A Study on the Market Characteristics of Wind Power System Using Learning Curves in Korea

Sungwook Hwang[*], Jongryul Won[**], Junghoon Kim[*]
[*]School of Electrical Engineering, [**]Dept. of Electrical and Electronic Engineering
[*]Hongik University, [**]Anyang University
[*]72-1, Sangsu-dong, Mapo-gu, Seoul, [**]708-113, Anyang 5-dong, Manan-gu, Anyang-shi
REPUBLIC OF KOREA

Abstract: - Nowadays the concern about development and diffusion strategies of new & renewable energy (NRE) and its technologies is getting higher globally as Kyoto Protocol has taken effect this year and oil has been rising in price tremendously. Developed countries have already commenced the study and research for this problem and are looking for various solutions. In this paper, environment of NRE in Korea is analyzed and estimated using the learning curve, which has been powerfully used for analyses of end-use equipments' characteristics in existing studies, as a pre-study for proposing appropriate strategies and feasible methods. The sample study shows how installation costs and the policies affect on the penetration of NRE.

Key-Words: - New & Renewable Energy (NRE), Wind Power, Diffusion Model, Learning Curve

1 Introduction

As Kyoto Protocol has taken effect in the year 2005, the concern about development and strategies of NRE and its technologies is getting higher. Developed countries such as the United States, Japan, Germany, and etc. have recognized these problems seriously. Hence, the authorities have tried to resolve this situation through various methods. Actually, each country is implementing various policies and strategies for developing of NRE resources through own methods corresponding their social and economical environments.

In Korea, 11 types of NRE resources are assigned by "Promotion Act of the New and Renewable Sources of Energy Development," which are photovoltaic, solar thermal, wind, fuel cell, biomass, waste, IGCC, hydrogen, small hydro, geothermal, and ocean energy. Recently, various support policies are in progress, which are public obligation, certification, expert enterprise, regional energy programs, loans, feed-in-tariff, subsidy programs, and solar house programs. In the public obligation, public organizations are obligated to invest in NRE facilities when constructing new buildings with the gross area of 3000 square meters. The certification has criteria that NRE facilities, such as solar collectors, solar water heaters, solar cell modules, and small wind power plants, meet over some level for more diffusion. The expert enterprise system derives national industrial development and improves the reliability through registration and fosterage high level enterprises that make a specialty of NRE installation. The regional energy program is promoted by local autonomous entities to develop the regional economy, which entities accomplish environment-friendly NRE supply system being suitable to own regional situation and rationalization of energy utilization in their regions. Loans are available for the production and purchase of NRE facilities at 3.5 percent floating interest rate with a long-term repayment period, which are asked by NRE installers and producers in the commercialized case. Through the feed-in-tariff, Korean government compensates for the difference between NRE generation cost and existing fossil fuel generation prices. By the subsidy program the government subsidizes installation costs to promote the marketing of developed NRE technologies and the revitalization of the diffusion [1][2].

From 1988 until 2004 a total of 391 billion KRW (Korean Currency Won, $1= KRW800) was invested in R&D of new & renewable technologies of 656 studies. These R&D studies are supported not by competition system but by government because of high initial cost. The support actions are different in these countries. In the case of Korea, the government supports by Feed-In Tariff (FID) and subsidies [1]. But in such, government's support could distort the essential function of market, that is to say, it is

necessary to evaluate the effect of support policies and strategies.

In this paper, to analyze the diffusion status of NRE, especially wind power energy, the learning curve concept is applied, which is very reasonable to explain the natural and social phenomenon and has been used broadly in various existing studies. Additionally, the learning curve is modified to explain and analyze exactly considering the distortion of NRE installation market situations.

2 Applications of Learning Curve in the NRE Facilities

Learning curve or learning concept is a reasonable tool to explain nature and social phenomenon easily, which had firstly developed in the aerospace industry to operate production line effectively and to cut down the cost. That is to say, the more production is creased, the more cost is reduced. Because NRE is on the early stage of the diffusion, the learning curve has a fluctuating tendency. In this paper, firstly the conventional learning curve and its formulation is introduced and a modified learning curve is proposed to explain real world exactly.

