Feasibility Study for the VPL Device to Improve Hosting Capacity of Renewable Energy Sources

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신재생에너지 전원의 수용성 향상을 위한 VPL 장치의 타당성 평가에 관한 연구

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Abstract

Many renewable energy sources are waiting to be connected due to the lack of power system infrastructure in Korea, and the need for research to solve the delayed problem for renewable energy sources are being required. As one of the counter-measure on the problems, there is an investment of power system infrastructure which requires enormous costs and long period of construction. Therefore, this paper presents the introduction model for VPL device, which is a virtual power line operation technology to improve hosting capacity of renewable energy source capacity without additionally expanding power system infrastructure, and also proposes an economic evaluation method to assess the feasibility of the VPL device. Where, the introduction model of the VPL device is categorized into small, medium, and large scales based on the scales of renewable energy sources. In addition, the economic evaluation method is modeled by cost and benefit elements, and the cost elements are consisting of construction and operation costs and also the benefit elements are pricing of hosting capacity and deferred investment in power system infrastructure. From the simulation results for VPL models depending on the small, medium and large scales, it is confirmed that the proper capacity of VPL can be more economical than the investment cost of expansion power system infrastructure in the conventional method.

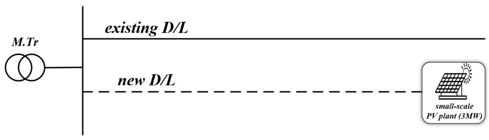
1. Introduction

Recently, the capacity of renewable energy sources connected to the distribution system has been rapidly increasing each year in line with the global Green New Deal and RE3020 policy. In particular, the customer voltage frequently violates the voltage allowable limit(207[V]~233[V]) due to the rapid increase in renewable energy source during daytime. To solve these problems, the installation of additional power facility infrastructure has been proposed, however, there is a need for research to reduce the investment costs of power facility infrastructure due to the high construction costs and long construction periods. Therefore, this paper presents introduction model, which is a virtual power line operation technology to improve hosting capacity of renewable energy sources without additionally expanding the power system infrastructure, and proposes a feasibility evaluation method for the economical implementation. Based on the introduction model of VPL device and economic evaluation model, it is confirmed that selecting an optimal capacity for VPL device model is more effective than investing in existing power facility infrastructure.

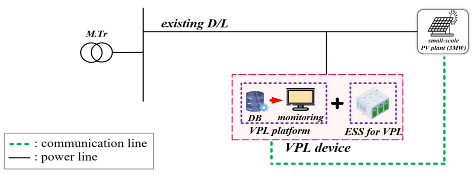
2. Introduction models for VPL device

2.1 Small-scale model in VPL device

Based on the classification of the installed capacity for renewable energy sources mentioned above, the small-scale introduction model of VPL device is illustrated as shown in Fig. 1. Where, Fig. 1(a) shows the conventional model which expands new overhead distribution line(D/L) and electric poles on existing power infrastructure when small scale renewable energy sources(3[MW]) are installed in distribution system and it means that the power utility should invest lots of facilities with low utilization rates to host renewable energy sources. However, Fig. 1(b) is new model of VPL device to manage distribution system in efficient manner by charging and discharging operation in ESS, which is located at existing distribution line, without additional investment in power system infrastructure.



(a) conventional model

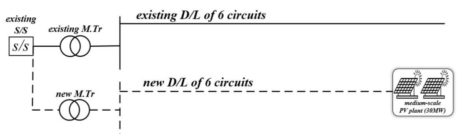


(b) new model in VPL device

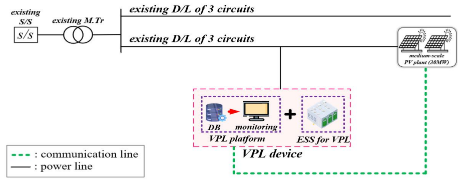
[Fig. 1] Small-scale introduction model in VPL device

