

POWER QUALITY IMPROVEMENT IN HYBRID MICROGRIDS USING UNIFIED POWER QUALITY CONDITIONER

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ABSTRACT:

The quick integration of renewable energy resources, BESSs, and electric vehicle (EV) charging infrastructure into modern power distribution systems has created many power quality, voltage regulation, reliability, and energy management issues. This project is a UPQC-Enabled Meshed Hybrid AC/DC Microgrid for Enhanced Power Quality, Renewable Energy Integration, and Grid Resilience for the improvement of the operational performance of future smart distribution systems. The proposed architecture is to create a parallel low voltage DC (LVDC) network with the existing low voltage AC (LVAC) network using the DC-link of a Unified Power Quality Conditioner (UPQC). The hybrid configuration allows for the effective integration of photovoltaic (PV) systems, battery storage units, EV charging stations and distributed DC loads with minimal power conversion losses. A comprehensive power management strategy is designed to enable the power sharing of active power to be coordinated between the AC and DC subsystems in normal power operating and abnormal power operating conditions. The UPQC can be used for voltage regulation, harmonic compensation, support of reactive power, current balancing and bi-directional power flow control. Additionally, the meshed connections offer several alternative power paths, increasing fault tolerance, flexibility, and reliability. The simulation and performance analysis of voltage sags, converter failures, renewable energy variations and load variations highlight improved power quality, voltage stability, renewable energy hosting capacity and energy utilization efficiency. The suggested system is scalable, reliable and sustainable for future smart grid, integration of renewable energy and electric vehicle supported distribution systems.

Keywords: : Hybrid AC/DC Microgrid, Unified Power Quality Conditioner (UPQC), Renewable Energy Integration, Battery Energy Storage System (BESS), Electric Vehicle Charging, Power Quality Improvement, Voltage Regulation, Smart Grid, Distributed Energy Resources, Harmonic Compensation, Grid Resilience, and Energy Management System.

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1.INTRODUCTION

With the rising demand for electrical energy, growing environmental concerns and fast depletion of fossil fuel resources, the shift towards sustainable and intelligent power systems has gained momentum. The clean and

environment-friendly nature of renewable energy sources like solar PV (photovoltaic) has made them a vital part of today's power network. At the same time, the use of EVs and BESSs is growing at a rapid pace to meet

carbon reduction targets and sustainable transport objectives. The wide-spread deployment of renewable energy sources, EV charging infrastructure and energy storage systems, however, presents a number of technical challenges such as voltage instability, harmonic distortion, reactive power imbalance, higher power losses, and lower reliability. Traditional AC distribution systems can struggle with the efficient integration of these distributed energy resources, as most renewable generators, storage solutions, and EV charging stations are based on DC power. Therefore, several power conversion stages are needed which leads to a higher level of complexity and lower efficiency. Hence, the development of advanced microgrid architectures that enable the integration of both AC and DC systems with high power quality and operation flexibility has gained much traction in the modern smart grid development world [1].

Hybrid AC/DC microgrids have proven to be an effective solution to the challenges faced by traditional distribution systems. These microgrids facilitate co-ordinated operation of AC and DC networks, and enable the efficient integration of renewable energy sources, battery storage systems, EV charging stations and DC loads. Moreover, meshed hybrid microgrid structures offer several power delivery routes, enhancing the system reliability, fault tolerance, and flexibility during dynamic operations. In spite of these benefits, power quality continues to be a major concern with the growing amount of power electronic converters and nonlinear loads. System performance and equipment life can be seriously impacted by voltage sags, voltage swells, harmonic distortion, unbalanced current and reactive power fluctuations. These problems can only be overcome with the use of advanced power quality compensation equipment. The Unified Power Quality Conditioner (UPQC) has proven to be a versatile device that can be used for voltage regulation, harmonic mitigation, reactive power compensation and power flow control. Moreover, with the inclusion of the renewable

energy system and battery storage system via the UPQC DC-link, the utilisation of the converter could be improved and the energy exchange between the AC and DC subsystems could be realised in a more efficient manner [2].

