Hybrid PV-Wind System With Power Quality Improvement Using PV-DVR

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Abstract: Owing to the rapid growth of Renewable Energy Sources, Microgrid finds greater significance in satisfying consumer need in today’s world. However, the increased number of Distributed Energy Resources might introduce power quality issues in a grid connected microgrid system due to the intermittent nature of such natural resources and power electronic converters associated with their conversion. So as to compensate such power quality issues, this paper proposes a Custom Power Device (CPD) namely Photovoltaic-Dynamic Voltage Restorer (PV-DVR), which uses a PV as a source for the Battery Energy Storage System (BESS). A PMSG driven PV Microgrid system with a MPPT controller for maximum power extraction from PV source and a hysteresis controller for effective grid synchronization and lesser harmonic distortion is taken for analysis. The dynamic performance of the grid connected microgrid system with DVR is analyzed for various loads and different power quality issues like voltage sag/swell, harmonics, interruption etc. Wavelet Transform based switching controller is used to detect the power quality event occurring and operate the PV-DVR accordingly.

1. Introduction

In the contemporary developing world, the reproducing populace and rising enterprises has expanded the critical need of power. In addition, inferable from the creating innovations, the expanded number of electrical machines have modernized and facilitated the human life. Thus, the power has become the essential need to private, business just as modern customers. In spite of the need, the electrical force utilization is outperforming the electrical force creation, which is currently draining the regular wellsprings of energy like coal, oil and so forth. Accordingly, the limitless and normally recharging sustainable power sources like breeze, water, daylight, tides geothermal warmth and different types of biomass, is increasing more significance, supplanting the lessening non-sustainable power sources.
Besides, the clean sustainable force produces zero burning dissimilar to dirtying petroleum derivatives[1]. Along these lines, the Appropriate Energy Assets (DER) like Sun based and wind energy are decisively changing the ordinary dispersion network with the incorporation of little scope Conveyed Generators, shaping a microgrid (Küçüker et al., 2017; Mahmoud et al., 2014).

A Microgrid is an electrical where the neighborhood loads are provided by nearby age. Such a group of burdens and DERs with characterized electrical limits, can work either in correspondence with the matrix under framework associated mode or as an islanded mode. The microgrid and the utility matrix can go about as supplement for one another in the midst of expanded burden request[2]. In any case, synchronizing the microgrid with the utility network is a more noteworthy test. At the point when the synchronization isn't done viably, recurrence bungle and a few other force quality issues emerge, which lessens the proficiency of the framework.

In current situation, the swelled number of non-straight loads, abrupt turning on/off of hefty loads and blames in the lines have expanded the event of different force quality occasions and issues. Also, the discontinuous idea of the Sustainable power sources in the microgrid, which are irregular in nature and force electronic converters related with them, which present consonant bends have additionally expanded the opportunity of intensity quality issues in the framework. The standard boundaries that characterize the nature of intensity exceeded can be named as voltage, recurrence, power factor, responsive force and consonant substance, of which voltage and recurrence are the most significant ones. Consequently, voltage and recurrence of the framework must be kept up inside the endorsed run in order to accomplish compelling synchronization with the lattice and clean capacity to the customers.

The generally watched power quality issues are voltage list, voltage swell, interference, glint, music, drifters, indent and so forth. In earlier many years, Adaptable Air conditioning Transmission Framework (Realities) gadgets like StaticCoordinated Compensator (STATCOM), Static Simultaneous Arrangement Compensator (SSSC), Bound together Force Stream Regulator (UPFC) were regularly utilized for upgrade of such force quality issues (Sunil and Loganathan, 2012) [3]. Custom Force Devices (CPD) like Unique Voltage Restorer (DVR), Appropriation Static Simultaneous Compensator (DSTATCOM) and Bound together force quality conditioner (UPQC) are prevalently utilized for upgrade of intensity quality, out of which DVR is similarly more proficient attributable to its quick reaction, little size and ease.

Distinctive control techniques for the DVR have been created by numerous scientists (Rauf and Khadkikar, 2015; Roncero-Sanchez et al., 2009). Control strategies dependent on simultaneous Reference outline (SRF) hypothesis (SRFT) is accounted for in (Kanjiya et al., 2013). The rating and plan of arrangement infusion transformer of the DVR is introduced in (Rauf and Khadkikar, 2015). Many examination works have been completed in the identification of voltage aggravations (Costa, 2014; Masoum et al., 2010; Beam et al., 2012)[4]. Such an identification procedure broadly utilized is wavelet change (Saleh, 2008). Notwithstanding, these recognition methods faces more difficulties when associated with an utility framework, as any force quality issue may straightforwardly influence the heaps associated with the matrix (Chankhamrian et al., 2014).

