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# “Hybrid Tactical Power System”

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## Abstract

Conducting military operations in deployed environments currently requires large amounts of electrical power in order to operate mission essential equipment such as communication systems, radar technology, and computer networks. Aside from mission critical loads, conveniences to soldiers from environmental space conditioning to powering personal electronic devices such as coffee pots, microwaves, computers, and stereo systems consume significant amounts of energy. The particular environment we examine is an off-grid Forward Operating Base (FOB). Diesel-fuel burning generators are the primary source of power for this environment. The burdened cost of diesel fuel and risk associated with fuel transportation convoys are extremely high. Most efficient generation occurs when generators operate at 50-90% of rated capacity. However, tactical generators are often operated at 10-20% of rated capacity due to a lack of field expertise and system planning capability. These result in inefficient fuel use along with increased operating costs, maintenance requirements, and risks associated with fuel transport. The goal of this work is to design and build a prototype Hybrid Tactical Power System (HTPS) to address these issues. The HTPS achieves this in several ways: integration of dissimilar sources such as photovoltaic panels and battery hybridization decreases generator operation, reduction of load variability via load aggregation better balances generator usage, and combining automated and user power and load control to the system improves generator efficiency. The prototype contains an automated controller, load control hardware for balancing and shedding loads, a PV source, and an emulated diesel generator via a grid interconnection. Our prototype HTPS improves generator fuel consumption and utilization by decreasing generator operation time, and improving generator load factor by automatically balancing generation over loads and incorporating demand response.

**Keywords: Microgrid, tactical power, diesel generation, photovoltaic power, renewable energy**

## 1. Introduction

The purpose of this work was to create a more efficient tactical power system without increasing the present complexity of operation. The primary motivation for is reducing fuel supply requirements. Diesel generators are the primary source of energy on small to moderate sized FOBs. According to the Defense Logistics Agency (DLA) the commodity price of a gallon of regular diesel fuel ranges from $3.11 to $4.31 [1]. The cost of fuel can be significantly higher in a deployed environment primary due to the cost of security and transportation through hostile and sometimes difficult terrain. The fully burdened cost of fuel (FBCF), which factors in these additional costs, can range from approximately $10 per gallon to as high as $600 per gallon based on estimates used by the Pentagon’s Comptroller office [2]. Fuel convoys also put soldier lives at serious risk. As such, reducing fuel consumption alleviates maintenance, cost, and risk. The proposed system in this work reduces diesel fuel consumption by introducing solar resources and improving generator efficiency through load balancing.

To minimize costs and risks of diesel fuel the power system must reduce diesel fuel consumption by generators. Our design will decrease generator fuel consumption by decreasing generator operation, balancing generation over loads, and increasing generator efficiency by properly sizing generator ratings to load size and minimizing generator damage due to wet-stacking. The Hybrid Tactical Power System (HTPS) achieves this in several ways: through integrating dissimilar sources such as photovoltaic panels and battery hybridization, and by combining automated and user power and load control to the system. In an example FOB microgrid environment, such as that shown in Figure 1 [3], an Intelligent Power Controllers (IPCs) would be implemented at points of generation (30kW gen., 60kW gen., etc). A Power Distribution Unit (PDU) would be implemented on a bus that feeds several demand sources, such as the bus with 6-interconnected huts. The primary purpose of the IPC is to monitor and control a generation source while the PDU monitors and controls the distribution of power. These units are networked together and share information and control strategies. For this work, the primary controller is implemented at the demand side, or at the PDU. Finally, the network GUI for the HTPS is implemented in a Tactical Operations Center (TOC), which would be a hut or tent dedicated to communications, control, and planning within the FOB.

