Load demand management optimization for Accommodating Electric Vehicle

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ABSTRACT

As the world paces towards environmental sustainability, the rapid adoption of electric vehicles, particularly in developing countries such as India, stands as a pillar of progress but also introduces complex challenges for the power distribution grid. This paper critically examines these challenges, focusing on demand-side management (DSM) load modelling as a strategic approach to accommodate the fluctuating demands of EV charging. It investigates the utilisation of advanced optimisation algorithms that promise to enhance grid stability by efficiently managing the additional load imposed by EVs. The narrative further explores the development of smart grid technologies, essential for the seamless EV integration into the power system. The paper also discussed the indispensable role of renewable energy sources in meeting the increased electricity demands, advocating for a symbiotic relationship between green transportation and sustainable energy generation. Through a comprehensive analysis, this paper aims to provide policymakers, energy sector professionals, and researchers with insightful strategies to navigate the complexities of EV integration. It underscores the importance of innovative solutions in building a resilient, efficient, and sustainable energy ecosystem that supports India's ambitious EV adoption goals. This paper also suggests a methodology for stochastic modelling of EV charging load and its challenges related to their impact on the power distribution grid, focusing on DSM and grid integration strategies. This holistic approach addresses the immediate technical and infrastructural challenges and aligns with the long-term vision of achieving energy security and environmental sustainability.

Keywords: demand-side management (DSM), electric vehicles(EV) , FAME, CIAS based DSM

1. INTRODUCTION

The market for electric cars (EVs) has witnessed unprecedented expansion over the course of the past several years, a phenomenon that has never been witnessed before. As a consequence of advancements in technology, concerns about the environment, and governments that are supportive of the usage of electric vehicles, electric vehicles are rapidly becoming a more familiar sight on highways all over the world. This transition not only signals a considerable adjustment in the patterns of energy use and the demands that are placed on the electrical grid, but it also heralds a change in consumer preferences, which is a significant event in and of itself [1]. An increase in load demand is brought about as a consequence of the widespread use of electric vehicles (EVs), particularly during peak hours. This may lead to overloads and even blackouts as a consequence of the increased demand. It is of the utmost importance to have an understanding of how this effects the load profile of the grid and to investigate the possibilities of developing measures to offset any negative consequences that may be received as a result of this. The use of renewable energy sources, in particular solar photovoltaic systems, is contributing to the reduction of the strain that electric vehicles (EVs) are imposing on the grid [8, 9]. As a result of the fact that it is accountable for regulating the demand for power in a manner that guarantees the grid's efficiency and equilibrium, the demand side management, which is generally referred to as DSM, is an essential component of this system [7]. This is in addition to the fact that the utilisation of renewable energy sources is contributing to the reduction of the burden." As can be seen in Figure 1, the utilisation of DSM techniques is one of the elements that contributes to the flattening of the load curve. This ensures that the grid will be able to meet the additional demand that will be brought about by electric vehicles (EVs) without compromising its stability or requiring costly alterations to the infrastructure. EVs are expected to bring about this demand. There are a number of solutions that need to be implemented in order to properly control the load.

The development of novel algorithms has been the foundation of successful DSM methods, which have enabled the optimisation of energy consumption without compromising the level of comfort experienced by end-users [14–16].

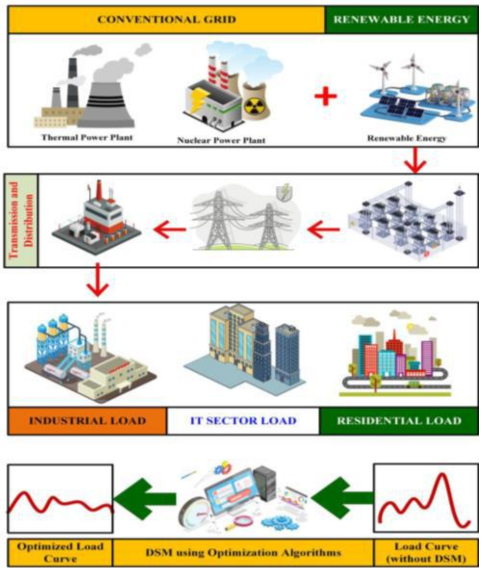

Fig 1.1: Demand side management system.