This paper presents a photovoltaic (PV) cluster took care of three stage Dynamic Voltage Restorer (DVR) for voltage pay of the microgrid framework. Other than voltage guideline, the proposed DVR decreases the energy utilization by appropriating sunlight based force from PV cluster to nearby DC and air conditioning loads through effective converters[5].

2. Microgrid

Fig.1 shows the square chart of proposed microgrid framework with Dispersed Fuel Sources like Sun based and Wind and Custom Force Gadget associated with touchy burdens for security against any force quality issues. The microgrid or DG framework which is totally founded on a solitary source, may be inclined to greater unwavering quality issues because of the discontinuous and arbitrary nature of the normal Inexhaustible sources. Consequently, a half and half microgrid with more DG’s are exceptionally dependable. Notwithstanding, as the sustainable power source coordination expands, the expanded number of DGs would offer ascent to more power quality issues.

In this work, a cross breed Microgrid framework (Singaravel and Daniel, 2015), which is a breeze driven PV source is picked. Here, the breeze energy drives a Lasting Magnet Coordinated Generator (PMSG), which is an immediate drive and doesn't need any apparatus box game plan, not at all like in Enlistment Generators. The PMSG yield, which shifts with wind speed, is corrected through an uncontrolled rectifier and took care of into a DC-DC buck help converter. The rectifier yield voltage, which changes with the breeze speed, is constrained by obligation cycle control of the DC-DC converter. The PV cluster terminals are attached to the yield of the DC-DC converter for the proposed framework to shape a typical DC interface between the DC-DC converter and the inverter. Due to this setup, the PV exhibit voltage (VPV) and the yield voltage of the DC-DC converter (VDC) are fixed. A MPPT regulator (Subudhi and Pradhan, 2013), which utilizes The essential Irritate and Watch (P&O) calculation controls the yield voltage of the DC-DC converter consequently as indicated by the greatest force point voltage of the PV exhibit, to fix both the voltages to a similar level[6].
The DC-DC converter is taken care of by a firm DC source (rectifier yield) rather than the PV cluster. Consequently, the Hysteresis current (Regulator 2), which controls the inverter, capacities with the end goal that it draws the greatest current from the PV hotspot for the given light.

**Figure 1.** Block diagram of proposed microgrid system

The hysteresis regulator additionally controls yield voltage of the current controlled inverter to such an extent that it synchronizes with the voltage, recurrence and period of the utility network. So as to draw greatest current from both PMSG and PV exhibit, the current took care of to the framework by the inverter is made to follow the reference current sign (Iref).

In any case, as the sustainable power source coordination expands, the force quality issues like voltage list, voltage swell, sounds, interference, homeless people and so forth become dominating, contaminating the force provided to the network. Thus, a framework associated microgrid framework is in extraordinary requirement for a force quality regulator. Here, Custom Force Gadget (CPD) specifically, Dynamic Voltage Restorer (DVR) is associated with touchy and basic burdens at the Purpose of Basic Coupling (PCC) in order to make up for such force quality issues.

### 3. Dynamic Voltage Restorer (DVR)

The voltage source converter (VSC), infusing transformer and DC interface capacitor are the premier significant segments of DVR. The DVR, not just improve the nature of yield voltage and current in disseminated framework, yet additionally give some additional remuneration ability to the neighboring network [7]. The he entryway heartbeats to the voltage source converter is created by a regulator dependent on numerous hypotheses. In this work, Coordinated Reference Edge (SRF) hypothesis (Singh et al., 2015) along with hysteresis control is utilized for creation of PWM beats [6]. The framework voltage, load voltage and reference voltage esteems are used to likewise deliver door beats, which further controls the arrangement infused voltage for pay. All in all, DC interface capacitor of DVR can be of two sorts: I. Battery-upheld, and ii. Self-upheld (capacitor upheld).

