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Analysis of the Value of Distributed Energy Resources through the Regional Electricity Market

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Abstract—

Electricity consumers are now able to make more effective use of decentralised energy sources because to the advancement of the "smart grid" (DERs). Prosumers are consumers who also engage in the act of selling and buying energy. By managing the HVAC load, deferrable load, and energy storage system (ESS), a Prosumer may minimise power cost and comfort issues while living in a comfortable environment. Prosumers may increase their earnings by sharing their electrical excess with the central grid or other local Prosumers. The primary goal of this research is to use the regional electricity price to examine the value of renewable energy and controlled loads in the Prosumers network, including HVAC, deferrable load, and ESS. Multiple case studies demonstrate how the excess and deficit of power from renewable energy Prosumers and the main grid electricity price affect the regional market's value.

Keywords:

Air conditioning loads, delayed loads, Prosumers, the electricity market

INTRODUCTION

The deployment of regulated loads, a growing population, and the need for more housing all contribute to a rising need for clean, consistent power. In light of this, the "smart grid" — a novel idea for the electricity infrastructure — is crucial [1]. Power is often distributed from large-scale plants through conventional power systems. Whereas traditional grids rely on fossil fuels, the smart grid makes use of renewable energy sources to power distributed energy resources (DERs) [2].
The incorporation of DERs allows customers to play a more active role in energy markets today [3]. Smart grid users may utilise DERs like solar photovoltaic and wind turbines to produce power and store that electricity in batteries. Prosumers are defined as "end users" in [4] who are able to act as both consumers and producers of electricity. Depending on the cost of electricity, prosumers may optimise their load patterns by using smart controls and communication technologies [5]. It will be necessary to devote further resources to DERs if Prosumers are to operate at peak amongst linked microgrids. Within the microgrid of P2P PV Prosumers, the issue of energy sharing was investigated in [6]. Based on the supply and demand ratio of PV energy shared, a suggested internal pricing model is provided for the functioning of the energy sharing zone. The authors of [7] investigated a Prosumer energy exchange in which power is transferred and traded between different consumers. The price of energy is what drives the market for energy. Additionally, to accomplish demand side control and optimise cost for Prosumers and utilities, [8] presented a Prosumer based energy sharing and management system. In [9], the authors suggest a model of energy management to aid Prosumers in managing their energy usage in light of their own abilities and the extent to which they have control over their own production and use of energy. The advantages of Prosumers who utilise solar power have been calculated using game theory by the authors of [10]. Linear Function Submission-Double Auction (LFS-DA) technique for balancing power supply and demand was investigated by the authors of [11].

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The supply and demand for power were perfectly in sync. In our earlier work [12] and [13], we have explored the impacts of LFS-DA algorithm on changeable loads in a network of Prosumers. By regulating the HVAC Load, Rugira was able to reduce the energy costs and customer dissatisfaction of the Prosumers (see [12]). The goal of the approach we developed in reference [13] was to keep Prosumers happy while keeping network operations costs to a minimum. To the best of our knowledge, the value of DERs, Controllable loads, and ESS on the regional market has not been established prior to the advent of Prosumer. This report thus proposes research into the area electrical market to assess the value of renewable energy, HVAC load, deferrable load, and ESS. Our study is unusual because it integrates HVAC load, deferrable load, and ESS in commercial buildings into the regional Prosumers network to determine which of these factors has the most impact on the operating costs of a Prosumer. By analysing the operational expenses of a Prosumer in the local power market, we were able to determine the DERs' worth. The remaining sections of this report are structured as follows. The organisation of the Prosumers' network and the

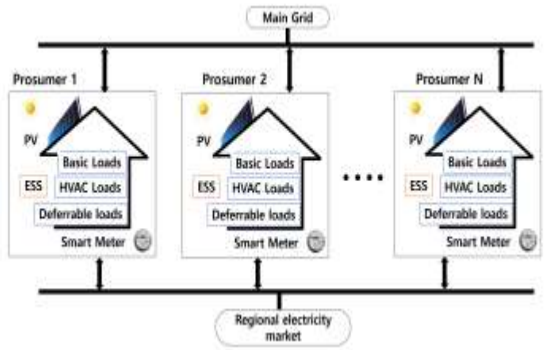

Fig. 1. Structure of the Prosumers' Network regional electricity market.