2. GOVERNMENT POLICIES PROMOTING EV GROWTH IN INDIA

The Indian government (at central and state levels) incentivises consumers and manufacturers to boost the adoption of EVs and back local EV production. The Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) scheme offers Consumer incentives and a Phased Manufacturing Plan (PMP) aim to promote EV production and assembly indigenously. $1.1 billion has been allocated by the FAME II scheme in demand-led incentives, and an additional $200 million has been allotted for charging infrastructure setup and operation. The Government also announced the Production-linked incentive (PLI) schemes to drive local cell manufacturing [5]. Furthermore, the government provides various incentives such as reduced Goods and Services Tax (GST) rates, exemptions from road tax, state-specific subsidies, direct investments in fleet electrification, and the establishment of charging infrastructure [5], [6]. To achieve this marvellous feat, the Indian government has already taken various steps towards the electrification of vehicles on Indian roads, which includes multiple programs to support the EV transition shown in Figure. 1 [7], [8], [9]. Various ministries and departments of the central and state governments also introduce many policies and initiatives to promote the sale of EVs and provide convenience in charging EVs by expanding the charging station network throughout the country. Some of the major policies adopted by the Government of India to throttle this huge target are shown in TABLE 1. Table 2 provides an overview of the varied and ambitious EV policies adopted by different states in India, highlighting their unique targets, incentives, and infrastructure plans to promote EV adoption [16], [17]. These policies reflect a concerted effort at the state level to support the central government's goal of increasing EV usage, thereby contributing to environmental sustainability and reducing carbon emissions across the country.

2.1 EV growth in recent years

These policies and initiatives have spurred notable growth in the EV market, overcoming the challenges posed by the global economic downturn caused by the Covid-19 pandemic. These well-designed policies have created an enabling environment for the adoption and expansion of EVs, establishing India as a prominent player in the sustainable transportation sector. In 2022, India witnessed a remarkable surge in EV sales, crossing one million units for the first time with a record YoY growth of 206%. EV sales in 2022 accounted for 4.7% of total automobile sales in India, amounting to 10,54,938 units. The high-speed e-2Wheelers segment captured the largest market share and grew 291%, while electric four-wheelers expanded by 178%. This significant rise in EV sales indicates a shift towards sustainable transportation in India. Additionally, the graph in Figure 2 shows the increasing trend of EVs in the Indian market over the past year (Feb 2022 to Feb 2023), indicating a steady growth rate. Notably, the Indian government has played a vital role in encouraging EV adoption by offering incentives and tax benefits to consumers and manufacturers [18]. The EV market in India has witnessed substantial growth over the years. Starting with 2,693 units sold in 2013, the market experienced fluctuations but showed remarkable growth from 2015 onwards. As a result, sales surged to 9,99,949 units in 2022, with total sales of 18,83,551 EVs in the last ten years. This data reflects the increasing acceptance and adoption of EVs in India [19]. This remarkable growth of India's EV market has substantial implications for the electrical grid. This surge in EV adoption introduces increased electrical load demands, necessitating advancements in grid management and infrastructure upgrades to accommodate the rising energy consumption. Furthermore, it emphasises the need for integrating renewable energy sources to ensure a sustainable and stable power supply for EV charging, thereby reducing the carbon footprint and enhancing energy security. This growth underscores the critical intersection between sustainable transportation and energy policy, driving innovations in smart grid technologies and DSM strategies to support the evolving energy landscape. This This paper significantly enhances the understanding of EV integration into the distribution grid in India, a developing nation, with a particular focus on demand-side management and the integration of renewable energy sources. It introduces a comprehensive methodology for modeling EV load demand and outlines strategies to boost grid stability and efficiency. The organization of the paper is structured as follows: The first section discusses the transition of India's transportation sector to EVs, highlighting supportive policies and programs from central and state governments. The second section reviews global and Indian charging technologies and standards, providing a foundational understanding of the technical aspects involved.

3. PROPOSED METHODOLOGY FOR ANALYZING ENERGY CONSUMPTION IN DSM FRAMEWORK

As part of the proposed methodology for analyzing energy consumption patterns within the Grid Network (GN) system simulation, a comprehensive evaluation of both residential and commercial sectors is conducted. The study focuses on a residential community comprising 6,000 households and an information technology enterprise employing approximately 3,000 individuals, with particular emphasis placed on neighborhood-level analysis. The primary objective of this methodology is to examine the impact of coordinated electric vehicle (EV) charging on overall grid operational performance [7] within these distinct environments.

