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Optimal Power Flow in Electricity Market using Demand Response

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Abstract: Due to the economy and environment issues, Distributed Generation (DGs) came in to existence along with Renewable Energy Sources (RESs) in the distribution system. However the diffusion of DGs in distribution system results not only in the voltage deviation beyond the statutory range but also in the inverse power flow towards the substation and generator. Hence it is very essential to introduce Real Time Pricing (RTP) by distribution company (DisCo) to recover the above complications and attain load levelling. This paper recommends the technique of Demand Response (DR) from RTP in electricity market and delivers reactive power to help customers for sustained voltage distribution within the appropriate range. This paper demonstrates the effectiveness of RTP and reactive power incentive by the simulation for DisCo and purchaser turnover.

I. INTRODUCTION

In recent years, there has been an increasing number of international conversations pointed at the continuous long-term bargain of CO_2 emissions. Distributed Generators (DGs) can supply electric power at even during islanding situations in blackout. In this regard, DGs have a gigantic economic and environmental potential, particularly when based on renewable energy sources (RESs) [1]. Therefore, DGs are progressively introduced in the distribution system to work towards the apprehension of a low carbon society and remote process. Nevertheless, the power output of DGs using RESs vary due to climatic circumstances and causes unevenness between supply and demand loads. Because of the output variations of these DGs, it is tough to maintain distribution voltage within the appropriate range. Moreover conventional power systems are usually not designed for reverse power flow towards the transmission system. Unfortunately the high penetration of DGs into distribution systems frequently causes voltage deviations beyond the statutory range and power flow reverses toward the substation transformer [2,3]. As the power flows in the reverse direction then the faults may occur not only in the electrical device but also result in the greater power outages. Hence it is essential to address the technical problems related to the introduction of high penetration of DGs into distribution systems. As numerous DGs are interconnected in the distribution system; it is difficult to control quick voltage variation using conventional transformers (i.e. the load ratio control transformer (LRT) and the step voltage regulator (SVR). The counter actions to this problem comprise of numerous approaches.

One of the procedures is to structure a reactive power altering device in the distribution system and must consist of reactive power control on the DG side [4]. Once the reactive power regulating device is installed on the customer side, the needs for supplementary devices within the distribution system are suppressed. The determination of optimal placement and capacity of reactive power altering devices to be installed to nullify the fluctuations in the distribution systems is challenging. The conventional approaches of reactive power regulator are to alter the DG power factor from the customer side to abolish voltage deviation.

Furthermore, another proposed technique is the use of inverter interconnected to PV Wind generator (WG). The inverter can compensate reactive power within the range of the inverter capacity. This paper proposes a system called the reactive power incentive system. This system is intended to encourage customers to output the suitable reactive power as demanded by the DisCo by permitting them to acquire rewards parallel to the reactive power output necessity of the DisCo. By employing this suggested method, the DisCo can save on costs due to the mitigation of the problem of some control apparatus and customers also get the benefit of getting incentives by following suitable reactive power output as from the DisCo. One of the finest functioning techniques suggested for the purpose of decreasing the BESS capability to be installed adjacent to the substation while levelling the power flow and evading reverse power flow and voltage deviance using the above-mentioned switching apparatus. However, this technique needs a very large volume of BESS in order to inhibit power flow reversing toward the substation [5]. From other prospective, the DisCo is similar to introduce RTP schemes. By the summary of RTP schemes, most customers will buy electricity at times when the charge of electrical power is low, and it is assumed these consumers will take schedules to decrease consumption at times when the charge of electrical power is high. Therefore, this analysis considers a condition that encourages demand response (DR) with the approval of RTP. The price of electrical power is determined in consideration of the power flow from customers. This paper proposes an optimal operation scheme to decrease the essential capacity of the BESS and maintain the distribution voltage within the proper range. Moreover, this paper shows that not only is it possible to increase profits for the Dis Co by the decrease of BESS capacity, but proposes a profit for consumer by the decrease of total electricity cost.

II. DISTRIBUTION SYSTEM

In this paper, the distribution system model shown in Fig. 1 is simulated with a base power of 5MVA. The fixed line parameters used for the simulation are shown in Table. I. From this table it can be confirmed that the BESS and inverter capacity have been greatly reduced by the proposed method.

