Superposed control strategies of a BESS for power exchange and microgrid power quality improvement

Markus Ovaskainen
Merus Power Dynamics Oy
Nokia, Finland
markus.ovaskainen@meruspower.fi

Jyri Öörni
Merus Power Dynamics Oy
Nokia, Finland
jyri.oorni@meruspower.fi

Aki Leinonen
Merus Power Dynamics Oy
Nokia, Finland
aki.leinonen@meruspower.fi

***Abstract*—A grid-connected battery energy storage system (BESS) has multiple applications as a grid supporting unit. Most common applications consider the ability of a BESS to decouple electric power generation and consumption in different contexts which is usually desirable from the grid operator point of view. A microgrid consisting of renewable energy sources connected with power electronic converters can experience difficulties with harmonic voltages and reactive inrush currents. Reactive currents may cause a voltage drop in the line impedances. Voltage fluctuations and harmonics can cause issues such as equipment tripping, overheating and malfunctioning. The stability of the microgrid is dependent upon the microgrid units' abilities to mitigate and compensate for these phenomena. A BESS can be used to simultaneously exchange active power between the battery and the grid and improve the power quality of a microgrid. With independent cascaded control of currents and active and reactive power, a BESS can control the reactive power balance in a microgrid and therefore ensure voltage stability. In addition, a BESS can serve as an active harmonic filter. Due to the transient nature of the described phenomena, these control schemes require control in real time. All the applications mentioned above can be realized simultaneously with suitable control design where the different controlled quantities are superposed. This paper reviews the technology of a BESS and the required control systems to realize the power quality features and presents simulation results as proof of their feasibility. The simulations demonstrate how a BESS can greatly contribute to microgrid stability while also performing active power exchange.**

Keywords—BESS, battery energy storage system, power quality, active harmonic filtering, dynamic reactive power compensation, microgrid

I. INTRODUCTION

Global energy production and consumption are continuously increasing. The use of traditional electrical energy sources pollutes environment which manifests in problems such as the climate change. These problems apply pressure to politicians to decrease the strain on the environment. The Paris Agreement [1], signed by almost all nations, sets the target of limiting the rise of the global temperature average to only 2°C. To meet this requirement, renewable energy sources must supersede the fossil fuel plants that have been the sources for most of the electrical energy generation thus far [2]. Due to their intermittent nature, the increasing penetration of renewable energy sources in the power system can cause challenges to the system stability. Energy storages have been recognized as a solution to overcome these challenges through their ability to decouple electricity consumption and production and as such, act as a stabilizing unit in the power system [3]. Among different options to store electrical energy, BESSs have advantageous qualities, such as pollution-free and efficient operation, high energy and power density, quick response time and flexibility [3]-[5]. The operation characteristics are dependent on the battery chemistry.

BESSs are connected to the grid with inverters which enable great flexibility in the control of the flow of electricity. Majority of the literature concerning energy storages focus on the abilities of a BESS to provide supporting active power in applications such as peak shaving, time shifting and frequency regulation. Advanced inverter real-time control methods allow the controlling of various quantities accurately beyond mere active power flow. This opens possibilities to use a BESS for power quality improvement alongside the active power exchange, as envisioned in [6]. Voltage sags and fluctuations caused by reactive power flow in power lines may cause problems to the units connected to the grid. The possibility to use an inverter coupled with an energy storage to control the output active and reactive power independently and thus compensate for the reactive power in the grid has been widely noted in the literature. In [7], a flywheel energy storage system was described in joint active power control and voltage conditioning through reactive power control. In [8], the voltage sags occurring in the Point of Common Coupling (PCC) of a small part of the grid were stabilized by Superconducting Magnetic Energy Storage System (SMES) by means of reactive power compensation. In [9] and [10], the use of the grid connected electric vehicle for local reactive power compensation was investigated. The use of a BESS in reactive power compensation in wind farms was described by various literature in [11]-[15], where it is used for both smoothing intermittent wind power generation and for power factor improvement. Apart from reactive power compensation, an inverter can be used to compensate voltage unbalance by controlling negative sequence currents as described by [16] and [17]. It is suggested in [17] that a BESS is specifically suitable for using sophisticated power quality control schemes because of its naturally stable DC-link. The BESS inverter can also be controlled to mitigate harmonic distortions in the grid. The methods to mitigate voltage harmonics described in the literature are based on canceling the harmonic currents in the grid by injecting opposite-phase harmonic currents such as described in [14], [16]-[19].

