleration [2].

Electric vehicles consumes less energy and provide almost same performance as a normal conventional vehicle. Therefore it operates near optimum efficiency [4]. It also exhibit lower emission of noise outside [5]. It is very essential to recharge the electric vehicles during the long tours due to its shorter cruising range but still one important problem is the charging stations, they are not popular or widely spread as the gas stations.

There are many approaches and algorithms are available for making the route of an electric vehicle an energy efficient one. In one approach, propose an answer for vitality ideal steering for EVs that meets the difficulties such as ability to regain their kinetic or potential energy during deceleration phases, it is complex to compute edge cost and it depends on number of parameters such as vehicle payload, auxiliary consumers etc and additional energy losses or gains can arise from taking a specific path by considering battery capacity, inside the system of A* inquiry. The key thought of the approach is to adventure space particular learning to recognize and bound diverse types of vitality, which offers ascend to a steady heuristic capacity and yields an O(n2) steering calculation that extends just as couple of hubs as vital. Besides, we then show how battery requirements can be joined into this calculation by powerfully adjusting edge costs amid the inquiry; hence, they can be taken care of in an indistinguishable route from parameters given at question time, without expanding the general run-time multifaceted nature. Our answer enhances by a request of greatness upon already distributed outcomes that introduced an O(n3) calculation for an improved form of the issue. We actualized our approach inside a prototypic course arranging framework for EVs [1].

Another approach addresses the problem of energy optimal routing for electric vehicles as an extension of general shortest path problem. Be that as it may, most ordinarily utilized SP calculations like contradiction hierarchies, highway hierarchies and travel vertex hierarchies can't be connected to our issue in view of the nearness of negative weights that outcome from recovery. What's more, SP does not consider the imperatives that outcome from the release and revive attributes of the EV's battery pack, in particular that it not one or the other can be released beneath zero, nor charged over its greatest limit. These two conditions on the charge level of the battery can be seen as hard and delicate imperatives, separately, on conceivable highways: a course is infeasible if there is a point where the required vitality surpasses the charge level, and a course is less favoured if there is a point where vitality could be recovered however the battery's most extreme limit is surpassed [2].

Another method used for energy based optimization is metaheuristic optimization. A reproduction based advancement approach will be demonstrated that utilizations metaheuristic calculations for figuring ideal charging procedures of an energized car fleet that both fulfil vitality request of individual auto clients and additionally join the physical attributes of the electric power network under the extraordinary state of mostly probabilistic supply. Since the power network will be considered through load stream re-enactments, imperatives can be viewed as that guarantee solid operation [3].

From the point of view of a grid operator power or the energy losses during the charging have to be reduced and overload have to be mitigated. Not only the power losses but also the quality of power is important for the grid operator [4].consumption of energy along the path should be minimum as possible for staying mobile. At the same time people are not willing to take long travelling times to save few KWh. Following queries reflect the multi criteria objectives from a users point of view.

1. What is the shortest or quickest path on which the EV does not run out of energy?
2. What is the most energy-efficient path which is at most xtimes longer than the shortest one (e.g. x= 1.05)?

A path in which EV does not run out energy is called feasible .there is no feasible path from source to destination without reloading. We should make decision where to recharge reasonably. So we have to balance distance or time, energy consumption and reloading efforts [5].

Contributions of another approach are battery constraints such as overcharging and running out of energy can be modelled as functions of cost on the edges which obeys FIFO property hence Bellman-Ford algorithm can be used to solve the problem in O(n). By applying Johnsons potential shifting technique to the negative cost functions makes Dijkstra applicable. This may result in an improved query time of O(n log n+m) [6].

Advantages

- No compromise of complexity
- No compromise of correctness
- Can gain energy
- Compute shortest path which does not run out of energy

Disadvantages

- Energy run out before arriving at the destination
- Dynamic changes in the energy consumption functions are not considering

B. Time Based Optimization

Apart from energy optimization criteria's some other approaches are based on time based optimization criteria's. That is the time required to recharge vehicle at the charging station. Some approaches assumes that vehicles travel at a constant speed hence we can predict the arrival time of vehicle at the charging station in a deterministic way [7]. Another approach assumes that recharging station is always available when request is made but it is not possible in the case of reality [8].

One approach introduces an electric vehicle routing problem with time windows which associates the case of recharging at one of the available stations using a recharging scheme that is the recharging time depending on the charge available on the vehicle at the arrival time of the station [9]. Moreover, the A large portion paramount useful. Necessities from claiming logistics suppliers utilizing battery EVs, in particular limit imperatives on vehicles Furthermore. Client time windows are incorporated. It also aims to minimize the number of employed vehicles and the total travelled distance. The effects for recharging time Also vehicle extent need aid determined on focus trends done. Particular fleet aspects including fleet size, Normal tour distance, also aggregate fleet distance travelled [10].

Another study presents a time-dependent model with time window constraints that incorporates speed and provides a schedule in transportation. Transportation system efficiency enhancement is its main objective. This model introduces different speed limits for different times of the day and it proposes a simulated annealing algorithm to find solutions in a timely manner with high quality. Here the speed control and travelling time were studied using a mixed integer programming model [11].

A path in which EV does not run out energy is called feasible .there is no feasible path from source to destination without reloading. we should make decision where to recharge reasonably. So we have to balance distance or time, energy consumption and reloading efforts. This may lead to more complex optimization criteria and it will reflect in the following questions [5].

3. Find the shortest/quickest feasible path with at most k recharging events.
4. Find a feasible path with a minimal number of recharging events and bounded distance/travel time.

Considering another approach which has a problem in which each edge is associated with a cost of travelling along the edge as well as the time required to travel along the edge. Here each node has a lower bound and upper bound on the time of departure from that node. Time dependent cost will varies linearly with the total waiting time along the path [12].