The cost optimization model used to analyse the value of DERs is presented in Section III. Section IV shows the case study and simulation results. In Section V, the conclusion is drawn.

ENERGIA MARKET IN THE REGION

The Organization of the Prosumer Community

There is a network of electrical Prosumers in the area, and they are all linked together to form what is known as the regional Prosumers network. Connecting prosumers allows them to sell their extra power to the grid or to other prosumers. In order to encourage energy sharing among Prosumers and lessen their reliance on the main grid, it is crucial to have access to a reliable regional power network. In Fig. 1 we see how the Prosumers network is structured. We take into account a system of N Prosumers, where each Prosumer is wired into the national grid and the local power market. Each Prosumer has a smart metre installed, which uses the individual's usage profile to facilitate the trading of power on the regional market and the equitable distribution of electricity supplied by DERs [11]. All Prosumers have an ESS and a variety of DERs, including solar panels, wind turbines, and batteries. In this study, we focus on Car to Grid (V2G) technology, therefore the ESS may be any battery-type plug-in electric vehicle. Charge the electric vehicle (EV) overnight when power from the main grid is inexpensive or during the day when PV energy is abundant. Each Prosumer also has HVAC and deferrable loads in addition to the fundamental loads shown in Fig. 2. The regional market's operating cost is optimised so that the value of DERs may be determined. Renewable energy excess and manageable loads might impact operating expenses. Setting a chosen temperature range regulates HVAC loads. Power consumption for deferrable loads is represented in such a manner that it may be varied throughout a window of their set operating duration. When a Prosumer generates more power than they need, they may either sell the excess to another Prosumer in the area or send it back into the main grid. However, a Prosumer who is short on power may purchase more juice from neighbouring consumers or the central grid. In this study, we assume that Prosumers may only sell their excess to the regional power market in an effort to encourage on-site consumption while keeping the computations as straightforward as possible.

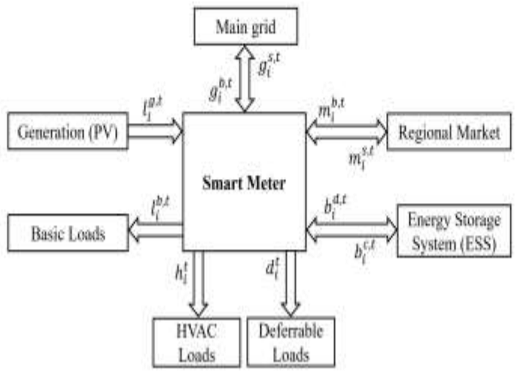

Fig. 2. An example of a Prosumer. The Prosumer is connected to the main grid on one hand and to the regional market on the other hand. Each Prosumer has an installed PV generator, an ESS, basic loads, HVAC and deferrable loads. The electricity flow is controlled by a smart meter.

REGIONAL MARKET COST OPTIMIZATION MODEL

The main goal of this paper is to analyse the value of DERs through the regional electricity market. In order to evaluate the value of the considered DER in this paper, we compared a cost optimization model to control the HVAC load and deferrable loads through the regional electricity market to a case when the Prosumers do not participate in the regional market. We assumed that all Prosumers are connected to the regional electricity market. The price of electricity in the regional market is determined by using LFS-DA algorithm [13]. A. Cost Model for Each Prosumer In this section, we scheduled the HVAC and deferrable loads with a goal of minimizing the operation cost for each Prosummer. For the Prosumers cost optimization, there are ten decasino variables which varies daily within t ∈ T time periods, where T: = {1, 2, ...T} is the set of the scheduling time. Each Prosumer receives a set of ten decision variables represented by

$$X_i \equiv \{l_i^{b,t}, l_i^{g,t}, h_i^t, d_i^t, b_i^{c,t}, b_i^{d,t}, m_i^{b,t}, m_i^{s,t}, g_i^{b,t}, g_i^{s,t}\}.$$

The operation cost for Prosumer I ∈ N: = {1, 2, ...N}, consists of the renewable energy generation cost, the profit of selling the electricity and the cost of purchasing electricity from the main grid and the profit of selling and the cost of buying electricity with the regional electricity market.