The active power exchange and mitigation of these power quality problems can be superposed. Simultaneous active harmonic filtering, reactive power compensation and peak shaving/load leveling has been demonstrated in [18] and [19]. This kind of versatile operation attests to the notable flexibility of a BESS in a power system. To the extent of the capacity of a given BESS, having all these functionalities available in the same unit, having multiple power quality conditioners such as Static Compensators (STATCOMs) and active filters may be rendered redundant.

Microgrids are self-contained electrical systems that can operate without a connection to distribution network [5]. The Distributed Energy Resources (DERs) installed in a microgrid, such as wind power systems, fuel cells, photovoltaic cells and gas turbines are typically interfaced with the grid with power electronic converters [20]. Power

978-1-7281-0653-3/19/$31.00 ©2019 IEEE

electronic converters facilitate versatile operation of the DERs but are also sources of harmonic currents. Besides the harmonics, because of the intermittent nature of DERs, a microgrid can experience active and reactive power fluctuations and voltage and frequency deviations. Microgrids are relatively small compared to wide area synchronous grids, and as such, less stiff in transient events. Thus, poor power quality may cause pronounced problems to the operation and jeopardize the reliability of the microgrid. Having a BESS as one of the elements in the microgrid could effectively address multiple power quality problems.

Present work aims to demonstrate the multi-purpose use of a BESS in a microgrid in controlling active power, reactive power and harmonic currents simultaneously. The purpose of this is to emphasize how a BESS should not be seen only as means to store energy, but as a system capable of locally improving power quality and grid stability in many ways. A control implementation capable of realizing this operation is introduced. The operation is simulated with MATLAB Simulink™ modeling software in a simple microgrid model.

II. BATTERY ENERGY STORAGE SYSTEM

A. Technology

A BESS is a system that is able to store electrical energy in a chemical form [4]. Various chemistries are used in a grid-scale BESS, such as lithium-ion and natrium-sulfide. The charging and discharging of energy may be performed at an arbitrary time within the limits of the battery capacity. It is interfaced with an electrical grid with an inverter or multiple parallel inverters. A grid-scale BESS is a system that consists of a self-contained battery with its own control and protection systems integrated in a Battery Management System (BMS). The BMS is required to ensure that the usage of the battery is safe and optimal, and for monitoring and supervisory control [4], [21]. The electrical terminals of the battery are connected to a DC-link which in turn is connected to the inverter terminals. A schematic illustration of the system is shown in Fig. 1.

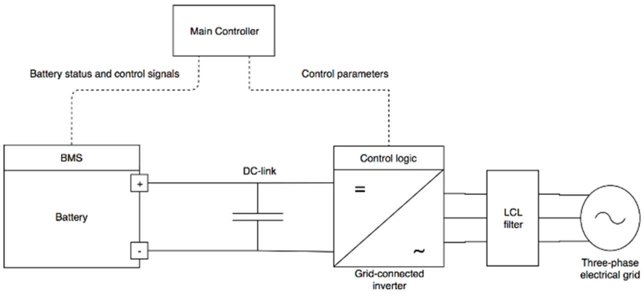

Fig. 1. A schematic illustration of a grid-connected BESS assembly.

The inverter consists of power semiconductor switches that are switched in high frequency in such a way that an approximate of the desired voltage waveform appears in the inverter output. The switches are typically Insulated-Gate Bipolar Transistors (IGBTs). The control of the switches in a coordinated manner is called modulation. In this paper the modulation technique is assumed to be Pulse-Width Modulation (PWM)-based. The inverter has a grid-side passive filter to smoothen the voltage waveform and eliminate switching frequency harmonics from the output.

The DC-link contains a capacitor (or capacitors, depending on the inverter topology) which is capable of absorbing or discharging transient currents that the inverter generates in rapid switching action. The DC-link voltage is controlled by the battery.