The remuneration voltage infused without anyone else upheld DVR is in quadrature with line current; subsequently, it doesn't need any dynamic force during consistent state. In any case, its fundamental impediment is that, the remunerated voltage delivered by DVR may not be in stage with the pre-hang or pre-swell voltage. In this manner, oneself upheld DVR is utilized just when the stage bounce, brought about by the quadrature voltage infusion, is reasonable (Singh et al., 2015) [8]. This paper manages a PV-DVR, in which the battery took care of by a PV source takes care of the DC connect capacitance of DVR. The capacity of this part is to flexibly the important energy to the VSC for changing over DC to air conditioning signal. Batteries are most generally utilized DC stockpiling unit. The measure of voltage which must be repaid decides the limit of the battery.
Fig 2 (a) and (b) shows the circuit graph and identical circuit of the DVR. The DVR infuses an arrangement voltage $V_c$ with the source voltage $V_{source}$ to acquire a variance and aggravation free Burden voltage $V_L$. In this manner, the Heap voltage of DVR can be composed as,

$$V_e = V_s + V_c$$  \hspace{1cm} (1)

Here,

$$\left| V_c \right| = \left| V_{DVR} \right| = \left| V_{presag} \right| - \left| V_{sag} \right|$$  \hspace{1cm} (2)

Where, $V_{presag}$ is the Voltage before droop, and $V_{sag}$ is the voltage during the event of sag occasion[9]. The point of the repaid voltage can be given as,

$$\angle V_c = \theta_c = \theta_s$$  \hspace{1cm} (3)

Where, $\theta_s$ is the angle of the supply voltage.

In PV-DVR, the DC connect capacitor is charged and released by PV board through DC-DC converter, from the microgrid, which further feeds nearby air conditioning and DC loads (Ramasamy and Thangavel, 2013; Rauf and Khadkikar, 2015)[10]. The battery bank worked during back-up, is constrained by a charge regulator.

4. Wavelet transform based PQ detection

This paper manages an Exchanging Regulator dependent on Wavelet Change (Gencer, Öztürk, and Erfidan, 2010) for identifying the start and finishing of any force quality occasion. The sign exposed to Wavelet Change gives two sorts of coefficients as yield to be specific, Surmised coefficients (Ca) and Detail Coefficients (Album)[11]. The inexact coefficients are the high-scale, low-recurrence parts of the sign and the detail coefficients are the low-scale, high-recurrence segments, gotten by going the sign through Low pass and High pass channels individually.

The discrete wavelet deterioration of a digitized time signal $Co(n)$ is disintegrated into estimated Ca(n) and detail coefficients Cd(n) as communicated by,

$$C_a(n) = \sum_{k=0}^{N} h(k-2n)C_a(k)$$  \hspace{1cm} (4)

$$C_d(n) = \sum_{k=0}^{N} g(k-2n)C_d(k)$$ \hspace{1cm} (5)

The discrete wavelet deterioration of a digitized time signal $Co(n)$ is disintegrated into estimated Ca(n) and detail coefficients Cd(n) as communicated by,

The wavelet deterioration of the following level is reliant on the inexact coefficients of the past level and not on $Co(n)$ (i.e.) the rough coefficients of the current level goes about as the base sign for next level disintegration[12,13]. The quantity of estimated and detail coefficients acquired is half of the disintegrated signal and consequently the coefficients must be up-tested at each level to keep up the quantity of tests consistent. Fig. 4 explains the operational flow chart of the wavelet based switching controller. The energy of the signal is calculated using Parseval’s Theorem (Ray, Mohanty and Kishor, 2011) as stated by:

$$E_{nergy} = \sum_{k=0}^{N} |C_a(k)|^2 + \sum_{k=0}^{N} |C_d(k)|^2$$  \hspace{1cm} (6)
At the point when the estimations of Energy and Standard Deviation is more prominent than the edge esteem, a force quality unsettling influence is distinguished and the exchanging regulator finds a way to work the DVR from the PV or battery source dependent on the accessibility. The previously mentioned Exchanging Regulator utilizes these Detail coefficients to restrict different force quality occasions like voltage hang, voltage swell, glimmer, transient, interference and so on[14,15].

![Flow chart of Wavelet based Switching Controller](image)

**Figure 3.** Flow chart of Wavelet based Switching Controller

5. Simulation Results

The mixture wind driven PV microgrid with DVR is mimicked utilizing MATLAB Simulink and the reenacted outcomes are talked about underneath. The boundaries of the mimicked test framework is given in Informative supplement – I.