The proposed approach accounts for the differing energy consumption characteristics inherent to residential and commercial sectors. Addressing the multidimensional challenges arising from complex electricity usage patterns requires collaborative efforts from energy analysts and policymakers to develop effective demand management strategies. Accordingly, this analysis provides an in-depth assessment of residential load profiles by examining diverse housing configurations, including single-bedroom units with one bathroom and kitchen, as well as multi-bedroom residences featuring two or three bathrooms. Each housing type is analyzed in relation to varying occupancy levels to accurately capture realistic consumption behavior across the residential landscape. Moreover, it takes into account the fact that living spaces might vary from one house to another. The patterns of electric load, which indicate a representation of energy consumption that is as diverse as the lives of the people who live there accordingly, are a reflection of the demographic diversity that exists in the area. Within these residences, a wide range of equipment, ranging from those that are essential to those that are only supplementary, are humming with activity. According to the data presented in Figure 3, the probability of each appliance being present is not the same. Despite the fact that some houses are crammed to the gills with electronic equipment, others adhere to the idea of simplicity, which has an effect on the overall load profile.

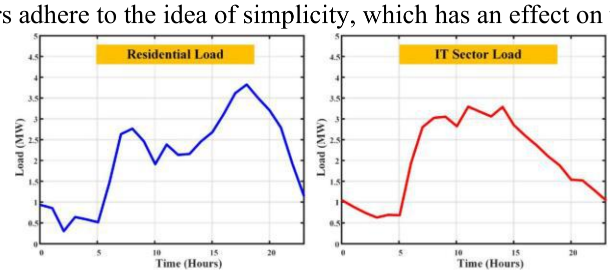

Fig 3.1. Load curves of residential and IT sector loads without DSM.

It is not always the case that the utilisation of appliances proceeds according to a predefined schedule. Randomisation is used to determine the usage times, and a certain amount of logic is applied to certain pieces of equipment, such as washing machines. It is necessary to establish a connection between the cycles of these devices and the levels of occupancy in order to provide a dynamic load profile that is not only startling but also genuine. A dynamic load profile is created as a result of this.

The installation of solar panels has become a shining example of sustainability on twenty percent of the rooftops as a direct outcome of the utilisation of energy. Due to the fact that these panels minimise the amount of electricity that is required from the grid during the hours when the sun is shining, a green glow is formed on the load profile. This is because the load profile is illuminated by the green glow. The daily departure of working inhabitants has a discernible effect on the load profile, which is left behind as a result of the impact that is left behind. Their absence during office hours is a silent indication of the ebb and flow of working life, and the shift in the demand for power is a reflection of their absence during those hours. In the energy design for the information technology sector, which is written with precise lines during the transition to the commercial sector, there is a computer for each of the 3,000 employees, servers that are buzzing at the heart of operations, and a variety of other appliances that contribute to the load. All of these components are included in the design.

It is necessary to have power for every single piece of gear, such as computers (which require 150W apiece), servers (which consume an average of 500W), lighting (20W per person), and air conditioning that is adjusted according to the size of the area (1 kW per 100 square meters). Furthermore, a symphony of additional appliances, each of which contributes its own chords to the overarching theme of energy, is also available. The load profile fluctuates in accordance with the rhythm of the day, reaching its peak during working hours when computers, lights, and air conditioners all operate together in harmony. This is when the load profile experiences its greatest movement. The load profile then progressively drops throughout the night, with less lighting and air conditioning use, but servers continue to keep a vigilant eye on things that are happening. This occurs after the previous point. An output is an estimation of the entire load, and it provides a precise perspective of the quantity of electricity that is consumed in commercial settings. The output is a pulse that quickens and slows with the operational heartbeat of an information technology company. If you are interested in learning more about the output, go here. The pulse is a pulse that is similar to the heartbeat of an organisation that deals with information technology. The load profiles of the residential sector and the information technology sector can be combined in order to give a comprehensive picture of the demand for energy. This is achievable because of the connection between the two sectors. The purposes of this picture are to highlight the varied patterns of consumption that may be observed in the homes of people who live their lives on a daily basis as well as in the centres of technological progress. It is possible to observe in Figure 4 that a simulation of the whole load profile of the demographic region has been carried out by making use of the information that was provided.