B. Applications

Most of the literature concerning the applications of a BESS concern exchanging active power with the grid and thus enabling time shifting energy consumption or production. Concurrent electrical grids operate so that the momentary consumption has to match with the production. If a notable proportion of the generating units of the grid are renewable energy sources, the power balancing may prove challenging due to the fact that the production of the renewables can’t be predicted with arbitrary precision. A BESS can meet this challenge by buffering the momentary power imbalance. This way the power generation and consumption only have to be in balance on average. Other general applications have to do with the flexibility of the power dispatch. BESS can be used as a backup power source if enough energy is stored in the battery. The battery can also be used as the leading unit of a microgrid black start [22]. Examples of these applications are presented in the following.

1) Peak Shaving

Peak shaving refers to using a BESS to inject active power to the grid during times of peak consumption or generation to stay below a predetermined power limit at the PCC. This makes it possible to avoid extra investments in generation to meet the peak demand. It also enables electricity price arbitrage by storing the generated energy peaks during low electricity price and selling it during higher price. Peak shaving operation can be particularly beneficial in a microgrid, where the expensive startup of reserve diesel generators (with related maintenance costs) can be avoided by providing the extra power from a BESS during peak demand [23]. From a technical point of view, the application requires control of the flow of active power, and a set point of the PCC power limit which determines when the extra power is dispatched.

2) Frequency regulation

Grid frequency is an indicator of the match between electricity consumption and production. To maintain the power balance in the wide area synchronous grid, dedicated frequency containment reserves are used to automatically adjust their power as a function of the grid frequency. In this operation mode the BESS is emulating the operation of a synchronous generator: it dispatches power to the grid whenever the frequency drops lower than the nominal and consumes power whenever the frequency is too high. This is done automatically by adjusting the output power based on the measured frequency.

3) Microgrid voltage and frequency control

A BESS can be used as a grid forming element in a microgrid due to the flexibility of the power dispatch. A BESS can be controlled as a voltage source that provides its own frequency reference when following the voltage phase angle of the mains is not possible because of a disconnection. Other inverter-interfaced loads in the microgrid can then follow the frequency generated by a BESS and be controlled as current sources. Other option is that all of the inverters can operate as droop-controlled voltage sources for automatic load sharing [24]. A BESS can also be used for a microgrid black start, where the voltage is ramped up slowly to control inrush currents caused by reactive loads such as transformers, transmission lines and direct online electrical motors.

III. CONTROL DESIGN

To realize the various applications of a BESS, the control system should be able to control the active and reactive power flow whenever there is a frequency reference available, and if a BESS is used as a voltage source, the voltage should be explicitly controlled. Independently of these control objectives, a BESS should also be able to control the harmonics and the reactive power in the network. The control of the IGBTs is realized with Space Vector Pulse Width Modulation (SVPWM), which requires a voltage vector in the stationary reference frame as an input. The conversion to this reference frame for arbitrary three-phase quantities is done with Clarke transformation [25]:

$$\begin{bmatrix} x_\alpha \\ x_\beta \\ x_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}, \tag{1}$$

where x_α, x_β and x_0 are arbitrary stationary reference frame quantities and x_a, x_b and x_c arbitrary three-phase quantities. Because the control of the instantaneous three-phase quantities is difficult as AC quantities, a reference frame transformation is applied to obtain DC quantities in the synchronous reference frame (dq-frame). This can be done for arbitrary three-phase quantities with Park transformation [25]:

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \begin{bmatrix} \cos\theta_s & \cos(\theta_s - \frac{2\pi}{3}) & \cos(\theta_s + \frac{2\pi}{3}) \\ -\sin\theta_s & -\sin(\theta_s - \frac{2\pi}{3}) & -\sin(\theta_s - \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}, \tag{2}$$

where x_d, x_q and x_0 are arbitrary synchronous reference frame quantities and θ_s the synchronous phase angle. To obtain phase quantities, the same transformation can be applied in inverse. In the dq-frame, the fundamental components of the grid currents and voltages correspond to pure DC quantities. To control the currents directly, a relationship between the voltage reference for the SVPWM and the currents must be established. If we neglect the resistance in the LCL filters and the 0-component in the analysis, the voltage at the LCL filter terminals can be written in the dq-frame as follows [26]:

