

Enhancement of Microgrid Efficiency through Strategic Management of Distributed Energy Resources Integrated Unified Power Quality Conditioner

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Abstract - The integration of distributed energy resources (DERs) into a microgrid is a viable solution for meeting the growing energy demand and promoting sustainable development in the power industry. However, because to this slow shift, the low inertia of the far placed low voltage small scale microgrid has an inordinate impact on power quality and dependability. Hence, the aim of this suggested study is to improve the functionality of low voltage microgrids using the unified power quality conditioner (UPQC) supplied from photovoltaic (PV) and battery energy storage systems (BESS). The control strategy of UPQC is devised to improve power quality, increase PV penetration with BESS, minimise grid stress and fast management of DC-link voltage under diverse system dynamics. This means that PV and BESS can be directly connected to the grid without requiring additional converters. Furthermore, the UPQC control algorithm is equipped with a switch protection approach. It protects the UPQC switches from very high magnitude current in any uncertainty caused by the load with no modification in the system arrangement or capacity. The BESS control is based on a dynamic battery reference power, which is updated with respect to the dynamics of load demand, PV power and battery state of charge (SOC). The proposed system is simulated in MATLAB/Simulink and an experimental prototype under several dynamical conditions.

Key Words: Battery, DERs, grid integration, microgrid, power quality, PV, switch protection and UPQC

1.INTRODUCTION

The electrical distribution network is buzzing with microgrids in this era of sustainable growth. The integration of renewable energy resources (RERs) has increased due to the increased use of power electronic based interface converters [1]. growth in power electronic devices has resulted in tremendous growth in power quality problems including voltage and current. Some specialist equipment such as unified power quality conditioner (UPQC), distribution static compensator and dynamic voltage restorer can be used to solve the power quality problems aroused in the distribution system [2, 3].

Therefore, UPQC is the best choice to solve the problems connected to current and voltage. Voltage source converters developed in UPQC have many other applications other from power quality improvement. It can facilitate the communication between RERs, the grid and the load, which is beneficial for power management [4]. It will improve power quality and reduce stress on the grid. The RERs addition has further advantages such as stabilising the DC-link voltage of UPQC under different system dynamics. However, RERs are not always reliable, making system smoothness a difficulty. The PV is directly connected through the UPQC DC-link.

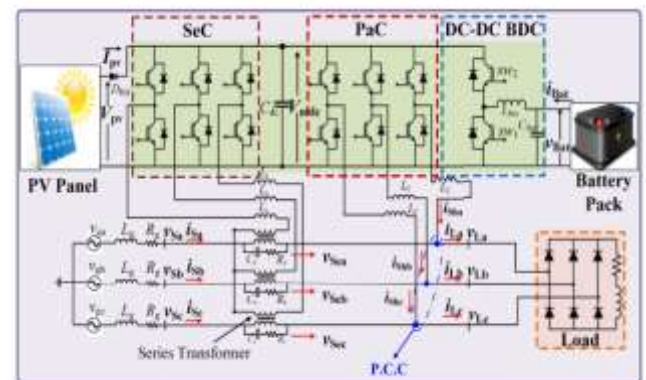


Fig. 1. System framework

burden on the grid. Also, due to the presence of RERs, it will stabilize the DC-link voltage of UPQC during various system dynamics. However, the intermittent nature of RERs may hinder the smooth operation of the system. The PV is connected directly across the DC-link of UPQC.

2. Proposed Control Strategy and System Arrangement

The schematic of battery supported PV-UPQC system in a microgrid is depicted in Fig.1. The considered system includes conventional main grid, a renewable energy resource (PV module), a UPQC, a bidirectional converter, battery pack, three single phase series injection transformers, coupling inductors. The sizing of SeC depends upon the rated system voltage and percentage of sag/swell, it should be able to compensate.

$$S_{Se} = P_{Se} = 3v_{Se-sag}i_{Se} = 3 \times 0.9 \times \frac{110}{\sqrt{3}} \times 10 = 1.7 \text{ kVA} \quad (1)$$

where, v_{Se} refers to the amount of sag in the grid voltage and here sag of upto 90% is considered. i_{Se} is the current rating of SeC which is considered 20-30% higher than the maximum rated load current. The sizing of PaC depends upon various factors such as PV maximum power (P_{PV}), maximum load reactive (Q_L) and harmonic (Harmonics) power, maximum sag compensating power (P_{Se}) and BESS power (P_{Bat}). Generally, in case of industrial or commercial settings, rectifier-based load causes 10% to 30% of THD in load current. Here, an average THD of 20% is considered for sizing of UPQC. Therefore, harmonics power ($H_{harmonics}$) is calculated as 20% of the rated load capacity (1530 kVA) of the system.

