Performance Analysis of Solar PV array and Battery Integrated Unified Power QualityConditioner for Micro-grid Systems

Nellore Meghana Bai[1], J.Suresh[2]

[1] PG Scholar, Audisankara College of Engineering & Technology, Gudur, nelloremeghana024@gmail.com

[2] Professor, Department of EEE, Audisankara College of Engineering & Technology, Gudur, suresh55j@yahoo.co.in

***Abstract*-An automated approach for switching between grid-connected and independent modes of operation for a solar PV array with a battery-integrated power quality conditioning system (PV-BUPQC) is described and studied in this study. A shunt and active filters in series are joined side by side using a shared DC-link in this arrangement. The method solves the problem of producing clean energy while simultaneously improving electricity quality. In addition, important loads are always powered regardless of grid availability because of the automatic transition. A PV-B-UPQC system's automatic transition with little impact on local loads is one of the main obstacles tackled. Experimental validation of the system operation is carried out under various dynamic conditions commonly encountered at a modern distribution network, including automated transition, electricity supply variations, grid unavailability, variation in the production of solar energy, load variation, and so on. Power quality, continuous power production, automated transition, solar photovoltaic generation, battery-powered storage, and a single quality conditioner for power are all terms that may be found in an index.**

I. INTRODUCTION

Power that is both controlled and of high quality is in high demand due to the proliferation of complex electronic equipment in places like data centers and the semiconductor industry. In addition, renewable energy is getting more attention, which means we're relying less on fossil fuels, which are finite resources that contribute to pollution and climate change [1, 2]. Renewable energy systems are necessary since they not only increase electricity quality but can continue to function even when the grid is down. Including a battery energy storage allows it to function independently. In addition, the energy stored in batteries may be used to mitigate power fluctuations caused by intermittent solar PV generation [3].

Recent studies have focused on multi-objective systems, which can increase both clean energy production and power quality. Research has mostly focused on topologies with shunt connections, which integrate solar inverter and Distribution Static Compensator (DSTATCOM) functionalities [4, 5]. A new approach to managing the power quality of PV power plants using the transformer integrated filter technology was introduced in [6]. On the other hand, unlike active filtering approaches, this approach is transformer design dependant and cannot be subsequently programmed.

In addition to injecting power from the PV array, topologies based on shunt compensation are able to compensate for nonlinear load current. Although these systems excel at addressing problems with current quality, they are unable to control the load voltage in the event of variations in PCC voltage. Power quality is enhanced by including series compensation with these systems. especially when linked to the grid, when it helps mitigate variations in PCC voltages and maintain a steady load voltage while compensating for poor load current quality [7]-[9]. There has been a lot of research on the distribution network's potential for improved power quality using a unified power quality conditioner (UPQC). There are a number of UPQC topologies that have been suggested for use with varying power levels and consumption needs [10]-[14].

Improving power quality, generating clean energy, and ensuring important loads always have access to power have recently been the targets of research into combining renewable energy with storage and specialized power devices [15]. When run independently, renewable energy systems rely on battery energy storage. When utilized for important loads, like hospitals or semiconductor companies, where a constant supply of high-quality power is vital, the system's higher battery cost is justified. The inclusion of utility system functionality is made possible by battery energy storage, which increases grid stability by smoothing the power pumped into the grid [16].

For the uninterrupted operation of the vital equipment linked to the system, it is essential to have an automated transition between islanded and grid connected modes. There has been research into the potential of several configurations of multi-functional systems that incorporate renewable energy sources and batteries for use in microgrid operations [17]. For photovoltaic (PV) arrays with integrated shunt compensation systems and batteries, a method for a smooth transition from freestanding to grid linked operation is suggested in [18]. It suggests controlling the system's power consumption using a self-normalized estimator. A single phase PV-battery integrated system has been suggested for minor residential operating needs [10], [19]. You may regulate voltage, compensate for load current quality, and generate clean energy by integrating renewable energy sources and storage with a UPQC system. Nevertheless, UPQC has its own set of problems that need fixing, such as how to transition with little impact on important loads, how to avoid series compensation while operating alone, and how to design the necessary control logic. Because PV-B-UPQC may run under voltage swells and sags, unlike traditional solar inverters, the voltage threshold must be considered during the smooth transition so that the system can continue operating until it enters independent mode. In [20], a plan for a smooth UPQC system transfer was laid forth. But there's a limit to how many cycles the system can correct for voltage sag before entering islanding mode. The findings are also predicated on software in loop simulations. This paper validates the system's performance by providing results on an actual scaled-down hardware prototype. Despite the description of islanded and grid interactive modes in [21], the DC-link storage system is absent from the system setup. The amount of PV electricity that the system generates has a significant impact on how well it operates in island mode.