Based on these requirements, this project aims to develop a UPQC-Enabled Meshed Hybrid AC/DC Microgrid for Improved Power Quality, Renewable Energy Integration, and Grid Resilience. The proposed architecture is based on a low-voltage DC distribution network, which is parallel to the existing AC feeder, with the UPQC DC-link as the central interface. PV generation units, battery energy storage systems, electric vehicle charging points, and distributed loads are connected to the hybrid network, enhancing its energy use and operational efficiency. A detailed power management plan designed to help manage the power flow between AC and DC networks during normal and converter fault conditions. The UPQC consists of a voltage regulator, harmonic compensation, reactive power compensation, and bidirectional power flow control, which is used to ensure stable operation under various load and generation conditions. Results from simulation and experimental tests show enhanced voltage profiles, power quality, system reliability, renewable energy hosting capacity, and fault tolerance. Thus, the suggested microgrid configuration is a scalable and sustainable solution for the future smart distribution systems and renewable energy based power networks [3].

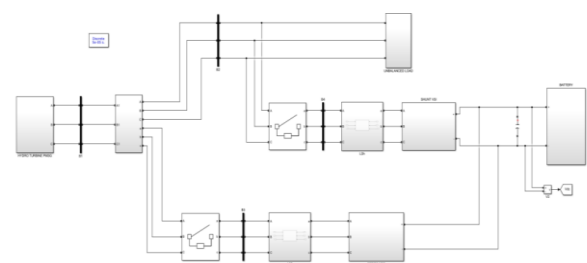


Fig.1. MATLAB/SIMULINK circuit of the Standalone hydroelectric system integrated UPQC.

The harmonic analysis in Figures 5(b) to 5(f) illustrates the effectiveness of the UPQC in enhancing the power quality performance. The Total Harmonic Distortion (THD) values of source voltage ($v_{s,a}$) and source current ($i_{s,a}$) by Fast Fourier Transform (FFT) analysis are higher when the UPQC is turned OFF, resulting from nonlinear load interaction and harmonics generated by the converter. This distortion decreases the efficiency of the system, causes thermal stress of electrical equipment and lowers power quality. Once the UPQC is active, both the voltage and current harmonics are significantly reduced. As shown in figure 5(d) load voltage distortion is minimized because of the voltage compensation of the series converter. In the same way, Figures 5(e) and 5(f) show the reduction of harmonic distortion in the load current and in the source current due to shunt converter absorbing the harmonic components of the nonlinear loads. The THD reduction will increase the power factor, will reduce losses in the transmission and will improve the efficiency of the hydro generation system. Better the wave form quality which means less overheating on electrical equipment and less Stress on passive components. Harmonic compensation is a feature of the UPQC that ensures that the system meets power quality standards, and enhances the reliability of sensitive loads. The results are established that UPQC integration has a great improvement in the harmonic mitigation capability and the UPQC has stable operation under practical loading condition.

II SURVEY OF RESEARCH

1. The authors of this paper, X. Yuan, J. Li, Z. Zhang and H. Liu, have suggested a hybrid multilevel converter with a Dual Active Bridge (DAB) converter for an EV fast charging system. This study was designed to improve the charging efficiency, voltage adaptability and power quality aspects of high-power charging. The modular multilevel converter is most effective in minimizing harmonic distortion and

switching stress; the DAB converter allows power to be transferred backwards and forwards, and is also able to create galvanic isolation. A set of soft-switching techniques were devised by the authors to reduce the switching losses and extend the life of the converter. The results obtained from the simulations and experimental tests were compared and reliability of charging was increased under the different voltage conditions of the batteries, and a reliable charging was achieved. The system is also equipped with Vehicle-to-Grid (V2G) functionality, which enables EV batteries to contribute to grid services. The proposed converter will increase the hardware complexity and implementation cost, however, will significantly enhance the charging flexibility and scalability. The research provides useful information on how to design efficient EV charging infrastructures, as well as advanced converter technologies for microgrid applications integrating renewable energy.

2. A new integrated modular multilevel converter (MMC) for multiport electric vehicle charging system was proposed by Z. Zhang, X. Yuan and Y. Wang. It can support several EVs to be powered simultaneously and achieve high efficiency and stable power delivery. A set of dynamic power sharing control algorithms were developed to share the charging power according to the vehicle load and SoC of batteries. Modular design makes it easier to scale up, safeguard against failures, and easily add more charging stations in the future. The experiments showed that with different load conditions, the total harmonic distortion, voltage regulation and reliability of the converter decreased. The converter is also designed to be redundant, so that if one of the modules fails the charging is not interrupted. The authors succeeded in proving that modular charging infrastructures are going to play an important role in the future large-scale deployment of EVs and in the smart transportation networks. It is a major step

towards developing intelligent charging stations and renewable energy-integrated power systems that will be able to accommodate the expanding penetration of EVs.