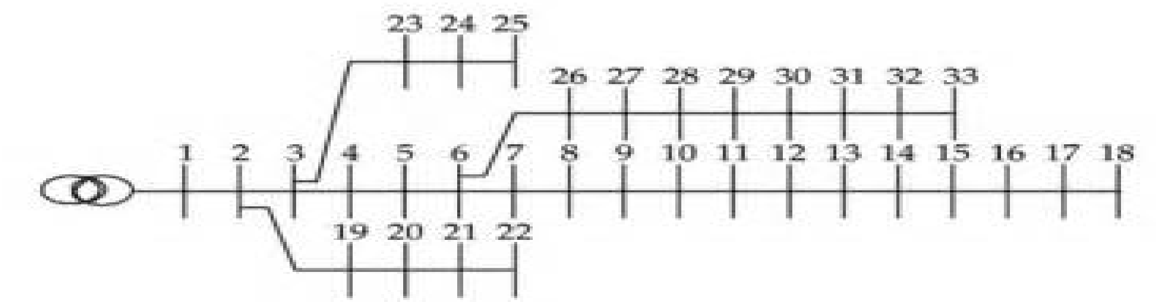

Fig. 1 Model of the distribution system

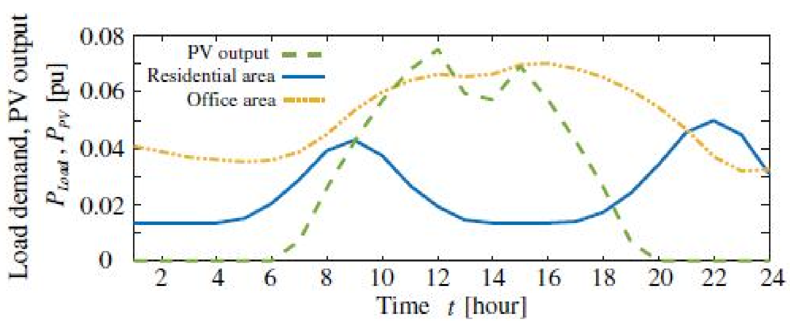

Fig. 2 PV output and demand load

Table .I

Parameters of distribution system	Without RTP	With RTP
Rated capacity interfaced inverter of BESS	0.8 pu	0.4 pu
Large BESS capacity	13 pu	5 pu
Line impedance at each section	0.04 + j0.04 pu	
Rated capacity PV node	0.08 pu	
Prated capacity interfaced inverter of PV	0.08 pu	

This model involves15 nodes Nodes 1 through 10 are assumed to be a residential area, nodes 11 through 15 are assumed to be an office area. It is also assumed that there are PV generators connected at all nodes within the distribution system. The total PV output and the load demand curve are shown in Fig. 2. The voltage range chosen to be the reference in this study from between 6,380 V (0.967 pu) and 6,600 V (1.0 pu) in the high-voltage side of the distribution system [2,4]. This is the defined acceptable voltage range in this paper. Maintaining the voltage of the high voltage power distribution system within an appropriate range through voltage control is the goal of the research described in this paper..

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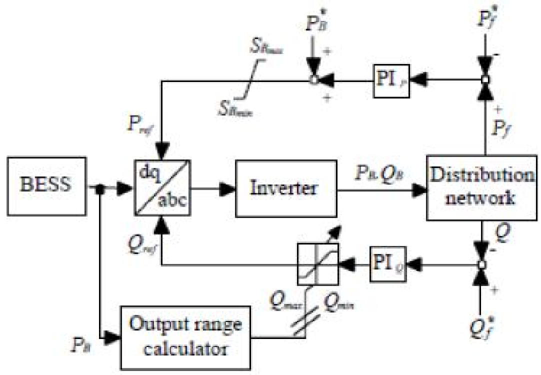

Fig.3 BESS control system

This segment defines the decision method for the tap changing of existing voltage control devices, the reactive power control scheme using inverters interfaced with the PV and the BESS control at the interconnection point.

A. Determination of control order value procedure

The objective function is used to minimize the distribution losses *PLoss*in terms of the node voltages, the tap positions, and the reactive power output of the inverters interfaced with the PV. It can be formulated as follows:

Objective function

$$min:F(PLB,QLB, PsB, Tk) = \sum_t^{24} \sum_i^n PLi(t) \quad (1)$$

Were N = the number of distribution nodes

Constraints

$$V_{min} \leq V_m \leq V_{max} \quad (2)$$

$$P_f^{min} \leq Pf\,(t) \leq P_f^{max} \quad (3)$$

$$Q_f^{min} \leq Qf(t) \leq Q_f^{min} \quad (4)$$

These are the voltage constraints in the distribution system, active power flow constraints, and reactive power constraints, respectively. The bandwidth of the voltage and active power flow are already mentioned. The reactive power flow bandwidth is as follows.