$$U_{d,lcl} = L_s \frac{d}{dt} I_{d,s} + L_r \frac{d}{dt} I_{d,r} - \omega_s \left(L_s I_{q,s} + L_r I_{q,r} \right), \tag{3}$$

$$U_{q,lcl} = L_s \frac{d}{dt} I_{d,s} + L_r \frac{d}{dt} I_{d,r} + \omega_s \left(L_s I_{d,s} + L_r I_{d,r} \right), \tag{4}$$

where $U_{d,lcl}$ ja $U_{q,lcl}$ are the voltages at the LCL filter terminals, L_s, $I_{d,s}$ ja $I_{q,s}$ the grid-side reactor inductance and currents, L_r, $I_{d,r}$ ja $I_{q,r}$ inverter-side reactor inductance and currents and ω_s the synchronous frequency of the network. The harmonic components emerge as AC components in the dq-frame. In this implementation of the control, regardless of whether the inverter is operating as a current source or a voltage source, the inner control loop is always current controller, presented in Fig. 2. The control design includes voltage feedforward to increase the inverter output impedance which decreases the probability for harmonic resonance to occur. The outer control loop can control active and reactive power or voltage d- and q-components according to the desired operation.

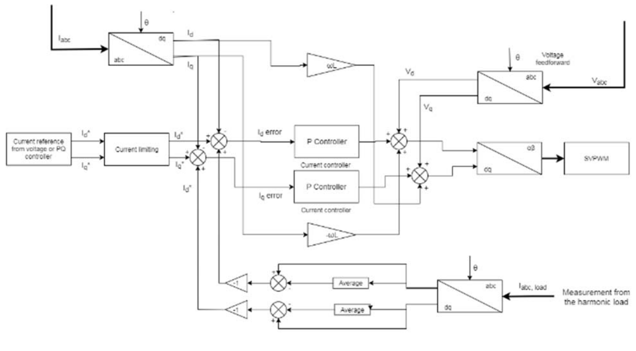

Fig. 2. BESS current controller. Bold lines represent buses which carry more than one signal.

This implementation enables superposing different strategies for current reference creation. As shown in Fig. 2, the current reference is created from the sum of the reference from the PQ/voltage controller and from the harmonic mitigation reference. The reference for canceling the measured harmonics is created in the dq-frame so that the average of the measured current d- and q-component (the DC component which corresponds to fundamental active and reactive power) is subtracted from the measurement and the resultant d- and q-components are inverted. For simplicity, it is assumed that the measured current with harmonic components corresponds to the load current only. This means that the harmonic content in the network is not controlled since there is no additional measurement from the PCC. If the measured current is the network current, the output of a BESS has to be subtracted from the measurements. A simple P-type controller is used for current control for simplicity. When the outer controller loop contains a PI controller, as with the control schemes in this case, the steady-state error of the inner control loop (caused by P-type control) is irrelevant, as the outer control loop ensures that the parameters controlled in outer control loop do not contain steady-state error.

The outer control loop is selected based on the application. A PQ control scheme is used to control the active and reactive power independently. In this mode of control, the inverter is operating as a current source and it requires an external frequency reference. The active and reactive power values are calculated from the fundamental network voltage and current. The active and reactive powers have to be decoupled by filtering the feedback quantities with a low-pass filter. In the voltage control scheme, the inverter operates as a voltage source and its output current is adjusted automatically to maintain the voltage at the point of measurement. To control the active and reactive powers in the PQ control scheme, the instant active and reactive powers have to be calculated in real time so that they can be fed as feedback to the controller. The calculation is carried out in the synchronous reference frame with [26]:

$$P = \frac{3}{2} \left(v_d i_d + v_q i_q \right), \tag{5}$$

$$Q = \frac{3}{2}\left(v_q i_d - v_d i_q\right), \tag{6}$$

where v_d, v_q, i_d and i_q correspond to the synchronous reference frame voltage and current quantities. The PQ control scheme is illustrated in Fig 3.

