Suppression of Voltage Violation in PV Connected Distribution System via Cooperation of Battery Energy Storage System and SVR

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***Abstract*--Nowadays, considering of environment protection, Photovoltaic (PV) is well developed in Japan and widely installed in distribution system. However, with the growth of PV, the voltage fluctuation caused by PV can't be ignored. Because PV totally relies on insolation which is variable and difficult to be predicted. Therefore, voltage profile in distribution system becomes complex and hard for regulation. The established devices in PV connected distribution system is insufficient when deal with the voltage fluctuation. Because the delay in operation and inflexible control ability leads to the voltage violation. Battery Energy Storage System (BESS) is applied to suppress the voltage fluctuation because it can provide the system with immediate, accurate and flexible control. Moreover, the feature of energy storage increases the efficiency of PV. However, cost is the biggest problem in BESS application. To promote the application of BESS, authors focus on two points. One is to realize the application of small-scale BESS. Step Voltage Regulator (SVR) is cooperated with BESS in voltage regulation and makes BESS focuses on the instantaneous voltage. The other is initiative State of Charge (SOC) management. Initiative SOC management realizes more excellent management of charge level in BESS, and it prolongs the lifetime of battery to increase the efficiency in BESS application. In this way, small-scale and long lifetime BESS realizes the economic and excellent control of voltage violation in PV connected distribution system.**

***Keywords:* voltage violation suppression, BESS, SVR, cooperation control, distribution system**

I. Introduction

With the concern of environment and the limit of traditional power resources, nowadays, renewable energy like PV, Wind Farm (WF) is under well development. In japan, PV is widely applied in distribution system like roof solar. However, with the growth of PV, the voltage violation caused by PV becomes notable. Because PV totally relies on insolation which is variable and can't be accurately predicted, the voltage profile becomes complex and difficult to control. The voltage suppression in PV connected distribution system is in urgent situation, as in [1]-[3]. To solve the problem of voltage control, the established voltage regulation devices like SVR, Load Ratio Control Transformer (LRT) become insufficient. Because the long settle time and inflexible control ability can't perfectly deal with the complex voltage profile caused by PV. Therefore, Power Conditioning System (PCS) is here in distribution system to give more excellent control. Such as Static Var Compensator (SVC), it can provide the system with immediate, accurate, and flexible control, as in [4]-[5]. However, cost is the obstacle in its application, and it only gives reactive power output which makes it not always the best choice for voltage control.

BESS with excellent control ability and the unique feature of energy storage draws authors' attention in voltage control. BESS provides both active and reactive power to system, and it is more serviceable for voltage control. Moreover, with the development Home Energy Management System (HEMS) and Electric Vehicle (EV) shown in [6]-[7], the battery in them is the potential backup of BESS. Therefore, the application method of BESS is urgent to be realized. A lot of study is done around BESS in prior work to promote its application. In [8] and [9], to increase the efficiency of established devices, BESS is cooperated with SVR and LRT in demand response for voltage control. And the limit output of BESS with consideration its capacity is discussed. In [10], State of Charge (SOC) of BESS is discussed. Because SOC is the index in the management of battery's lifetime in BESS. SOC management of BESS keeps the charge level of battery in proper range. Therefore, battery is protected from overcharge/discharge. In [11], BESS deals with the voltage fluctuation caused by PV, with the active and reactive power from BESS, voltage in distribution system is regulated in proper range. And moreover, based on SOC management, the better charge level of battery is discussed in [12], a relatively long lifetime of battery is realized.

In this paper, authors focus on the voltage violation suppression in PV connected distribution system. And BESS is applied in dealing with voltage violation caused by PV. Moreover, BESS can absorb the reverse power flow caused by PV, and it increases the efficiency of power utilization. However, in the application of BESS, cost is the biggest obstacle. To promote the application of BESS, two points is proposed by authors. One is to realize the application of BESS with small-scale, and the other is to prolong the lifetime of battery in BESS.

For the application of small-scale BESS, the cooperation of BESS and SVR is proposed. SVR cooperates with BESS to solve the long-term voltage violation. BESS only deals with the transient voltage violation, in this way, voltage control with small-scale BESS is realized. Moreover, the

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delay of SVR operation is solved by BESS. For the other point, initiative SOC management is proposed. SOC management is operated in no voltage violation period to make more available capacity for voltage control. With the cooperation of BESS and SVR and initiative SOC management, small-scale BESS and long lifetime battery realizes the high efficiency and economic application of BESS. And in this way, the cost in BESS application is relatively reduced.