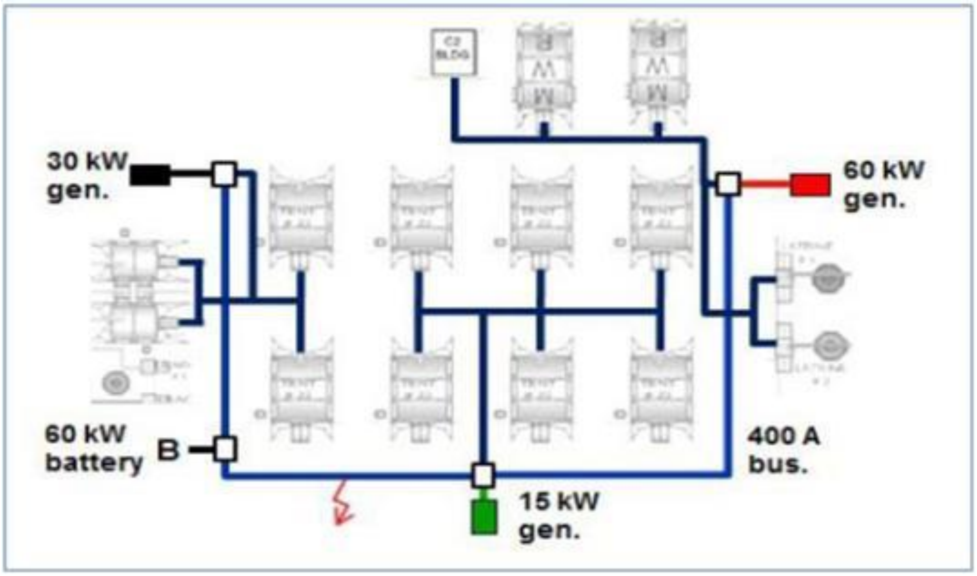


Figure 1: Example microgrid layout

## 2. Methodology

The Hybrid Tactical Power System is meant to be a series of improvements and additions that can be fitted into current microgrids in Forward Operating Bases. The components, such as the PDU with load balancing, can be scaled and integrated into essentially any interface between load and generator. This system, therefore, can be employed in a multitude of ways. For this HTPS, a FOB would consist of structures with a PV panels either on the structures, or located near the structures. A flexible PV panel tent [4] could also be used and placed over the structure. This would help reduce HVAC energy consumption given the shade and solar resources. The solar resources, alone, will decrease diesel operation and the magnitude of consumption. However, higher penetration of PV can reduce efficiency of diesel generators and create imbalances across electrical phases. The PDU and ability to balance loads helps integrate these components and improve the efficiency of the generators when they have to run, such as when PV is not available, consumption is at peak, or for high priority equipment. The sketch in Figure 2 is a basic high level view of what the system looks like and its primary features. The initial prototype is designed to replace a spot generation system, which consists of a single diesel generator and loads, with an integrated system containing diesel generation, PV generation, and demand side control to include load balancing. Control actions are realized through a LabVIEW 2014 [5] based controller and Intelligent Power Controller, and hardware built at the demand side of the system combined with the PDU. The system will be implemented in a test bed configured of a standard and prototype barracks hut, 2kW PV source, battery storage, and a grid interconnection (to emulate diesel generation). The PV source is monitored by DC voltage and current transducers which interface with the A/D converter in the IPC.

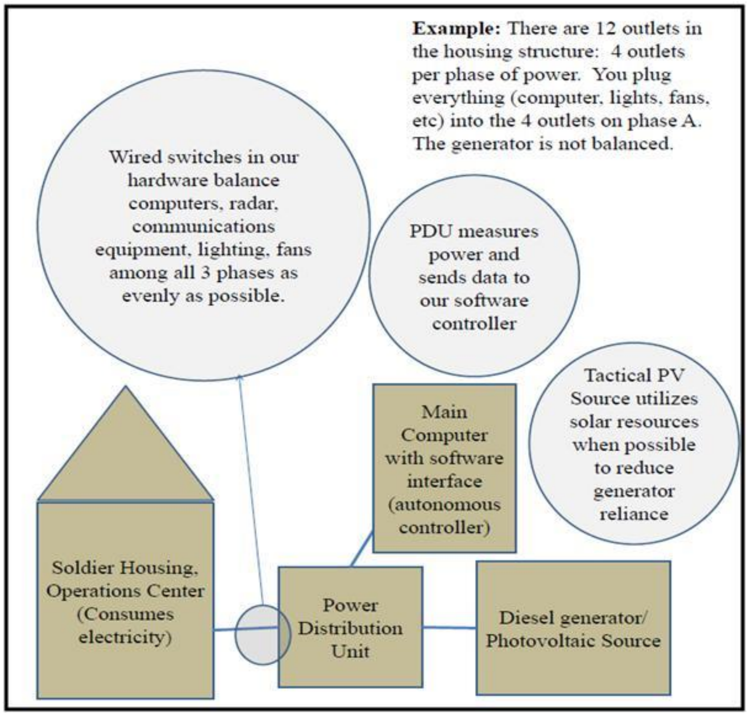


Figure 2: HTPS Concept Sketch

HTPS is designed to be a durable system that does not affect the interface between generators and consumption or between soldiers and the point of consumption. These are primary specifications for this system:

