

Energy Loss Minimization Modelling for Given Energy Path in Vehicular Energy Network

Lae Yeop Lee*, Seong Gon Choi*

* Information & Communication Engineering, Chungbuk National University, Cheongju-si Chungcheongbuk-do, Korea
omegamon@chungbuk.ac.kr, choisg@chungbuk.ac.kr

Abstract— We suggest energy loss minimization model while maximizing transfer energy under given energy path condition. When energy paths of vehicular energy network are given, total loss minimization can be seen as linear program. So, we use method of Lagrange multiplier to get dual problem. And then, Karush-Kuhn-Tucker conditions is applied on this dual problem. Advances in intelligent transportation systems and smart grid technologies offer great promise to widely popularize electric vehicles, and have the potential to revolutionize urban transportation systems and power systems. Vehicular energy network is a vehicular network capable of transmitting energy effectively over a large geographical area by means of EVs.

Keywords— Electric Vehicle, Energy Path, Optimization, Smart Grid, Vehicular Energy Network.

I. INTRODUCTION

A smart grid(SG) is advanced electric power system that integrates conventional power system and information and communication technology. Also it integrates renewable energy systems, energy storage systems, smart metering. SG can operate flexibly depending on their operational purpose. However, the conventional power grid operators would hesitate to introduce the smart grid innovations into the existing power grids. One of the possible ways to bring them to the table is to let the existing power system function as it is and to let the new innovations unite with the existing system in a loose and flexible manner. To do this, we need a supplementary power delivery system which is easy to build and can complement the existing power system[1].

The use of electric vehicles is increasing nowadays, because electric vehicles provides advantages over the conventional vehicles using fossil fuels, such as: less noise, more easy maintenance and less pollution[7]. Many companies are eager to develop electric vehicles, and many policies are being announced to support electric vehicle development and diffusion in many countries. Furthermore, advances in intelligent transportation systems and smart grid technologies offer great promise to widely popularize electric vehicles (EVs), and have the potential to revolutionize urban transportation systems and power systems[2],[5],[6].

VEN is a vehicular network capable of transmitting energy effectively over a large geographical area by means of EVs. It is built upon the existing road networks, where EVs traverse the vehicular network along certain routes completely based

on the drivers' wills. To build VEN, Wireless (dis)charging facilities and small energy storage are installed at certain road junctions. With the advanced vehicular communications technologies, we can acquire the travel plans of the participating EVs and a set of vehicular routes with known traffic flows can be determined. When a particular EV comes across a road junction, it is wirelessly charged with (a small amount of) energy. When it reaches an appropriate road junction, it discharges the energy and then the energy is stored in a storage facility for subsequently charging another EV. Hence we utilize EVs as carriers to convey energy from one place to another. By selecting proper EV to carry energy, we can control the energy transmission rate over the road connections[3].

To transmit energy over VEN, energy paths establishment is essential, which are composed of segments of vehicular routes, while satisfying various design objectives. In [1], VEN routing was investigated through constructing energy paths for a particular energy source-destination pair. The divide-and-conquer method to find all feasible energy paths, heuristic method to reduce computation time. By the way, when energy path is given, their optimization problem, which purposes for minimizing total energy loss, can be seen as a linear program[1].

In this paper, we suggest energy loss minimization model while maximizing transfer energy under given energy path condition.

II. RELATED WORK

The authors of [3] suggest a framework to model an energy delivery architecture for transporting energy from one place to another by means of EVs, called VEN. VEN is a vehicular network capable of transmitting energy effectively over a large geographical area by means of EVs. it is built upon a road network.

Reference [3] is extended in reference [1]. To delivery energy over VEN, energy paths should be established. Energy path routing is required to transmit energy while satisfying various design objectives. a study to give foundations of VEN routing is introduced in [1]. method of heuristic and method of divide and conquer to establish the power path was presented.

A variety of goals can be considered in EV driving (e.g., distance, charging costs, etc.). in [2], It deals with driving optimization of EV fleet, which provides pickup and delivery

service. Multi-objective optimization model, which minimize route distance, travel time and charging cost while fulfilling customer delivery service, is proposed. it also provides results including the impact of the charging station price policy on the driver's charging behavior, the difference in load depending on the location of the charging station, and the difference in EV operating costs depending on battery capacity.