II. RELATED WORK

[1] k. giri, s. r. arya, and r. maurya,are suggested as solutions to compensate for power quality issues such load balancing, neutral current compensation, and load current distortions in small-scale wind renewable energy systems operating in remote areas. This is achieved by operating the voltage source converted using an adaptive theory-based momentum least means square (MLMS) algorithm, which improves the system's power quality. Under mechanically and electrical transients, this control is also accountable for maintaining a steady voltage and frequency at the point where common interface. Furthermore, reactivity is also adjusted. In order to achieve better adaptation performance, the MLMS makes use of the previous gradient information rather than the present value. This is a modified oversight of the basic LMS. The reliance of weight convergence on choosing of the step measurement parameters is one of the drawbacks of LMS algorithms that this control has eliminated. It has also been noted that the MLMS algorithm works better with inputs that include a lot of noise. In wind-based power production, when all input conditions are unknown, the suggested control appears to be the best use. The whole system is built and tested within a real-time environment using MATLAB/SIMULINK. Everyone can see that the performance is paying off.

[2] S. Roy Ghatak, S. Sannigrahi, and P. Acharjee, are proposed to Regarding the smart grid setting, there is global agreement on the need for a significant amount of renewable energy sources (RESs) to address many social, economic, and technological issues. According to this view, a practical, effective, and intelligent solution to the power quality issues is to integrate RESs with a battery storage system (BSS) and a distributed static compensator (DSTATCOM). This research aims to optimize the technical, economic, plus ecological impact of the system by designing a complete strategic model to best combine RESs, BSS, and DSTATCOM. The existing planning framework uses new and logical formulae to evaluate the advantages. These include reliability indices, which measure predicted energy not offered, environmental benefit index, network voltage profiling improvement index, and benefit cost ratio. In order to strategically include the devices while considering the real security restrictions, a fuzzy-based enhanced version of the nondominant separating genetic algorithm, NSGA II (E_NSGA II) is used. Applying the suggested multi-objective method to a 69-bus radial distribution framework while taking time variant actual load models into account yields results that are compared to those of other multi-objective algorithms in order to confirm the method's effectiveness and efficiency.

[3] K. K. Prasad, H. Myneni, and G. S. Kumar, are proposed to The research suggests a strategy for optimizing the distribution static compensator's dc-link voltage according to the load compensation demand by combining a photovoltaic (PV) system with a reduced switches count multilevel converter (RSC-MLC). This approach may enhance power quality by adjusting reactive power, imbalance, and harmonics that are required by three-phase imbalanced and nonlinear loads that are linked to the distribution side. And when called upon, it may actually provide power assistance to the load, keeping the source from being overwhelmed. Reducing the dc-link voltage during off-peak loads decreases switching losses and voltage-stress across the inverter's switches. A dc voltage source is necessary for the change of the dc-link voltage to be supplied by RSC-MLC. This approach makes use of solar cells and other renewable energy sources to generate dc voltage. The PV panel's output voltage is increased by means of a high gain turbo converter before being sent to the RSC-MLC. Applying the Perturb and Observe method allows PV panels to monitor their greatest power points. The results were validated by means of computational and empirical investigations.

