Graphical User Interface of an Aggregation System to control a Multitude of Distributed Generation during Power System Restoration

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***Abstract*—A part of a distribution management system (DMS) is presented on a conceptual level, focusing on the graphical user interface (GUI) to operate an aggregation system in an active distribution network. Power plant functionalities with numerous of small distributed generation (DG) shall be provided to the network operator in order to assist during system restoration. Two main challenges arise. On the one hand, large amounts of available information from DG must be condensed to be handleable by a human operator. On the other hand, an interface should be designed to provide effective control to the combined capabilities of DG. Literature review, as well as expert workshops involving the personnel of network operator's control center, identified several key features for the planning and execution of build-together and top-down restoration approaches, exploiting the potential of task-specific forecasts in an improved manner by e.g. enabling an easy aggregation and visualization of these. Especially the identification of geograhical areas with reliable and flexible residual loads are of interest to a distribution system operator (DSO) as well as the actual control over DG to influence the residual load and to provide frequency maintaining ancillary services. The proposed GUI is specifically designed to be a crucial part of a future DMS used by DSOs in the case of critical grid situations or power system restoration with high shares of DG.**

***Keywords*—active distribution network, distributed generation, distribution management system, graphical user interface, power system restoration, user experience design**

I. Introduction

As the energy transition in Germany progresses and the planned phase-out of nuclear and coal-fired power plants goes on, the generation structure changes from a few large power plants to a high number of smaller and very small generators (typically known as distributed generation, DG) [1]. Due to the large number of PV systems on private houses and small commercial buildings, more than 1.7 million systems with a total capacity of around 26 GW were connected to the German low voltage (LV) grid by 2018 [1], [2]. This trend is expected to continue in the coming years. At the same time, Germany has decided to phase out nuclear power by 2022 and coal-fired power (between 2035 and 2038). Large nuclear and coal-fired power plants with an installed capacity of around 53 GW were connected in 2019 [3]. But in 2035 there might be no or only a few coal-fired power plants on the grid (between 0 and 7,8 GW are expected) [3]. This is accompanied by a decline in directly controllable power generation and the availability of ancillary services. The grid and system operator (SO) is thus deprived of options for action to stabilize the grid and system status. This is already a challenge during normal operating state and is even more so in critical network situations and during power system restoration (PSR), when the power plants are directly assigned from the network operator's control centre to avert danger or to restore the system [1], [4]–[7].

With DG there is an additional challenge as, in contrast to conventional power plants, the units do not have their own control room but are operated unmanned. In order to counter this trend, systems must be developed with which a large number of DGs can be combined in a suitable way, in order to provide power plant characteristics to the network and SOs (as stated e.g. in [6]–[12]). The selection must have the necessary flexibility according to the grid conditions and should be adaptable during operation if necessary. In order to provide information about the available feed-in capacity, forecasts have to be implemented.

With the beginning of the German roll-out of advanced metering (AM) (”intelligente Messsysteme”) since February 2020, sometimes named “smart meters” in Germany, the opportunity arises to establish bidirectional communication links to high numbers of single units which enables a coordinated operation of numerous of small DG [13], [14]. On top of that, with the 450 MHz frequency band, available to critical infrastructure, a blackstart capable information communication technology (ICT) infrastructure could be created, if the German government allocates the frequency band from 2021 onwards[1] [15], [16]. All these activities are or can be a part of the creation of an active distribution grid [17].

Within the research project “SysAnDUk“ (“Ancillary services provided by distributed generators to support network operators in critical situations and during system restora-

[1]The governmental discision between the needs of the criticial infrastructure, preferred by the Federal Network Agency, and the public authorities and defence and security organisations remains open with the publication of this paper. [15]

tion"), amongst others an aggregation system shall be developed to provide power plant characteristics with numerous numbers of small DG in the lower network levels [1].

As the first step of the aggregation system's development, the conceptual basis should be addressed. Part of this process is this paper focusing on the graphical user interface (GUI). Details about the design methodology, its general scope and relevant assumptions can be found in Section II. Afterwards, in Section III, the proposed GUI and its underlying features will be presented.