$$S_{Sh} = \sqrt{(P_{PV}^{MPP} + P_{Bat} + P_{Se})^2 + Q_L^2 + H_{Harmonics}^2}$$

$$= \sqrt{(1490 + 500 + 1714)^2 + (300)^2 + (0.2 \times 1530)^2}$$

$$= 3.8 \text{ kVA} \quad (2)$$

The overall control approach of the proposed system is represented in Fig. 2. The steps involved in the control approach are discussed below:

A. Extraction of Harmonic and Fundamental Quadrature Component of Load Current. based on N-CF-SOHO estimator In this subsection, the load harmonic current components (i_{habc}), fundamental quadrature (i_{fqabc}) and in-phase (i_{fpabc}) load current components for all the phases are evaluated, subsequently, these components are utilized for implementation of the switch protection scheme and for control of UPQC. For evaluation of various components of load current requires fundamental positive sequence-based grid voltage in-phase unit templates (U_{iabc}) and fundamental load current component (i_{iabc}).

In this article, i_{fabc} is extracted by using modified inverse notch filter as depicted in Fig. 2b. And, U_{iabc} is generated by using ANF fed N-CF-SOHO, then, quadrature unit templates are (U_{qabc}) generated by using U_{iabc} as shown in Fig. 2a. The aforementioned two steps are elaborately discussed in [12]. Then, by utilizing the extracted i_{fabc} and in phase unit templates, the quadrature component of load current is extracted as in Fig.2b. When U_{iabc} reaches zero magnitude, the zero-crossing detector (ZCD) triggers the sample and hold block (SH) to store the magnitude of i_{fabc} at that instant and process it till the next event of zero crossing of U_{iabc} . Absolute value of fundamental quadrature component is determined for each of the phases (I_{fqabc}). Similarly, using U_{qabc} and i_{fabc} , I_{fpabc} is extracted. The fundamental active (i_{fpa}, i_{fpb} and i_{fpc}) and reactive (i_{fpa}, i_{fpb} and i_{fpc}) current signals of

load current for each of the three phases are obtained as illustrated below:

$$i_{fpa} = I_{fpa} \times U_{ia}, i_{fpb} = I_{fpb} \times U_{ib}, i_{fpc} = I_{fpc} \times U_{ic} \quad (3)$$

$$i_{fqa} = I_{fqa} \times U_{qa}, i_{fqb} = I_{fqb} \times U_{qb}, i_{fqc} = I_{fqc} \times U_{qc} \quad (4)$$

Then by using (3) and (4), harmonic current components are obtained below and also shown in Fig. 2b.

$$i_{ha} = \sqrt{i_{La}^2 - (i_{fpa}^2 + i_{fqa}^2)}, i_{hb} = \sqrt{i_{Lb}^2 - (i_{fpb}^2 + i_{fqb}^2)},$$

$$i_{hc} = \sqrt{i_{Lc}^2 - (i_{fpc}^2 + i_{fqc}^2)} \quad (5)$$

B. Proposed UPQC Switch Protection Factors

During undesired increase in load demand or transient load conditions, the current in the system rises to accommodate the increased load requirements. This peak current can exceed the safe operating capacity of converter, imposing a risk of damage to the VSC switches of UPQC. This risk is significant because the PaC of UPQC deals with the reactive and harmonic power required by the load to maintain power quality at P.C.C. When the current increases the reactive (i_{fqabc}) and harmonic (i_{habc}) components of load current may also increase. Hence, the amount of current fed by PaC for compensating non-ideal load current should be controlled dynamically w.r.t maximum rated capacity of PaC. The regulation process of DC-link voltage (V_{mdc}) is necessary for compensating non-ideal grid and load conditions. UPQC extracts active current (IDC) from the grid to regulate V_{mdc} . To regulate V_{mdc} rapidly during sudden rise in the load demand, very high value of current is drawn by PaC from the grid which can damage the UPQC switches. Therefore, restriction should