$$\sqrt{P_{LB}^2 + Q_{LB}^2} \leq S_{LB}(t) \quad (5)$$

$$\zeta_B(t+1) = \begin{cases} \zeta B(t) - \frac{WB(t)/\mathrm{n}}{CB} & (P_B(t) \geq 0) \\ \zeta B(t) - \frac{WB(t).\mathrm{n}}{CB} & (P_B(t) < 0) \end{cases} \quad (6)$$

$$\zeta_B^{min} \leq \zeta LB(t) \leq \zeta_B^{max} \quad (7)$$

Equations (6) and (7) are the large capacity BESS inverter constraints, considering the loss in charging and discharging of the BESS for each power constraint, and state of charge (SOC) constraints to prevent rapid degradation of the BESS respectively.

$$\sqrt{P_{\mathrm{PV}}^2 + Q_{\mathrm{PV}}^2} \leq S_{\mathrm{PV}}(t) \quad (8)$$

$$T_K^{min} \leq TK(t) \leq T_K^{max} (9)$$

Equations (8) and (9) are the PV inverter capacity constraints, and tap transformer tap position constraints respectively.

B. Photovoltaic generation scheme

In this paper, the hypothetical DGs are established on PV generators, which are fetching to be popular in smart houses. The reactive power output from the inverters interfacing the DGs is used to control the distribution system voltage. Therefore, in this study, reactive power control is performed based on the control value. It is assumed that reactive power is controlled within the system inverter capacity without restrain of the PV output. The control constitution of the inverter is the same as that discussed in reference [5]

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C. *cuckoo search algorithm*

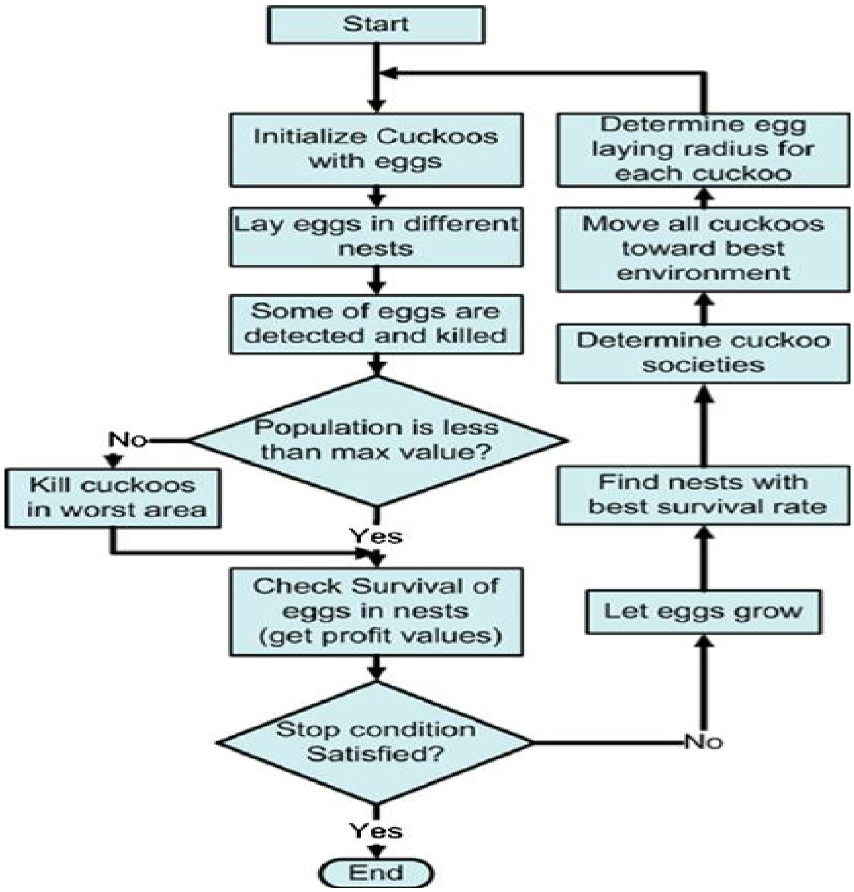

Fig.4 Flow chart of Cuckoo Search.

Cuckoo Search is a heuristic search algorithm proposed by Yang and Deb. The algorithm is inspired by the reproduction strategy of cuckoos. At the most basic level, cuckoos lay their eggs in the nests of other host birds, which may be of different species. The host bird may discover that the eggs are not it's own and either destroy the egg or abandon the nest all together. This has resulted in the evolution of cuckoo eggs which mimic the eggs of local host birds. To apply this as an optimization tool, Yang and Deb used three ideal rules:

(1) Each cuckoo lays one egg, which represents a set of solution co-ordinates at a time and dumps it in a random nest

(2) A fraction of the nests containing the best eggs or solutions will carry over to the next generation.