III. SYSTEM MODEL

In this section, we provide reference model which minimize total energy loss in VEN and modified model which is considering maximum transferable amount of energy.

we refer to loss minimization model and math notation in [1]. The reference model to minimize total energy loss as followed:

$$\text{minimize} \quad \sum_{j=1}^{|P(s,t)|} \left(\frac{1}{z^{|p_j|}} - 1 \right) x_j \quad (1-a)$$

$$\text{subject to} \quad 0 \leq x_j \leq (T - d(p_j)) z^{|p_j|} g_j, \quad j = 1, \dots, |P(s,t)| \quad (1-b)$$

$$0 \leq g_j \leq w f_i^j, \quad i = 1, \dots, |p_j|, j = 1, \dots, |P(s,t)| \quad (1-c)$$

$$\sum_{j|a \in p_j} \frac{g_j}{w} \leq h_a, \quad h_a \in A \quad (1-d)$$

$$\sum_{j=1}^{|P(s,t)|} x_j \geq \underline{X} \quad (1-e)$$

Equation (1) is an optimization problem of reference model. In equation (1-a), which is objective function for minimizing total energy loss transferred along established energy path, maximum transferable energy x_j is defined as $(T - d(p_j)) z^{|p_j|} g_j$. (∵ equation (1-b)) x_j is determined by g_j , because reference model, which energy path is established, consider g_j only. The overall energy transmission of energy path, denoted by g_j , should hold that g_j is smaller than or equal to the minimum of the energy transmission rates of all its composite segments. Namely, equation (1-c) can be simple by considering minimum f_i^j as f^j , which is minimum EV flow rate of its composite segments. Therefore, modified model, which is additionally considering maximum transferable amount of energy, followed:

$$\text{minimize} \quad \sum_{j=1}^{|P(s,t)|} \left(\frac{1}{z^{|p_j|}} - 1 \right) \left((T - d(p_j)) z^{|p_j|} g_j \right) \quad (2-a)$$

$$\text{subject to} \quad 0 \leq g_j \leq w f^j, \quad j = 1, \dots, |P(s,t)| \quad (2-b)$$

$$\sum_{j|a \in p_j} \frac{g_j}{w} \leq h_a, \quad h_a \in A \quad (2-c)$$

$$\sum_{j=1}^{|P(s,t)|} \left((T - d(p_j)) z^{|p_j|} g_j \right) \geq \underline{X} \quad (2-d)$$

Under given energy path condition, this optimization problem can be seen as linear program with one variable, g_j . So we can use method of Lagrange multiplier for solving this optimization problem.

IV. LOSS MINIMIZATION WHILE TRANSFER ENERGY MAXIMIZATION

By dividing (2-b), Modified optimization problem can be represented as followed:

$$\text{minimize} \quad \sum_{j=1}^{|P(s,t)|} \left(\frac{1}{z^{|p_j|}} - 1 \right) \left((T - d(p_j)) z^{|p_j|} g_j \right) \quad (3-a)$$

$$\text{subject to} \quad -g_j \leq 0, \quad j = 1, \dots, |P(s,t)| \quad (3-b)$$

$$g_j - w f^j \leq 0, \quad j = 1, \dots, |P(s,t)| \quad (3-c)$$

$$\sum_{j|a \in p_j} \frac{g_j}{w} - h_a \leq 0, \quad h_a \in A \quad (3-d)$$

$$\underline{X} - \sum_{j=1}^{|P(s,t)|} \left((T - d(p_j)) z^{|p_j|} g_j \right) \leq 0 \quad (3-e)$$

Optimization problem (3) is linear program. Because this paper assume that energy paths are given. So, we then define a Lagrangian associated with the above problem (3) as

$$\begin{aligned} L(g_j, \alpha_j, \beta_j, \gamma, \delta) = & \sum_{j=1}^{|P(s,t)|} \left(\frac{1}{z^{|p_j|}} - 1 \right) \left((T - d(p_j)) z^{|p_j|} g_j \right) \\ & - \sum_{j=1}^{|P(s,t)|} \alpha_j g_j + \sum_{j=1}^{|P(s,t)|} \beta_j (g_j - w f^j) \\ & + \gamma \left(\sum_{j|a \in p_j} \frac{g_j}{w} - h_a \right) \\ & + \delta \left(\underline{X} - \sum_{j=1}^{|P(s,t)|} \left((T - d(p_j)) z^{|p_j|} g_j \right) \right) \end{aligned} \quad (4)$$

