Development options for distribution tariff structures in Finland

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Abstract— **In this paper, we study the development options of tariff structures in electricity distribution in Finland. We compare the impacts of three different tariffs from the viewpoints of customers, distribution system operator (DSO), electricity supplier, and society. Analyzed tariffs are (1) energy oriented tariff, which is currently in use, (2) power limit tariff, and (3) power tariff. Based on the analyses, it seems that it is justified to include power based price component in distribution tariff. Generally, the impacts of both analyzed power based tariffs are quite similar. However, it seems that power tariff is a bit stronger candidate. Nevertheless, it should be noted that benefits of power-oriented pricing, illustrated in the paper, could be achieved only by well-designed tariff system. Although analyses are based on Finnish case, most of the results are generalizable to other countries also.**

Index Terms—**Distribution tariffs, demand response**

I. Introduction

The cost-reflectivity and demand response (DR) incentives of the present energy based tariff structure in electricity distribution are insufficient, as illustrated for instance in [1]. However, this has not been major issue in stable operational environment, where the development of the amount of energy and power transmitted through the network has been quite constant and easy to predict. However, at the moment there are changes under way in the energy sector, which can be considered ground-breaking for the whole industry. Intermittent micro generation, mobile and stationary energy storages, energy efficiency improvements, changes in heating methods (e.g. heat pumps), and demand side management (DSM) are game changers, which are changing the fundamental principles of the planning and operation of the power system, as well as business logic in whole energy sector, as presented for instance in [2]. Hence, to ensure the cost-reflectivity and incentive provision properties of the distribution pricing, novel structure for the distribution tariffs has to be developed. The goal is that distribution tariff, together with pricing of energy supplier and taxes, should provide end-customers with incentives for demand response and resource efficiency, ensure adequate incomes for the DSO, support the functioning of the energy markets, and promote resource efficiency of whole energy system.

In this paper, we consider the developing options of distribution tariff structure in Finland. As presented in [3], designing of the distribution tariffs can be divided into two parts: (1) the determination of the total allowed revenue and (2) the allocation of the revenue requirement among the users. In this paper, we focus on second issue, and assume that the changes in the pricing structure do not affect the total revenue of the Distribution System Operator (DSO), but only to the allocation of costs between end-users. Furthermore, we focus our studies only to small-scale customer, which in this case means customers whose main fuse is 63 A or smaller. In practice, our interest is in the household customers, as they are the largest customer group measured by the number of customers. Although case-analyses of this paper are for Finnish operational and market environment, most of the results are generalizable for other countries also.

The structure of the paper is as follows. In chapter two, background and motivation, including the properties of the present DSO tariff structure in Finland, are presented. In Chapter three, we illustrate the suggested novel tariff structures. In the fourth chapter, we present the criteria for selecting the tariff structure, and the strengths and weaknesses of each tariff structure from the viewpoint of different stakeholders. Finally, conclusions will be drawn and future research needs will be considered in Chapter five.

II. Background and motivation

In earlier studies, it has been proven by simulations that market based demand response increases the peak powers of the distribution network, while the amount of the transmitted energy remains the same, see for instance [2] or [7]. Again, customers' own micro-generation, especially PV (photovoltaic), will decrease the amount of energy transmitted through the network, while the peak powers in many cases remain at the present level [2]. Hence, the need for the energy system does not disappear for these customers, since the PV production is not available at all times. Eventually, the peak-operating time of the network is changing, and because of that, the energy oriented pricing may not be viable option in future.

A. Present distribution pricing structure in Finland

At the moment, pricing of the network services typically includes two components; an energy based fee (c/kWh) and a fixed standing charge (€/month), of which latter one may depend on the size of the main fuse. The proportion of the fixed fee varies between companies and between customer types. According to [4], the average proportion of the fixed fee in year 2013 was 35.7 % for electric heated detached house (annual energy consumption 20 MWh/a) and 53.2 % for small apartment (annual energy consumption 2 MWh/a). However, distribution tariff is only one part, approximately one third, of customer's total electricity cost, other parts are electricity supply (also about one third), and one third is taxes, including electricity tax and value added tax. In Finland, customer receives two separate bills, one from local DSO, which includes also electricity tax, and one from supplier, which the customer can select freely.