In section 2, the cooperation control of BESS and SVR in voltage regulation is described; in section 3, simulation and results is shown; and finally in section 4, conclusion is presented.

II. COOPERATION OF BESS AND SVR

To realize the difficult voltage control in PV connected distribution system, BESS is applied because it can provide the system with fast, accurate, and soft control. However, along with the highlight of BESS, the cost of BESS prevents its large-scale application. To reduce the cost, small-scale BESS is wanted and SVR is cooperated with BESS to realize voltage control. The other element of cost reduction is to prolong the lifetime of battery in BESS. Different from prior work, in this paper, initiative SOC management is proposed to protect battery from overcharge/discharge as well as makes more available capacity for voltage control. The cooperation of BESS and SVR realizes the application of small-scale and long lifetime BESS for cost reduction.

A. *Control of SVR and BESS in cooperation*

In distribution system, SVR regulates the voltage to keep it in adequate range. However, with the growth of PV, SVR can't perfectly deal with the complex voltage profile in distribution system. Because SVR as Fig.1 shown realizes voltage control through tap change which needs settle time to realize its operation. In Fig. 2, the grey part shows the voltage violation during SVR settle time. To suppress the voltage violation in settle time, BESS gives immediate output. The operation time of SVR is requested by BESS to solve the long-term voltage violation.

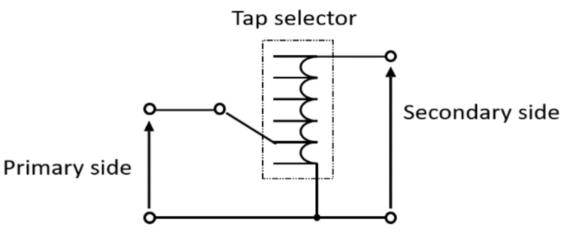


Fig.1 Simple model of SVR

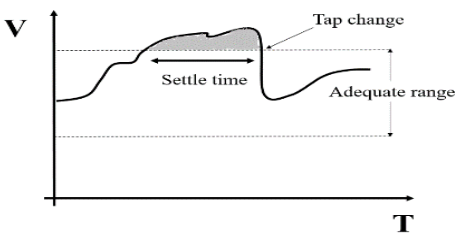


Fig. 2 voltage violation during SVR operation

In this paper, different from the previous studies which take time or BESS's inverter capacity as a constraint of SVR's operation command, the proposed cooperation of SVR and BESS is based on possible voltage violation caused by PV. The preserved capacity of BESS takes the necessary output for voltage violation suppression during SVR settle time as reference. Therefore, with the excellent voltage control of BESS, the utilization of it increases by avoiding the unnecessary preserved capacity during the cooperation with SVR. For fast power flow calculation, the method in [13] is applied.

In Fig. 3, the model of distribution system is shown. SVR and BESS are set in the distribution line. P and Q is load consumption. Z is impedance of distribution line.

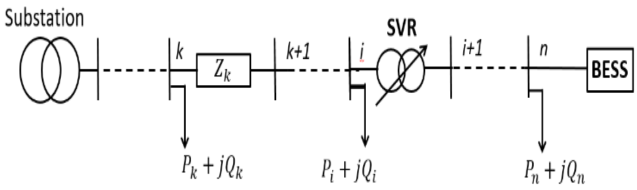


Fig. 3 Distribution system model with SVR and BESS

The voltage regulation of node n is taken as an example. V_n is the voltage of node n; V_{ade} is the reference voltage of its adequate range. When V_n runs out of its adequate range. BESS firstly gives the immediate control. BESS is taken as current resource. (1)-(4) show the apparent power calculation of BESS. $\dot{I}_B$ is current output of BESS; $\dot{S}_B$ is apparent power of BESS.

$$\Delta\dot{V}_n = \dot{V}_n - \dot{V}_{ade} \tag{1}$$

$$\dot{I}_B = \Delta\dot{V}_n / \sum_1^n Z_j \tag{2}$$

$$\dot{S}_B = \dot{V}_{ade} * \dot{I}_B{}^* \tag{3}$$

After arrangement, the apparent power of BESS is shown in (4).

$$\dot{S}_B = \dot{V}_{ade} * (\Delta\dot{V}_n / \sum_1^n Z_j)^* \tag{4}$$

Substituting (1) to (4), the arranged apparent power of BESS is shown in (5).