[4] Q. Liu, Y. Li, L. Luo, Y. Peng, and Y. Cao, are proposed to a novel approach to managing power quality in photovoltaic (PV) power plants including filtering inside the transformer. A two-stage filtering station, including a 110 kV grid-dependent transformer depending on the inductive filtering technique and a box-type transformer with an integrated filter, is an innovative component of the PV power plant. To achieve the adaptable layout of the passive filter and the box-type transformer, the filtering reactor may be incorporated as a decoupled winding. The grid-connected transformer's power quality is enhanced at the point where there is common coupling and the presence of harmonic resonance of the grid and the passive filter is reduced when the inductive filtering technique is used. The first step is to present the PV power plant's hierarchical structure. The next step is to create a mathematical model of the main filtering station and an analogous circuit model of the secondary filtering station. Additionally, the impact of the integrated reactor's weak coupling on filtering efficiency is examined. With parameter disturbance as a test case, we compare the inductive filtering technique's antijamming capabilities to those of the conventional filtering approach. Lastly, the site tests for the PV power plants with the transformer integrated filtering technique have been conducted. The results demonstrate that the PV grid-connected system, which includes a two-stage filtering station, exhibits excellent power factor, stable operation, and low harmonic emission.

[5] P. J. Chauhan, B. D. Reddy, S. Bhandari, and S. K. Panda, are proposed to offers a system for controlling a microgrid that operates independently, using a system that stores energy from batteries and a wind turbine generator with a fixed pitch and variable speed that cannot be dispatched. A unidirectional DC-AC convert connects the BES to the WTG at the point that experiences common coupling (PCC), whereas the WTG is simply interfaced with the PCC. The control strategy stands out because the BES uses active-reactive power compensation to regulate voltage and frequency at the PCC. It also makes sure that the WTG is properly synchronized and disconnected during variations in wind velocity. This allows for a smooth transition between operating modes with and without the WTG, and it ensures that critical loads are supplied uninterrupted. To prove the scheme's capabilities, we model and construct the control algorithm in a MATLAB/Simulink environment and evaluate its performance for each function and transition.

III. METHODOLOGY

Distribution Network Power Flow Analysis When evaluating the efficiency of power distribution networks and other electrical power systems, Power Flow Assessment (PFA) is an essential tool. Finding the power, current, and voltage values at various places in the system while taking into account things like generation, load, as well as network impedances is the primary goal of PFA. Using PFA, operators of distribution networks may better comprehend how the system reacts to changes in load, generation, including voltage swings, among other

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

---

operational circumstances. Conventional power systems, which depend on centralized transmission and generation, have traditionally been used for PFA. On the other hand, power flow analysis for distribution cables has become trickier due to the increasing integration of DERs such as PV systems. Problems with voltage profiles and power quality maintenance may arise as a result of distributed resources' introduction of bidirectional power flow.

Distribution Network Power Quality Problems What we mean when we talk about power quality is how well the power source can keep the voltage, frequency, as well as waveform characteristics constant. The incorporation of irregular loads, energy electronic devices, including renewable energy sources has made power quality a major challenge in contemporary distribution networks. The following are examples of distribution network power quality issues:

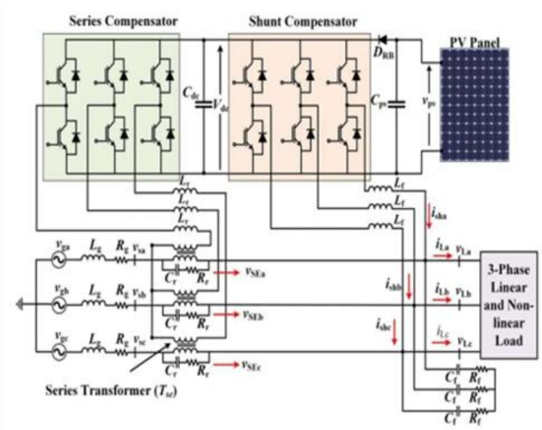


Fig 1 Structure of PV fed UPQC System

The control philosophy of PV-B-UPQC incorporates a bidirectional converter, SEC, and SHC. What follows is an expanded description of these subsystems.

Approach to Shunt Compensation and Control In normal situations, the SHC of PV-BUPQC operates in current control mode; in islanding conditions, it operates in voltage control mode. As seen in Figure 2, the shunt converter is shown in action. Dsync is the synchronization decision signal that controls the mode transition.