- Autonomous load switching to balance load across electrical phases.
- Loads switched phase to phase within ½ an electrical cycle (~8.3 ms for 60 Hz) to ensure continuous operation of loads.
- Logical and physical protection against faults while switching loads.
- Measurement and monitoring of voltage and current from battery bank, power from PV and generator sources, and measurement of load voltage, current, and power.
- Plug and play interface into FOB power systems that utilizes diesel generation and/or solar resources.

The HTPS block diagram, shown in Figure 3, encompasses the primary designs of our work over two semesters as well as the future integration of the test bed and other future work such as integration of total power monitoring and output to the commander. The main idea is that some sort of information or status can be output to show how much energy is being consumed compared to how much energy has been available in a very easy to read and easy to understand file such that a battalion or company level commander can understand if their generators are properly sized. This will allow them to better size generators in the future as well as know what to request.

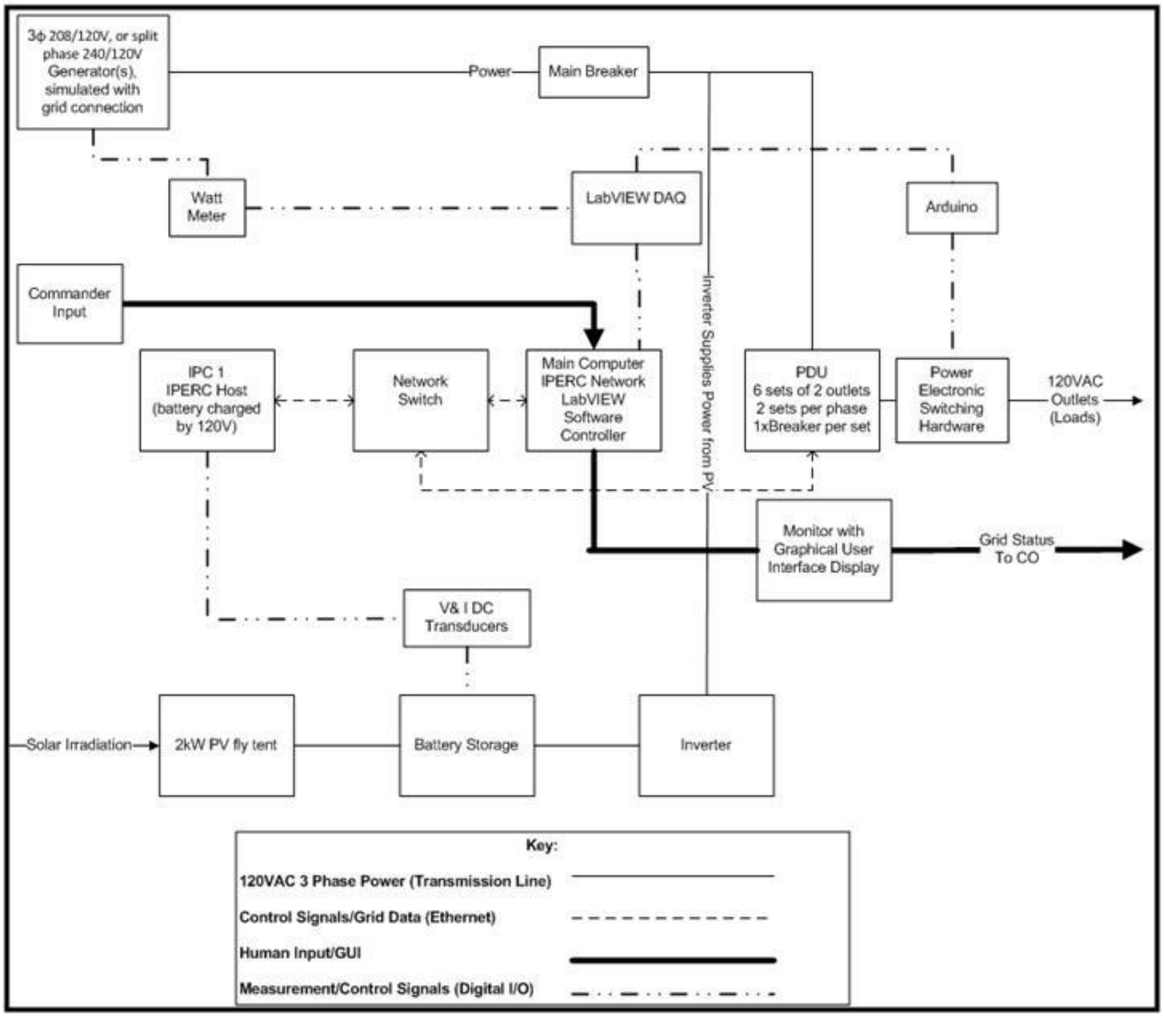


Figure 3. System Block Diagram

## 3. Data and Discussion of Results

Our system meets almost all of our specifications. Our system autonomously receives the PDU measurements and makes a control decision to optimize the load balancing. The PDU is supplied with three phase power through a standard MIL-SPEC 5-pin connector. Additionally, the PDU supplies power to its loads through standard 120 VAC outlets. These power connections meet our specifications for not changing the end user interface and being able to integrate the system into any power system. The load interface and phase balancing hardware are shown in Figure 4. We conducted extensive testing to ensure that our system was able to switch loads to a new phase within ½ an electrical cycle. Loads we tested include R, RL, RC loads on a lab bench (tested as low as 0.5 PF for RL and RC loads), incandescent, fluorescent, and LED lights, computers, computer monitors, soldering irons, and large industrial fans. All of these loads maintained proper operation during load balancing. The only noticeable effect that switching had on any of these loads was a small flicker in the lights during switching actions. This was most noticeable with the incandescent bulb. This small flicker in the lights will not affect any critical operation in a deployed environment. Switching results for an RL load are shown in Figure 5. The load voltage is shown in green, and control signals for switching the load to a specific phase are in yellow and blue for phase A and B respectively. This screen capture from an oscilloscope shows the load being switched between the two phases repeatedly. The controller logic prevents phase A and B switches from operating simultaneously and provides a deadband between switching signals to prevent a fault upon switching. The controller logic is implemented via LabVIEW.