The possibility that electric vehicles (EVs) are present in a house varies with the size of the property, which can range from a small house with one bedroom to a large house with three bedrooms. An additional layer of complication is added to the overall picture of power consumption by the fact that each of these dwelling sizes has its own likelihood of holding zero, one, or even two electric vehicles. This load from electric vehicles has an impact on the normal load profile, which is a very important consideration. In addition to the fact that electric vehicles have a charge schedule that is not uniform, which results in an increase in the peak demand of the system, there are at least two other issues that need to be resolved. There is a likelihood that the load demand of the region will increase, and there is also the possibility that the region will become more dependent on the grid. As is evident from looking at Figure 5, the load distribution on the load curve has been created in such a way that it takes into consideration the load that is caused by electric vehicles.

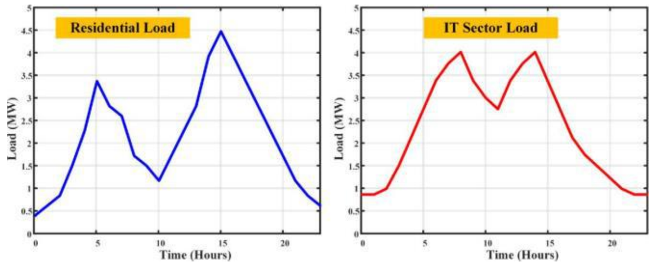

Fig 3.2. Including electric vehicle loads in the load curves of the residential and information technology sectors.

4. RESULTS AND DISCUSIONS

An in-depth and quantitative method for analysing the complex energy usage dynamics that are present in both residential and commercial settings, particularly in a typical residential neighbourhood and an information technology corporation, is provided by the equations that were established for the GN system simulation. This method is particularly efficient in analysing the dynamics of energy usage in residential neighbourhoods. All of these simulations have been painstakingly developed in order to incorporate various patterns of energy use that are the consequence of a number of significant factors. The use of a wide range of appliances, the frequency with which they are used, occupancy rates, the number of operational hours, and the incorporation of solar energy systems and electric vehicles are some of the elements that contribute to this.

The development of the DSM with the updated restrictions has been accomplished through the application of a variety of optimisation strategies. Figure 7 is a flowchart that illustrates the various optimisation algorithms that were implemented for the DSM model. Additionally, the steps that were involved in the execution of the algorithm and the pseudocode that corresponded to it were described in detail as follows:

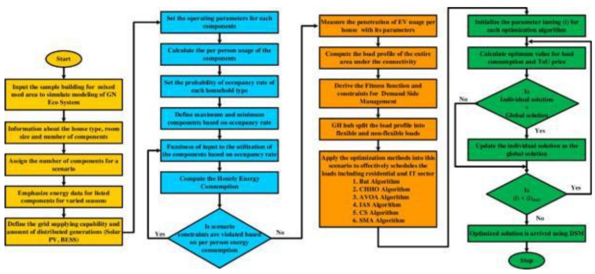

Fig 4.1. DSM optimization method implementation flowchart.

PSO algorithm results:

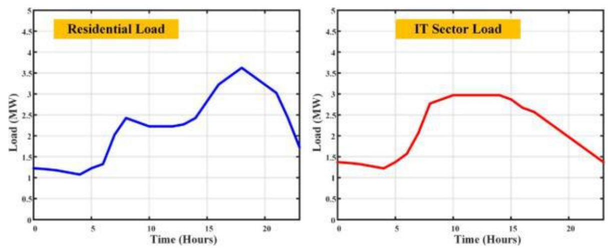

Fig 4.2. Load curves of residential and IT sector loads with CIAS based DSM.

GWO algorithm results

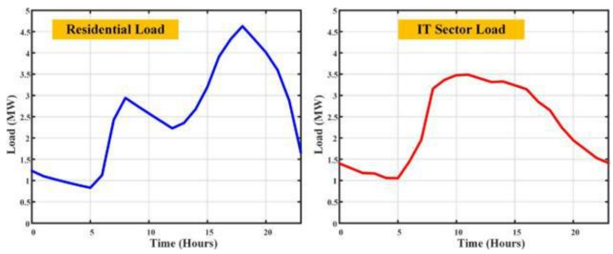

Fig 4.3. Load curves of residential and IT sector loads with CS algorithm based DSM.