$$\dot{S}_B = \Delta\dot{V}_n{}^2 + \Delta\dot{V}_n * (\dot{V}_n / \sum_1^n Z_j)^* \tag{5}$$

From (5), the value of $\Delta\dot{V}_n$ decides the apparent power output of BESS. The smaller the value of $\Delta\dot{V}_n$ is, the small the apparent power output of BESS is. Hence, the author proposes that the voltage variation caused by BESS has the same angle with its connected node. That is, $\Delta\dot{V}_n$ and $\dot{V}_n$ have the same angle. In this way, the minimum value of $\Delta\dot{V}_n$ realizes the decreasing of BESS's output. Moreover, the decreased need of BESS's output achieves the application of small- scale BESS for cost reduction.

The lifetime of battery is an important index of cost reduction. And SOC management protects battery from overcharge/discharge. In the application of BESS, active power output of BESS directly connects with SOC calculation. Therefore, according to (4), the active power P_B of BESS is shown in (6). And SOC of BESS is shown in (7). Ts and To are start and stop time of BESS operation.

$$P_B = real(\dot{V}_{ade} * \left(\frac{\Delta \dot{V}_n}{\sum_1^n Z_j}\right)^*) \tag{6}$$

$$\mathrm{SOC} = \int_{Ts}^{To} P_B \tag{7}$$

In distribution system, voltage profile varies with PV. The voltage violation caused by reverse power flow gets the maximum value in sunny day. The case of BESS active power output in sunny day P_{Bsunny} is taken as reference. To solve the delay of SVR operation, BESS needs to provide output for voltage control during settle time of SVR. Therefore, the capacity of BESS for voltage control in settle time need to be ensured. Because SOC management limits the output of BESS, SOC becomes the index for the available capacity of BESS in settle time. Td is settle time of SVR. Based on (7), SOC variation in Td, SOC_{Td} is shown in (8). In (8), P_{Bsunny} is applied in SOC calculation, and the available capacity of BESS calculated according to (8) can deal with all cases voltage violation in settle time. And (9) shows the updated SOC_{ref} of BESS. t is sample time.

$$\mathrm{SOC}_{Td} = \sum P_{Bsunny} * \mathrm{Td} \tag{8}$$

$$\mathrm{SOC}_{ref}(\mathrm{t}) = SOC(t) + \mathrm{SOC}_{Td} \tag{9}$$

After arrangement, SOC_{ref} is shown in (10). The first part in (10) is the variation of SOC for voltage control. The second part is the predict SOC variation of BESS in settle time of SVR.

$$\mathrm{SOC}_{ref}(\mathrm{t+Td}) = \int_{Ts}^{t} P_B + \int_{t}^{t+Td} P_{Bsunny} \tag{10}$$

According to (10), the updated SOC is calculated. And SVR operation is decided through (11).

$$\begin{cases} Tap = 1 \quad if \ \ \mathrm{SOC}_{ref} < \mathrm{SOC}_{lowerlimit} \\ Tap = 0 \quad if \ \ \mathrm{SOC}_{lowerlimit} < \mathrm{SOC}_{ref} < \mathrm{SOC}_{upperlimit} \\ Tap = -1 \quad if \ \ \mathrm{SOC}_{ref} > \mathrm{SOC}_{upperlimit} \end{cases} \tag{11}$$

In (11), if SOC_{ref} is lower than its lower limit $\mathrm{SOC}_{lowerlimit}$, SVR takes one tap up to increase the voltage. If SOC_{ref} is in its adequate range, SVR keeps its state. If SOC_{ref} runs larger than its upper limit $\mathrm{SOC}_{upperlimit}$, SVR takes one step up to decrease voltage. SOC of BESS is always measured. And according to the rules in (11), BESS sent the request to SVR.

The proposed control method of cooperation between BESS and SVR in this section realizes voltage violation in SVR operation. And the request of SVR operation based on PV's output avoids unnecessary preserved capacity of BESS for high utilization.

B. Initiative SOC management in cooperation

In the application of BESS, SOC management realizes the long lifetime of battery in BESS. And the long lifetime of battery brings the high efficient and low cost of BESS application. The previous studies on SOC management mainly regulate SOC to keep it in its adequate range. However, during voltage suppression, when SOC runs to its boundary BESS stops its operation unless the voltage violates its opposite limit. Hence, for small-scale BESS, there is always a non-operation period and in this way, it can't make sure all voltage violation suppression, taking the voltage violation when one more step change of SVR is needed as an example. Considering of increasing the efficiency of BESS, the novelty of proposed SOC management is to make more available capacity of BESS in voltage control. And it is divided into two cases considering of PV's output. Through initiative charge/discharge of BESS, proposed SOC management realizes variation of available capacity of BESS for voltage control.