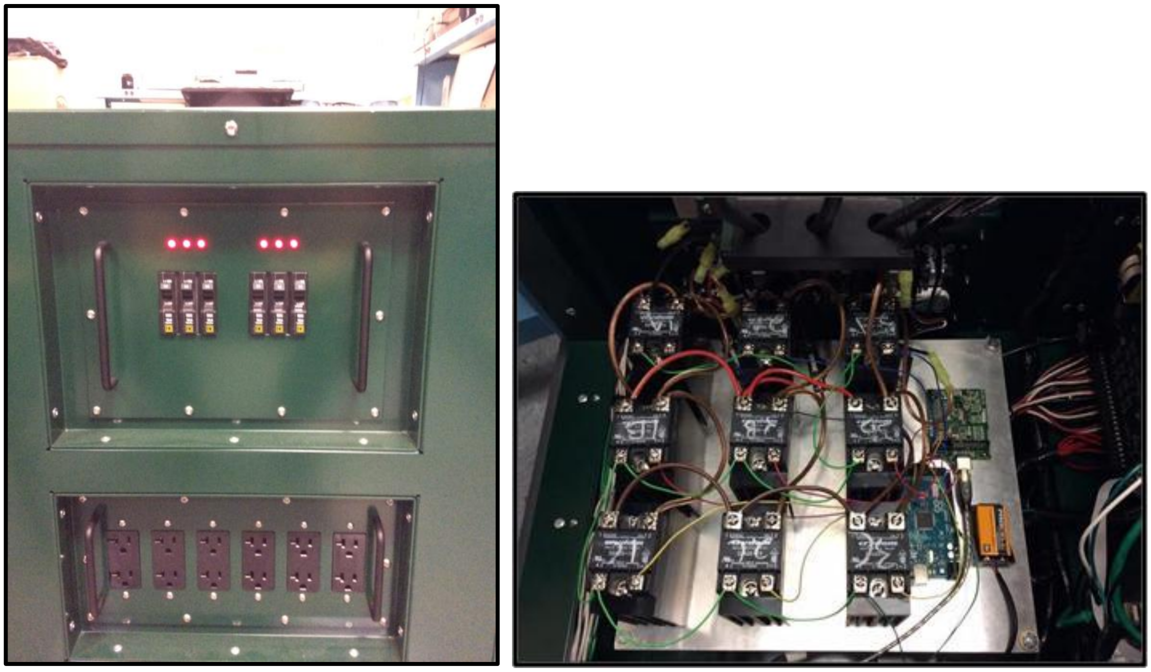

Figure 4. Power Distribution Unit and Phase Balancing Hardware

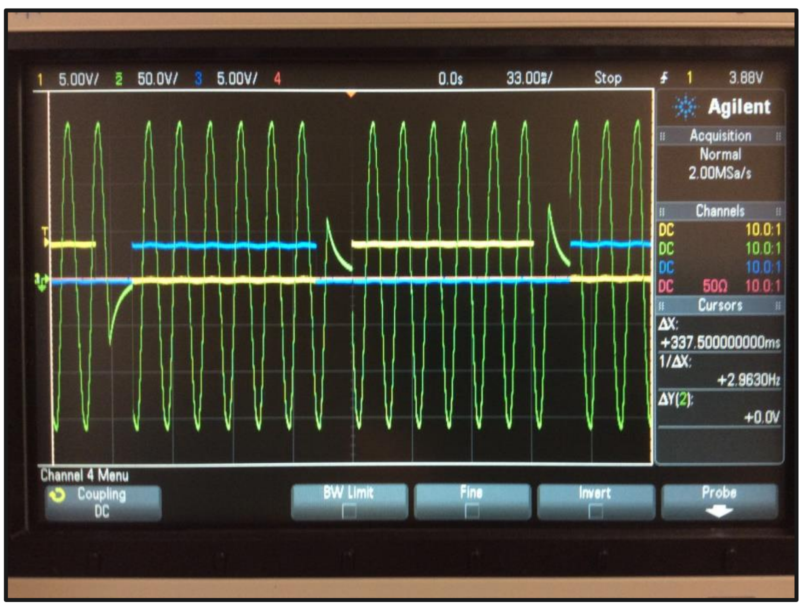


Figure 5: Load Switching Results for an Inductive Load

The LabVIEW GUI is shown in Figure 6. The prototype consists of six electrical outlets for connecting loads and three of these outlets are included in the phase balancing scheme. Measurements of current, voltage, and power are obtained for each phase. If the imbalance across phases, defined as the variance of power between the three phases, exceeds a specified threshold then the load balancing algorithm is initiated. This algorithm quickly switches between different operating states, calculates variance for each state, and then selects the state with the lowest variance for operation. The operation of this system has been tested and verified in a laboratory environment. The next step is to integrate the system in the testbed shown in Figure 7. In this testbed the system will be integrated with a 2kW PV shade, a grid interface emulating a generator, and real electrical loads within the housing structures (lighting, HVAC, computers, etc.). Estimated performance of this system has been quantified.