The total operation cost is given by

$$C_i(X_i, p_t^s, p_t^b, p_t) = \sum_{t\in T} C_i^t(l_i^{g,t}) - \gamma p_t^s g_i^{s,t} + p_t^b g_i^{b,t} - \gamma p_t m_i^{s,t} + p_t m_i^{b,t}, \quad (1)$$

where p s t, and p b t represent the rates of selling and buying electricity with the main grid respectively. While pt. denotes the regional electricity market price. γ is the transmission efficiency in the Prosumers network. B. Cost Optimization for the Regional Electricity Market in the Prosumers network, neighbouring Prosumers can share their surplus of generation at a reduced price compared to the main grid price, this is to motivate the on-site consumption of renewable energy generation. The goal of the regional market cost optimization is to determine the optimal schedule for the HVAC and deferrable loads. This scheduling problem is formulated in terms of minimizing the Prosumers total cost.

The regional electricity market cost minimization problem is given by

$$min \sum_{i\in N} C_i(X_i, p_t^s, p^b{}_t, p_t), \quad (2)$$

Subject to

$$h_i^t + d_i^t + l_i^{b,t} - l_i^{g,t} + b_i^{c,t} - b_i^{d,t} + m_i^{s,t} - m_i^{b,t} + g_i^{s,t} - g_i^{b,t} = 0 \quad (3)$$

$$T_{in}^{min} \le T_{in}^t \le T_{in}^{max}, \quad (4)$$

$$0 \le l_i^{b,t} \le l_i^{b,max}, \quad (5)$$

$$0 \le l_i^{g,t} \le l_i^{g,max}, \quad (6)$$

$$h_i^t = A \cdot Temp_i^t + B, \quad (7)$$

$$T_{in}^{t+1} = T_{in}^t + (\frac{T_a^t - T_{in}^t}{\tau} - Temp_i^t), \quad (8)$$

$$h_i^{min} \le h_i^t \le h_i^{max}, \quad (9)$$

$$0 \le m_i^{s,t} \le m_i^{s,max}, \quad (10)$$

$$0 \le m_i^{b,t} \le m_i^{b,max}, \quad (11)$$

$$0 \le b_i^{c,t} \le b_i^{c,max}, \quad (12)$$

$$0 \le b_i^{d,t} \le b_i^{d,max}, \quad (13)$$

$$g_i^{s,t} \ge 0, \quad (14)$$

$$0 \le g_i^{b,t} \le g_i^{b,max}, \quad (15)$$

$$\sum_{t=t_{i,s}}^{t_{i,e}} d_i^t = D_i, \quad (16)$$

$$0 < d_i^t \le d_i^{max}, \quad (17)$$

$$d_i^t = 0, \quad if \quad t \in T \setminus T_{i,def}, \quad (18)$$

$$0 \le S_i^{init} + \sum_{t\in T} (\eta_i b_i^{c,t} - b_i^{d,t}) \le S_i^{max}, \quad (19)$$

In this optimization problem, all the ten control variables are bounded (4), (5), (6), (9), (10), (11), (12), (13), (15), (17). As discussed in [13], equation (7), shows the HVAC load model. Equation (8) describe the indoor temperature model. The indoor temperature is maintained in the preferred comfort zone for each Prosumer. Equations (16), (17), and (18) introduce the model of deferrable load. In this paper we considered the scheduling to shift the operational period of the deferrable load. Each Prosumer needs to pre-set the start time times and the end of time time that the deferrable load can be scheduled. The set of time in which the deferrable load can be shifted is given by Ti,def = [ti,s, ti,e] ∈ T. The model of deferrable load used in this paper was retrieved from [14]. Moreover, in equation (19), we described the ESS status during the scheduling period. To solve this optimization problem, the regional electricity market price is needed. In this paper we used the LFS-DA algorithm, detailed in [11], to decide the regional electricity market price.

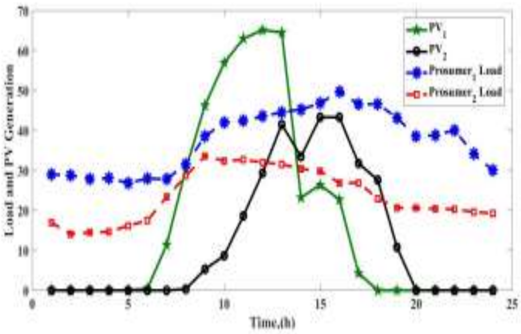

Fig. 3. P V1 is the PV generation of P rosumer1. P V2 is the PV generation for P rosumer2. The basic loads' curves for two Prosumers within the Prosumers' network are illustrated.