Economic regulation of the electricity distribution business in Finland defines the reasonable levels for operational costs, depreciations, and profit (return on capital). Hence, regulation sets in practice upper limit for the revenue. However, regulation does not set requirements for tariff structure. In national legislation, it is required only that pricing has to be reasonable and follow the rules of the spot-pricing (a.k.a. postal stamp tariff system) [5].

B. Challenges with present tariff structure

As illustrate above, present tariff structure consist of fixed fee and energy fee. Although the system has been in use since deregulation of the electricity markets (mid 90s), it is not an optimal system, either for customers or for DSOs.

Electricity distribution is capital intensive business, where key cost drivers are the geographical location of customers and supply points (generation and main grid connections), and their energy and power demand. Major cost elements are capital, operational, and maintenance costs of the distribution network, while the costs of losses and transmission network fees are typically in a minor role in respect of total costs [6]. Hence, costs of the DSOs are mainly fixed in the short term, and in the long-term, they are mostly driven by power demand. Amount of the delivered energy, again, has only small impact on the costs. Therefore, the present energy based pricing is not cost-reflective from the DSO viewpoint.

From the customer viewpoint, the key weakness of the present tariff structure is that customers cannot affect the fixed fee component. Moreover, the tariff structure does not provide incentives for the customers to decrease peak power, which could decrease the costs and hence prices of the electricity distribution in the long run.

III. PROPOSED NOVEL TARIFF STRUCTURES

Solution for discovered drawbacks of present tariff structure is to develop distribution pricing towards capacity (or power) oriented one, which would provide customers with incentives for smoothing their load curve with demand response and other measures. For this purpose, novel tariff systems can be used. In this paper, we introduce two alternative power based tariff structures and we compare their properties and impacts with those of the present energy oriented tariff.

A. Power Limit Tariff

The basic idea in the power limit tariff, which is also called as power-band tariff, is that customer subscribes certain network capacity (kW) from the DSO, and commits not to exceed this limit. However, this is a soft limit, which can be exceed, but there is predefined procedure for exceeding the limit. This procedure could be, for instance, changing the power limit of the customer according to measured peak power, or some kind of a penalty fee for using power above the limit. Moreover, power limit is stepwise with predefined steps, that is power limit can be for instance with 5 kW steps (5 kW, 10 kW, 15 kW and so on) or with 3 kW steps (3 kW, 6 kW, 9 kW, 12 kW, and so on). Furthermore, the power limit can be set to be in effect for one year, one month, or one season at a time. This tariff structure is illustrated in more detail for instance in [1] and [6]. In the analyses provided in this paper, both monthly and yearly limits are considered, and it is assumed that there are no other components but the power fee in the distribution tariff.

B. Power Tariff

In power tariff, pricing is mainly based on measured peak-power of the customer (€/kW), but there is also a fixed standing charge (€/month) and an energy-based pricing component (c/kWh). Key difference between power limit tariff and power tariff is that, in the first one, the pricing is based on the pre-ordered power capacity with stepwise limits, while in latter one, pricing is based on measured power, without pre-defined steps. Furthermore, latter one has three price components (a standing fee, a power fee, and an energy fee), while power limit tariff has only one component. In practice, billing can be based, for instance, on yearly or monthly peak powers, or average of the highest powers. This tariff structure is illustrated with a case study for instance in [8]. Additionally, one variation of this tariff can include a predefined power threshold (e.g. 5 kW). In this case, only customers, whose peak power is higher than specified threshold value would have to pay a separate power charge.

IV. IMPACTS OF DIFFERENT TARIFF STRUCUTRES

We evaluate the impacts of the tariffs for different stakeholders, namely customer, DSO, electricity retailer, and society. Furthermore, in these analyses, we also consider how the incentives for demand response, micro generation, and energy storages will evolve, if the tariff structure is changed. As an outcome, we provide comparisons of the strengths and weaknesses of the different tariff options.

The analyses are outcomes from the researchers' workshops, and they have been evaluated by the representatives of DSOs, TSO, and retailers in the project steering group. Furthermore, some of these impacts have been discussed in stakeholders' workshop, with representatives of customers, energy service providers, DSOs, and TSO.

A. Criteria for impact assesment

We are assessing the impacts of the tariffs from the viewpoints of different stakeholders, from the viewpoint of criteria illustrated in Table I.