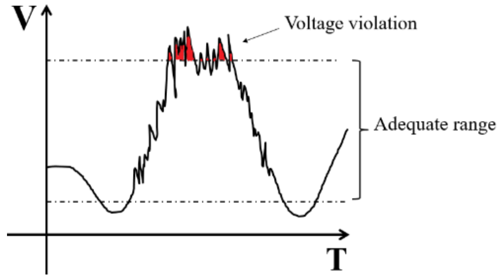
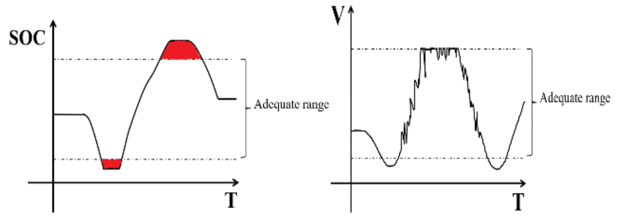
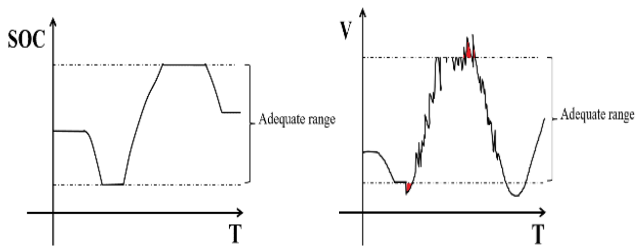


Fig. 4 voltage profile of distribution line



(a) SOC violation in voltage control



(b) Voltage violation in SOC management

Fig. 5 SOC management for voltage control

Because cost of BESS is the largest obstacle in its application, BESS with small-scale is wanted for cost reduction. In Fig. 4, the voltage profile in distribution line is illustrated. The red part is voltage violation caused by reverse power of PV. To suppress the voltage, BESS provides the immediate control. However, with small-scale BESS, the voltage control with SOC management leads to an unacceptable results as Fig. 5 shows. In Fig. 5(a), SOC runs out of its adequate range for voltage suppression, while Fig. 5(b) shows voltage violation with SOC management of BESS. To make the available capacity of BESS as much as possible, the initiative charge/discharge of BESS is proposed. And it is divided into two cases.

[case 1] 0<t<Tp

Here, the intensity of solar radiation is R_s. With the variation of R_s, voltage profile is different. According to the voltage profile in sunny day, the maximal voltage V_{max} caused by PV's reverse power flow is got, and the time of

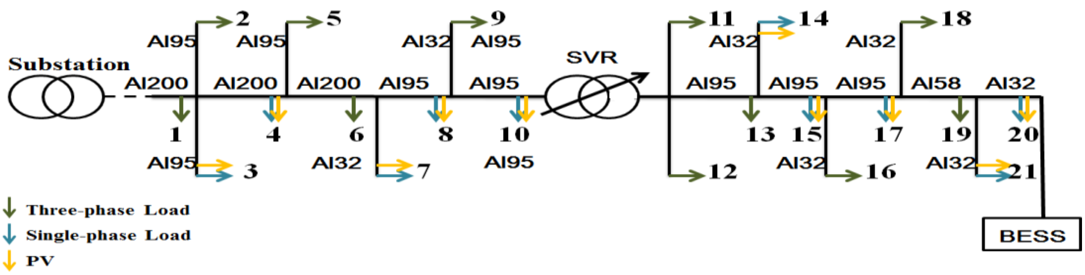


Fig.6 Model of distribution system with PV connected

peak output of PV is Tp. Before Tp, BESS always operates initiative discharge to make more available capacity for reverse power flow. With the same example in Fig. 3, based on (6), (12) shows the initiative discharge of BESS. $V_{upperlimit}$ is the upper limit of voltage and w is the weight coefficient. SOC_{ini} is SOC variation during period, Tini, of initiative discharge. and (13) shows the calculation.