(3) The number of nests is fixed and there is a probability that a host can discover an alien egg. If this happens, the host can either discard the egg or the nest and this result in building a new nest in a new location. Based on these three rules, the basic steps of the Cuckoo Search

D. Large BESS control system to install interconnection points

According to the Electricity Law in Japan, the statutory range of voltage at the residential consumer side is set up within 101±6 V. In the distribution systems, between pole transformer for 6.6 kV high-voltage distribution system and consumer side for 100V system. When load is heavy, it occur up to 6.5V voltage drop and when reverse power flows to the system from distributed generators, it occur up to 2 V voltage rise [10]. So the range of voltage at the residential consumer side is from 101.5 V (0.967 pu) to 105 V (1.0 pu). If we set tap of all the pole transformers at 6,600 V : 105 V, the voltage range to be maintained within 6,380 V (0.967 pu) to 6,600 V (1.0 pu) in high-voltage distribution system. To suppress large variations of power flow at the interconnection point, the active power and reactive power are controlled using BESS at that point. Based on a control reference schedule optimized while considering forecast information, the BESS is controlled to satisfy the power flow bandwidth constraints at the interconnection point. In this paper, the BESS is assumed to have NAS batteries. The charge discharge efficiency of the BESS is 80%, not considering self discharging of the BESS. The control constitution of inverter is the same as that discussed in reference [5]

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III. DEMAND RESPOSE BY RIAL TIME PRICE AND REACTIVE POWER INCENTIVE

The DR using the proposed RTP is discussed in this paper. By adopting RTP, the DisCo can change the price of electricity with more flexibly than is possible with the conventional fixed electricity price. RTP promotes consumer electricity consumption by setting low prices in the daytime to prevent reverse power flow and achieves reduction in size of the large BESS by customer power consumption. In addition, the consumers can reduce the total purchase cost when the electricity price is expensive, they do this by reducing their consumption of electricity, and when the price is low, they can purchase more electricity for less than the conventional price. In this paper, the DisCo and consumer can mutually communicate in the distribution system via the smart grid communication technologies. In the DisCo, the consumer load change response to the real time price of power in the distribution system shall be known by the technique ofsystem identification. Furthermore, all customers own a home energy management system (HEMS), and the DisCo notifies the HEMS of the real time electricity price and the HEMS automatically coordinate the load demand based on the price

A. Setting scheme of the electricity price to use RTP

The following are shown flow the determination of the day price of electricity.

[Step 1] Make the power flow command values of all nodes.

First active power flow is measured from each node and the desirable active power flow is determined. Here, the desirable active power flow is that which does not cause reverse power flow. Equation (10) shows the active power flow P_{fG} that is flowing from the grid to customers.

$$P_{FV}(t) = P_{LOAD}(t) - P_{PV}(t) \qquad (10)$$

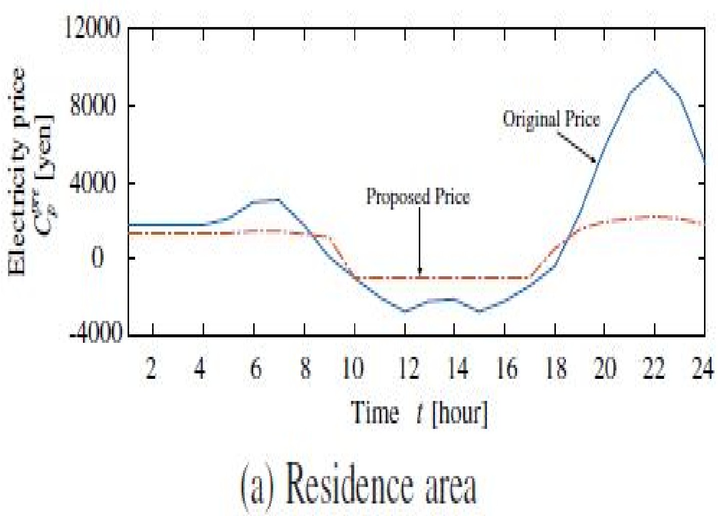

Fig 6(a)