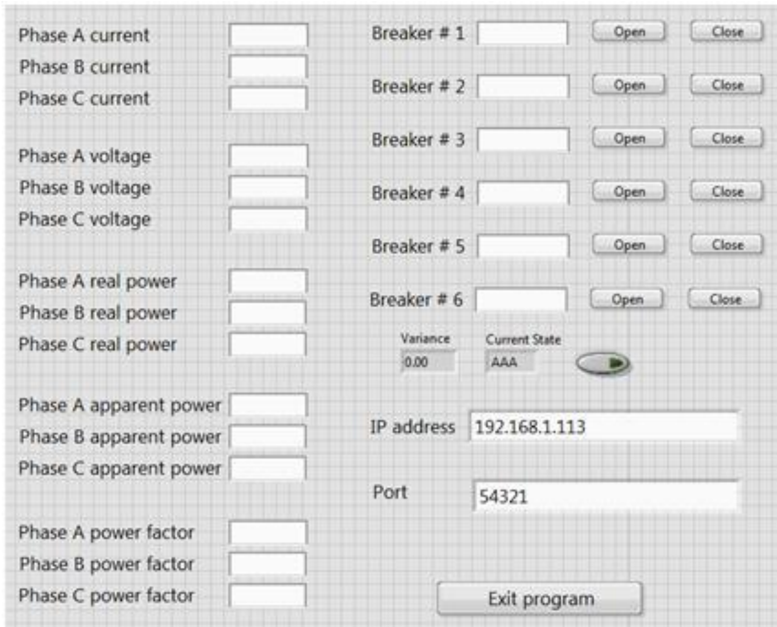


Figure 6. LabVIEW Graphical User Interface

Figure 7: Test Bed for HTPS Prototype

The HTPS will reduce diesel fuel consumption through load balancing, proper generator sizing, and integration of PV resources. These are all complementary improvements that will yield a much more optimized system as compared to traditional spot generation in which most generators are oversized as discussed in [3]. Estimated diesel generator fuel consumption data is shown in Table I for various loading levels. From this data the effects of load balancing were enumerated in Table II. For this particular scenario, correct sizing of the generator and load balancing can reduce fuel consumption by 11.47%. The effects of a PV source coupled with diesel generation were studied in [6]. Based on an optimal sizing of PV generation and diesel generator an additional 33% reduction in fuel requirements is estimated.

Table I: Generator Fuel Consumption Data

| Load (kW) | 20 kW Generator | | 40 kW Generator | | 60 kW Generator | |
|---|---|---|---|---|---|---|
| | Percent loading | Gal/Hr | Percent loading | Gal/Hr | Percent loading | Gal/Hr |
| 5 | 25% | 0.374 | 12.5% | 0.464 | 8.3% | 0.528 |
| 10 | 50% | 0.672 | 25% | 0.747 | 16.7% | 0.842 |
| 20 | 100% | 1.250 | 50% | 1.343 | 33.3% | 1.412 |
| 25 | | | 62.5% | 1.640 | 41.7% | 1.714 |

Table II: Calculated Fuel Consumption for Load Balancing Scenario

| | Load (kW) | | | | |
|---|---|---|---|---|---|
| | Phase A | Phase B | Phase C | Total | Gal/Hr |
| 60 kW Generator | 6.67 | 5 | 8.33 | 20 | 1.412 |
| 40 kW Generator | 6.67 | 5 | 8.33 | 20 | 1.343 |
| 20 kW Generator | 6.67 | 6.66 | 6.67 | 20 | 1.25 |

Table III: Fuel Consumption with PV Resources

| PV (kW) | Diesel Used (L) | Generator Hours | Diesel Savings (L) |
|---|---|---|---|
| 0 | 4047 | 8760 | 0 |
| 1 | 3679 | 8745 | 368 |
| 2 | 3275 | 8292 | 772 |
| 3 | 3005 | 7759 | 1042 |
| 4 | 2687 | 6903 | 1360 |
| 5 | 2492 | 6385 | 1555 |
| 6 | 2362 | 6050 | 1685 |

## 4. Conclusion and Future Work

The HTPS developed in this work had a goal of reducing fuel consumption and, as a result, reducing the risk to soldiers protecting fuel convoys. In order to do this, many specifications were established in order to give direction to the project. Primarily, the project would switch loads autonomously, have limited effect on the user interface, switch loads from phase to phase within a half a cycle, sustain operation of electrical loads, and be able to integrate into any power system. The initial prototype has met these specifications. The prototype is able to autonomously switch loads from phase to phase through the use of the PDU measurements fed to the controller which autonomously makes decisions to switch loads and choose the best load scheme. The user interface, the part that soldiers and leaders interact with, has not changed. They will still see the standard 120VAC outlets that are used in every building. Every load that is switched is done within the ½ electrical cycle window that was specified such that they never lose power long enough to malfunction. Hardware and software components were included to protect against line to line faults during load balancing, therefore supplying power at all times. Initial estimates indicate that diesel fuel consumption can be reduced by up to 44% by incorporating a PV source, load balancing, and proper diesel generator sizing. Future work includes integrating this into our testbed and validating the performance gains of the system. Additionally, additional control actions, start-up/shutdown sequences and load shedding/prioritization, will be implemented.

## 5. Acknowledgements

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