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Research article

Enhancing Voltage Stability of a Microgrid in the Presence of PV Plants Using Storage System

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Abstract: Due to the nearly inertia-free nature of the voltage source converter (VSC) based microgrid (MG), any fluctuations in the generation profile have an extremely detrimental effect on the voltage profile. A load imbalance at the point of common coupling (PCC) exacerbates the issue even further. Energy storage systems are critical components that ensure stability and dependability in microgrids with a significant proportion of renewable energy sources (RES). Coordination control between the PV (photo voltaic) and the BESS is necessary for power balance. This article describes a corrective voltage control (CVC) scheme for microgrid voltage regulation. An active and reactive power control strategy is suggested to reduce voltage fluctuations and thus mitigate the adverse effects of an unbalanced load. Incorporated battery energy storage devices will undergo dynamic charging during off-peak hours to minimize voltage dropouts and discharge during peak hours to prevent voltage spikes while regulating the PV inverter output's rapid fluctuations to a predetermined value. The outcomes validate the viability of the control schemes and Ess's integration into the microgrid.

Keywords: Corrective voltage control; Renewable energy source; Photo voltaic; Battery energy storage system

1. Introduction

The necessity to decarbonize to mitigate the effects of climate change and the difficulties associated with meeting the rising demand for electrical energy has brought to the forefront the significance of microgrids in facilitating the efficient integration of renewable energy sources. Despite the considerable research on microgrids over the past few years, numerous unresolved obstacles require attention. The ongoing risk of voltage collapse continues to make voltage stability analysis and development a significant concern for operators of power systems.

A microgrid is an integrated collection of distributed energy resources (DERs), storage systems, and connected loads that can communicate with the primary grid via a single point of common coupling (PCC) [1]. The utility's point of common coupling (PCC) is the only connection point for disconnecting or reconnecting. A microgrid must meet the interface and interoperability standards set up at the PCC, such as the one for connecting inverters in IEEE Standard 1547 [2]. So, MGs can be utilized to deliver electricity to remote places, making it easier to produce, distribute, and control the flow of electricity to consumers in the area. Microgrids are similar to conventional power grids in many respects. Like standard grids, they make power, send it to where it's needed, control it with voltage regulation, and switch gears. Microgrids provide closer intimacy between electricity generation and consumption than conventional electrical networks. It leads to greater efficiency and reduced transmission loss. MGs are one of the key concepts that will promote the deployment of high renewable energy source (RES) penetrations in our electricity systems[3]. Table 1 shows the difference between a microgrid's autonomous and grid-connected modes.

Table 1. Differences between grid-connected and autonomous microgrids

Specifications	Independent	Grid Connected
Operating mode	Isolated	Incorporated with grid
Primary driving factors	Sustainability of remote and rural locations and efficiency as well	Cost, efficiency, and Power quality reliability enhancement,
Use of demand response strategies	Required	Desirable
Use of Storage	To be independent	For reacting to signs of price

By participating in ancillary services, microgrids can support the primary grid. They can aid in voltage regulation, frequency control, and power quality enhancement, thereby enhancing the stability and dependability of the grid. In certain circumstances, extra power generated by microgrids can be transferred back to the central infrastructure, strengthening the system's overall resiliency and adaptability. Microgrids play an essential role in today's electrical infrastructure by increasing reliability, incorporating renewable energy, boosting energy efficiency, facilitating demand response, assisting the grid, and strengthening local communities. Microgrids will likely be more significant in attaining a resilient and sustainable energy future as the energy landscape changes.

There has been a notable surge in the need for cleaner energy resources in recent decades. As a result, decision-makers in every nation have devised long-term strategies to secure energy from renewable sources. Therefore, these strategies diminish reliance on conventional energy sources and implement alternative energy technologies in their place. Consequently, there is an emerging international trend among nations to transition towards sustainable energy sources and diminish reliance on conventional fossil fuels for energy provision. Among various renewable energy sources, solar and wind energy are considered the most reliable sources. In the last decade, solar Photovoltaic (PV) capacity has increased rapidly globally [4]. Integrating photovoltaic (PV) plants into microgrids is gaining popularity and has substantial advantages to energy systems. The projected installed capacity was anticipated to peak at 714 gigawatts (GWp) by 2020 [5]. Moreover, with an incremental annual power generation of 127 GWp in the same year, solar photovoltaic (PV) emerged as the swiftest-growing renewable energy technology. Given ongoing cost reductions, this trajectory is expected to endure, leading to a global tripling of installed solar PV capacity by the decade's end [6]. Integrating photovoltaic (PV) systems into microgrids reflects the expanding recognition of the advantages of green energy, distributed generation, and energy resilience. As PV technology keeps getting better and costs go down, PV plants are likely to play an even more significant part in the future growth of microgrids, helping the move towards cleaner, more sustainable, and decentralized energy systems.