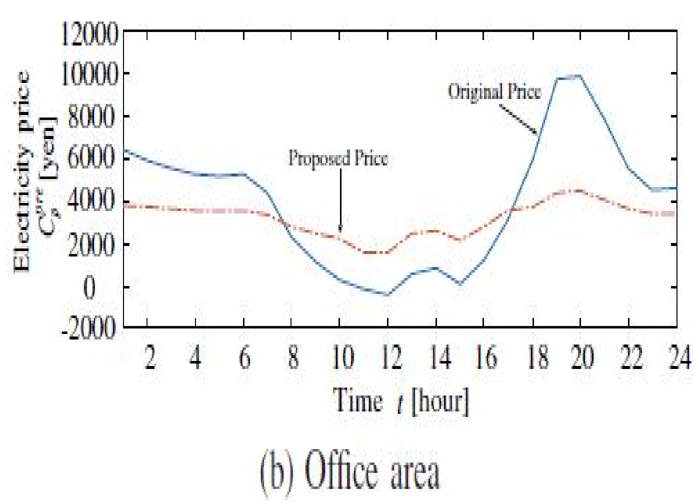

Fig 6(b)

Figure 6(a) shows the active power flow of the residential area *PfG*as a solid line, and the desired power flow for the Dis Co*Pf G*as a dashed line. Similarly, the active power flow of the office area *PfG* is shown in Fig. 5 (b).

Fig.5.a and 5.b Power flow from grid to customer (P^*_{fG}) and the desire power flow (P^*_{fG}) for DisCoFig.5.c and 5.d Difference

(ΔP_{Load}) between $P_{fG}$and P^*_{fG}.

[Step 2] Create a load demand such as to match the power flow command value.

The difference of load demand ΔP_{Load} and required power flow P^*_{fG} is denoted ΔP Load and is calculated by the following equation.

$$\Delta P_{Load}(t) = P^*_{FG}(t) - P_{FG}(t) \qquad (11)$$

The ΔP Load of each area is shown in Figure 5.c and 5.d

[Step 3] Determine the day ahead electricity price $C^{pre}_p$by using ΔPLoad. $C^{pre}_p$is first determined using the setting function showing Figure 5 the Day ahead electricity price for ΔPLoad. Then consumers are notified of the electricity price C^{pre}_p

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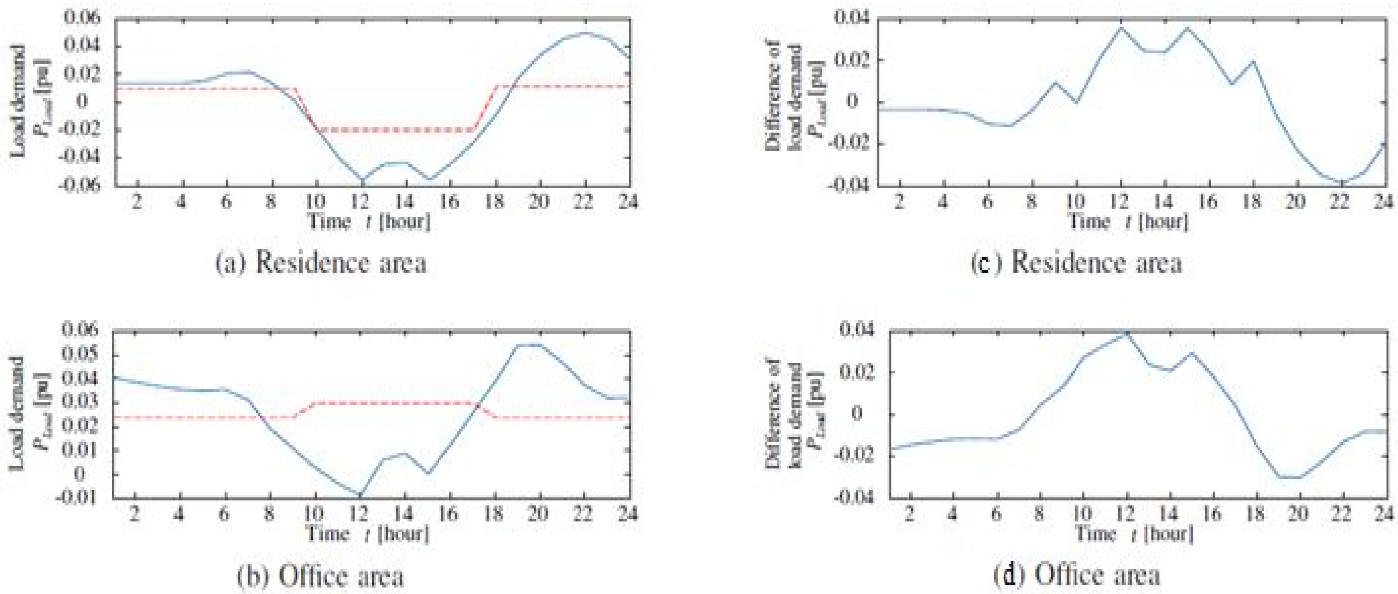

Fig 5

In Fig. 7, the electricity price is set to 25 [yen / kWh] as base price and the load demand shift is prompted by a cheap electricity price when the daytime reverse power flow occurs. It is confirmed that daytime electricity price $C^{pre}{}_{p}$is cheaper than the base electricity price and the night time price $C^{pre}{}_{p}$is more expensive than the base price as seen in in Fig. 7.