$$P_B = real(\dot{V}_{upperlimit} * w * \left(\frac{\dot{V}_n - V_{upperlimit}}{\sum_1^n z_j}\right)^*) \quad (12)$$

$$SOC_{ini}(t) = \sum P_B * Tini \quad (13)$$

With SOC_{ini}, the updated state of charge SOC_m is shown in (14). α and β are weight coefficient.

$$SOC_m(t) = \alpha * SOC(t) + \beta * SOC_{ini} \quad (14)$$

When R_s is larger than its reference value γ, the output of PV has high probability to increase the voltage. The operation of initiative SOC management is based on (15).

$$\begin{cases} \alpha = 0 \text{ and } \beta = 1 \\ if \quad V_{lowerlimit} < V_n < V_{upperlimit} \\ \alpha = 1 \text{ and } \beta = 0 \\ if \quad V_{upperlimit} < V_n \end{cases} \quad (15)$$

And when R_s is smaller than its reference value γ, (16) shows the operation of SOC management.

$$\begin{cases} \alpha = 0 \text{ and } \beta = 0 \quad if \quad V_{lowerlimit} < V_n < V_{upperlimit} \\ \alpha = 1 \text{ and } \beta = 0 \quad if \quad V_{upperlimit} < V_n \end{cases} \quad (16)$$

[case 2] t>Tp

After Tp, the intensity of insolation decreases, BESS needs to store power for voltage regulation in nighttime. (17) shows active power output of BESS. $V_{upperlimit}$ is the upper limit of voltage.

$$P_B = real(\dot{V}_{lowerlimit} * w * \left(\frac{\dot{V}_n - V_{lowerlimit}}{\sum_1^n z_j}\right)^*) \quad (17)$$

The initiative charge of BESS is the same with its initiative discharge. And the calculation of SOC is realizes via (13)-(17).

With the initiative SOC management proposed in this section, the increase of available capacity for voltage control of BESS is realized. And the variation of available capacity in BESS through initiative SOC management is changed with its coefficient w for different desire in voltage regulation.

III. SIMULATION AND RESULTS

A. Simulation conditions

Fig.6 gives the detail model of distribution system which has 21 loads with PV. In this model, BESS is set as current resource. PV's factor is equal to 1.0 and just provides the system with active power. And the verification is realized by MATLAB through power flow calculation.

The green arrows stand for three-phase loads. The blue arrows stand for single-phase loads that are residential load. PVs are connected at the same placement of single-phase loads, PV in sunny day is selected as the reference and PV in cloudy day is chosen to verify the suppression of voltage fluctuation.

BESS is set at the end of distribution line and SVR is set in the middle of distribution line to verify the cooperation of BESS and SVR. Table 1 shows the parameters. Table 2 shows the single-phase load's placement.

Table 1. Distribution line's data.

Impedance of distribution line	Al32:0.899 + j0.389Ω/km Al58:0.497 + j0.331Ω/km Al95:0.301 + j0.315Ω/km Al200:0.182 + j0.288Ω/km
Total length of the line	3.09km

Table 2. Connection of single-phase load.

Connection phase	Load No.
a-b	3, 8, 15, 21
b-c	4, 10, 17, 20
c-a	7, 14

The pattern of three-phase loads is illustrated in Fig.7 and consumption is 125kW of each one. Fig.8 shows the load pattern of single-phase load which ranges from 108kW to 648 kW. Fig.9 illustrated the output in cloudy day. The capacity of PV equals to the maximum single-phase load consumption. All of them are given in proportion.