II. Methodology

The theortical background of the design process is known as user experience (UX) design and shortly introduced in Section II-A. [18]. One key component is the availability of human experience. For the purpose of power system restoration it will be the one of control room operators. As the main focus, the distribution grid, personnel from the distribution system operator (DSO) Westnetz GmbH could be acquired for three workshops to gather valuable experience as well as receiving feedback from the operators' perspective.

Scope of the UX-design is mainly the use case of a classical top-down PSR [19]. Hereby the role of the DSO is primarily the provision of coordinated active power exchanges (load and / or generation) to his upstream transmission system operator(s) (TSO(s)) within a defined band [8], [10]. This exchange band is provided by the TSO as the coordinator for the PSR process [4]. Further details about the UX design's scope can be found in Section II-B.

A. User Experience Design

The development of the user interface is guided by the simple conceptual model of user experience design as introduced e.g. in [18] (visualized in Fig. 1):

- Starting with the "Why": Identify the reasons, the feelings and the meanings of an activity based on human experience.
- Followed by the "What": Determine specific functionalities that serve the reasons of the "Why" question.
- Finally, ending with the "How": This is the way in which a functionality is realized in a product, or in this instance, a graphical user interface of an aggregation system.

To visualize the GUI the prototyping method of static wireframes will be applied, which represent a first version of the possible layout of a future web-based GUI implementation [20]. For creating these wireframes the open-source software tool "Pencil" by Evolution Solutions is used (version: 3.0.4) [21]. In the wireframes some icons are sourced from the "Clarity Design System" by VMware, Inc. as well as their GUI guidelines will be taken into consideration [22].

B. General Scope of the UX-Design

In contrast to a conventional control system of a DSO it is assumed that there will be an additional system that allows specific control over DG located in the medium and low voltage level (as shown in Fig. 2). As a result it will not be like a single fully integrated distribution management system (DMS) as described e.g. in [23]. Nevertheless, the system will still be available at a central control center of a DSO with the three general functionalities of a DMS [23]:

- "System Monitoring": Provides an overview of the current and future state of the the system.
- "Control actions": Allow e.g. remote control actions over assets in the supervised distribution grid.
- "Decision support": Provide the operator with a selection of possible solutions to reach higher efficiency and reliability.

With regard to the aggregation system there are two main assumptions that should be noticed for the design process. First, the general aggregation level are post code areas, a simplification in the project "SysAnDUk" to avoid the use of real grid data. Consequently, real grid structures and their limits of responsibility are neglected.

The second is the availability of bidirectional communication links, e.g. via mobile communication, for the DSO. Currently, DG is usually connected through unidirectional systems like ripple control or radio control systems on the medium/low voltage (MV / LV) level [24]. However, this will change with the upcoming smart meter rollout for renewable generators, regulated by the German Renewable Energies Act ("Erneuerbare Energien Gesetz"), currently in amendment [25]–[27]. Nevertheless, this shift will take time due to grandfathering of existing metering/control technology and the rollout process itself [24], [28].

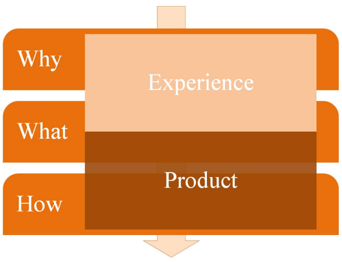

Fig. 1. Three level approach to get from human experience to a product by answering the "Why", the "What" and the "How" (sourced from figure 7 in [18]).

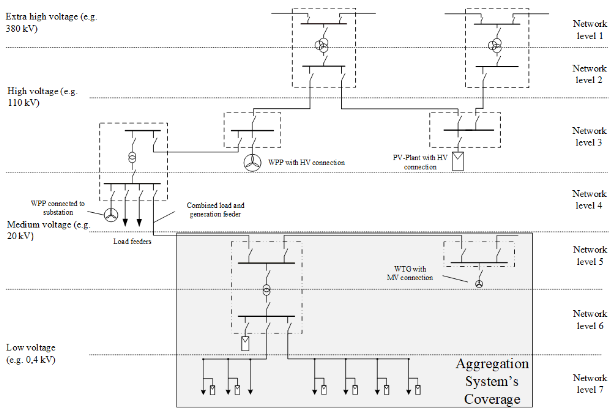

Fig. 2. The proposed aggregation system's concept potentially covers the medium and low voltage grid. However, the detailed grid structure is neglected because the assumed aggregation level are post code areas.