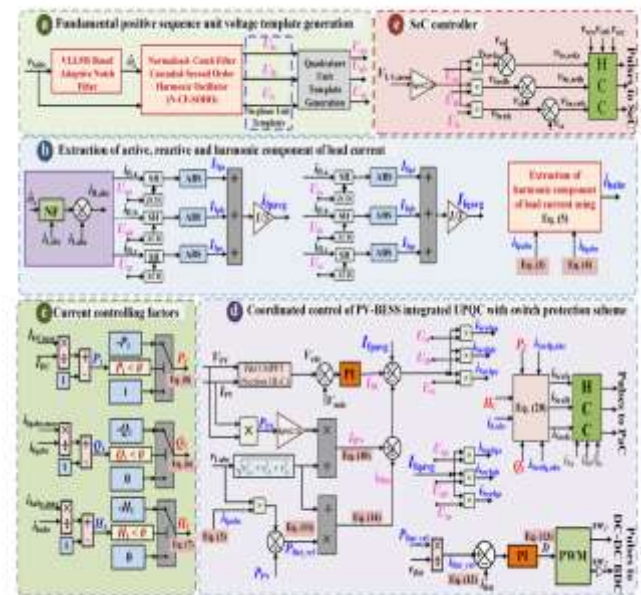


Fig. 2: Overall control and operating principles of PV-BESS integrated UPQC be imposed on the amount of current drawn by PaC from grid.

To maintain power quality, PaC encounters three components of current - harmonic component (i_{habc}), reactive component (i_{fqabc}) and DC-link regulation component (IDC). Hence, current controlling factor

should be incorporated to restrict the amount of these current components through the PaC switches within its rated capacity. As PaC is operating in current control mode and manages all the current flow through the system by controlling the DC-link even under dynamic conditions. Therefore, the current limitation is implemented only in the PaC control scheme. Since, undesired condition occurs for few cycles only, so, the objective is to protect the power electronic based switches from such uncertain conditions of few cycles from damage. The current controlling factor must be considered in such a way that, if the reactive and harmonic currents goes beyond the rated capacity of PaC that extra share of undesirable current w.r.t its rated capacity is then provided by grid to protect the UPQC from permanent damage. The current controlling factors Q , H and P for i_{fqabc} , i_{habc} and I_{DC} respectively are evaluated by using (9), (4) and (5) as shown in Fig. 2c.

$$Q_C = \begin{cases} 0, & \text{if } Q_1 \geq 0 \\ -Q_1, & \text{if } Q_1 < 0 \end{cases} \text{ for } Q_1 = \frac{i_{fqabc,max}}{i_{fqabc}} - 1 \quad (6)$$

$$H_C = \begin{cases} 0, & \text{if } H_1 \geq 0 \\ -H_1, & \text{if } H_1 < 0 \end{cases} \text{ for } H_1 = \frac{i_{habc,max}}{i_{habc}} - 1 \quad (7)$$

$$P_C = \begin{cases} 1, & \text{if } P_1 \geq 0 \\ -P_1, & \text{if } P_1 < 0 \end{cases} \text{ for } P_1 = \frac{I_{DC,max}}{I_{DC}} - 1 \quad (8)$$

The maximum value of i_{habc} , i_{fqabc} and I_{DC} are $i_{habc,max}$, $i_{fqabc,max}$ and $I_{DC,max}$ respectively. These are determined from the sizing of UPQC as carried out in section 2. $i_{fqabc,max}$ is evaluated from QL and $i_{habc,max}$ is determined from $H_{\text{Harmonics}}$. $I_{DC,max}$ depends upon sag compensating power P_{Se} and maximum conduction losses of the UPQC switches (generally loss is considered as 50% of total load active power). In the proposed work, PaC is operating under indirect current control method, where switching of PaC is controlled by generation of reference grid current. Therefore, by incorporating the above obtained current controlling factors in the reference grid current generation process, the grid is directed to provide that extra share of harmonic and reactive power in order to protect UPQC switches from permanent damage as shown in Fig. 2d

C. Contribution of PV in the System Operation

In the PV-BESS-UPQC system, the DC-link voltage regulation of the UPQC is carried out by PaC. The PV and PaC configuration is similar to the current setup, with V_{rdc} being determined using the Perturb and Observe (P and O) based Maximum Power Point Tracking (MPPT) method. The PV system's voltage rating is chosen such that the minimum PV voltage during solar PV hours (SPV hours) is at least equal to the UPQC's minimum working voltage. The maximum voltage of the PV system, known as the open circuit voltage, is dependent upon the voltage tolerate capability of the DC capacitor and the power

electronic switches within the UPQC. This will ensure optimal utilisation.