2.2 Medium-scale model in VPL device

Based on the classification of the installed capacity for renewable energy sources mentioned above, the medium-scale introduction model of VPL device is designed as shown in Fig. 2. Where, Fig. 2(a) shows the conventional model which expands new main transformer of 45/60[MVA] in distribution substation, including overhead distribution line of 3 circuits and electric poles on existing power infrastructure when medium scale renewable energy sources(30[MW]) are installed in distribution system and which means for power utility to invest lots of facilities with low utilization rates to host renewable energy sources. While, Fig. 2(b) is new medium scale model of VPL device to manage distribution system in efficient manner by charging and discharging operation in ESS, which is located at existing distribution line of 3 circuits, without additional investment in power system infrastructure.



(a) conventional model

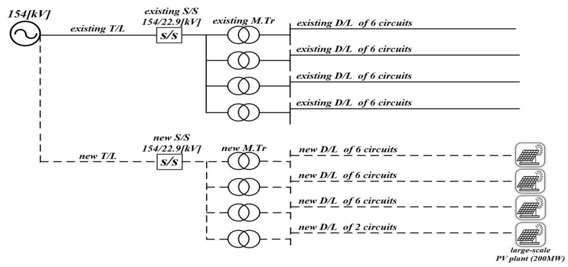


(b) new model in VPL device

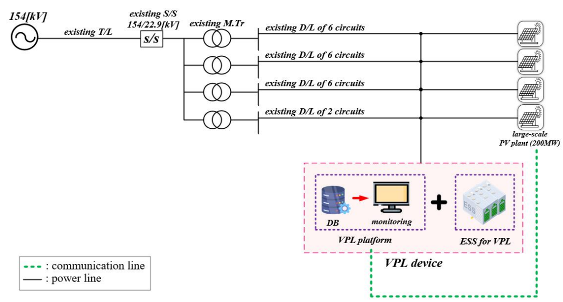
[Fig. 2] Medium-scale introduction model in VPL device

2.3 Large-scale model in VPL device

Based on the classification of the installed capacity for renewable energy sources mentioned above, the large-scale introduction model of VPL device is configurated as shown in Fig. 3. Where, Fig. 3(a) shows the conventional model which expands new underground transmission line, including distribution substation with 4 main transformers, overhead distribution line of 20 circuits and the numerous electric poles on existing power infrastructure and which means for power utility to invest lots of facilities with low utilization rates to host large scale renewable energy sources. However, Fig. 3(b) is new large scale model of VPL device to manage distribution system in efficient manner by charging and discharging operation in ESS, which is located at existing distribution line of 20 circuits, without additional investment in power system infrastructure.



(a) conventional model



(b) new model in VPL device

[Fig. 3] Large-scale introduction model in VPL device

3. Economic evaluation method of VPL device

3.1 Cost elements

The cost elements for introduction of VPL device consists of construction cost and maintenance and operation cost. The construction cost of VPL device is composed of ESS and platform costs as shown in Eq. (1) and The operation and maintenance cost is calculated by considering a constant percentage of the initial construction cost of the VPL as shown in Eq. (2), reflecting the inflation rate annually.

$$C_{VPL} = [(C_{PCS} \cdot Q_{PCS}) + (C_{bat} \cdot Q_{bat})] \cdot (1+\alpha) + \beta \quad (1)$$

$$C_{op} = \sum_{i=1}^{n} [C_{ESS} \cdot r_{op} \cdot (1 + r_{inf}(i))^{i-1}] \quad (2)$$

Where, C_{VPL}: construction cost of VPL(won/kWh), C_{PCS}: construction cost of PCS system (won / kW), Q_{PCS}: capacity of PCS system(kW), C_{bat}: construction cost of battery system (won / kWh), Q_{bat}: capacity of battery system(kWh), α: rate of VPL platform(%), β: replacement cost of battery(won/kWh), C_{ESS}: total construction cost of ESS for VPL(won), C_{op}: total operation cost(won), $r_{inf}(i)$: inflation rate(%), i: economic evalution year, n: entire year