To take this development into account three categories of DG will be introduced (compare Fig. 3.):

- Category A: Under this category falls all DG without a bidirectional communication link, e.g. if ripple control is used.
- Category B: If a generator has in principle a bidirectional remote control, however, this is not available during a power outage, e.g. due a missing uninterruptible power supply (UPS) [16].
- Category C: In the situation that the bidirectional link is available and a DG unit can be remotely controlled under the circumstances of a power outage, corresponding DG falls under the category C.

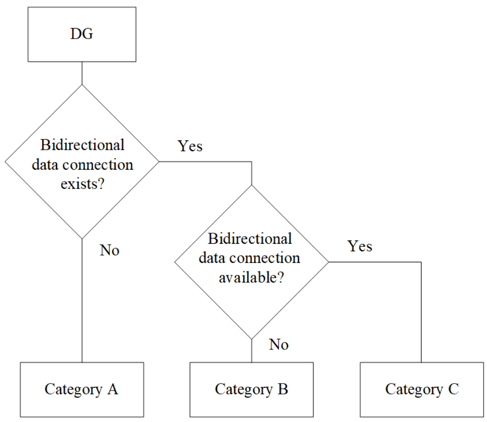

Fig. 3. Categorization of distributed generation (DG) in dependance to the existence and availability of bidirectional communciation links.

III. GUI CONCEPT

With the methodology of UX design as a guideline and the scope on the medium and low voltage grid different features have been identified to be considered in the proposed GUI concept. The presentation of this concept is separated by the two main phases of PSR: First, the planning phase in Section III-B, and, second, the execution phase in Section III-C. The background of these phases is introduced in Section III-A in combination with the identification of relevant PSR phases for the analyzed aggregation system.

A. *Identification of relevant PSR Phases*

In reference [6] three phases of PSR have been introduced which will be further extended as follows: System restoration can generally devided into the "planning phase" and the "execution phase" (see Fig. 4.). Within the planning phase, the network operators collect information from different partners involved to get an overview about the situation. Classically, the DSO is responsible for providing loads in order to stabilize the system and to ensure required loading of power plants during system restoration phase. DG will have a significant impact onto the system when the appropriate parts of the grid are reconnected, so information about status and expected behavior of DG is needed in the planning phase. A restoration strategy is developed upon the collected information. This strategy has permanently to be checked and it needs to be adjusted if necessary.

In the first three stages of the execution phase, the grid will be prepared. Then black start units will be started to

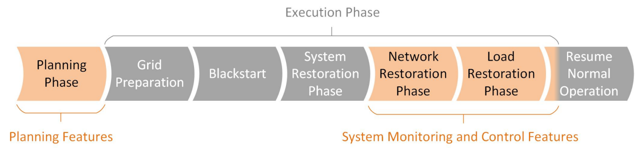

Fig. 4. Phases of a present power system restoration approach with highlighted phases (light orange) where the proposed aggregation system can assist with different functionalities (extended figure 1 in [6]).

energize the grid and to provide start-up power for larger power plants (present situation).

When most parts of the transmission system are rebuilt, the bulk restoration of the distribution grids can start in dependency of system stability and available power generation. In this phase many DG in the lower network levels will be energized. Uncontrolled reconnection, active power increase of high numbers of DG and fluctuating active power feed-in can lead to a collabse of the system again. The aggregation system shall support the process during the network and load restoration. By providing information about and control features for DG, reconnection can be optimized and DG can be applied in a structural way.

B. *Planning Phase*

During the planning phase of a PSR SOs must collect relevant data in a short period. One important aspect in the context of DG is the identification of grid areas with expected high shares of generation. In a traditional PSR these parts would be skipped in the early phase of network restoration phase and, if possible, their reconnection postponed until the middle or end of the load restoration phase when the grid allows higher fluctuations [10]. With increasing shares of DG this strategy will be more complicated until it may not be possible anymore.

1) Relevant Active Power Forecasts for PSR with controllable DG: As an alternative areas with high shares of DG, equipped with remote control (category B & C), can be the new priority for faster resynchronization [6]. In a best-case scenario, these assets are part of category C. Nevertheless, this information is only valid for the current point in time. A loss of communication in the next hours is still possible e.g. triggered by an empty UPS at the remote control communication unit of a distributed generator.