3.Simulation Results and Discussion

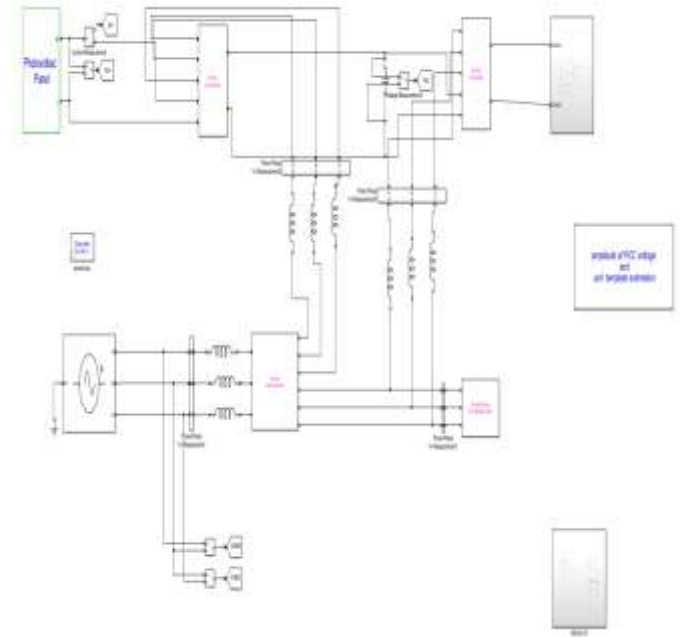


Fig. 3. Simulation Diagram

The proposed work based on performance enhancement of microgrid by integration of PV and battery through UPQC along with incorporated switch protection scheme is analyzed in MATLAB/Simulink. The effectiveness of the system is studied under varying solar irradiance, varying load demand and grid voltage sag/swell and harmonics.

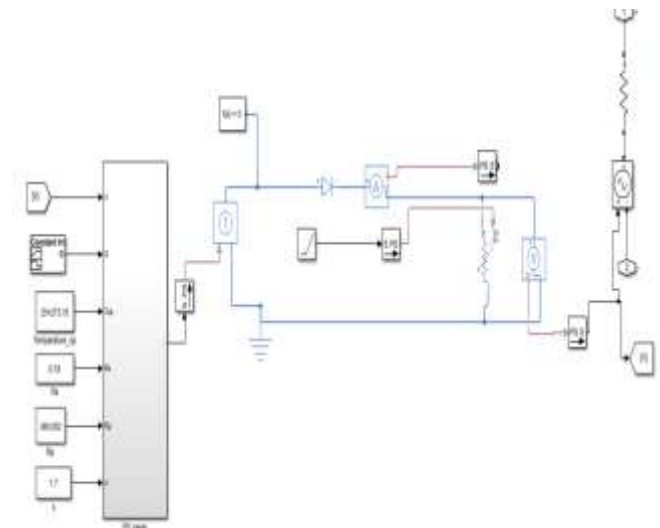
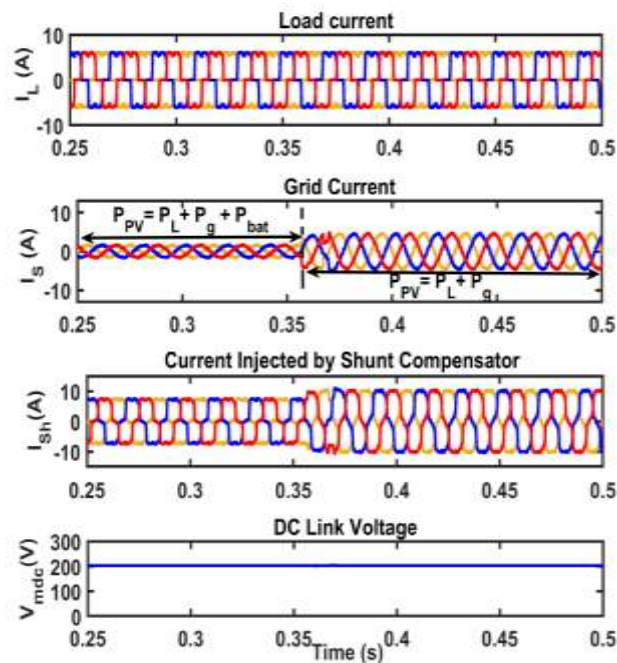
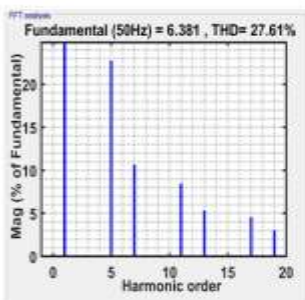