Comparative analysis

The patterns of energy demand can vary dramatically between residential and information technology sectors. A framework for intelligently altering these patterns is presented by DSM. This framework ensures that energy usage is more closely aligned with sustainable practices. Significant peak load reduction has been achieved through the implementation of DSM techniques and algorithms, which has resulted in a more balanced pattern of energy usage. The data in Table 1 show that a peak load of 4.67 MW and a low load of 0.47 MW are produced by the baseline energy demand that does not include DSM. An enormous gap of 4.2 MW has been seen between the low demand and peak demand in the residential sector. Data scientists have determined that the IT industry's peak consumption is 4.23 MW, with a low demand of 0.99 MW. The disparity between the two demand levels is 3.24 MW as a result of this. There is less room for error in the home and IT sectors when using the general DSM model. The IT load falls to 3.61 MW and the residential load to 4.52 MW as a result of a reduction in peak demand.

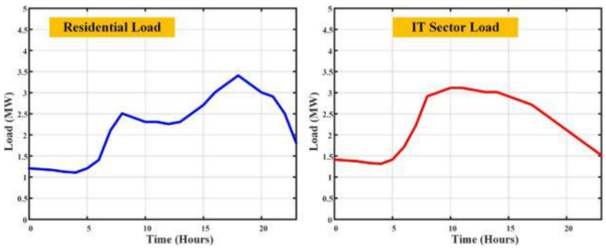

Fig 4.4. Load curves of residential and IT sector loads with SMA based DSM.

The energy consumption profiles of both industries have significantly improved since DSM was put into place. The installation of DSM has led to a decrease in peak loads and an equal increase in low loads, proving this point. This strongly suggests that, in the last several years, both sectors have significantly reduced their energy usage. Figure 14 is a graph showing the peak, lowest, and maximum loads for the residential and IT industries compared to one another. Also shown on the graph is the maximum load. As shown in Figure 15, the algorithm's effectiveness can be found by calculating the difference between the two extreme data points of demand.

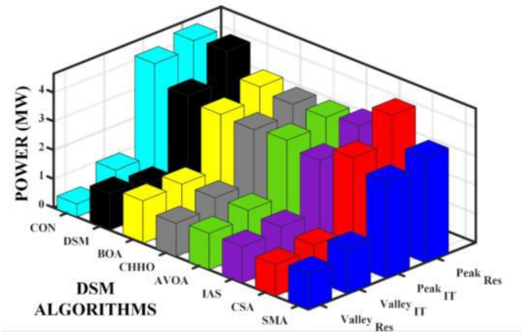

Fig 4.5. Performance comparison chart of the different DSM algorithms.

Figure 4.8 shows the results of a comparison of the calculation times of several algorithms, organised by their respective algorithms of origin. In order to run the algorithms in the same environment, a computer setup with a powerful Intel i7 13th generation 1335 processor and 16 GB of RAM was used. In terms of efficiency and output, we wanted to find out which approach worked best.

As seen in Figure 4.6, which plots fitness values versus iteration over time, the convergence curves of each approach have been displayed. You may see a graph that looks a lot like this one in the figure. It is reasonable to conclude that GWO is the best method because the ninth iteration had the least amount of convergence and the fitness value remained low at 155, which could indicate the discovery of the global minimum. The fact that one can draw this conclusion suggests that it is a reasonable conclusion to reach. It is feasible to reach this outcome with the help of this plot. Using this story as a guide, it is possible to arrive to this conclusion. Although PSO shows fast convergence, it hits a plateau somewhat early on. It could be inferred from this that failing to achieve the global minimum early in the search increases the likelihood of not finding it. On the other hand, the global minimum might not even exist. Yet another option exists here. One alternative method outperforms the others in terms of consistent convergence in output, in contrast to the algorithms. This feature proves useful while navigating a GN-based rough search space with the potential for encountering local minima. Global Work Organisation, in contrast, consistently displays a low score, suggesting that it does well initially but fails to show significant improvement over time. Two possible explanations for this are as follows: This happens, for instance, when a near-ideal solution is found early on or, conversely, when a less-than-ideal solution is found, when it becomes difficult to escape a local minimum. This occurrence could have two possible origins.