For an operator is the active power forecast of this group of great importance due to its higher certainty of availability in the restoration process. Therefore, it should be clearly distinct from the other DG to allow a prediction of this amout of "secured" generation (densely dashdotted line in Fig. 5).

Besides this socket of category C units, the overall DG with remote control is relevant as well. When an area is reenergized communication links will come back, even so it may take days in some incidents when historic blackout events are factored in [29]. At this point the proposed new 450 MHz ICT infrastructure with a planned 72 h coverage could become very valuable [16]. To evaluate the potential of controllable assets an additional forecast for group B & C is necessary (dashdotdotted line in Fig. 5).

At last, the total feed-in of DG is of importance to a grid operator (solid line in Fig. 5). Based on this information the scale of a possible impact is more plannable and the lack of non-bidirectional/uncontrollable units (category A) is estimable. To form an opinion about the uncertainity in all these different time series as an operator, multiple point forecasts should be provided instead of only the expected value one (with different safety levels in a 15 min resolution). Besides this aspect, in the light of more widespread remote controllability of specific LV grids in the future [30], a separation of forecasts between MV and LV for a post code area is suggested.

If a region in a power network will be chosen, another aspect can influence the dicision. For DG a special behavior must be taken into account in comparison to large power plants [10]. These assets automatically reconnect to the grid if the grid conditions are suitable. As soon as the effective grid regulation the ramping behavior of DG can vary significantly: Here are two typical examples for the German LV and MV grid [10], [31], [32]:

- Unlimited ramping: The maximum power point of the generator will be reached in a few minutes after reenergizing without any limitations in ramping.
- Limited ramping: After synchronization the unit only increases its power output per minute by 10 % of the installed nominal power.

For a grid operator grid areas with high shares of DG with unlimited ramping might be avoided in the earlier phases of restoration if this information is accessable. Reason behind such an approach is the reduction of stress to the system due to less potential frequency and voltage increases. If a grid area additionally consists of consumers, cold load pickup, a higher demand of thermostatically controlled loads after reenergizing [33], can act as a counterpart to this increase [6]. For the specific case of only DG with combined ramping characteristics, limited and unlimited, the resulting forecasted DG output can be seen in Fig. 5 (dashed line).

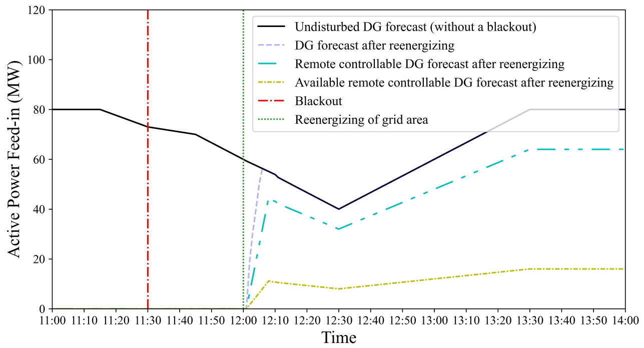

Fig. 5. Overview of the most important active power forecasts of DG in PSR (example: expected value) – exemplary influence of ramping behaviour of DG after the assumed re-energization at 12:00 (further assumptions: 10 % of the DG power forecast is provided by units without ramping limits and 90 % with a 10 % per minute gradient; remote controlled DG (80 % of total 100 MW DG including 20 % of this group with available remote control): 100 % limited ramping; simplification: all DG has the same share of the total feed-in; one minute unitl all DG starts with feed-it; unlimited DG: another minute until maximum power point production).

2) GUI Wireframe for Forecasting: The explained different kind of forecasts are planned to be embedded in the GUI as shown in Fig. 6. In this wireframe they are part of a “graphical analysis” sub navigation within a top level navigation of “time series”. A user can here choose post code areas in a tree view on the left hand side, optionally separated by LV/MV-level. If multiple areas are (partially) selected, the time series will be aggregated in one single curve for each DG forecast.

The relevant forecasts of DG should not only be available during the planning phase of PSR. For this reason exists a toogle switch that allows this special planning view (located at the sub navigation level on the right hand side). When activated, like in Fig. 6 , the starting point of reenergizing can be adapated. If this occurs, the three DG forecast curves, that incorporate ramping behavior, will be adjusted according to the circumstances at the chosen time. If this feature should be deactivated, e.g. during the execution phase, the user needs to switch off this toogle. At this point all time series are available as unchanged curves.