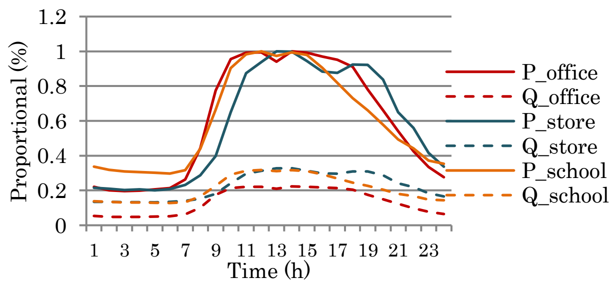


Fig. 7 Three-phase load's pattern

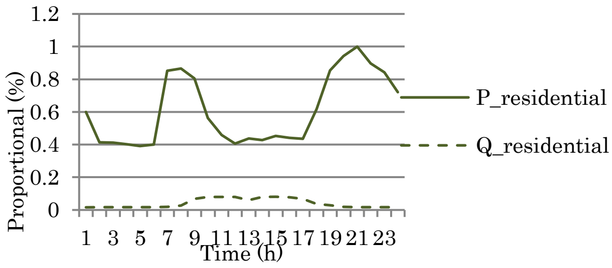


Fig. 8 Single-phase load's pattern

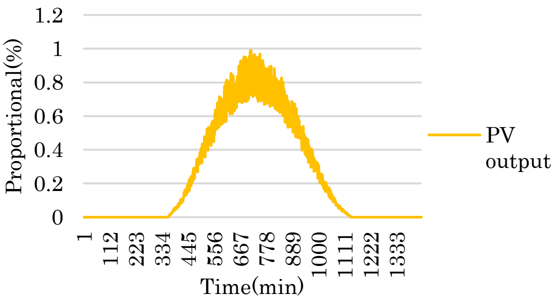


Fig.9 PV output in cloudy day

The time step of the simulation is 1 min. The adequate range of line voltage is from 101 to 107 conversed to low voltage side using voltage ratio (= 6600/105). In Table 3 gives the simulation conditions.

Table 3. Simulation conditions.

Simulation time	2hours
Simulation interval	1.0min
Adequate range's $V_{upper\ limit}$	107V (up voltage)
Adequate range's $V_{lower\ limit}$	101V (low voltage)
Ratio of voltage	6600/105
Sending voltage of substation	6600V
BESS capacity	500kWh
State of charge's SOCupper limit	80%
State of charge's SOClower limit	20%
Initial SOC	50%
One tap of SVR	150V
Capacity of battery	30kWh

Table 4 shows the simulation cases. Case 1 is the original distribution system without BESS and SVR, and it is taken as a reference case. Case 2 has BESS and SVR without cooperation and initiative SOC management in voltage control. The cooperation of BESS and SVR is done in case 3 without the initiative SOC management to make a comparison. Case 4 discusses the proposed cooperation of BESS and SVR with initiative SOC management.

Table 4. Simulation cases.

Case 1	No BESS and SVR
Case 2	BESS and SVR without cooperation and initiative SOC management
Case 3	BESS and SVR cooperation without initiative SOC management
Case 4	BESS and SVR cooperation with initiative SOC management

B. Results

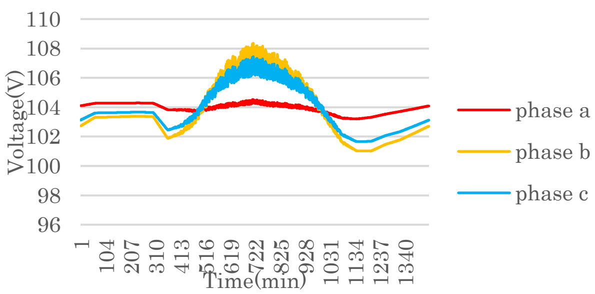


Fig. 10 voltage profile in the end of distribution line

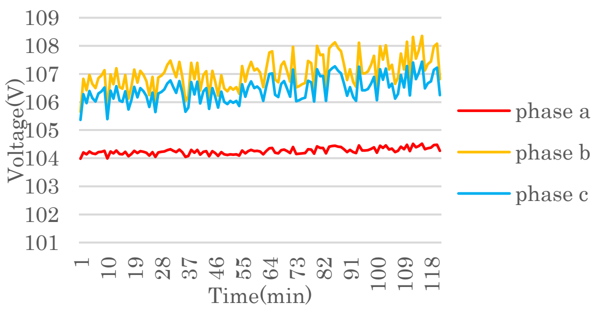


Fig. 11 voltage profile from 10am to 12pm

In Fig. 10, the voltage profile of node 21 where has the severe voltage violation is illustrated. It can be seen that voltage runs out of its adequate range with the reverse power flow caused by PV. Here, in this paper, authors select the period from 10am to 12pm as Fig. 11 shows to verify the proposed method in suppression of voltage violation caused by PV.