TABLE I. CRITERIA FOR ASSESMENT OF TARIFFS

Criteria	Definition
Additivity	Distribution tariff is not in conflict with present and foreseeable pricing structure of the electricity suppliers and other operators.
Cost-reflectivity	Tariff reflects the costs of the distribution system, within the limits of the spot pricing. Tariff ensures the viability of the electricity distribution business.
Feasibility of practical implementation	Practical implementation of the tariff is cost efficient and realizable with present and foreseeable technology (i.e. metering and ICT systems). In addition, customer communication issues are not a barrier for implementation.
Incentives for efficient use of electricity	Distribution tariff, together with electricity supply price and taxes, provides customers with incentives for resource efficient use of electricity. Customers have genuine possibilities to affect their distribution bill through their own actions.
Intelligibility	Customer understands how the total price of the electricity distribution is formed, and how he/she can affect the total fee.
Neutrality for third party	Tariff does not constrain the operation and business of third parties (e.g. in the case of the demand response services), whenever such operation follows the technical limits of the distribution system.

B. Customer viewpoint

For a customer, it is essential that he/she can understand how the total distribution bill is formed, and by which action the total fee can be decreased. Obviously, it is also important that the customer has genuine possibilities to affect the costs. Customer viewpoints to present tariff structure are illustrated in Table II.

TABLE II. PRESENT TARIFF STUCTURE FROM CUSTOMER VIEWPOINT

Energy based (present) tariff structure	
Strengths	***Weaknesses***
• Tariff structure has been in use for decades, and is similar to pricing in electricity sales • Customer has possibilities to affect the energy based part of the electricity bill, by energy saving, energy efficiency, and own generation	• Customer cannot affect fixed standing charge, and on the other hand, this fixed charge does not provide any inventives for changing energy or power usage. • Cross-subsidies between small and large energy users, as well as consumers and prosumers, may lead to free-ride effects

Key strengths for a customer are familiarity of the tariff structure, and energy based component, in which customer has possibilities to affect. However, key weakness is a fixed component, as customers do not have possibilities to have an impact on that part of the pricing. Situation changes, if power based tariffs are introduced, as can be seen from Tables III and IV, where the impacts of power limit tariff and power tariff, respectively, from customer viewpoint are illustrated.

TABLE III. POWER LIMIT TARIFF FROM CUSTOMER VIEWPOINT

Power limit tariff	
Strengths	***Weaknesses***
• Simple tariff structure, only one price component • Customer can affect whole network bill, by decreasing power demand (e.g. by DR and/or energy storages). • Incentives for such behavioural changes in energy usage, which lead to lower costs of the power system, and thus decrease the price for a customer in long-term • No energy fee in distribution tariff, which means that customer may get more benefits from real-time supply pricing (price of energy will be low also for customers during low price hours in wholesale markets)	• Distribution pricing for whole year may be based on one peak hour of the year. Such a case would be somewhat unreasonable for a customer, and decrease the motivation to cut the loads during other times of year • Term "power" may not be familiar for average end-user. • Automation or own activity of a customer is needed for controlling the peak power • Sparse steps in power limit (e.g. 5 or 3 kW) may decrease the possibilities to get savings in distribution bill by optimized power consumption. Distribution fee cannot be decreased anymore, if customer's power limit is at the lowest step. • May decrease the profitability of the PV, if own generation do not have impacts on peak powers (typical in winter-peaking systems). This is challenge especially, if customers have invested in own generation by assuming present tariff structure in profitability calculations.

TABLE IV. POWER TARIFF FROM CUSTOMER VIEWPOINT

Power tariff	
Strengths	***Weaknesses***
• Customers can affect both power and energy fee by their own actions • Incentives for such behavioural changes in energy usage, which lead to lower costs of the power system, and thus decrease the price for a customer in long-term. • Smaller cross-subsidies between customers than in present tariff structure	• A large portion of the annual distribution fee may be based only one peak hour of the year. • Term "power" may not be familiar for average end-user. • Automation or own activity of a customer is needed for controlling the peak power • More complex than present tariff structure, as it has three price components (a power charge, an energy charge, and a standing charge) • May decrease the profitability of the PV based microgeneration (smaller energy based charge than in present tariff), if own generation do not have impacts on peak powers.