2.1 Learning Curve Formulation

Since the decreasing property of production cost according to continuous routine works had been found in the aerospace industry, the concept of learning curve has been broadly applied to other fields by theorization systemically. Thus learning curve shows the fact that inputs of direct labor decrease to scale according to the incensement of cumulative production. If there is learning property, the average cost decreases systemically as the cumulative production increases, so that this is able to be formulized to a simple model as (1).

$$y = ax^{-b} \tag{1}$$

where y, x, a, and b are estimate of average cost, cumulative production (or diffusion capacity), the production cost of the first unit, and coefficient of learning curve, respectively.

Learning ratio means that when the cumulative production is to be twice, the average cost per unit decrease with (1-r) x 100[%], so that the learning ratio r and the coefficient b of learning curve have a relation as follows:

$$r = \frac{y'}{y} = \frac{a(2x)^{-b}}{ax^{-b}} = 2^{-b} \tag{2}$$

From (2) the coefficient b is derived as follows:

$$b = -\frac{\log r}{\log 2} \tag{3}$$

On the other hand, it is possible to find learning curve by estimating the coefficient b through regression analysis, which estimates how a variable or some variables affect(s) on the others, and which has mathematical formula form, in the case that data are sufficient. In the case that data are not sufficient, by estimating learning ration r using a similar product case and estimating production costs, learning curve can be found.

2.2 Finding Coefficients of Learning Curve

To find NRE's learning ratio by resources, firstly average cost according to the cumulative production of NRE's facilities, total cost or marginal cost must be collected sufficiently and NRE's learning curve is made up.

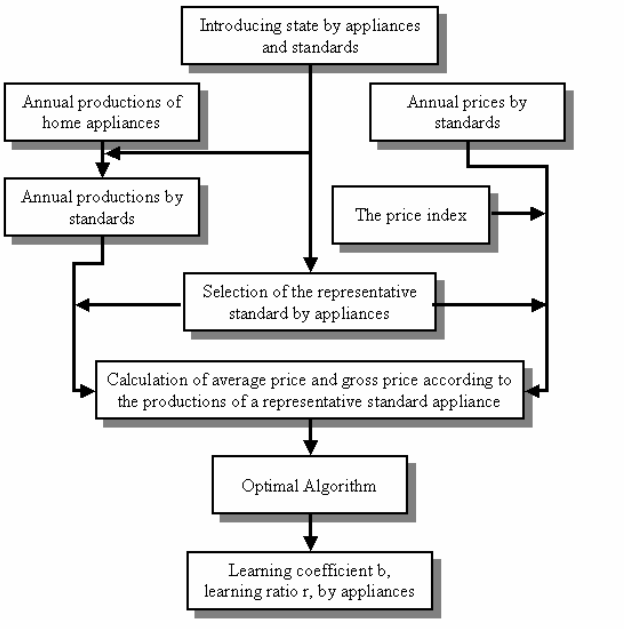

Fig. 1 The flow chart to estimate the learning rates of each load appliance

The calculation of the ratio is followed using (3). Therefore, the associated data, which are NRE facilities' quantities and prices by resources, are firstly

analyzed and the algorithm [3] is applied using the diffusion status of NRE facilities, the price index, and etc. in order to find learning ratio of NRE resources. The algorithm flow chart to estimate the learning rates of each load appliance is shown in Fig. 1. And the coefficients of learning curve are found out from time series data by numerical analysis. In this paper, the least-square method is applied to estimate the coefficients.

2.3 Modified Learning Curve

In general, learning curve is expressed as one smooth form as like Fig. 2 but real world data, especially time series data, have distortions due to market status, development of new technologies, various policies, etc. In other words, elements such as technology or policy could affect on some change of learning curve. Therefore, a new application method of learning curve is needed to analyze diffusion characteristics exactly. In this paper, the data distortion is considered really and the curve is modified by dividing into several sections as like Fig. 3.