3. C. Li, S. Dusmez and A. Khaligh presented a detailed review of Electric Vehicle Fast Charging Systems (EVFCS): Three-phase bidirectional AC-DC Converter. The topologies of the converter (2-level, 3-level and multi-level converter structure) with regard to the efficiency, power density, harmonic performance and the implementation complexity are considered. Bidirectional converters were recognized as crucial components to enable Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) solutions. Power factor correction, thermal management, galvanic isolation and electromagnetic compatibility are important for high power charging systems, the authors noted. The multilevel converter was shown to have better harmonic performance and lower switching losses than the conventional converter designs. This paper also discussed the use of Silicon Carbide (SiC) and Gallium Nitride (GaN) devices to enhance the converter's efficiency and to make the system compact. The research found that future smart charging infrastructures with renewable energy resources and hybrid microgrid architectures require the use of advanced converter technologies and intelligent control methods.

4. T. Das et al. developed Sliding Mode Control (SMC) approach for a modular multilevel converter (MMC) based dual electric vehicle charging system. The main goal was to make the converter more robust and to enhance its charging capabilities when operating in uncertain conditions and with varying loads. The controller can independently adjust the charging power of two EV charging outlets, and at the same time share the charging power and maintain the voltage of the DC link. The simulation and experimental results

demonstrated that the proposed controller has better dynamic response and less steady state error than the conventional proportional-integral controller. The SMC method can effectively cope with the uncertainty of the parameters and external disturbances, thereby ensuring the reliability of charging and the stability of the system. Moreover, better voltage tracking performance and lower overshoot have been seen in the charge transfer transitions. Even though a number of challenges were faced, it was a very successful study from a performance perspective for the converter in the presence of advanced nonlinear control techniques in the dynamic environment where the chattering phenomena was encountered. It's very applicable to the smart EV charging and hybrid micro grid control applications.

5. Y. Deng, W. Xiao and J. Wu reviewed the Electric Vehicle Charging system under Dual Active Bridge (DAB) based isolated DC-DC converter. The study pointed out that the DAB converter has a high efficiency, has a bidirectional transfer capacity and is compact and has galvanic isolation. Different modulation methods and converter configurations have been considered with the aim of enhancing the power transfer performance under changing load conditions. Soft-switching operation was one of the important features identified that was needed to reduce switching losses and to attain high converter efficiency. The paper also concerned itself with the design of the high frequency transformers of the DAB converter and their major drawbacks namely, magnetic losses, leakage inductance and thermal stress. The authors finally determined DAB converters to be highly appropriate for inclusion in the future EV charging infrastructure, which can be easily adapted for use with renewable energy systems. But converter control complexity and the optimization of the transformer are still key research challenges. This study provides valuable insights into the main design principles of high performance and compact charging

systems in hybrid AC-DC microgrids and smart grid scenarios.

6. In order to develop the fast charging stations for EVs, P. García, M. Blanco and A. García-Cerrada proposed energy management strategies using renewable energy resources and battery storage systems. The proposed framework links the energy flow between PV systems, batteries, energy distribution networks, and charging stations in an optimal way to use energy efficiently and minimize costs. Smart load balancing algorithms have been developed which distribute charging power depending on the needs of the vehicles, grid load and availability of renewable energy. The simulation results showed increased charging flexibility, lower peak demand and higher renewable energy utilization. During fluctuations in the generation of solar energy and fluctuation in charging demand, this system was also proved to be very useful in supporting the system. To ensure efficient operation of the charging stations under dynamic conditions, the changes in real-time monitoring and communication technologies were used. The authors have also determined that as sustainable infrastructure for EV charging and future smart grids can only be achieved with advanced energy management systems being implemented. The research holds great potential for the development of intelligent hybrid microgrid system that has improved reliability, energy efficiency and renewable energy integration.