The findings from the case study and the simulations

Here, we look at the regional power market and how DERs might contribute to its value chain. There were two possibilities that we mulled about. In the first scenario, two Prosumers make up the Prosumers network. In the second scenario, we take into account a more complicated situation in which 10 Prosumers across a network with varying PV generating capacities and load cures. The benefit of the regional electricity market is discussed in terms of the value of DERs; this benefit is obtained by contrasting the cost optimization achieved when a Prosumer transacts only with the main grid with the cost optimization achieved when the Prosumer participates in the regional electricity market. We also look at how DERs' value changes depending on whether or not they are producing power.

Contexts in General

For the purposes of this work, we define a scheduling period of 24 hours, with each hour of that period separated by a time gap of t > T = 1 hour. Table I lists all of the relevant parameters for the Prosumers in this article. All Prosumers in the first scenario have photovoltaic (PV) generators, energy storage systems (ESS), basic loads (including HVAC and deferrable loads), and HVAC. There are eight PV-equipped Prosumers in the second scenario, but only six surplus-generating Prosumers. We looked at several cases, each with its own load profile and PV generation profile, and assessed the results. In the first scenario (shown in Fig. 3), the daily basic load and PV generation curves are displayed. It is assumed that the PV production and fundamental loads are known in advance. As can be seen in Fig. 3, there is a surplus of PV production between the hours of 9 AM and 5 PM, making it viable for power to be traded amongst Prosumers at those times. Prosumers have access to electricity from the grid when it is not dark outside. Figure 4 confirms the aforementioned; it depicts the price of power on both the main grid and the regional electricity market. As can be seen in Fig. 4, the cost of electricity from the main grid decreases as night falls. During the day, the cost of power from the main grid is much higher than the rate offered by the regional market. One reason Prosumers take part in the regional power market is because of the low prices of electricity. Because Prosumers have PV power excess throughout the day, they are able to trade with one another on the local electricity market. There is no major bottleneck in a network of 10 Prosumers.

TABLE I

PARAMETERS AND BASIC VARIABLES USED FOR SIMULATION

Parameters and variables used in this paper	
Number of Prosumers	$N = 2$ and $N = 10$ buildings
Scheduling period	$T = 24h$ divided into 24 equal time slots
Deferrable load's operation period	$T_{i,def} = [t_{i,s} = 3PM, t_{i,e} = 9PM]$
Battery bounds	$b_i^{c,max} = b_i^{d,max} = 10kWh$
Regional market bounds	$m_i^{s,max} = m_i^{b,max} = 40kWh$
Battery state of charge	$S_i^{init} = 0,\ S_i^{max} = 40kWh$
Maximum purchase from the main grid	$g_i^{b,max} = 500kWh$
Battery efficiency	$\eta_i = 0.85$
Transmission efficiency	$\gamma = 0.95$
PV generation cost	$C_i^t = 0$
PV generator capacity	$72.55kW$ and $55.6kW$
HVAC load bounds	$h_i^{min} = 0,\ h_i^{max} = 10kWh$
Constants	$A = 2.9,\ B = 1.1,\ \tau = 11,$ $D_i = 10.2kWh,\ d_i^{max} = 3.3kWh$
Indoor temperature bounds (comfort zone)	$T_{in}^{min} = 20^oC,\ T_{in}^{max} = 24^oC,$ $T_{in}^1 = T_{in}^{24} = 20^oC$

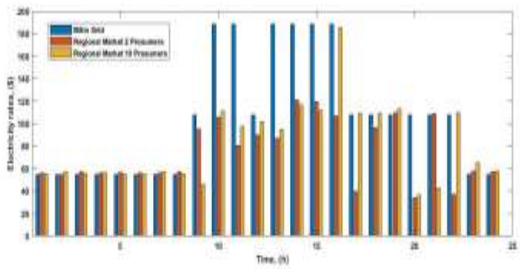

Fig. 4. Comparison between the main grid utility price and the regional market price in two Prosumers network and in a ten Prosumers network.