Advantages
- Control the speed
- Control the time
- Different speed limits for different times of the day

Disadvantages
- Vehicles travel at a constant speed
- Vehicles can complete the entire trip in a single charge

C. Distance Based Optimization

In distance based optimization criteria some approaches assumes that vehicles can complete the entire trip in a single charge with no charging stops in the midway. Modern vehicle’s navigation system are equippied with a optimum path selection modules that are used for finding the shortest path between the origin and destination pair in a road network. Methods used for finding the shortest path in EVs are different from those are used in internal combustion engine vehicles.

One approach assumes that a vehicle’s optimum path selection module is placed in the navigation system. Electric vehicle’s navigation system are connected with the Global Positioning System (GPS) OR V2X communication system to obtain the information regarding the road networks. Optimum path selection unit uses the information of navigation system to find shortest paths [13].

Another approach impose a driving range demand which ensures that each stretch for not less than rkm covered by at least one station. This problem comes under the family of Flow Interception Facility Location Problems (FIFLPs). Where demand is expressed by source sink flows on a directed graph. It assumes that drivers can recharge at their origin or at their destination. This implies recharging is not an issue on origin destination paths not exceeding rkms [14].

One approach proposes a mobile charging vehicle management module it can decrease the driving distance of electric vehicles to find recharging stations.it will also prevent electric vehicles from halting in the mid-way because of running out of electricity [15].

Advantages
- Requires less computational time
- Executes efficiently on fast processor based embedded system
- Gain of driving range
- Flexibility recharging vehicles
- Optimize network performance
- Computing shortest path

Disadvantage
- Incomplete reloading is not considering here

D. Battery Based Optimization

Promising alternative to reduce the emission of greenhouse gases are the usage of battery electric vehicles. In earlier years battery electric vehicles failed due to the higher battery prices and shorter driving range. It is necessary to visit charging station with limited battery capacity during tours. There are mechanisms to monitor the current state charge in the vehicle and the availability of the charge in the battery at the arrival time of vehicle in the charging station [9].

It is important to consider the charge and battery degradation of battery electric vehicle. Here is one approach that co-ordinates the charge scheduling and cost of operation of battery electric vehicles. Operating costs can be simplified by considering both charging fees and battery degradation.

Scheduling of charges are taken into account by considering the energy tariff variations during the peak and non-peak hours of the day. Another important thing to consider is the battery health, because the charging and discharging actions are sensitive. Also the most expensive component of battery electric vehicles is the battery, therefore the efficient planning of a charge schedule will increase the battery life time and reduce the operational cost [16]. Main features that influence battery degradation are State Of Charge (SOC), Depth Of Discharge (DOD) and battery temperature.

Another approach assumes that Plug in Hybrid Electric Vehicles (PHEVs) provides higher fuel flexibility. It may have larger batteries and more powerful motors. Capacity of its batteries is about 10kWh and power of the electric motor is 70kW. Most difficult part of such vehicles are storage of the electrical energy because of battery limiting factors. PHEVs are more expensive than HEVs because of their extra battery capacity [4].

International Journal of Scientific Engineering and Science
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Advantages

- High performance
- Increased battery life time
- Minimizes the operation cost
- Provide valuable fuel flexibility
- Have larger battery and more powerful electric motor

Disadvantages

- Overloads have to be minimized
- Power losses during charging have to be minimized
- Charging station concurrent use is not taken into account
- It assumes that vehicles can complete the entire trip in a single charge

E. Congestion Based Optimization

Delay or waiting time due to looking for a charging station is one of the important parameter to be considered. Due to the high expense of building new charging stations it is important to consider the location of charging stations.

Here one approach defines a query and reservation protocol between an electric vehicle and routing service which enables the user 1) to query about the availability of the charging station in advance at any time 2) if any charging station is available, reserve a time slot to recharge 3) to be notified when a charging station is available. The routing service is one which serve a region and provide a broker between the EV user and the energy provider. Broker provides the best charging station match with respect to the availability of required resources needed for charging. User provided information consists of two parameters that help the user to route and reserve resources at the selected charging stations. Time window that I the estimated arrival and leaving time and the energy needed [17].

Another approach provides a dual objective model that minimizes the waiting time at the charging station and maximizes the service accessibility for locating charging stations and these are based on several rational hypothesis [18].

In another approach we can see the provoking impact due to the deployment of EVs on the network voltage profile, branches' congestion level, grid losses and imbalances between phases are evaluating using three phase power flow [19].

Another method describes a brokerage function for searching charging station between the vehicle user and the charging service provider and it provides a methods to reduce the EV created load in the grid. It is considered with the routing and reservation services for EVs [20].

Advantages

- Provide more charging options
- Optimize waiting time for charging
- Maximum service accessibility for locating electric vehicle charging station
- Enables congestion prevention
- Most efficient usage of the resources
- Optimizes the electric vehicle created load in the grid
- Provide routing and reservation scheme

Disadvantages

- The number of charging piles of each station are not considering here
- Not considering the charging time of each electric vehicle
- The relationship between energy consumed and distance travelled under different road conditions are not considering here
- Accuracy has to be improved
- It assumes that charging station is always available when a request is made which is not possible in the case of reality

III. CONCLUSION

This paper provides a survey of different models or techniques used for the routing of electric vehicles. For that it analyses five techniques namely energy based optimization, time based optimization, distance based optimization, battery based optimization and congestion based optimization. From this survey can arrive at a conclusion that by using different optimization criteria's can minimize the associated cost travelling time, charging time and energy consumption along the route of electric vehicles. Similarly can reserve and easily spot public charging stations and also can avoid the congestion and reduce the waiting times at the charging stations.

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