B. Reactive Power Encouragement

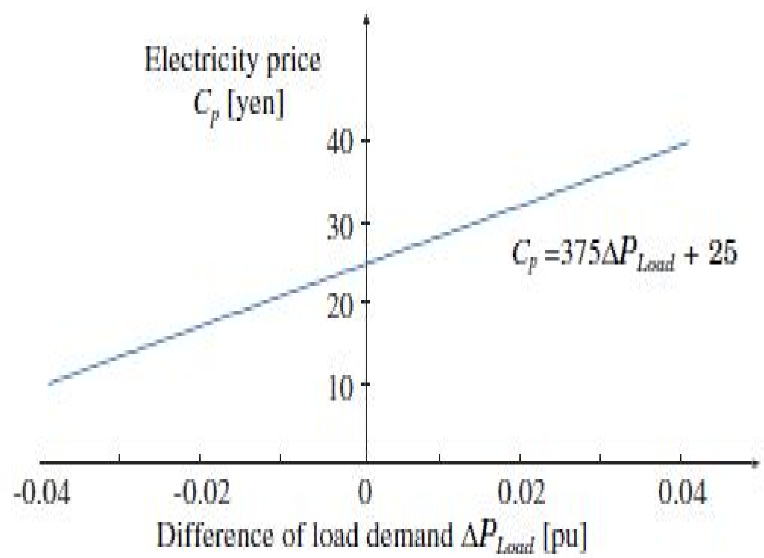

Fig.7Day-ahead electricity price $C^{pre}{}_{P}$ setting function of Dis Co against $\Delta PLoad$ possible.

In this segment, the reactive power incentive scheme is proposed in this paper. The DisCo should maintain voltage equipment such as voltage regulator or reactive power compensators. The costs for this equipment include maintenance costs, upgrade cost and operation cost and so becomes a burden to the DisCo. In the scheme of reactive power incentive, some of the burden of the DisCo is transferred to the customers. By improvements of the smart grid, communication between the customers and the DisCo is
In addition, within the smart grid, each smart house has a Home Energy Management System (HEMS). Due to the development of smart grid, a new control method using HEMS in many of the reference have been proposed [6-9]. The information from the

DisCois received by the customer through HEMS. If all customers follow the DisCo's request for the specified reactive *power* output Q^*_{PV}, the DisCo can remove the unnecessary burdens of equipment cost. Therefore, the DisCo can distribute the saved cost to customers participating in the incentive program. In the following subsection, details of this proposed method are described.

1) *Calculation of Reactive Power Incentive Unit Price:* The reactive power incentive unit price υq is divided into two groups. The first category is the investment cost of the reactive power compensator *CSVC (What is CSVC)* required to achieve regulation of distribution voltage. Another category is the introduction cost of the *CSV (What is CSVR)* to achieve regulation of the distribution voltage. To derive these two costs, it is required that there be a way to perform an optimal operation that does not rely on customer's coordination. When these costs are derived, υqcan obtained from the following
2) *Equation:*

$$V_q = \frac{C_Q}{20\times365\times24\times S_{SVC}\times N}\text{[yen/kVarh]} \qquad (12)$$

The number of 20 means pay back year. The detail of in the above equation *CQ* is followed.

$$C_Q = C_{SVC} \times N + C_{SVR} \times 3 \quad (13)$$

TABLE II: Parameters of comparison case

variable	introduce cost [yen] & capacity [kVar]
C_{SVC}	1.3×10^7
ΔC_{LB}	1.2×10^{10}
C_Q	1.22×10^{10}
S_{SVC}	300
υ_q	7.7 [yen/kVarh]

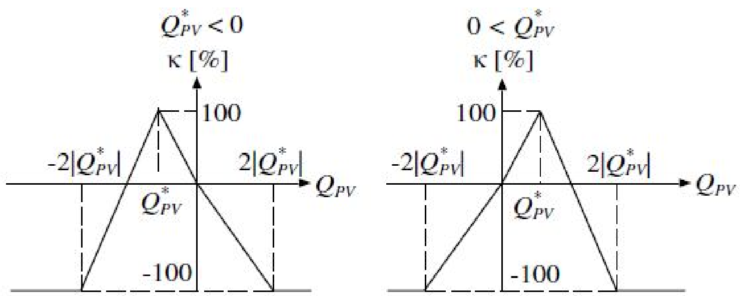

Fig.8 Contribution factor of reactive power incentive.