![Output voltage of the DC-DC buck-boost converter](image)

**Figure 4.** Output voltage of the DC-DC buck-boost converter

![Output current of the DC-DC buck-boost converter](image)

**Figure 5.** Output current of the DC-DC buck-boost converter

The yield from the PMSG wind turbine is first redressed to air conditioning box an uncontrolled rectifier, controlled through DC-DC buck support converter to get greatest force separated and afterward rearranged back to air conditioning with
wanted voltage and recurrence for better synchronization with the utility framework[16]. Fig.4 and 5 shows the yield voltage and yield current of the DC-DC buck-support converter. Fig.6 and 7 shows the voltage.

Figure 6. Load side voltage of the hybrid system

Figure 7. Load side current of the hybrid system

The presentation of PV-DVR under different force quality occasions and aggravations is mimicked utilizing MATLAB Simulink and the outcomes are talked about beneath. Fig. 8 and 9 shows the Framework voltage (Vs), Burden voltage (VL), repaid voltage (Vc), wavelet coefficients (Cd) for voltage hang and swell happening between the time 0.1 and 0.3 sec.

Figure 8. (a) System voltage Vs, (b) compensated voltage Vc, (c) Load voltage VL, (d) wavelet detection for Voltage sag between 0.1 and 0.3 sec
Figure 9. (a) System voltage $V_s$, (b) compensated voltage $V_c$, (c) Load voltage $V_L$, (d) wavelet detection for Voltage swell between 0.1 and 0.3 sec

Figure 10. (a) System voltage $V_s$, (b) compensated voltage $V_c$, (c) Load voltage $V_L$, and (d) wavelet detection for harmonic load with sag between 0.1 and 0.15 sec and swell between 0.2 and 0.25 sec

Figure 10 shows the Framework voltage ($V_{versus}$), Burden voltage ($V_L$), repaid voltage ($V_c$) and wavelet coefficients (Album) for a symphonious burden when a voltage List is presented somewhere in the range of 0.1 and 0.15 sec and swell somewhere in the range of 0.2 and 0.25 sec. The THD of the yield load voltage is seen to be 4.78% for this situation.
Figure 11. Percentage of compensation for varying magnitude of sag and swell

Figure 11 shows the diagram plotted for changing extents of list and swell and their relating level of effective pay by the DVR. The Wavelet Change disintegration is done for 12 levels and the energy is determined at each level utilizing the Parseval’s hypothesis (eqn. (6)). The size of energies at each level is plotted in Fig.12 for different force quality occasions. The pinnacle of energy extent happens in seventh and eighth disintegration level for voltage hang, voltage swell or voltage interference happens[17]. It is watched the pinnacle extent is more for voltage droop and less for voltage swell contrasted with unadulterated sine wave. For a consonant mutilated waveform, the pinnacle extent of energy happens at tenth, eleventh and twelfth degree of decay.

Figure 12. Energy plot of various power quality events

6. Conclusion

A Unique Voltage Restorer dependent on Photovoltaic source has been proposed for power quality remuneration in microgrids. The PV board supplies the heap when sun oriented force is accessible and charges the battery without sun based force. Likewise the PV source assumes the twin function of providing the heaps just as the DVR, in the midst of activity. The charge regulator is utilized to properly charge and release the battery. The proposed DVR based Microgrid is additionally tested for different force quality occasions like voltage list/swell, homeless people, music, interference. Wavelet Change based Exchanging Regulator precisely recognizes the start and end of the force quality occasion and likewise works the PV-DVR. The DVR is seen to give adequate pay against these issues and convey clean capacity to the customers.
## Appendix

The accompanying tables shows the breeze and PV boundary esteems utilized in plan and recreation of the mixture microgrid framework.

### Table 1  System specifications for wind

| PARAMETER       | VALUE       |
|-----------------|-------------|
| Rated Power     | 20kW        |
| Rated wind speed| 12 m/s      |
| Rated rotor speed| 22.0958 rad/s |
| Blade radius    | 2.7m        |
| Pitch angle     | 0 degree    |
| Air density     | 1.225 kg/m³ |

### Table 2  System specifications for PV

| PARAMETER                          | VALUE       |
|------------------------------------|-------------|
| Maximum power (Pmax)               | 200(+10%/-5%) |
| Maximum power voltage (Vmpp)       | 26.3V       |
| Maximum power current (Impp)       | 7.61A       |
| Open-circuit voltage (Voc)         | 32.9V       |
| Short circuit current              | 8.21A       |
| Power Rating                       | 20x200=6000W |
| Temperature                        | 25°C        |
| Irradiation                        | 1000W/m²    |
| Series Connected cells             | 54          |

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