C. Execution Phase

1) GUI’s Monitoring and Decision Support Features: With the beginning of larger load reconnections in the PSR’s load restoration phase, e.g. requested by neighbouring TSO, the necessity for a selection of suitable grid areas occurs. In this process multiple factors can play a role in the decision. For each a suitable indicator is proposed:

- Availability of controllable DG (category C units) to be later used for e.g. frequency control: Current available controllable DG forecast / current forecasted residual load in %
- Existing controllable DG (category B & C units) to assess the extent of potential useable assets: Current existing controllable DG forecast / current forecasted residual load in %
- Availability of longer “secured” constant generation (category C units) for different time scales (e.g. 15 min / 2 h / 8 h), which is notably of interest during the beginning of load restoration when less fluctuations are preferred: Current “secured” DG forecast / current forecasted residual load in %

All these different indicators should be calculated on the post code level. When a grid operator tries to compare different areas, selected parts of the grid will be highlighted in a green to red color scheme, with greener colors meaning higher percentage values.

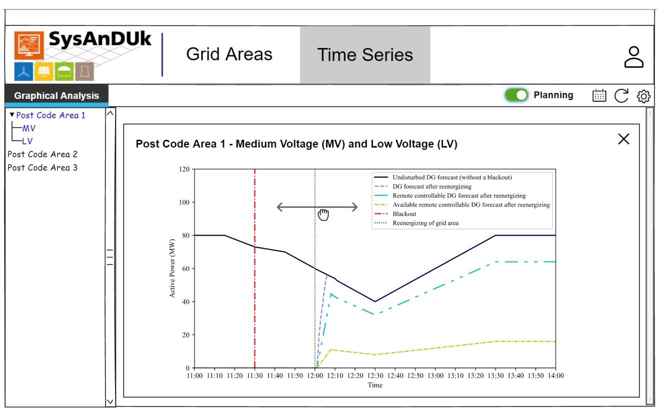

Fig. 6. Wireframe of the proposed GUI with the overview of the DG forecasts in the planning phase (including icons from [22]).

Together with such an overlay, or separated, filtering of post code areas should be possible. The background: A grid operator receives from a TSO a specific load request in MW. Now is the question which part of the grid is suitable. By providing a specific number of "x" MW residual load only post code areas are still selected that can fulfill this request in the best manner (e.g. based on "secured generation"). Please note that the details of this selection process are still open for discussion.

All these features will be included in the "grid area" navigation under "topology" as illustrated in Fig. 7. Moreover, this view allows a fast overview over important real time data. It is displayed with a mouse-over on the post code area aggregation icon. The following data points are proposed:

- Current forecast value of the residual load,
- Current residual load set-point for this area,
- Constant minimum/maximum of the residual load for a specific period (e.g. 15 min / 2 h / 8 h),
- Active power forecast of DG (categories A-C),
- Active power forecast of controllable DG (category B & C),
- The actual measured active power of controllable DG (category C units).

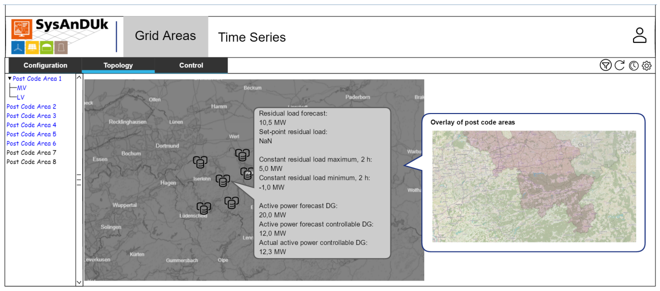

Fig. 7. Wireframe of the proposed GUI focusing on the map-based grid area view (with icons from [22] and "OpenStreetMap" data [34]).

As already introduced, the lack of detailed grid data in the assumed system, may complicate the practical handling between the existing control systems in the control center and the aggregation system. One proposal to mitigate this possible issue is the addition of transformer locations in this map.