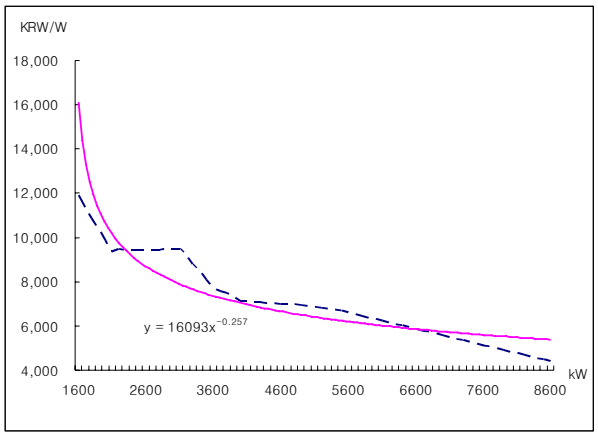

Fig. 2 A General Learning Curve

The modified learning curve is formulated as follows:

$$y = \sum_{p} a_p x^{-b_p} \quad \text{(p=1, 2, 3, ...)} \qquad (4)$$

where

$p = 1$, if $0 < x < x_1$,

$p = 2$, if $x_1 < x < x_2$,

$p = 3$, if $x_2 < x < x_3$,

a_p, b_p: the learning coefficients when policy p is initiated.

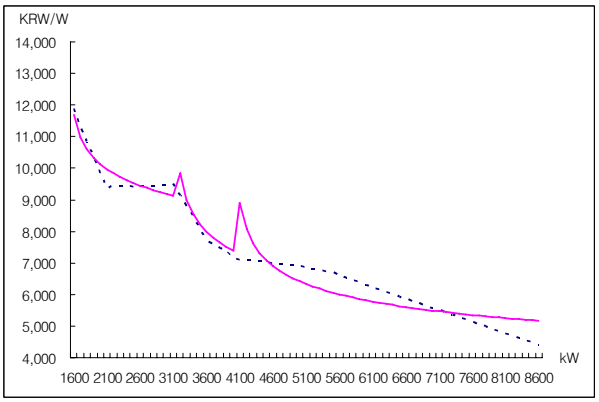

Fig. 3 A Example of the Modified Learning Curve

3 Case Study

In this paper, as a case study, wind power generation facility is considered. The diffusion status and installation cost are shown in Table 1. The installation costs are shown as invariable prices.

Table 1 The Diffusion Status and Installation Cost in Wind Power Systems

Year	Diffusion capacity (kW)	Installation cost ($/kW)	Consumer Price index	Invariable price ($/kW)	Average cost ($/kW)
1997	303	2,178	90.2	2,415	2,415
1998	1,200	3,394	97.0	3,499	3,280
1999	2,895	3,083	97.8	3,153	3,196
2000	1,501	2,557	100.0	2,557	3,034
2001	2,036	2,404	104.1	2,309	2,848
2002	4,757	2,858	106.9	2,674	2,782
2003	5,467	2,344	110.7	2,117	2,582
2004	50,903	2,941	114.7	2,564	2,569
2005	29,664	2,661	117.8	2,259	2,476

Because the learning curve of NRE is not made up by market function but is affected by diffusion policies, it is necessary to analyze how policies affect on the curve and to convert it to the original curve, which means that policy effects are eliminated from the curve. About the year 2000, the learning curve is distorted, that is, the price is increased. In this sense, we consider that in the year 2000 supports for NRE programs had been initiated, and the estimation that original prices would be changed should be carried out. In existing study[5], the learning curve is rough and reliability is low because the distortion of data is not

considered appropriately as like Fig. 3.Coefficients a and b of the curve are 5524 and 0.071, respectively, and the learning ratio is 0.9520. And the equation of learning curve is shown in (5).

$$y = 5524x^{-0.071} \quad (5)$$

On the contrary in this paper, distortions of real data are considered by dividing into several sections as like Fig. 4. Three learning curves are combined and this modified curve has 2 learning ratios by sections (or periods). Learning coefficients and ratios of each section are shown in Table 2. And the equations of learning curves are (6) anc (7), respectively, by sections.