transaction at 4 PM because the electricity price in the regional market is almost equal to the main grid price. Furthermore, there is also a transaction in the regional market at time 8 PM and 10 PM for the two Prosumers case. In addition to this, the transaction is possible at 8 PM and 9 PM, in the ten Prosumers case. The transaction is possible due to the available surplus of electricity that can be shared among Prosumers, and additionally, the amount of power stored in the ESS can be shared in the regional electricity market. The main grid price used in this paper was retrieved from the Korean Electric Power Corporation (KEPCO) [15].

Effectiveness of Controllable Loads in the Regional Market

Prosumers can manage their daily consumption pattern by controlling the ESS and flexible loads such as HVAC and deferrable loads, therefore minimizing their electricity cost and their discomfort. Controlling the ESS, HVAC load, and deferrable results in a reduction of the Prosumers' total operation cost in the regional market. However, compared to the total cost of Prosumers who transact only with the main grid, the regional market has a marginal gain through controlling ESS and controllable loads. In Table II, we observe the value of ESS, HVAC, and deferrable loads through the

TABLE II

EFFECTIVENESS OF CONTROLLABLE LOADS AND ESS IN THE REGIONAL MARKET

HVAC Load	Deferrable Load	ESS	Without Regional Market [$]	With Regional Market [$]	Gain [%]
X	X	X	80.9	72.0	**11.01**
O	X	X	76.8	68.1	**11.32**
X	X	O	69.7	61.8	**11.24**
X	O	X	81.0	73.9	**8.78**

regional market. This results for each HVAC, deferrable load, and ESS is obtained by assuming that all the other loads are fixed. It is assumed that Prosumers are generating electricity from their PV generators. In the Table II, X denotes that the load is fixed or simply that the load is not controlled while O denotes that the load is controlled. We compare the Prosumer's total cost in the regional electricity market to their total cost when a Prosumer with installed PV transacts only with the main grid. Numerical results in Table II, show that the Prosumer's total cost is high when the HVAC and ESS are fixed and when the deferrable loads is used in the peak time hours. The price of electricity can be minimized by controlling the operation time and setting of the HVAC, deferrable load and ESS. However, the gain of the regional market is still marginal by only relying on managing the daily consumption. For simplicity, we assumed that all Prosumers have the same initial characteristics excepts for basic loads and PV generation capacity. In this case study, deferrable were controlled by shifting their operation period. We consider two cases, first, the deferrable load is considered as a fixed load when they operate during the nighttime from 1 AM to 6 AM, therefore, using the cheap electricity from the main grid. Second, the deferrable load is considered controlled loads when their operation time is in the afternoon from 3 PM to 9 PM.

Value of PV Generation in the Regional Electricity Market

In this subsection, our objective is to check the efficacy of PV generation in the regional electricity market. We analyzed the value of PV generator by checking their generation-time performance in the regional market optimization problem and the time during which they are not producing electricity. We assumed that the HVAC load, Deferrable load, and ESS are fixed. As shown in Fig. 3, all Prosumers have the surplus of electricity, we observe that the transaction of electric power between Prosumers is possible from 9 AM to 6 PM and at 8 PM, and 10 PM. Numerical results in Table III show that the gain of the regional electricity market is 11.01% when both Prosumer's PV generators are generating the electricity. The regional electricity market gain decreased to 5.91% and 3.28% when either P V2 for P rosumer2 or when P V1 for P rosumer1 is shut down, respectively. This means thatP V1 for P rosumer1 has much value in the regional electricity market compared to P V2 for P rosumer2. The reduction of the regional market

TABLE III

THE VALUE OF PV GENERATOR THROUGH THE REGIONAL ELECTRICITY MARKET

PV_1	PV_2	Without Regional Market [$]	With Regional Market [$]	Gain [%]
X	*X*	163	163	**0.00**
X	*O*	127	123	**3.28**
O	*X*	117	110	**5.91**
O	*O*	80.9	72.0	**11.01**