The key strengths of both power oriented tariffs from customer viewpoint are the improved incentives for demand side management actions. Furthermore, possibilities to have an impact on own distribution bill may increase, especially if the proportion of fixed standing fee is high in present tariff.

However, in power limit tariff, these possibilities are limited by predefined power limit steps.

One of the key weaknesses is that tariff structure may decrease the profitability of the microgeneration. This is a negative issue especially if the customer has invested in PV by assuming that the present tariff structure remains. In such a case, a profitable investment may turn to be unprofitable as a consequence of the changes in distribution pricing. Other weaknesses are mostly related to intelligibility, as novel tariff structure might be difficult to understand.

C. Electricity supplier viewpoint

For an electricity supplier, the impacts of distribution pricing are mostly indirect, especially since customers in Finland get separate bills from the supplier and the DSO. For supplier, it is essential that the distribution tariff does not limit the suppliers' business opportunities, in present or future services, that is energy sales and flexibility related services (e.g. aggregation). From this viewpoint, the power limit tariff may limit the possibilities to increase energy usage (e.g. charging energy storages) during down-regulation hours. However, the same issue can, in some cases, turn to be opportunity, as optimizing the power limit by demand response services may turn to be a new business opportunity for supplier.

Furthermore, changes in distribution pricing may decrease the accuracy of the load forecasting in the transition phase. This has a negative impact on the balance management of the suppliers. However, it can be assumed that suppliers quickly learn the impacts of novel tariff structure on load behavior, and eventually, power limit tariff may even increase the predictability of the load behavior.

D. DSO viewpoint

From DSO perspective, tariffs should enable reasonable and predictable revenue that ensures viability of distribution business. Furthermore, it should provide customers with incentives to optimize their energy usage so that capacity utilization rate in distribution network is optimized.

The key strengths and weaknesses of the present tariff structure, from viewpoint of the DSO, are presented in Table V.

TABLE V. PRESENT TARIFF STUCTURE FROM DSO VIEWPOINT

Energy based (present) tariff structure	
Strengths	***Weaknesses***
• Tariff structure has been in use for decades, hence, there are long experiences on impacts of tariff structure • Metering and ICT systems are designed for present tariff • If fixed standing fee is dependent on the size of the main fuse, it have a slight impact on the customers' peak powers, hence incentivizing capacity efficiency	• There are no incentives for customers to decrease, or avoid the increase of their peak powers. This may lead to increased peak powers in network, and thus, reinforcement needs. • Changes in energy consumption (e.g. due to weather variation or energy efficiency) cause uncertainty to revenues of DSOs • Customers' own microgeneration decrease the revenues of DSOs, while costs remain the same

Challenges in energy based pricing are drivers for increasing the share of the fixed charges in present tariff structure. However, this kind of development is harmful for incentive provision properties of the pricing. This is one reason for introduction of novel tariff structures. In Tables VI and VII, the key impacts of the power limit tariff and the power tariff from viewpoint of a DSO, are illustrated.

TABLE VI. POWER LIMIT TARIFF FROM DSO VIEWPOINT

Power limit tariff	
Strengths	***Weaknesses***
• Revenues are stable and well-predictable • Improved cost-reflectivity, compared to present tariff • Pricing provides customers with incentives to decrease their peak loads. This may lead to lower peak loads in network, and decreased costs of DSOs • Technical properties of the present AMR meters are adequate for practical implementation of tariff, as they measure and register hourly average powers. However, meters do not provide real-time information of the power or notice about exceeding the power limit.	• When the power demand of a customer is below the power limit, there are not any incentives for optimizing the power demand • As the basis of the pricing changes from enegy to power limit, it might lead to increasing challenges in communications towards customers • At present, larger customers typically have a power tariff. It might be confusing for customers, if there are different types of power based tariffs • May require some modifications to the ICT systems

TABLE VII. POWER TARIFF FROM DSO VIEWPOINT

Power tariff	
Strengths	***Weaknesses***
• More stable and predictable revenues compared to present tariff structure, but variation may be higher than in the power limit tariff • Improved cost-reflectivity, compared to present tariff • Pricing provides customers with incentives to decrease their peak loads. • This tariff structure is at the moment in use for larger customers, hence, there are already experiences on implementation of such a tariff • Change from energy based tariff to power tariff can be done by increasing the share of power based price component gradually • Technical properties of present AMR meters are adequate for practical implementation of tariff. However, metering equipment do not provide real-time information of the power.	• Introducing new pricing component (i.e. power price) might lead to increasing challenges in communication towards customers • May require some modifications to ICT systems