III. WORKING METHODOLOGY

The proposed UPQC-Enabled Meshed Hybrid AC/DC Microgrid for Enhanced Power Quality, Renewable Energy Integration, and Grid Resilience aims to effectively connect renewable energy sources, battery energy storage systems (BESSs), electric vehicle (EV) charging stations, and typical distribution loads into a single hybrid network. The architecture includes the installation of a low voltage AC

(LVAC) distribution system in parallel with a low voltage DC (LVDC) distribution system and interconnection between the two using a Unified Power Quality Conditioner (UPQC). The primary control and compensation device is called the UPQC, which is used to enable bi-directional power flow between the AC and DC subsystems, and to allow the power quality to remain unchanged. The PV systems and battery storage units are seamlessly connected to the LVDC network, eliminating the need for extra power conversion steps and improving the system's overall efficiency. Under normal operating conditions, PV systems generate renewable energy which is used to power local DC loads and EV charging stations. The battery energy storage system stores excess energy or sends excess energy to the AC network via the UPQC. When the renewable energy is insufficient, the electricity is taken from the electricity grid with the same voltage and current characteristics. This parallel energy management strategy maximizes the use of renewable energy sources, reduces losses in the load generation and transmission system, as well as allows increased flexibility in the operation when there are changes in load generation.

In the case of an AC-DC power flow management, it is controlled by the intelligent converter coordination and compensation techniques based on UPQC. The series converter of the UPQC injects the compensating voltage to minimise the voltage sag/swell and shunt converter performs the reactive compensation, current balancing and controls the DC link voltage. The electric power generated by PV system is provided by:

$$[P_{PV}] = V_{PV} \times I_{PV}$$

V_{PV} is the PV voltage, I_{PV} is the PV current and P_{PV} is the output power of the PV system. The amount of active power and reactive power that can be switched in the micro-grid is determined by:

$$[P=VI\cos\phi]$$

$$[Q=VI\sin\phi]$$

where (P) = Active power, (Q) = Reactive power, (V) = Voltage, (I) = Current and (ϕ) = Power factor angle. These parameters are monitored constantly by the UPQC and the UPQC dynamically changes these parameters according to the disturbances in power quality. The controller automatically moves power to the DC or AC grid, depending upon conditions, such as changes in voltage or when many EVs are plugged in simultaneously. This joint effort helps to maintain voltage stability, reduce harmonic distortion and maximize the utilization of DER resources in a hybrid microgrid system.

BESS is an important component to help ensure energy balance and reliable operation of microgrids. The battery will help to store excess renewable energy when the sun is producing more electricity than the grid needs and will draw electricity from the battery when the sun isn't producing as much electricity as the grid requires. The battery state-of-charge (SOC) is calculated based on the following:

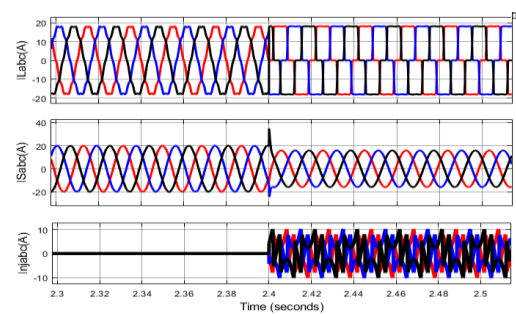
$$[SOC(t)=SOC(t-1)+\frac{P_{ch}\eta_{ch}-P_{dis}}{E_{bat}}\Delta t]$$

The charging power is P_{ch} and the discharging power is P_{dis} and the charging and discharging efficiencies are (η_{ch}) and (η_{dis}) respectively, the capacity of the battery is (E_{bat}) and the sampling time is (Δt). The total electrical balance of the hybrid microgrid is given by:

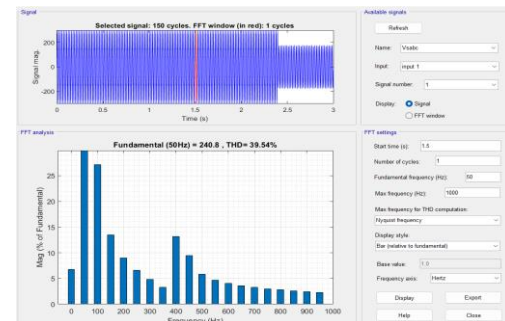
$$[P_{Grid}+P_{PV}+P_{BESS}=P_{Load}+P_{Loss}]$$

where, (P_{Grid}) is the utility power, (P_{PV}) is the solar generation power, (P_{BESS}) is the battery power, (P_{Load}) is the total load demand and (P_{Loss}) is the system losses. Through intelligent power management, UPQC compensation and meshed AC/DC interconnection, the proposed methodology can ensure reliable operation, high power quality, high hosting capacity of renewable energy and high fault and disturbance tolerance in future smart grid network.