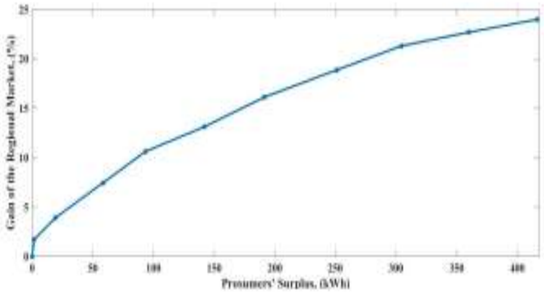

Fig. 5. The gain of regional electricity market depends highly on the PV generation surplus.

profits are proportional to the amount of energy that Prosumers produce in excess. Further, as shown in the first line of Table III, there is no benefit to engaging in the regional power market if PV excess is not available. This implies that the excess electricity is crucial to the success of the regional power market. According to Table III, the profit rises in line with the size of the region's electrical excess, which may then be distributed to other markets. Fig. 5 shows the finding to be true. This graph shows how, up to a certain point, the regional power market gains a substantial amount of money. Since no benefit would accrue to the regional power market in the absence of a surplus, it is clear that one must be created. However, the Regional power market stands to benefit substantially with increased excess.

Example of a Complicated Prosumer Network

Our optimization issue was addressed by taking into account a complicated Prosumers' network with 10 Prosumers of varying features, proving the importance of PV generation in the regional market. Eight out of ten Prosumers have PV generators installed, while two do not. Two Prosumers with PV generators installed do not have an excess of power. Table IV displays numerical data showing that when Prosumers have a PV generator with an excess of power but no controlled loads, the regional market's ideal cost is $393.15. Prosumers may engage in trade on the regional energy market since they generate and use enough power to meet their needs while also sharing with one another. If the PV generator is not used, the operating expenses are $ 832.03. PV generators have a far higher operating cost when they are turned off, compared to when there is a surplus to sell on the regional power market. Consequently, the importance of PV power to the regional electricity market has been shown. According

TABLE IV

THE VALUE OF PV GENERATOR THROUGH THE REGIONAL ELECTRICITY MARKET

CASE with 10 Prosumers	Without Regional Market [$]	With Regional Market [$]	Gain [%]
Without PV and controllable loads	832.03	832.03	**0.00**
With PV without controllable load	448.61	393.15	**12.36**
With PV and Deferrable loads	451.07	400.71	**11.16**
With PV and ESS	399.28	343.10	**14.08**
With PV and HVAC	430.83	362.40	**15.88**

to Table IV, with the PV generator installed with a certain amount of surplus and assuming that the both the ESS and controllable loads are fixed, the gain of the regional electricity market is 12.36%. Furthermore, both the PV generation surplus and ESS increase the gain of the regional electricity market to 14.08%. The regional electricity has a significant value with a gain of 15.8% when Prosumers can control their HVAC loads, and they have PV generators installed with sufficient amount of surplus.

CONCLUSION

In this study, we aim to assess DER worth in the context of the local power grid. We envisioned a group of Prosumers, each with their own photovoltaic power plant, energy storage system (ESS), basic loads, heating, ventilation, and air conditioning (HVAC), and deferrable load. Plug-in electric vehicles (EVs) may take the role of the ESS in order to facilitate Vehicle to Grid (V2G) technology. For Prosumers, we created an optimization framework that lets them trade while still maintaining a steady interior temperature and running their deferrable load at the scheduled time. Prosumers have the ability to manage their ESS, HVAC loads, deferrable loads, and transact in the regional market to lower their operational costs. Without access to a regional market, Prosumers can only resort to pre-cooling and ESS to save costs in the operation. Local markets, however, allow Prosumers to pool their resources and benefit from a more manageable burden and excess. When there is an excess of power, the regional market benefits greatly up to a certain point. Numerous case studies demonstrate the critical importance of Prosumers' PV surplus to the regional market. As a result of the PV excess and ESS management, the regional power market is better off by 14.08%. Additionally, from our case studies, we can see that when Prosumers have the PV generating excess and they are able to regulate their HVAC loads, the value of the regional market increases. The regional market benefit due to the PV generator surplus and HVAC load management is 11.32% in the two Prosumers network scenario and 15.88% in the ten Prosumers network example. Prosumer gains in the regional market are increased by climate control and ESS load management, although this only adds a small amount to the regional market's overall profit.

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