From DSO viewpoint, better cost-reflectivity, improved predictability of revenues, and stronger incentives for customers for peak-cutting are key strengths of both power oriented tariffs. Key weaknesses, again, are especially related to customer communication. When comparing different power oriented tariffs, it seems that power tariff has more strengths, as it is already in use for larger customers, and it might be easier to shift from present tariff system to power tariff.

E. Society viewpoint

From society viewpoint, it is important that distribution pricing, together with supplier pricing and taxes, promote resource efficient and renewable energy system. Hence, distribution pricing should provide customers with incentives to change their energy usage, so that resource efficiency is improved, and tariffs should not be a barrier for renewable microgeneration. Viewpoints of the society to present tariff structure are illustrated in Table VIII.

TABLE VIII. PRESENT TARIFF STUCTURE FROM SOCIETY VIEWPOINT

Energy based (present) tariff structure	
Strengths	***Weaknesses***
• Energy based pricing provides customers with incentives to decrease their energy consumption, by energy savings, energy efficiency, and own generation • If the fixed standing fee is dependent on the size of the main fuse, it have a slight impact on the customers' peak powers, hence incentivizing power efficiency	• Weak incentives for resource efficiency, as customers do not gain compensation for decreasing their peak powers • Cross-subsidies between small and large energy users, as well as consumers and prosumers, may lead to free-ride effects and inequality of customers • No incentives for developing and implementing novel DSM solutions.

Based on aforementioned properties, it seems that present tariff system provide incentives for energy efficiency, energy savings, and microgeneration. However, it lacks incentives from the viewpoint of resource efficiency, that is, it does not encourage to demand response and other forms of flexibility. The key properties of studied power oriented tariffs from society's viewpoint are presented in Tables IX and X.

TABLE IX. POWER LIMIT TARIFF FROM SOCIETY VIEWPOINT

Power limit tariff	
Strengths	***Weaknesses***
• There are incentives to decrease peak powers. This may lead to improved resource efficiency and decreased costs of the power system. • Incentives to develop new DSM solutions may provide new business opportunities for industry (e.g. for manufacturers and service providers). Possibilities to have home market references for export markets. • No energy fee in distribution tariff means that price of energy will be low also for end-customers during low price hours in wholesale markets. Hence, customers may gain higher benefits from low-cost electricity.	• Decreased profitability of PV based microgeneration. This is especially problematic, if investments for own generation have been done by assuming present tariff structure in profitability calculations. • Power limit may limit the flexibility potential of customers, especially during down-regulation hours.

TABLE X. POWER TARIFF FROM SOCIETY VIEWPOINT

Power tariff	
Strengths	***Weaknesses***
• Smaller cross-subsidies between customers than in present tariff structure • There are incentives to decrease peak powers, for instance by demand response and energy storages. This may lead to improved resource efficiency, and decreased costs of the power system • Incentives to develop new DSM solutions may provide new business opportunities for industry (e.g. for manufacturers and service providers). Possibilities to have home market references for export markets. • Change from present tariff structure can be done smoothly by increasing the share of the power based price component. This may improve the acceptability of the tariff	• Decreased profitability of PV based microgeneration (smaller energy based charge than in present tariff), if own generation do not have impacts on peak powers.

Both analyzed power oriented tariffs provide incentives for resource efficiency, which is their key strength from society viewpoint. Furthermore, they both include incentives for novel demand side management solutions, which may provide new business opportunities, and possibilities to have home market references of such solutions as references for export markets. On the other hand, in both options, incentives for customers' own generation decrease, which is weakness from sustainability viewpoint.

The impact of the power oriented, especially power limit tariff, on the flexibility potential is interesting question. From one perspective, such a tariff structure decreases the flexibility potential, especially in the situations, where power demand should be increased (e.g. by charging energy storages). However, if there is not an energy fee in distribution pricing, and a customer have a real-time pricing contract (based e.g. on day-ahead market price), price variation in wholesale markets is reflected to customers more directly than with present price system. In other words, in such case electricity is cheaper for a customer during low-price hours, since customer do not have to pay energy based fee for electricity distribution. This may provide incentives for finding novel ideas to benefit from low-cost electricity from wind and solar.