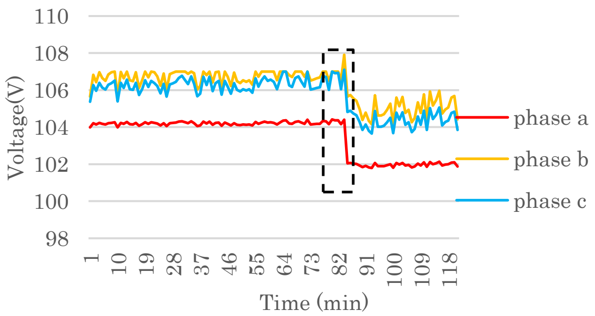


Fig. 12 voltage in case 2

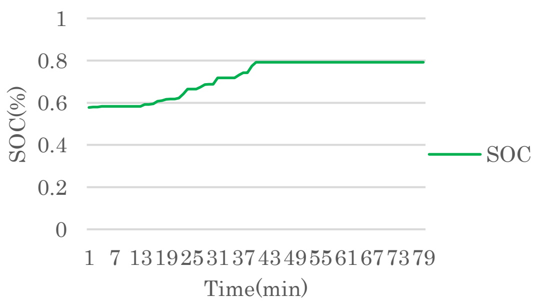


Fig. 13 SOC of BESS in case 2

In Fig. 12, the voltage profile in case 2 is illustrated. BESS gives the immediate control to suppression the voltage.

However, for long-term voltage regulation, without the proposed cooperation, voltage violation in settle time of SVR appears in the dashed box. In Fig. 13, SOC of BESS is well control in its adequate range.

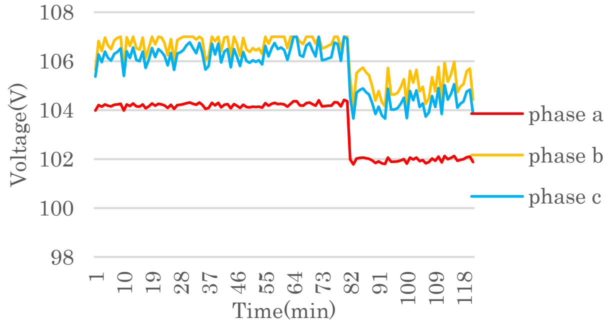


Fig. 14 voltage in case 3

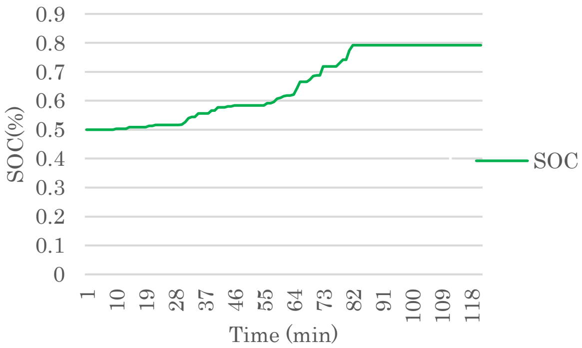


Fig. 15 SOC of BESS in case 3

In Fig.14, the voltage profile in case 3 is illustrated. With the cooperation of BESS and SVR, the voltage violation is suppressed. And the voltage violation caused by SVR operation delay is solved with the proposed method in section 2. In Fig. 15, SOC of BESS is in its adequate range.

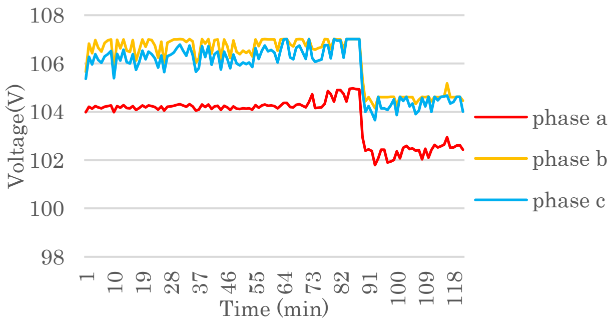


Fig. 16 voltage in case 4

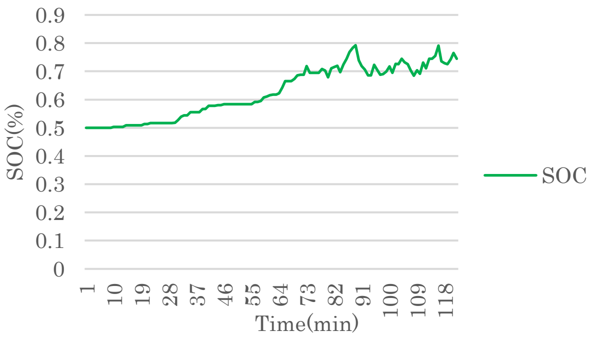


Fig. 17 SOC of BESS in case 4

Fig. 16 shows the result of voltage suppression with proposed method and initiative SOC management. It can be seen that the voltage is well controlled. With the proposed method, the application of BESS with small-scale is realized. Compared with case 3, the initiative SOC management provides more alternative capacity of BESS for voltage control as shown in Fig. 17.