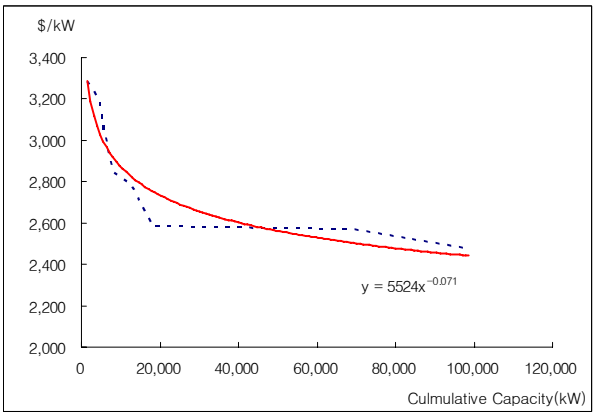

Fig. 4 A General Learning Curve of Wind Power

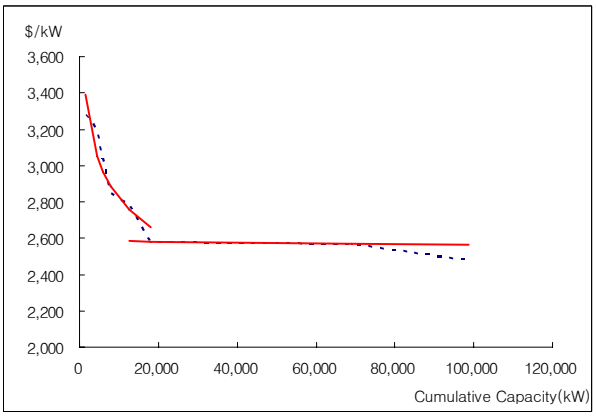

Fig. 4 A Modified Learning Curve of Wind Power

Table 2 The Diffusion Status and Installation Cost in Wind Power Systems

section	a	b	ratio
Section 1	6880	0.0968	0.9351
Section 2	2683	0.0039	0.9973

$$y = 6880\ x^{-0.0968} \quad (6)$$

$$y = 2683\ x^{-0.0039} \quad (7)$$

Comparing differences between learning ratios of each section, it is possible to estimate intensity of policies. For example, from the period of first section to the second section, the difference of learning ratios is 6.65%. Consequently, we can regard that a policy affects on the market of NRE facilities at the point that the distortion of learning curve appears. Furthermore, in the light of differences of ratios by sections, the intensity of second policy is higher than first policy.

4 Conclusion

A modified learning curve to explain the distortion of NRE installation cost (or market) is proposed. At points that the distortion of learning curve appears, we estimate NRE policies would affect on the market of NRE installation. In order to analyze the intensity of the policies deeply, further study is necessary considering the economical and physical status of NRE. And the modified learning curve in this paper can be applied to NRE as well as other field such as DSM policies.

Acknowledgements:
This work has been supported by KEMCO (2005-03-0159-0-000), which is funded by MOCIE (Ministry of commerce, industry and energy), Korea.

References:

[1] KEMCO, Annual Report, 2006
[2] http://racer.kemco.or.kr
[3] Kim, Jung-Hoon, et al., “The Comparison of Developing New Technologies by Willingness and DSM Strategies on the Influence of End-Use Learning Curves”, in Proc. 2002 ICEE in Korea, July 2002.
[4] Hwang, Sung-Wook, et al., “Estimation of Equipment’s Cost of New & Renewable Energy Based on Learning Curve,” in Proc. 2005 KIEE PES Autumn Conf., pp. 165-167.
[5] Hwang, Sung-Wook, et al., “Diffusion State Estimation of New & Renewable Energy Using Diffusion Model,” in Proc. 2005 KIEE EMECS Autumn Conf., pp. 320-322.