Where

$\alpha = \{\alpha_j : \alpha_j \geq 0, j = 1, 2, \dots, |P(s,t)|\}$, $\beta = \{\beta_j : \beta_j \geq 0, j = 1, 2, \dots, |P(s,t)|\}$, $\gamma \geq 0, \delta \geq 0$ are Lagrangian multiplier vectors corresponding to the feasible transmission rate constraints. In addition $|P(s,t)|$ denotes the number of given energy paths.

then, the dual function of (4) is given by

$$h(\alpha, \beta, \gamma, \delta) = \min_{g_j} L(g_j, \alpha_j, \beta_j, \gamma, \delta) \quad (5)$$

And the dual problem corresponding to problem (3) is expressed as (6)

$$\begin{aligned}
& \text{maximize} && h(\alpha, \beta, \gamma, \delta) \\
& \text{subject to} && \alpha \geq 0 \\
& && \beta \geq 0 \\
& && \gamma \geq 0 \\
& && \delta \geq 0
\end{aligned} \tag{6}$$

The Karush-Kuhn-Tucker(KKT) conditions, which is a method of finding optimal values by using conditions that satisfy the strong duality between the primary and the dual problem, can be applied on (4) to get fixed Lagrange multiplier vectors[4]. Then we have

$$\begin{aligned}
\frac{\partial L}{\partial g_j} &= \frac{\partial \sum_{j=1}^{|P(s,t)|} \left(\frac{1}{z^{|p_j|}} - 1 \right) \left((T - d(p_j)) z^{|p_j|} g_j \right)}{\partial g_j} \\
&\quad - \frac{\partial \sum_{j=1}^{|P(s,t)|} \alpha_j g_j + \sum_{j=1}^{|P(s,t)|} \beta_j (g_j - w f^j)}{\partial g_j} \\
&\quad + \frac{\partial \gamma \left(\sum_{j|d \in p_j} \frac{g_j}{w} - h_a \right)}{\partial g_j} \\
&\quad + \frac{\partial \delta \left(\underline{X} - \sum_{j=1}^{|P(s,t)|} \left((T - d(p_j)) z^{|p_j|} g_j \right) \right)}{\partial g_j} \\
&= \left(1 - z^{|p_k|} \right) \left(T - d(p_j) \right) - \alpha_k + \beta_k + \frac{\gamma}{w} - (T - d(p_j)) z^{|p_j|} \delta \\
&= 0
\end{aligned} \tag{7}$$

We can get optimum Lagrange multiplier vector using (7). And gradient descent method can be applied to calculate the optimum values for variables. In this paper, because we focus on optimization problem modeling, we skip process for obtaining precise optimum value.

V. SIMULATION

We simulate optimization problem that described in (3). Parameter values, which are used in simulation, are listed in table 1. Figure 1 shows relation between transmission rate and total energy loss. Because total energy loss is determined by transmission rate in given energy path condition, a linear graph is gotten. Black line is energy transmission rate without any constraints. In the black line, segment of a line bounded by red squares is transmission rates, which are satisfy all constraints. With all constraints, minimum transmission rate is about 3.5.

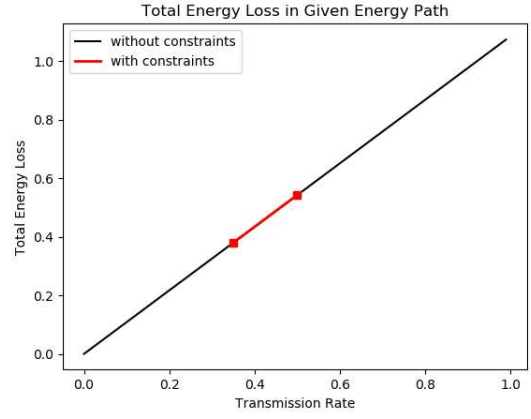


Figure 1. Total energy loss on transmission rate

TABLE 1. SIMULATION PARAMETERS

Parameter	Value
$ P(s,t) $	1
z	0.9
$ p_j $	3
T	5
$d(p_j)$	1
f^j	0.5
w	1
h_a	0.7
$\underline{X}$	1

VI. DISCUSSION AND CONCLUSION

When we have optimum variable g_j^* and optimum Lagrange multiplier vector $\alpha^*, \beta^*, \gamma^*, \delta^*$, KKT conditions are satisfied below:

- 1) Partial derivative of Lagrangian with respect to g_j must be 0, $\frac{\partial L}{\partial g_j} = 0$
- 2) All inequality constraints of equation (3) with respect to g_j^* must be less than or equal to 0.
- 3) Each of optimum Lagrange multiplier vectors ($\alpha^*, \beta^*, \gamma^*, \delta^*$) must be greater than or equal to 0.
- 4) Every multiple of inequality constraint with respect to g_j^* and Lagrange multiplier vector corresponding its inequality constraint must be equal to 0.