3.2 Benefit elements

3.2.1 Improvement benefit of hosting capacity for renewable energy sources

Improvement benefit of hosting capacity for renewable energy sources is composed of system marginal price(SMP), renewable energy certificate(REC) and merit of reduction amount of carbon emissionbased on the production amount of renewable energy sources as shown in Eq. (3) ~ Eq. (5).

$$B_{kWh} = P_{kWh} \cdot U_{SMP} \cdot P_{loss} \quad (3)$$

$$B_{REC} = \sum_{i=1}^{m} P_i \cdot k_i \cdot U_{REC,i} \quad (4)$$

$$B_{co_2} = \sum_{t=1}^{T} E_{co_2}(t) \cdot CER \quad (5)$$

Where, B_{kWh}: electrical pricing by improving the power curtailment(won), P_{kWh}: capacity of power transaction(kWh), U_{SMP}: power trading unit price(won/kWh), P_{loss}: power loss of line(%), B_{REC}: pirce of REC(won/kWh), P_i: power generation of i energy sources, k_i: weighting factor of REC in renewable energy sources, $U_{REC,i}$:price of REC(won/kWh), B_{CO_2}: cost of carbon emission(won) in target year, $E_{CO_2}(t)$: carbon emission in time interval(ton), T: time interval in target year, CER: unit cost of CER in time interval(won/ton)

3.2.2 Deferred investment benefit of power facility

Deferred investment benefit in power system infrastructure is as shown in Eq. (6)~Eq.(9).

$$B_{\mathrm{def}}(i) = \sum_{i=1}^{m} X_i \quad (6)$$

$$X_1 = C_{D/L} \cdot L_{D/L} \cdot N_{D/L} + C_{U/P} \cdot \frac{L_{D/L}}{P_{span}} \quad (7)$$

$$X_2 = C_{bank} \cdot k \quad (8)$$

$$X_3 = C_{T/L} \cdot L_{T/L} + C_{S/S} \cdot S_{type} \quad (9)$$

where, $B_{\mathrm{def}}(i)$: deferred investment benefit in power system facility by scenario(won), i: scenario(i =1: small−scaled, i=2: medium−scaled, i =3: large−scaled), m: the number of scenario, $C_{D/L}$: construction cost of distribution feeder(won/km), $L_{D/L}$: the length of distribution feeder(km), $N_{D/L}$: the number of line in a distribution feeder, $C_{U/P}$: construction cost of utility pole(won/km), P_{span}: span of utility pole(m), C_{bank}: construction of main transformer(won/kW), k: the number of bank in substation(won), $C_{T/L}$: construction cost of transmission line(won/km), $L_{T/L}$: the length of transmission line(km), $C_{S/S}$: construction cost of substation(won/kW), S_{type}: type of substation

3.3 Present worth method

Economic feasibility is evaluated by calculating the cost and benefit factors as values at the same time point as shown in Eq. (10).

$$PW = \sum_{1}^{n} \frac{CF}{(1+d)^n} \quad (10)$$

where, PW: prevent worth cost(won), CF: cash flow of i year(won), n: unit period of year, d: discount rate(%)

4. Case studies

4.1 Test conditions

In order to evaluate the economic feasibility of the VPL device for improving hosting capacity of renewable energy sources, this paper assumes simulation conditions as shown in Table 1. And also, Table 2 shows the component cost of the VPL device, with unit price of 90 [thousand won/kW] for the PCS and 500 [thousand won /kWh] for thebattery and also, the costs of operation and maintenance and VPL platform are assumed as 2.5[%], 10[%] of the total cost in the VPL device, respectively. Where, the replacement intervals for the PCS and batteries of the ESS for VPL device are set at 20 yea r and 10 year, respectively. Additionally, the unit installation cost for the components of the power infrastructure are assumed to be 4,520,000[thousand won/km] for underground T/L, 23,000,000[thousand won] for distribution S/S, 6,000,000[thousand won] for M.Tr, 98,000[thousand won/km] for D/L, 97,500[thousand won/km] for electric pole. Furthermore, introduction capacity of the VPL device is determined as 3[MW]/13[MWh] for the small scale model, based on the proposed optimal capacity estimation method, and the capacities of medium and large scale models are assumed as 30[MW]/120[MWh], 200[MW]/800[MWh] with long duration application for battery, respectively.