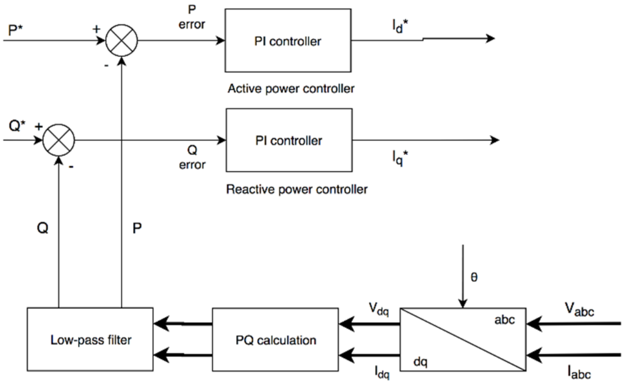

Fig. 3. The outer PQ control loop.

If a BESS is used as a standalone voltage source, it can produce its own frequency reference. In case an external frequency reference is used, as is necessary with PQ control, the grid phase angle needs to be tracked. In a three-phase network, the grid phase angle can be detected from the grid phase voltages with a Synchronous Reference Frame Phase-Locked Loop (SRF-PLL) [27]. The control diagram of the SRF-PLL is shown in Fig. 4.

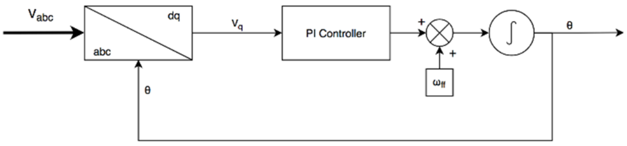

Fig. 4. SRF-PLL.

The SRF-PLL has its internal control loop that strives to maintain the v_q component of the grid voltage at zero, which corresponds to where the output phase angle is locked to the grid phase angle.

IV. SIMULATIONS

A. Microgrid model

The BESS operation in a simplified microgrid is simulated with MATLAB Simulink simulation software. The microgrid contains a natural harmonic current and reactive power source. The purpose of the simulation is to elaborate on the possibility to use a BESS for simultaneous active power exchange, reactive power compensation and harmonic mitigation. Voltage control is omitted in this simulation. The microgrid model used in the simulation is presented in Fig. 5. The power lines are modeled as pi-section lines.

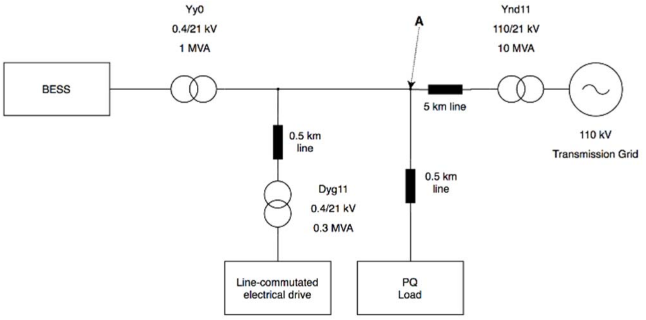

Fig. 5. The microgrid model used in the simulations.

Point A indicates the PCC in the model where the measurements are taken. The electrical drive controls an induction machine with a frequency converter. The rectifier is a diode-bridge, which is a source of harmonics and reactive power in the grid. The PQ load is a generic Simulink block which acts as an ideal current sink or source in the grid. The nominal power of the BESS is chosen to be 200 kW and the power electronic components used in the inverter modeling are chosen accordingly. The transmission grid is modeled with its own internal impedance. The BESS is chosen to operate in a peak shaving mode so that the active power drawn by the loads from the grid should not exceed 100 kW. It is used simultaneously to compensate all of the reactive power produced by the electrical drive and all harmonic currents the drive generates. It is assumed in the model that the reference for the required active and reactive powers is available from direct measurements. The electrical drive and the PQ load are used at an arbitrary load level.

B. Results

The system is simulated for five seconds in two cases – in the other the BESS is operating in peak shaving mode, compensating reactive power and filtering harmonics at the same time, and in the other case the BESS is neglected in the microgrid. Fig. 6 shows the active and reactive powers at the PCC during both simulations. Fig 7. presents the active and reactive powers of the BESS in the case where it is operational. The polarity of the active and reactive powers is inverse to the ones at the PCC.