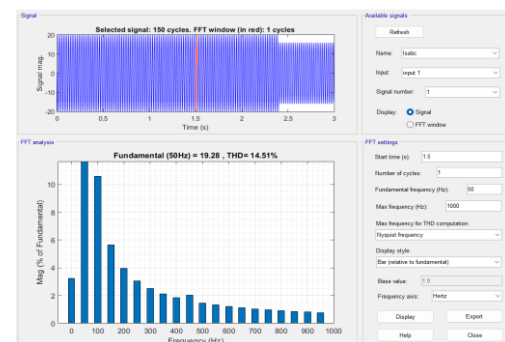
IV RESULTS EXPLANATIONS



(a)

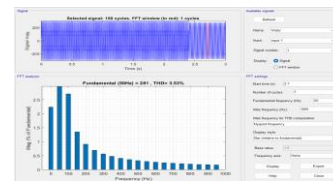


(b)



(c)

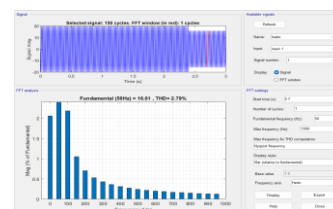
The dynamic behavior of the system with load unbalancing is depicted in Figure 2(a). During load disturbances voltage imbalance and current fluctuation are seen in the source and load waveforms because of the imbalance in the load. The response of the UPQC is to produce compensating voltage and current in the series converter and shunt converter. The voltage injected in the injected voltage waveform is used to counteract disturbances in the supply and bring the load voltage back into a balanced state. Likewise, injected current waveforms offset current unbalance, and minimize source current distortion. Temporary oscillations are noticed during transient events because the PI controller takes finite time to respond to the disturbances. But, the controller manages to stabilize the system after the transient and resumes normal operation. As seen in the results, the source currents are relatively balanced with the load variations, which means that the compensation is successful. Under unbalanced loading, the UPQC can compensate for it and enhance generator protection, and alleviate the operational stress on the electrical components. Additionally, balanced current operation will help to reduce the negative sequence current, which might impact machine efficiency and reliability. Hence, the dynamic compensation results confirm the ability of the UPQC to ensure the satisfactory operating conditions under different load conditions.



(d)



(e)

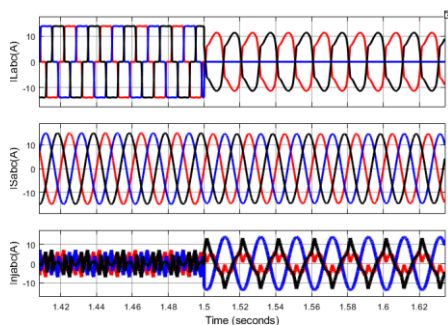


(f)

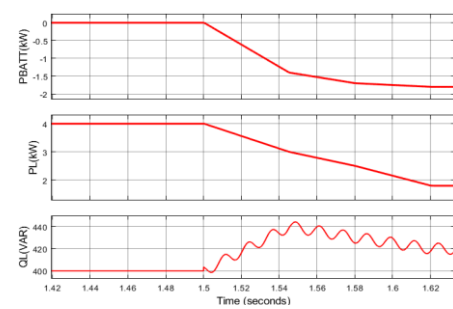
Fig. 2. Performance of standalone hydroelectric based PMSG system without and with integration of UPQC. (a) vs,abc, vL,abc,vinj,anc, iL,abc, is,abc, iinj,abc, (b) THD depiction for vs,a when UPQC is OFF, (c) THD depiction for is,a when UPQC is OFF, (d) THD depiction for vL,a when UPQC is ON (e) THD depiction for iL,a when UPQC is ON, (f) THD depiction for is,a when UPQC is ON.