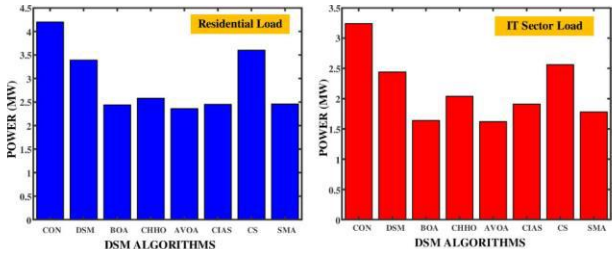

Fig 4.6. Efficiency improvement in terms of different between peak to valley.

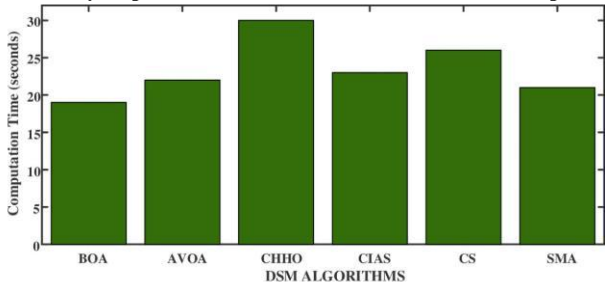

Fig 4.7. Comparison chart of computation time.

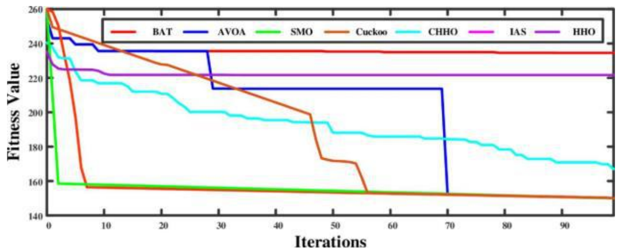

Fig 4.8. Convergence curve of each DSM algorithms.

5. CONCLUSIONS

In addition, studies have shown that electric vehicle integration into the power grid poses significant difficulties for load management, even while it helps reduce carbon emissions. Even while it helps reduce emissions, this is still the case. The created optimization-based DSM algorithm has proven to be capable of rising to these hurdles. Additionally, this algorithm shows remarkable improvement in managing the system's daily demand and load curve.

In addition to reducing peak loads, the proposed solution enables the production of a more stable and balanced grid. You can achieve your goal of being able to shift loads associated with charging electric automobiles. This claim was supported by research that compared different algorithms with those that are already in use. These findings have two important implications. Firstly, they show how advanced DSM strategies can improve grid management during the electric vehicle expansion. Secondly, they describe how utilities and energy managers can use optimization-based DSM algorithms for EV charge scheduling and other operational strategies. It is crucial to consider both of these aspects. Both of these implications are important. These two ramifications are significant in their own right. In order to highlight the respective capabilities of both of these algorithms, a comparison can be made between the remarkable efficiency in residential areas and the excellent performance of the GWO Algorithm in the field of information technology. When it comes to the coordination of workload management techniques, it is very necessary to have individualised solutions. This is due to the fact that each algorithm provides a distinct level of efficacy across a wide variety of sectors. When one investigates the inner workings of DSM algorithms further, one discovers surprising insights regarding the capacity of these algorithms to build energy consumption curves. Compared to other algorithms, the GWO algorithm works better when applied to residential loads. On the other hand, the PSO algorithm performs better when implemented in conjunction with the GWO technique when applied to the load of the information technology industry. On the other hand, when compared to PSO and other algorithms, GWO has a higher rate of convergence than those other algorithms. When all of the loads that are present in the GN system are taken into consideration, it also performs well in terms of objective functions and constraints. Taking into consideration the findings of this study, it is recommended that additional research be carried out in order to evaluate the scalability of DSM techniques over a wide range of geographical and demographic contexts. In the event that this research is successful, it has the potential to ultimately result in energy management solutions that are both widely applicable and reliable for a wide range of electric grid scenarios. These solutions might include a number of approaches for charging electric vehicles.

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