IV. CONCLUSIONS

In this paper, the suppression of voltage violation is discussed. The cooperation of BESS and SVR is proposed and verified by MATLAB. With the proposed method, two points is conducted.

1). With the assistance of SVR, comparing with large-scale BESS, the application of small-scale BESS with relatively low cost is realized. And preserved capacity of BESS for voltage suppression in SVR's settle period is calculated based on PV's output. Hence, unnecessary preserved capacity of BESS is avoided.

2). The initiative SOC management is proposed. The novelty of the proposed strategy provides much more available capacity for voltage control and increases the efficiency of BESS via decreasing its non-operation period.

For future study, to realize more excellent voltage control, more severe cases in PV connected distribution system need to be discussed. The predict of voltage profile in PV connected distribution system is also wanted for more accurate control. Moreover, the details in initiative SOC management is wanted to prolong the lifetime of battery for high efficiency and economic application of BESS.

V. REFERENCE

[1] T. Tsuji, "Voltage Control Technology in Distribution Systems with a Large Amount of Photovoltaics," *IEEJ Trans. Electronics, Information and Systems*, vol. 133, pp. 610-615, Mar. 2013.

[2] Takahashi, T. Makino, J. Imai and S. Funabiki, "Power Smoothing Control of Photovoltaic Generation Systems using a Difference Vector Method," *IEEJ Trans. PE*, vol. 136, pp. 268-274, Mar. 2016

[3] K. Kouno, E. Nakanishi, Y. Nagano and M. Hojo, "Reactive Power Control of Mega-solar System for Voltage Regulation with Long Distribution Line," *IEEJ Trans. PE*, vol. 135, pp. 276-289, May. 2015

[4] N. Takahashi and Y. Hayashi, "Proposal of Dynamic Voltage Control using SVC with Variable Dead Band in Distribution System," *IEEJ Trans. PE*, vol. 133, pp. 396-403, Apr. 2013

[5] S. Kawasaki, N. Terada, H. Taoka and M. Koyama, "Improvement of Power Quality in Distribution System by Residential PV Systems," *IEEJ Trans. PE*, vol. 136, pp. 268-274, Feb. 2016

[6] T. Noda, Y. Kabasawa, K. Fukushima, K. Nemoto and S. Uemura, "A Method for Compensating Customer Voltage Drops due to Nighttime Simultaneous Charging of EVs Utilizing Reactive Power Injection from Battery Chargers," *IEEJ Trans. PE*, vol. 132, pp. 163-170, Feb. 2012

[7] Y. Miyamoto and Y. Hayashi, "Effectiveness of Improvement of Benefit of the Electric Power Selling Charges and Electricity Charges using Battery Storage System and Heat Pump Water Heater for High Penetration PV," *IEEJ Trans. PE*, vol. 136, pp. 245-258, Mar. 2016

[8] K. L. Dinh and Y. Hayashi, " Coordinated BESS and LRT Control for Voltage Stabilization of a PV-Supplied Microgrid," *IEEJ Trans. PE*, vol. 134, pp. 875-884, Oct. 2014

[9] K. L. Dinh and Y. Hayashi, " Online Optimal Power Flow Based on HPSO-TVAC Coordinates with Centralized BESS and LET Control to Stabilize Voltage in PV-Supplied Microgrid," in: *IEEE PES ISGT Europe, Copenhagen*, Oct. 2013

[10] N. Li, Y. Liu, J. Wang, Y. Ji and B. Xie, " Dynamic allocation method of DC side power based on the SoC of battery for STATCOM/BESS," *Electric Power Systems Research*, vol. 125, pp. 141-149, 2015

[11] S. R. Deeba, R. Sharma and T. K. Saha, " Coordinated Control of Multi-Functional Battery Energy Storage System in Unabalanced Network," in: *AUPEC, Perth, Australia*,2014
[12] X. Wu, X. Wang, J. Wang, C. Qu, C. Liu and J. Duan, " Schedule and operate combined system of wind farm and battery energy storage system considering the cycling limits," *Int. Trans, Electr. Energ. Syst*, pp. 3017-3031, 2015
[13] S. Kawano, Y. Hayashi, N. Itaya, T. Takano and T. Ono, "Development and Evaluation a Fast Voltage Calculation Method for Low-Voltage Distribution System," *IEEJ Trans. PE*, vol. 133, pp. 343-349, Apr. 2013