CQ is the total cost for voltage regulation and *SSVC* is thecapacity of the SVC. Here the number 3 means the number of SVCs Introduced in the distribution system for voltage regulation. These SVCs are located between nodes 2 and 3, between nodes 2 and 7, and between nodes 4 and 11, and are called SVR1, SVR2, SVR3, respectively. Because the S_{SVC} should distribute to all customers, the value is derived by the number of branching nodes in the distribution system.

3) *Profit Obtained by Customers*

Once $\upsilon q$is determined, customers can calculate their own obtained profit υ following the order from the DisCo. However, for cases when the reactive power output order Q^*_{PV}exceeds the customer's PV capacity or in the event of a communication failure or when customers do not obey the command value, the DisCo can set a contribution factor κ for each customer. This contribution factor κ is described in Fig. 8, and the profits obtained by the customers can be derived using equation (15).

$$\upsilon = Q'_{PV} \times \upsilon_q \times P_{base}\text{[yen]} \qquad (14)$$

The P_{base}in the above equation means the base power [kw]. In this paper, $P_{base}$is 5,000 [kW]. In addition, $Q'_{PV}$is the reactive power incentive considering the contribution factor κ, and is described by the following equation:

$$Q'_{PV} = |QPV| \times \kappa \qquad (15)$$

Therefore, customers can obtain a maximum bounty close to Q'_{PV}. Since all customerr carry out the commands the profit is maximized, the DisCo can maintain the voltage using this incentive. The κ derived by Fig. 8.

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IV. SIMULATION RESULTS

In this paper, in order to demonstrate the effectiveness of DR by RTP and reactive power incentive based on reference optimal control introduced in the distribution system simultaneously. Simulations were performed using Fig. 1 model with the parameters shown in Table 1. Moreover some case studies shown in Table III were simulated to compare the proposed method.. DisCo can get profit that it is possible to reduce distribution losses shown in Fig. 10 and Table IV, and reduction of large BESS shown in Table VI and control devices for maintain power quality. Therefore, DisCo can suppress huge investment cost. On the other hand, customers of all nodes get reactive power incentive to follow the optimal scheduling presented by DisCo shown in Fig. 10. Moreover it is possible to reduce total electrical price per days shown in Table VII to participate the RTP in electricity market. Therefore, in this paper it is mentioned that the proposed method is not only DisCo profits but customer profit as well.