When operating in grid-connected mode, the SHC's principal role is to input PV electricity into the grid and compensate for load currents. With modest irradiation changes and load imbalance conditions, the SHC system is set up to feed electricity into the grid at a steady rate. A battery bank is used to acquire the extra power. Because of this, the distribution network becomes more stable as the electricity flowing into the grid becomes more uniform. By using the following formulas to the PCC voltage phase voltages, we may get the PCC voltage templates:

$$V_s = \sqrt{\frac{2}{3}(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)} \quad (1)$$

$$u_{sa} = \frac{v_{sa}}{V_s} u_{sb} = \frac{v_{sb}}{V_s} u_{sc} = \frac{v_{sc}}{V_s} \quad (2)$$

The reference power to be injected into grid P^*_{grid} is predetermined and based on this thereference current magnitude per phase (I^*_s) is evaluated.

$$I_s^* = \frac{2}{3}\frac{P_{grid}}{V_s} \qquad (3)$$

The instantaneous currents are calculated as follows,

$$i_{sa} = I_s^* \times u_{sa};\, i_{sb} = I_s^* \times u_{sb};\, i_{sc} = I_s^* \times u_{sc} \qquad (4)$$

In order to regulate the SHC, a hysteresis current regulator receives the reference currents and produces pulses. Isolated functioning of the SHC ensures that the load voltage remains constant regardless of changes in solar irradiation as well as load current. The digital signal processor microcontroller generates the phase for each of the voltage references inside. The immediate load voltage comparison is obtained by multiplying the voltage at the load reference by the sine of the three phases. This reference is then compared with the detected load voltages to get the load current reference. In standalone mode, the current controller for hysteresis compares the reference and detected load current and then creates gating signals that regulate the SHC.

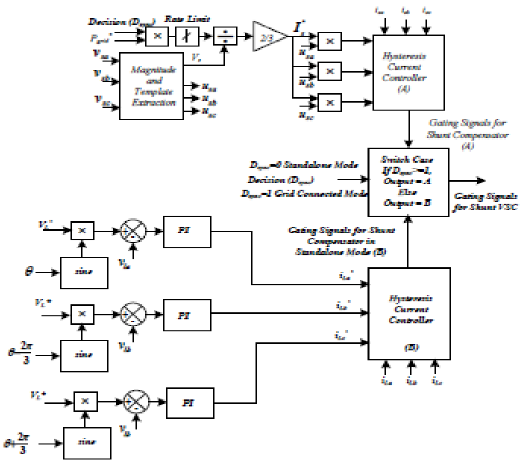


Fig. 2. Control of Shunt Compensator of PV-B-UPQC system

1) Fig. 3 shows the SHC's phase generating logic, which is used during islanded operation to generate the phase angle. When grid power is available and greater than 0.7 pu, the logic for phase generation synchronizes the phases of the load voltage with the grid voltage. This is accomplished by use of a pair of phase-locked loops (PLL), one for the load voltage and one for the grid voltage. A sine function block is used to smooth out any sudden fluctuations in the voltages of the PCC and the load, which are different in phase. A propoprtional-integral controller is entrusted with the task of creating a frequency component.

$$\Delta\omega_L = \{K_{psync} + \frac{K_{isync}}{s}\}\{\theta_s - \theta_L\} \qquad (5)$$

An integrator block is supplied this frequency component together with the load frequency; it then creates the phase for each of the three phases of the shunt VSC.

$$v_{La}^{*} = V_L^{*} sin(\theta) \quad (6)$$

$$v_{Lb}^{*} = V_L^{*} sin(\theta - \frac{2\pi}{3}) \quad (7)$$

$$v_{Lc}^{*} = V_L^{*} sin(\theta + \frac{2\pi}{3}) \quad (8)$$

As a result of the frequency shift, the load voltages will attempt to phase with the PCC voltages.

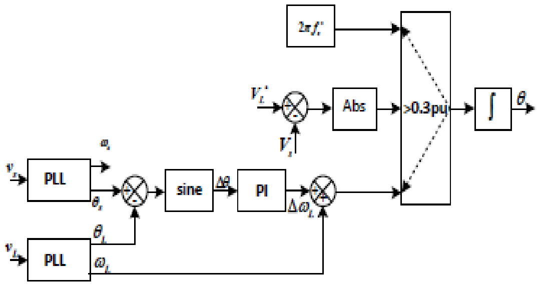


Fig. 3. Generation of Phase Angle during Islanded Operation

2) The control signal enable PES to connect or detach from the grid, as well as to change between islanded versus grid linked mode, is generated by the synchronization logic. The synchronization logic block diagram is shown in Figure 4. Four criteria are used to assess the synchronization logic output, including the phase difference between the PCC voltages and the load voltages.