V. CONCULSIONS AND DISCUSSION

In tariff design, it is important to analyze the impacts of the tariff changes from the viewpoint of all the relevant stakeholders, that is customers, DSOs, electricity retailer, and society. Moreover, it is also highly relevant to consider the impacts of tariffs for different energy and flexibility resources; microgeneration, demand response, energy storages, energy saving, and energy efficiency. However, it should be kept in mind that besides DSO tariffs, customer pays also energy supply prices, and taxes. Hence, the incentives for end users are formed as a sum of all these prices and costs. Moreover, there might even be contradiction between the steering effects of these different price components. Eventually, to ensure the realization of the price incentives, it is essential that customers understand how the electricity bill is formed, and how customer can affect its magnitude. Furthermore, when considering the impacts of the power based pricing, it should be noticed that decrease in peak-powers can be achieved particularly by appropriate planning of the electric installations, implementation of energy management systems, and by optimal (i.e. resource efficient) dimensioning of the devices. All these issues typically take a place during the constructing or renovation of the buildings, and hence, the impacts of the novel pricing structure can be seen mainly in the long run.

Based on the analyzed strengths and weaknesses of different tariff systems, it seems justified to include power based price component in the distribution tariff. Such tariffs provide incentives to decrease the peak powers, which may improve resource efficiency in energy end use and, thus, decrease the costs of the power system in long run. Furthermore, changing from energy oriented to capacity or power oriented pricing in electricity distribution would promote the smart grid concept, where electricity distribution system can be seen as a multi-directional platform for distributed energy resources and electricity markets.

Generally, the impacts of both analyzed power based tariffs, that is power tariff and power limit tariff, seem to be quite similar. However, it seems that power tariff is a bit stronger candidate. Nevertheless, it is essential to put efforts in careful planning of practical implementation of pricing, as the benefits of power-oriented pricing, illustrated here, can be achieved only by well-designed tariff system.

The key disadvantage in change from energy oriented to power oriented pricing is decreased profitability of micro-generation. This issue realizes especially in winter-peaking system, where PV generation decreases the amount of transmitted energy, but do not have impacts on the peak powers. From DSO viewpoint, change towards more cost-reflective pricing would ensure that such changes, which do not decrease the costs, would not either decrease the revenues. However, this issue might become a problem from customers' perspective. Customers may have done investments in own generation by assuming the benefits from present energy based distribution pricing. If there is structural changes in pricing, it might lead to decreased profitability of such investments, and longer pay-back period. Moreover, from society viewpoint, there should be incentives for emission free renewable power generation, and PV is key technology in this field. However, key question here is whether such incentives should be provided via DSO pricing, and if this justifies non-cost-reflective pricing.

A. Future Research Needs

When striving for improved sustainability of energy system and increased resource efficiency, one of the key challenges is how to encourage customers to change their energy usage (for instance, by investing to energy management automation), so that resource efficiency and sustainability of system is increased. Typically this means that energy usage should be more flexible. In many cases, motivation for behavioral changes is provided by price incentives, which have been studied in this paper. However, there are some significant challenges in pricing development, which call for multi-disciplinary research in future:

Developing the pricing of electricity, so that customers can save in their energy costs by changing their behavior, would mean that prices for those customers who cannot or would not change their behavior, will increase. However, there are customers, who have difficulties to understand the novel pricing structures, or who cannot afford to invest home automation. Hence, such development in pricing of electricity may cause energy poverty, if this issue is not carefully studied and taken into account when planning such incentive mechanisms.

Another challenge is resistance of customers against price changes, even if price levels would not change, but only the allocation of the costs between different types of energy users (e.g. flexible and non-flexible users). This kind of development would mean that prices are more cost-reflective, there is less cross-subsidizing between customers, and thus distribution of the costs among customers would be more equitable. In long-term, such cost causation based pricing would lead to decreased costs of the power system, and hence, it would decrease also costs paid by customers. The problem here, which calls for research efforts in future, is how to motivate customers to change their behavior in short-term, so that their benefits are maximized in long-term.

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