Besides the map-based view the workshops have shown that another representation of the residual load can be of value in PSR. The requirement is connected with the possible band of an active power exchange between e.g. a DSO and TSO [10]. To estimate if the currently active grid areas allow the fulfillment of a discussed power band, it can be helpful to check the flexibility of the residual load, provided by remotely controllable DG (category C units). One possible graphical representation is shown in Fig. 8 (solid line as the historic or forecasted residual load). It would be available in the GUI under the "time series" navigation in the execution phase as selectable curves (comparable to Fig. 6).

2) GUI's control features: All the described features so far focused mainly on monitoring actions during PSR. However, DG cannot only be managed based on information, they can also assist during a restoration situation [6], [7]. With regard to active power control, two potential control functionalities could be identified to be of greater interest to an operator (in conjuction with literature like [6] or [7]):

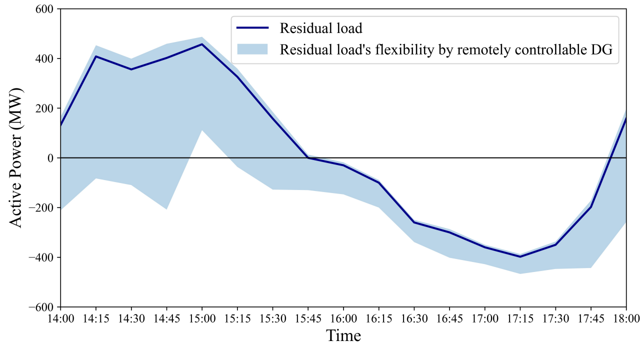

Fig. 8. Exemplary visualiszation of the residual load and its flexibility, possible by adjusting the power output of remote controlled DG (category C units).

- Setting a fixed active power for the residual load: Each new re-energizing of an area must be aligned with the currently available power reserves (e.g. provided by a neighbouring TSO). If controllable DG could support maintaining a residual load of a newly reconnected area, it could reduce impacts of unpredicted behavior in the PSR process (like outbalancing of unsuspected load behavior).
- P(f) control: A frequency-power control would be the next step. When less directly controlled assets like coal power plants exist, the need for new frequency reserve units arises. At this point, the aggregation system can control DG not only according to a fixed point, it would adjust the residual load if a frequency drop or increase occurs based on a set static (in MW/Hz).

For further improvements of the grid stability in PSR it should be possible, as an option, to limit the ramping behavior of the controlled residual load. As an operator it would then be possible to provide a ramping limitation in MW/min for each control action.

At last, another option has been discussed as well in the workshops. Besides the active control over selected grid areas, it must be assumed that it may not be possible to fulfill the residual load target value with the available DG as planned. For this case it is useful to set a upper and lower limit for each control action. If these bands are exceeded, the user should be notified.

A potential implementation into a control system is depicted in Fig. 9. Under the sub navigation "control" an operator can select controlled post code areas via the known tree view. Then the user can choose between the different control modes (static P / P(f)) with the discussed options of ramping limitations and limits. Furthermore, if a control is not necessary anymore, a reset functionality is included. One application of this feature might be the last PSR phase of resuming normal operation, when all DG control will be transferred back to the market aggregators and other market-oriented actors.

IV. CONCLUSION AND FUTURE WORK

With the increasing numbers of distributed generation as well as the phase out of nuclear and coal power plants in the

Fig. 9. Wireframe of the active control handling in the proposed GUI of an aggregation system including the monitoring elements to observe the fulfillment with residual load abbreviated as RL (with icons from [22]).

German power system new challenges arise with regard to system restoration. The proposed concept of a user interface of an aggregation system can be one crucial element to tackle these challenges by allowing system operators more insight into expected active power feed-in and capabilities of relevant DG by condensing an otherwise overwhelming flood of information. The simplified aggregation level of post code areas can be adapted in future works to specific grid structures. Moreover, the flexibility of the demand side should be included as well, especially driven by the advanced metering infrastructure development e.g. in the context of "§14a Energiewirtschaftsgesetz" (German Energy Act) [25], [26].

Altogther, the concept is still a draft that will be further sharpened in the progress of the corresponding project "SysAnDUk". In the following steps of implementation and laboratory/field tests, additional features and adaptations are to be expected, especially in connection with control features, which will be investigated in more detail in this research project. Beyond this, additional user experience should be gathered to possibly meet the needs of a broader user base.

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