The frequency at which the voltages supplied by the PCC and the load are different.

Voltages at the PCC and the load are different in magnitude. Mode of operation.

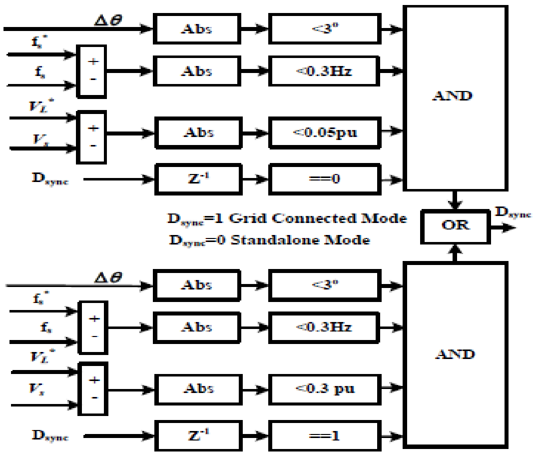


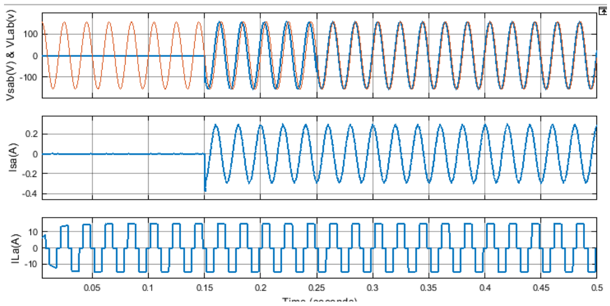
Fig. 4. Control Logic for Deciding Between Islanded Mode and Standalone Mode

From Figure 4, we can see that when the grid becomes accessible while operating in isolated mode, the system checks to see whether the phase variance between the PCC voltages and the load voltages is less than 3. In addition, it verifies whether the frequency difference is under 0.3 Hz and the magnitude difference is under 0.05 pu. We feed the results from each of these criteria into an AND computing block. Once the system is running in grid linked mode, the criteria for magnitude difference, frequency difference, and phase difference are verified once more. Under these circumstances, the tolerance for magnitude differences is up to 0.3 pu. We feed the results of these criteria into the AND logic. After receiving the results from both the AND logics, the ultimate synchronization decision, Dsync, is generated by the OR logic. With Dsync=1, the mode is grid linked, while with Dsyn=0, it is islanded.

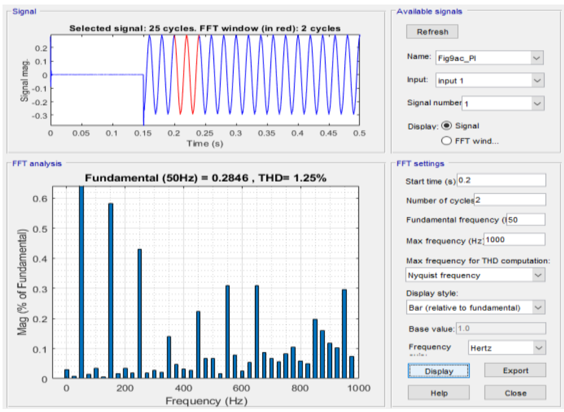
IV. EVALUATION AND SIMULATION OUTCOMES

By subjecting a prototype to a battery of dynamic situations in both grid-connected and independent modes of operation, we can assess the three-phase PV-B-UPQC's behavior.

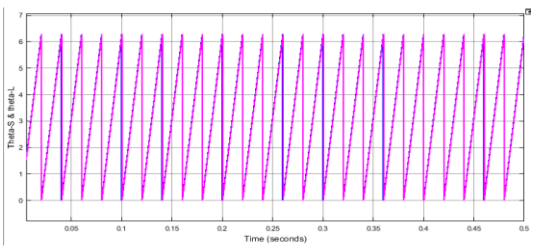
Integrated Power Quality Controller for Microgrid Systems: Analyzing the Performance of Solar PV Arrays and Batteries