1.1 The Concept of Voltage Stability and its Significance in Power Systems

Voltage Stability is integral to Power Systems. This is the ability of a network to keep voltage levels steady and acceptable at all places within the system. It ensures that the magnitudes of voltage and phase angles stay within acceptable limits so that electrical equipment can work well and the power grid stays stable overall.

A microgrid-integrated system exhibits voltage instability when at least one bus/feeder demonstrates a negative V-Q sensitivity. The phenomenon of microgrid voltage stability is classified broadly according to system disturbances. However, it can be further categorized according to several other factors. This includes distinguishing whether the microgrid operates in isolation or is connected to the primary grid. Additionally, the focus of the study can be delineated by examining the stability of the DC-link voltage, analyzing the system's response to minor or significant disturbances, and comprehensively addressing various variables affecting microgrid voltage stability. These variables encompass the sensitivity of the Q-V droop, load behavior, inverter dynamics, and the dynamics of other components such as tap changers in under load transformers. Figure 1 visually represents specific classifications and their corresponding influencing factors.

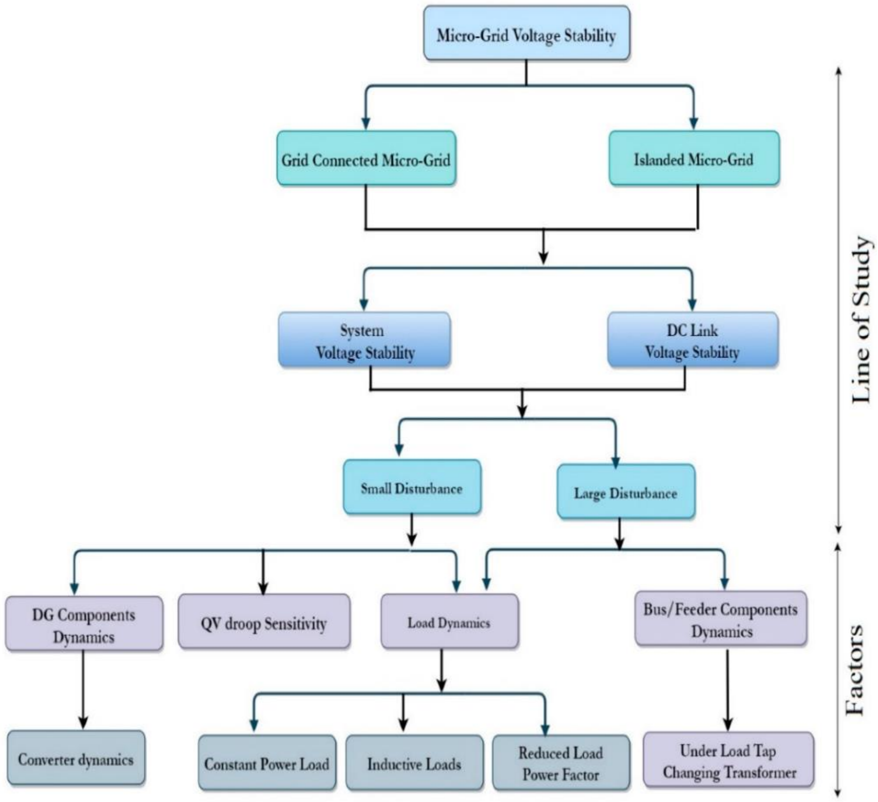

Figure 1. Study line in microgrids for voltage stability.

1.2 Importance and Objective of the Research

In recent years, there has been a discernible shift in focus from conventional power sources to renewable energy alternatives for electricity generation due to concerns related to air pollution and raw material shortages. This transition aims to ensure the production of high-quality electric power to meet the demands of consumers. In tandem with this shift, microgrid systems have been developed to integrate renewable-based power generation with traditional sources, effectively addressing load demand fluctuations. Integrating renewable energy sources, conventional power systems, and energy storage systems in a microgrid configuration offers a comprehensive solution for stabilizing frequency and voltage at PCC during emergency load situations. This approach mitigates the shortcomings associated with conventional power systems and obviates the need for a secondary controller, a notable advancement in power system design. This paper aims to make a microgrid with solar (PV) plants more stable in terms of voltage. A corrective voltage control (CVC) method is used to make this happen. This paper aims to suggest and study how well the CVC plan works to control and keep voltage levels in the microgrid system within acceptable boundaries.