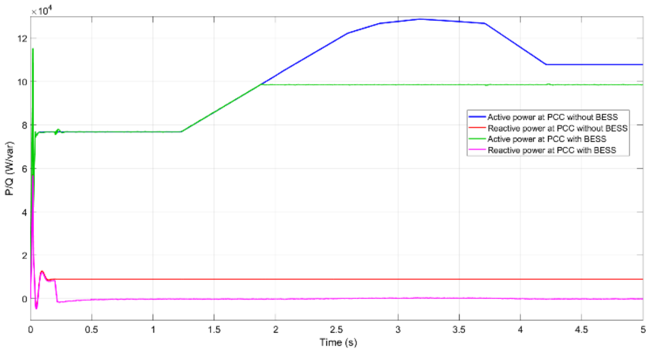

Fig. 6. The active and reactive powers at the PCC.

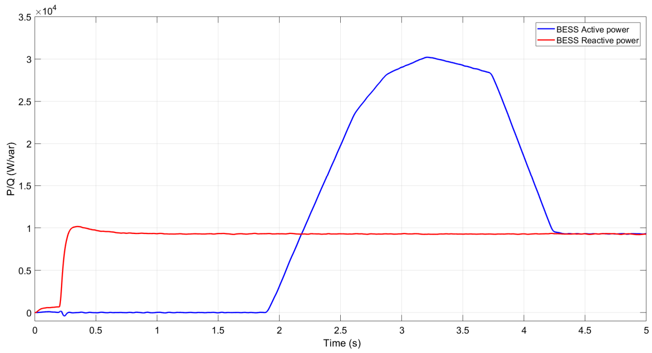

Fig. 7. The active and reactive powers of the BESS.

When the BESS is operational, the active power is limited to 100 kW and the reactive power is compensated to zero in the PCC as was desired. Fig. 8 shows the current waveform at 3 seconds at the PCC when the BESS is not operating as an active harmonic filter. Figure 9. shows the harmonic spectrum and THD.

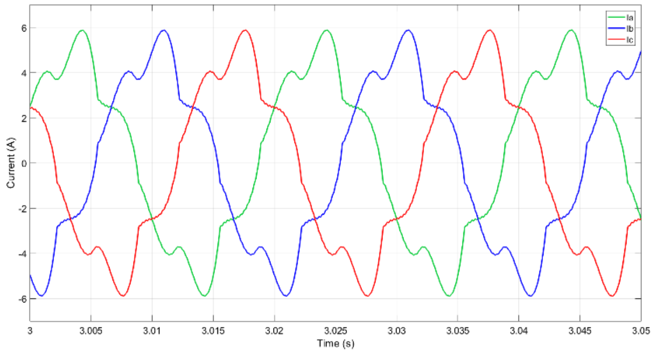

Fig. 8. The phase currents at the PCC without active harmonic filtering.

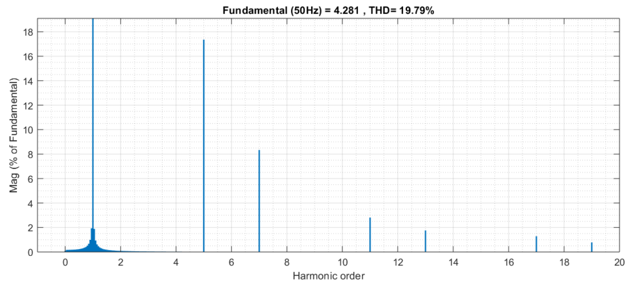

Fig. 9. The harmonic spectrum of the currents at PCC without active harmonic filtering.

Fig. 10 shows the current waveform and Fig. 11 the harmonic spectrum and THD when the BESS is mitigating the harmonics. When compared to the waveform at the case where BESS was not operational, harmonic distortion is greatly reduced and the waveform close to sinusoidal. In addition, the peak current has been reduced.

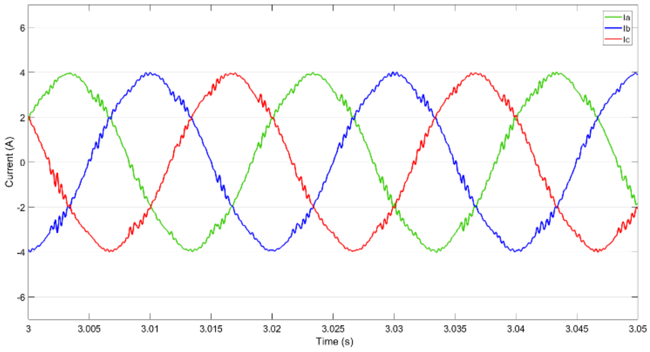

Fig. 10. The phase currents at the PCC with active harmonic filtering.