(a) PCC and Load Side Signals During Synchronization

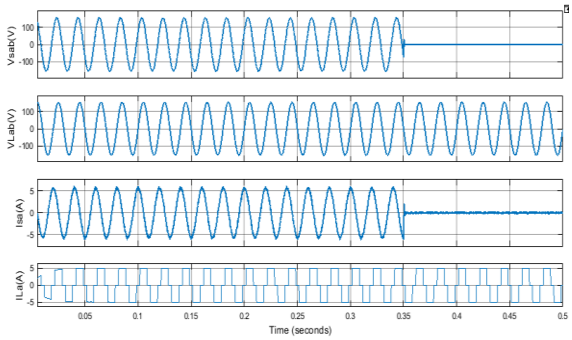


THD of Grid Current

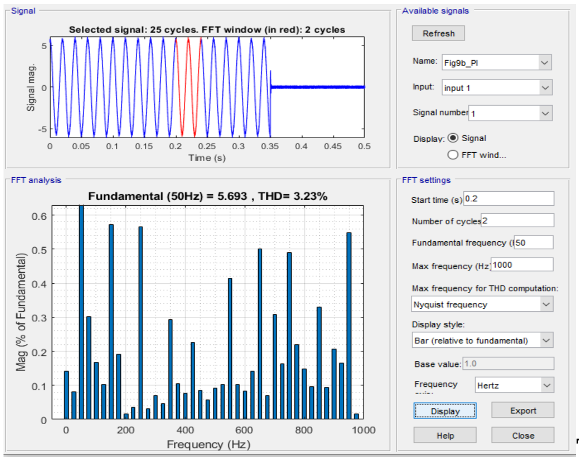


(c)Salient Signals of PV-B-UPQCDuring Synchronization

ISSN: 1001-4055
Vol. 45 No. 4 (2024)

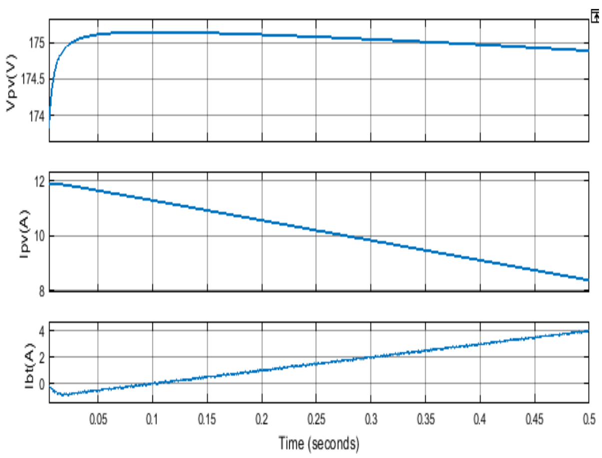


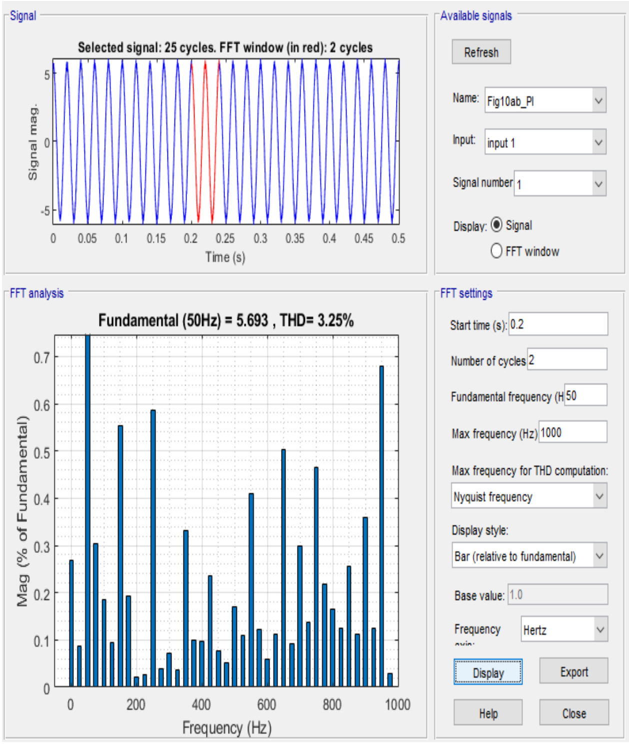
(b) PCC and Load Side Signals During Grid Fault Conditions