[Table 1] Conditions of economic evaluation

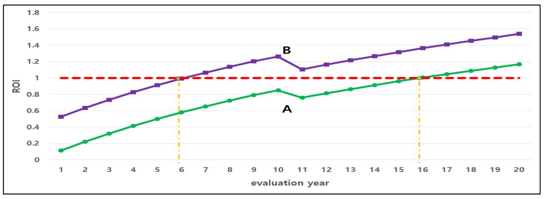
items	contents
economic target year[year]	20
discount rate[%]	5.5
inflation rate[%]	3
price of SMP[won/kWh]	250.74
price of REC[won/kWh]	56.48

[Table 2] Conditions of economic evaluation

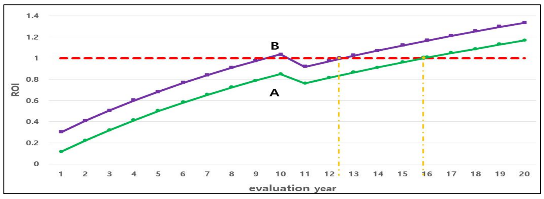
items		contents
ESS	PCS[thousand won/kW]	90
	battery[thousand won/kWh]	500
operating cost		2.5% of construction cost in ESS
cost of VPL platform		10% of construction cost in ESS

4.2 Economic evaluation to improve hosting capacity in renewable energy sources

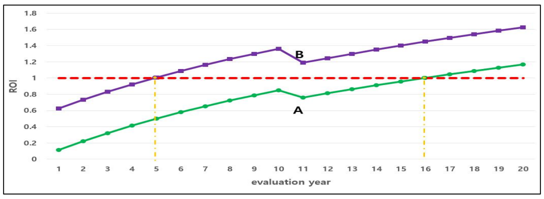
Based on the economic evaluation conditions mentioned earlier, the economic evaluation of VPL device to host renewable energy source in D/L is illustrated as shown in Fig. 4. Fig .4(a) shows ROI of VPL device to host small renewable energy source, when considering only improvement benefit for hosting capacity of renewable energy sources, the ROI is obtained to be about 15.9 year, while when additionally considering the benefits of deferred investment in power system infrastructure, the ROI is calculated as about 6.1 year, indicating that the economic feasibility can be definitely guaranteed. Fig .4(b) is ROI of VPL device to host medium renewable energy source, when considering only improvement benefit, the ROI is obtained to be about 15.9 year, while when additionally considering the benefits of deferred investment in power system infrastructure, the ROI is calculated as about 12.6 year, indicating that the economic feasibility can be definitely guaranteed. And also Fig .4(c) shows ROI of VPL device to host large renewable energy source, when considering only improvement benefit for hosting capacity of renewable energy sources, the ROI is obtained to be about 15.9 year, while when additionally considering the benefits of deferred investment in power system infrastructure, the ROI is calculated as about 4.8 year, indicating that the economic feasibility can be definitely guaranteed.



(a) small-scale model



(b) medium-scale model



(c) large-scale model

[Fig. 4] ROI characteristics for introduction model in VPL device

5. Conclusions

This paper presents the introduction model for VPL device, which is one of the ways to improve hosting capacity, and proposes an economic feasibility analysis of the VPL device based on the scales of renewable energy sources using the net present value method. As a result of evaluating the feasibility for VPL device to interconnect renewable energy resources, the economic feasibility deteriorates as the VPL platform costs increase, it is found that selecting the optimal capacity of the VPL model is more effective than investing in existing power facilities.

References

[1] H. D. Lee, “A Study on Economic Evaluation Modeling of MVDC Distribution System for Hosting Capacity of PV System”, Journal of the Korea Academia-Industrial cooperation Society, Vol. 22, No. 3, pp. 1-12, 2021.