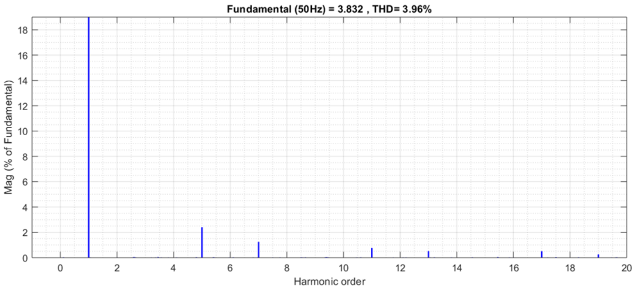

Fig. 11. The harmonic spectrum of the currents at PCC with active harmonic filtering.

The results show that the BESS is capable of addressing these three control tasks at the same time thus improving the grid power quality greatly. The performance and precision of the simulated system depends on the control system type, its tuning and simulation step time. The capability of the power calculation to isolate only the fundamental power by filtering is also relevant, since additional harmonic components would be fed to the control system and thus cause additional harmonics in the output.

V. CONCLUSIONS

This paper has presented a review of technology of a BESS and a control system required to control active and reactive power and current harmonics in the grid. The simultaneous multi-purpose use of the system was demonstrated with simulations in MATLAB Simulink. A BESS may be regarded as an extremely flexible unit as a part of a microgrid due to its capability to simultaneously perform in various control tasks. The reviewed control system exhibits minimum performance for real usage.

Future work will constitute of choosing the most adequate controllers for each control task and dynamic analysis of the control dynamics. The performance of the control needs to be proven in transient events. The voltage control of a microgrid during transients with simultaneous harmonic mitigation requires further study. In larger BESSs several parallel inverters are required to reach higher power output. The interaction of parallel inverters in control dynamics is another relevant study topic.

REFERENCES

[1] United Nations, "Paris Agreement," 2015.

[2] O. Edenhofer, R. Pichs-Madruga, Y. Sokona, and K. Seyboth, "IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation," Cambridge, United Kingdom and New York, NY: Cambridge University Press, 2011.

[3] X. Luo, J. Wang, M. Dooner, and J. Clarke, "Overview of current development in electrical energy storage technologies and the application potential in power system operation," Applied Energy, vol. 137, (Supplement C), 2015, pp. 511-536.

[4] B. Dunn, H. Kamath and J. Tarascon, "Electrical Energy Storage for the Grid: A Battery of Choices," Science, vol. 334, issue 6058, 2011, pp. 928-935.

[5] F. Díaz-González, A. Sumper and O. Gomis-Bellmunt, "Energy Storage in Power Systems," New York: John Wiley & Sons. 2016.

[6] K. K. Leung and D. Sutanto, "A new topology of a battery energy storage system," 1998 International Conference on Energy Management and Power Delivery, vol. 1, 1998, pp. 253-258.

[7] H. Akagi, "Active filters and energy storage systems for power conditioning in Japan," 2004 First International Conference on Power Electronics Systems and Applications, 2004, pp. 80-88.

[8] M. R. Alizadeh Pahlavani, "Compensation of Reactive Power and Sag Voltage Using Superconducting Magnetic Energy Storage System," in Power Quality - Monitoring, Analysis and Enhancement, Zobaa, Ahmed F. [Online]. Available: https://www.intechopen.com/books/power-quality-monitoring-analysis-and-enhancement/compensation-of-reactive-power-and-sag-voltage-using-superconducting-magnetic-energy-storage-system. [Accessed Feb. 15, 2019]. 2011, pp. 255-279.

[9] C. Silvestre, D. M. Sousa and A. Roque, "Reactive power compensation using on board stored energy in Electric Vehicles," IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society, Montreal, QC, 2012, pp. 5227-5232.

[10] S. Golshannavaz, "Cooperation of electric vehicle and energy storage in reactive power compensation: An optimal home energy management system considering PV presence," Sustainable Cities and Society, vol. 39, 2018, pp. 317-325.