THD of Grid Current

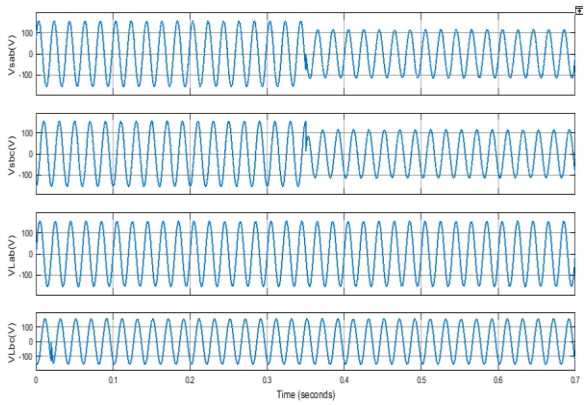
Fig. 9. Synchronization and De Syncrhonization Operation of Three Phase Three Wire PV-B-UPQC



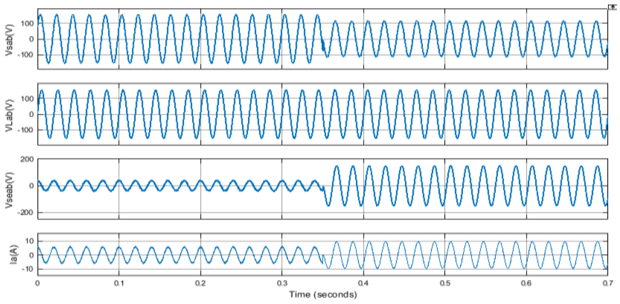


THD of Grid Current

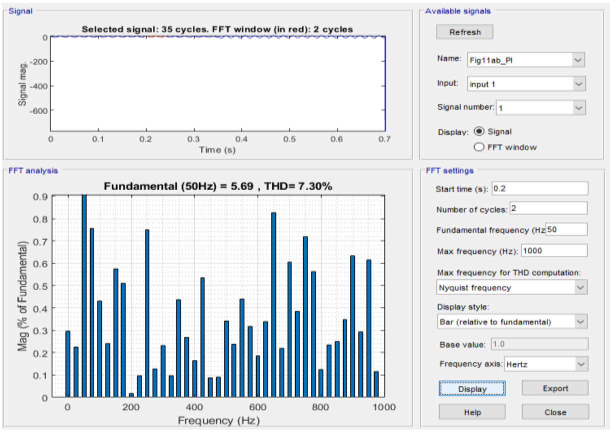
Fig. 10. Performance of Three Phase Three Wire PV-B-UPQC During Variation in Solar Irradiation



(a) Salient Signals During PCC voltage Sag



(b) PCC and Load Side Voltages During Sag in PCC Voltage



THD of Grid Current

V. CONCLUSIONS

This paper presents the design and efficacy of UPQC that integrates solar PV with batteries. In the event that the grid goes down, the system may continue to provide electricity to essential loads by running independently thanks to its battery bank, which stores energy. To top it all off, the technology smooths out power production by reducing power fluctuations caused by weather-related PV power generation. The whole system becomes more stable as a result of this. At steady state, the system behaves as expected, and the PCC currents are within the tolerances for total harmonic distortion (THD) set forth by the IEEE-519 standard. There has been much testing of the PV-B-UPQC's responsiveness in both grid-connected and freestanding configurations. Under a variety of situations, including varying irradiance, load imbalance, and PCC voltage sags and swells, the responsiveness of PV-B-UPQC is good. The PV-B-UPQC can continue to provide the distribution network with a steady stream of electricity even when faced with these disruptions. Without disturbing the sensitive or essential load, the system switches automatically between grid-tied and islanding operation. Systems running sensitive and important loads, including those found in servers, hospitals, and industries, where a constant supply of electricity is paramount, are ideal candidates for the three-wire PV-B-UPQC. Combining batteries with renewable energy sources reduces reliance on the electrical grid for peak demand power and allows excess PV electricity to go back into the grid to power neighboring loads at PCC.

REFERENCES

[1] S. Singh, B. Singh, G. Bhuvaneswari, and V. Bist, “A power quality improved bridgeless converter-based computer power supply,” IEEE Transactions on Industry Applications, vol. 52, no. 5, pp. 4385–4394, Sep. 2016.