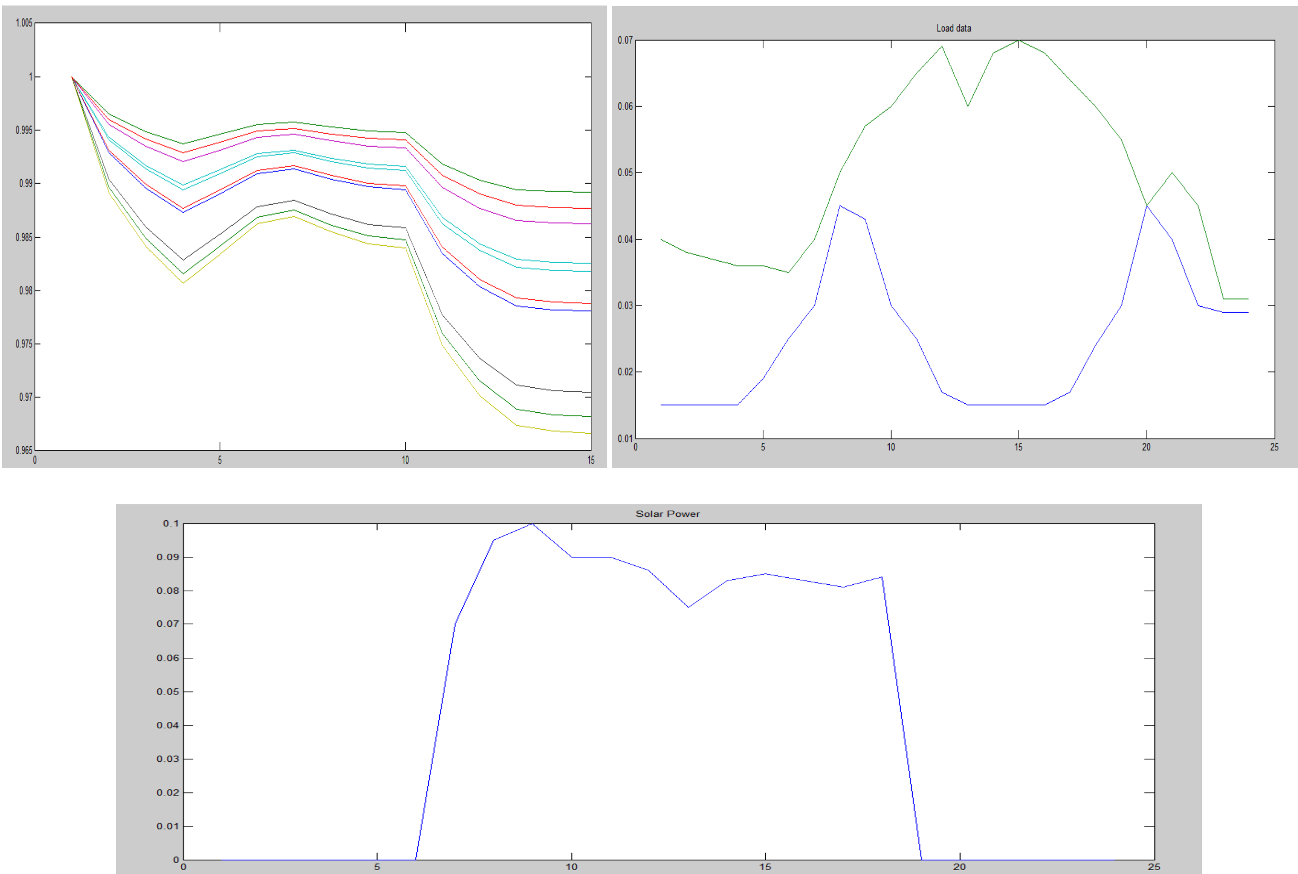

Fig9: Simulation results

TABLE III: The conditions of each case

CASE	CONDITIONS
Case 1	without control and without RTP
Case 2	without control and with RTP
Case 3	with RTP
Case 4	with RTP (variable power flow bandwidth)

TABLE IV: Distribution losses of each case

case	Distribution losses	Rate of reduction
Case 1	7,709 [kWh]	-
Case 2	4,918 [kWh]	36.2 [%]
Case 3	992 [kWh]	87.1 [%]
Case 4	1,014 [kWh]	86.8 [%]

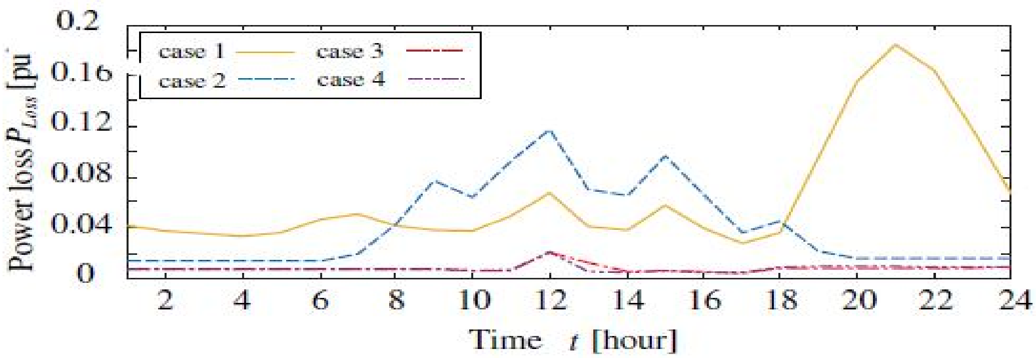

Fig 10: Reduced distribution loss

TABLE V: Comparison of large BESS capacity and inverter in case 3,4

	Case 3	Case 4
large BESS capacity	5 pu	3.5 pu
inverter capacity of large BESS	0.4 pu	0.35 pu

TABLE VI: Total electricity cost residential area and office area per a building

Area	Residential area [yen]	Office area [yen]
Electricity price	66.5	1.90×10^3
Incentive	173	952
Total price	-106	946

V. CONCLUSION

This paper proposed a method for setting the electricity price for DisCo considering the participation of customers in RTP and reactive power incentives for the optimal scheduling. From the simulation results, the consumer changed their load demand to the load desirable at DisCo by RTP. The reduction of the total cost of electricity price and possibly the reduction of the large BESS is achieved through RTP Reactive power incentive could reduce additional devices for high penetration of DGs. It is confirmed that proposed method can get the benefit for DisCo and customer. Thus the use of either method RTP of reactive power system is profitable. This proposed method could promote the participation of customers in electricity market

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