The objective function of equation (3) is linear function of g_j . So it cannot have global minimum without any constraint. But global minimum can be obtained by setting limits the domain of objective function via constraints. If $\alpha^*, \beta^*, \gamma^*$ and δ^* , which satisfying the above conditions, are given, we can

obtain g_j^* that fill all constraints. In other words, when α^* , β^* , γ^* and δ^* are fixed, Within the range of g_j that satisfies the constraints, combination of system constants, which meet $\frac{\partial L}{\partial g_j} = 0$, minimize total energy loss while maximizing transfer energy.

In this paper, we suggest minimization total loss while maximizing transfer energy in given energy paths and apply method of Lagrange multiplier. Total loss optimization problem of VEN can be seen as linear program, when determined energy paths are given[1]. In this case, we could get that given system constants and sole variable, overall transmission rate g_j , can control performance of VEN. Reference [1] provided the basis for VEN routing by comparing solution quality, computing time, solvable problem size, and applicability based on the results of the divide-and-conquer method and the heuristic method through simulation. But, they provide insufficient information for reappearance. So, we will study to make optimum values and system reproduction, in the future.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2019R1A2C1006167).

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(2020R1A6A1A12047945)

*corresponding author is S.G. Choi (choisg@cbnu.ac.kr)

REFERENCES

- [1] A. Y. S. Lam and V. O. K. Li, "Opportunistic Routing for Vehicular Energy Network," in IEEE Internet of Things Journal, vol. 5, no. 2, pp. 533-545, April 2018, doi: 10.1109/IIOT.2017.2752222.

- [2] T. Chen, B. Zhang, H. Pourbabak, A. Kavousi-Fard and W. Su, "Optimal Routing and Charging of an Electric Vehicle Fleet for High-Efficiency Dynamic Transit Systems," in IEEE Transactions on Smart Grid, vol. 9, no. 4, pp. 3563-3572, July 2018, doi: 10.1109/TSG.2016.2635025.
- [3] A. Y. S. Lam, K. Leung and V. O. K. Li, "Vehicular Energy Network," in IEEE Transactions on Transportation Electrification, vol. 3, no. 2, pp. 392-404, June 2017, doi: 10.1109/TTE.2017.2649887.
- [4] S. Boyd and L. Vandenberghe, Convex Optimization. Cambridge: Cambridge University Press, 2004.
- [5] M. Buechel et al., "An automated electric vehicle prototype showing new trends in automotive architectures," in Proc. IEEE 18th Int. Conf. Intell. Transp. Syst. (ITSC), Las Palmas, Spain, Sep. 2015, pp. 1274-1279.
- [6] W. Su, H. Rahimi-Eichi, W. Zeng, and M.-Y. Chow, "A survey on the electrification of transportation in a smart grid environment," *IEEE Trans. Ind. Informat.*, vol. 8, no. 1, pp. 1-10, Feb. 2012.
- [7] I. M. A. Nnatha, A. B. Muljono, I. M. Ginarsa, S. M. Al Sasongko and I. B. F. Citarsa, "Smart Energy Meter for Electric Vehicle Based on Bluetooth and GSM Technology," 2018 International Conference on Smart Green Technology in Electrical and Information Systems (ICSGTEIS), Bali, Indonesia, 2018, pp. 7-12, doi: 10.1109/ICSGTEIS.2018.8709139.



Lae Yeop Lee received B.S. degree in the College of Electrical & Computer Engineering, Chungbuk National University, Korea in 2020. He is currently a M.S. candidate in School of Electrical & Computer Engineering, Chungbuk National University. His research interests include Smart Grid, Optimization, Electric Vehicle Application.



Seong Gon Choi received B.S. degree in Electronics Engineering from Kyeongbuk National University in 1990, and M.S. and Ph.D. degree from Information Communications University, Korea in 1999 and 2004, respectively. He is currently an associate professor in College of Electrical & Computer Engineering, Chungbuk National University. His research interests include smart grid, IoT, mobile communication, high-speed network architecture and protocol.