[2] A. K. Giri, S. R. Arya, and R. Maurya, “Compensation of power quality problems in wind-based renewable energy system for small consumer as isolated loads,” IEEE Transactions on Industrial Electronics, vol. 66, no. 11, pp. 9023–9031, Nov. 2019.

[3] N. Saxena, I. Hussain, B. Singh, and A. L. Vyas, “Implementation of a grid-integrated pv-battery system for residential and electrical vehicle applications,” IEEE Transactions on Industrial Electronics, vol. 65, no. 8, pp. 6592–6601, Aug. 2018.

[4] S. Roy Ghatak, S. Sannigrahi, and P. Acharjee, “Multi-objective approach for strategic incorporation of solar energy source, battery storage system, and dstatcom in a smart grid environment,” IEEE Systems Journal, vol. 13, no. 3, pp. 3038–3049, Sep. 2019.

[5] K. K. Prasad, H. Myneni, and G. S. Kumar, “Power quality improvement and pv power injection by dstatcom with variable dc link voltage control from rsc-mlc,” IEEE Transactions on Sustainable Energy, vol. 10, no. 2, pp. 876–885, Apr. 2019.

[6] Q. Liu, Y. Li, L. Luo, Y. Peng, and Y. Cao, “Power quality management of pv power plant with transformer integrated filtering method,” IEEE Transactions on Power Delivery, vol. 34, DOI 10.1109/TPWRD. 2018.2881991, no. 3, pp. 941–949, Jun. 2019.

[7] T. A. Naidu, S. R. Arya, and R. Maurya, “Multiobjective dynamic voltage restorer with modified epll control and optimized pi-controller gains,” IEEE Transactions on Power Electronics, vol. 34, no. 3, pp. 2181–2192, Mar. 2019.

[8] K. Palanisamy, D. Kothari, M. K. Mishra, S. Meikandashivam, and I. J. Raglend, “Effective utilization of unified power quality conditioner for interconnecting pv modules with grid using power angle control method,” International Journal of Electrical Power and Energy Systems,vol. 48, DOI http://doi.org/10.1016/j.ijepes.2012.11.026, pp. 131 – 138, 2013.

[9] V. S. Cheung, R. S. Yeung, H. S. Chung, A. W. Lo, and W. Wu, “A transformer-less unified power quality conditioner with fast dynamic control,” IEEE Transactions on Power Electronics, vol. 33, no. 5, pp. 3926–3937, May. 2018.

[10] S. Devassy and B. Singh, “Performance evaluation of islanded and grid connected operation of solar pv-battery based universal active power filter,” in 2018 IEEE 8th Power India International Conference (PIICON), pp. 1–6, Dec. 2018.

[11] R. J. Millnitz dos Santos, J. C. da Cunha, and M. Mezaroba, “A simplified control technique for a dual unified power quality conditioner,” IEEE Transactions on Industrial Electronics, vol. 61, no. 11, pp. 5851–5860, Nov. 2014.

[12] B. Singh, A. Chandra and K. A. Haddad, Power Quality: Problems and Mitigation Techniques. London: Wiley, 2015.

[13] V. Khadkikar, “Fixed and variable power angle control methods for unified power quality conditioner: operation, control and impact assessment on shunt and series inverter kva loadings,” IET Power Electronics, vol. 6, no. 7, pp. 1299–1307, Aug. 2013.

[14] S. B. Karanki, N. Geddada, M. K. Mishra, and B. K. Kumar, “A modified three-phase four-wire upqc topology with reduced dc-link voltage rating,” IEEE Transactions on Industrial Electronics, vol. 60, no. 9, pp. 3555–3566, Sep. 2013.

[15] S. Devassy and B. Singh, “Implementation of solar photovoltaic system with universal active filtering capability,” in 2018 IEEMA Engineer Infinite Conference (eTechNxT), pp. 1–7, Mar. 2018.

[16] V. Rallabandi, O. M. Akeyo, N. Jewell, and D. M. Ionel, “Incorporating battery energy storage systems into multi-mw grid connected pv systems,” IEEE Transactions on Industry Applications, vol. 55, no. 1, pp. 638–647, Jan. 2019.