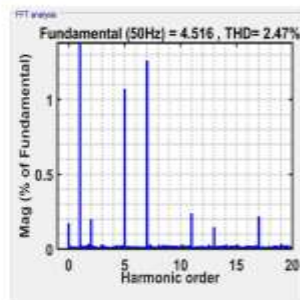
Fig.4. Solar panel



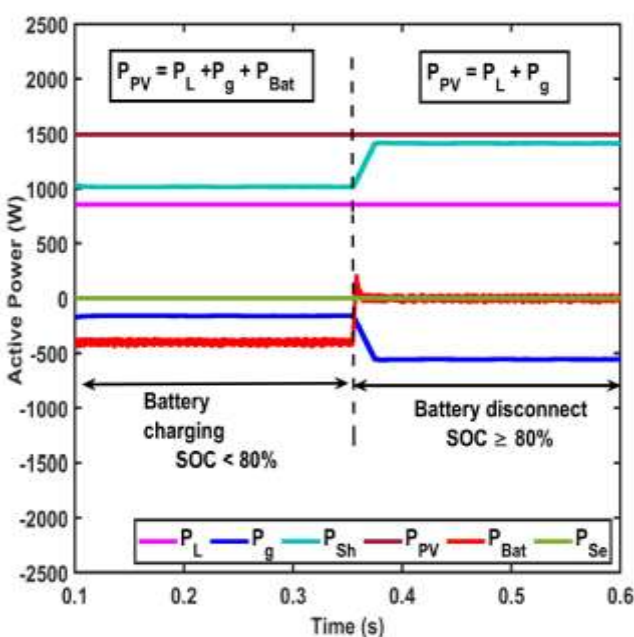
(a)



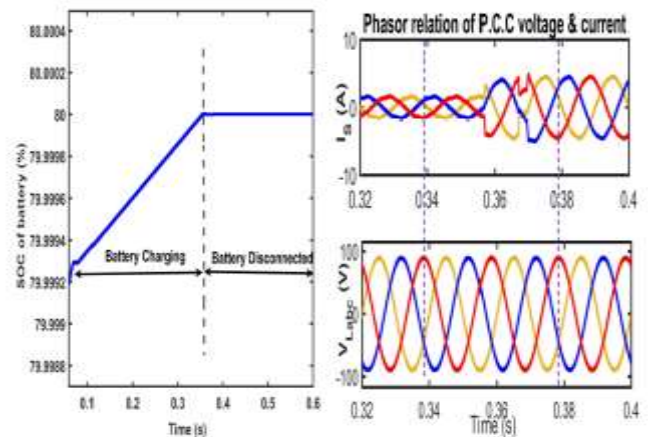
(b)



(c)



(d)



(e)

(f)

Fig. 5: Simulation results investigating power quality improvement and power management (a) Performance of PaC (b) THD of load current (c) THD of grid current (d) Active power flow analysis (e) Battery SOC (f) UPF operation

3. CONCLUSIONS

The research work illustrates a grid-interfaced PV and battery integrated UPQC for performance improvement of low inertia low voltage remotely placed microgrid. The primary focus of the application of UPQC is to enhance the inertia and efficiency of the system by mitigating non-ideal circumstances such as weak grid condition, poor power quality, dependency on conventional energy source, RERs intermittency, transient current etc. Implementation of a PV and BESS-fed UPQC, validated through both simulation and experimental analysis, not only enhances power quality (reducing the high THD content of grid current from 27.61% to 2.47%, ensures UPF operation at P.C.C and maintains rated load voltage during sag) but also serves as an interface to supply power, reduces burden on grid and supports sustainable energy management. Additionally, the incorporated switch protection scheme in the control algorithm activates within 10 ms to 20 ms of the occurrence of transient due to simple method of evaluation of current limiting factors.

Estimation of various load current components based on N-CF-SOHO and notch filter, with execution speed of around 20 ms makes the whole process faster. The system and its control approach have performed efficiently in simulation as well as experimental under load induced transient, varying battery SOC, grid disturbance and load unbalance. Proposed PV and BESS fed UPQC can be a feasible solution for the remotely placed low voltage industrial loads which are sensitive to voltage variation and additionally, it will provide green energy support. Further, the proposed work can be studied under various types of faults such as single line to ground fault, line to line fault etc as the future scope of the presented work.

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