Figure 2(b) shows the responses of DC-link voltage (V_{DC}), source active power (P_s), source reactive power (Q_s), battery power contribution (P_{Batt}), load active power (P_L) and load reactive power (Q_L). It is crucial to maintain stable DC-link voltage because the medium of energy exchange

between series and shunt converter is the DC-link. The voltage of the DC-link will have variations during transient conditions, due to the sudden change in compensation demand. The PI controller does the voltage control and stabilizes the system following transient oscillations, however. The active power wave shape has a smooth power transfer from the source to the load, whereas reactive power compensation reduces the load on the hydro electric generator. Battery support plays a role in maintaining energy balance and enhances the compensation capability during disturbances. The improvement in the amount of reactive power that is not drawn from the source allows the generator units to be utilised more efficiently, resulting in an improvement in overall efficiency. Moreover, when the load changes, the power sharing coordination between source, battery and load guarantees reliable operation. The results show that the energy management system which integrates UPQC is able to achieve stable operations and enhance power quality. In addition, the proper regulation of active and reactive powers components also helps to improve voltage stability and reduce the power losses throughout the system.



(a)



(b)

Fig. 3. Dynamic performance during load unbalancing condition. (a) $v_{s,abc}$, $v_{L,abc}$, $v_{inj,abc}$, $i_{L,abc}$, $i_{s,abc}$ and $i_{inj,abc}$ (b) V_{DC} , P_s , Q_s , P_{Batt} , P_L and Q_L .

Overall, the simulation results demonstrate its effectiveness in improving the power quality, harmonic mitigation, voltage regulation, and system stability of a standalone hydroelectric system connected to a UPQC. The compensation based on the PI controller successfully reduces the harmonic distortion, controls the DC link voltage and allows balanced operation even with dynamic loading. Under a sudden disturbance, transient overshoot and slow settling is noted, but the controller is able to return to the steady state operation within the acceptable limits. This is because the reduction in harmonics will directly benefit system efficiency by reducing losses and strain on electrical equipment. The UPQC also optimizes generator utilization by compensating reactive power and providing an improved source current quality. Dynamic load unbalancing analysis shows that the system performs well, even in difficult operating scenarios. Moreover, the stability of power-sharing actions among source, battery, and load components also verifies the correct power-sharing coordination of the converter and the best energy management. Hence, it is seen that the standalone hydroelectric power system integrated with UPQC is a viable solution to enhance the power quality and reliable operation of isolated renewable energy power systems. The results confirm the suitability of

the UPQC compensation method for future stand-alone applications of renewable energy with high stability and power quality requirements.

V.CONCLUSION

In this work, the modeling, simulation and performance evaluation of stand-alone hydroelectric Permanent Magnet Synchronous Generator (PMSG) power system with the Unified Power Quality Conditioner (UPQC) for the improvement of power quality and enhancement of the system stability during dynamic operating conditions is presented. The designed system has been implemented and analyzed in MATLAB/Simulink to study its voltage regulation, harmonic mitigation, compensation capability and performance under load variations and nonlinear operating conditions. The UPQC architecture comprising series and shunt compensation converters, was capable of harmonics compensation, reactive power demand compensation and load imbalance conditions, thereby effectively improving the voltage quality and reduce current distortion. The simulation results found that the source voltage and current waveforms were much smoother after the UPQC integration and the Total Harmonic Distortion (THD) was also greatly reduced from the uncompensated operation. Under load unbalancing conditions, dynamic analysis under load showed that the compensation system has achieved a balanced operation without the occurrence of transient disturbances and provided system variable stabilization. A DC-link voltage regulation mechanism was implemented to stabilize the energy exchange between compensation converters, and improve the reliability of operation under varying load conditions. Besides, it optimized the utilization of generators and alleviated the stress of system components due to active and reactive power coordination. The PI controller presented a moderate transient overshoot and slower settling time for sudden disturbances, but had a stable steady state performance and acceptable

compensation results. Overall, the proposed stand alone hydroelectric power system with UPQC is an efficient and reliable solution to improve the power quality, increasing the operational stability, reducing the harmonic distortion and enhancing the performance of the standalone power system based on renewable energy sources.

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