[11] J. Zeng, B. Zhang, C. Mao and Y. Wang, "Use of Battery Energy Storage System to Improve the Power Quality and Stability of Wind Farms," 2006 International Conference on Power System Technology, Chongqing, 2006, pp. 1-6.

[12] S. Kirmani and B. Kumar, "Power quality improvement by using STATCOM control scheme in wind energy generation interface to grid," IOP Conference Series: Earth and Environmental Science, vol. 114, 2018.

[13] E. Muljadi, C. P. Butterfield, R. Yinger, and H. Romanowitz, "Energy Storage and Reactive Power Compensator in a Large Wind Farm: Preprint," National Renewable Energy Laboratory, U.S. Department of Energy, Golden, CO, 2003.

[14] J. Mundackal, A. C. Varghese, P. Sreekala, and V. Reshmi "Grid power quality improvement and battery energy storage in wind energy systems," 2013 Annual International Conference on Emerging Research Areas and 2013 International Conference on Microelectronics, Communications and Renewable Energy, Kanjirapally, 2013, pp. 1-6.

[15] S. M. Muyeen, R. Takahashi, T. Murata, J. Tamura and M. H. Ali, "Application of STATCOM/BESS for wind power smoothening and hydrogen generation," Electric Power Systems Research, vol. 79, Issue 2, 2009, pp. 365-373.

[16] J. M. Guerrero, P. C. Loh, T. L. Lee, and M. Chandorkar, "Advanced Control Architectures for Intelligent Microgrids-Part II: Power Quality, Energy Storage, and AC/DC Microgrids," in IEEE Transactions on Industrial Electronics, vol. 60, no. 4, pp. 1263-1270, April 2013.

[17] L. Xu, Z. Miao, L. Fan, and G. Gurlaskie, "Unbalance and harmonic mitigation using battery inverters," 2015 North American Power Symposium (NAPS), Charlotte, NC, 2015, pp. 1-6.

[18] M. I. H. Omer, "Peak Load Shaving and Power Quality Improvement for the Louis-Hippolyte-La Fontaine Tunnel in Montréal," Master´s thesis, Dept. of Electrical and Computer Engineering, Concordia University, Montréal, Québec, 2018.

[19] B. Singh, R. Niwas and S. Kumar Dube, "Load Leveling and Voltage Control of Permanent Magnet Synchronous Generator-Based DG Set for Standalone Supply System," in IEEE Transactions on Industrial Informatics, vol. 10, no. 4, pp. 2034-2043, Nov. 2014.

[20] T. Hornik, "Power Quality in Microgrids," Doctoral dissertation, University of Liverpool, Liverpool, 2010.

[21] M. T. Lawder et al., "Battery Energy Storage System (BESS) and Battery Management System (BMS) for Grid-Scale Applications," in Proceedings of the IEEE, vol. 102, no. 6, pp. 1014-1030, June 2014.

[22] J. P. Lopes, C. L. Moreira and F. O. Resende, "Micrograds black start and islanded operation," 15th Power systems computation conference (PSCC), Session 27, Paper 4, Liege, 2005.

[23] A. Oudalov, R. Cherkaoui and A. Beguin, "Sizing and Optimal Operation of Battery Energy Storage System for Peak Shaving Application," 2007 IEEE Lausanne Power Tech, Lausanne, 2007, pp. 621-625.

[24] J. A. P. Lopes, C. L. Moreira and A. G. Madureira, "Defining control strategies for MicroGrids islanded operation," in IEEE Transactions on Power Systems, vol. 21, no. 2, pp. 916-924, May 2006.

[25] B. Wu, Y. Lang, N. Zargari, and S. Kouro, "Power Conversion and Control of Wind Energy Systems," Hoboken, N.J: Wiley, 2011.

[26] R. Teodorescu, M. Liserre, and P. Rodríguez, "Grid Converters for Photovoltaic and Wind Power Systems," Hoboken, N.J: Wiley, 2010.

[27] T. Suntio, T. Messo and J. Puukko, "Power electronic converter: dynamics and control in conventional and renewable energy applications" Weinheim: Wiley, 2017.