2. Literature review

The increasing power of RES will affect how the current energy system works. The biggest problem with RES is that it's hard to know how much power will be available in different weather situations. Research findings demonstrate that alterations in power, referred to as "ramp rates," can lead to a substantial power escalation or reduction, amounting to as much as 90% of the estimated capacity per minute [8] and up to 66% within a 10-second timeframe. According to the International Electrotechnical Commission (IEC) standard 61000-2-2 [9], swift voltage fluctuations exceeding 3% of the nominal value are deemed unacceptable for low-voltage (LV) distribution systems. Voltage consistency is essential for the correct operation and durability of electrical equipment. Most equipment is designed to function effectively within a particular voltage range. Voltage levels that are too high or too low can cause equipment malfunctions, decreased performance, and even equipment damage [10].

Unstable or fluctuating voltages can cause variations in frequency, flickering lighting, overheating equipment, and distorted waveforms [11]. By offering stable voltage levels, the quality of power is improved, providing consumers with a reliable and efficient source of electricity. Maintaining consistent voltage demands careful attention to managing several moving parts, including generators, transformers, capacitors, and control devices. Maintaining system dependability, optimizing power transfer, and easing the integration of new technologies and renewable energy sources are all possible by conducting a voltage stability study and implementing suitable voltage control measures. PV facilities can have positive and adverse impacts on power system voltage stability. Understanding these effects is essential for effectively managing voltage fluctuations and reactive power imbalances. Consequently, a remedy for balancing the power outputs of photovoltaic and wind energy is required. Furthermore, voltage fluctuations are the most detrimental at the distribution grid level, threatening the regional electricity grid and its devices. In contrast, governments and regulatory bodies have demanded a higher power quality standard due to increased irregular loads, power utilization, and the proliferation of distributed generation (DG) systems [12].

Instability of the voltage is primarily a local phenomenon that begins with a reactive power imbalance. Significantly contributing to voltage instability is a sudden change in demand. In addition, transient clouds rapidly affect the power output of the PV systems. Some power quality problems, like voltage swings in the LV grid, are usually solved by grid reinforcement to strengthen the LV grid [13, 14]. Voltage fluctuations are diminished when the grid is reinforced due to the LV grid cables' increased capacity and decreased resistance. Nonetheless, this method of voltage regulation is prohibitively expensive and requires the replacement of a large number of LV cables; as a result, it is considered undesirable [15]. Another method to regulate voltage is power curtailments [16]. Curtailment serves as a method for managing the power output of a photovoltaic (PV) system by manipulating the working voltage and current within the system's inverter [17]. This involves restraining the power output of the PV system, particularly in response to sudden increases in power output or uniformly in anticipation of an impending degradation. Alternative approaches to regulate the voltage profile encompass reactive power control and the deployment of tap changers [18, 19]. However, the efficacy of reactive power control is constrained in low-voltage (LV) grids, particularly within urban LV grids, owing to the relatively short cable lengths [13], [20]. Tap changers are considered insufficient in addressing voltage fluctuations, as their capability is limited to regulating voltage near the transformer substation [21]. In contrast, the challenges posed by voltage fluctuations induced by photovoltaic (PV) power generation are particularly pronounced at the remote end of the cable [22].

In low-voltage distribution networks, particularly in distribution lines where line parameters exhibit significant disparities, solutions derived from transmission line applications prove only partially effective. In this context, reactive power compensation demonstrates diminished adequacy compared to the combined benefits of active and reactive power compensation. This phenomenon is notably pronounced in lines where substantial series resistance dominates the overall impedance of the line. The confluence of heightened load demand levels and intermittent fluctuations in solar photovoltaic (PV) power output precipitates gradual and abrupt voltage oscillations within the corresponding low-voltage (LV) distribution feeder. For economic reasons, electricity systems work closer to their operating limitations, increasing the likelihood of blackouts. Many recent extensive blackouts, such as those in Southern California [23] and South Australia [24] in 2016, were caused by voltage breakdowns. The incidents were ascribed to the absence of dynamic voltage support (DVS) capabilities in the presence of voltage drops and the inability to endure multiple faults. Substantial research has been conducted on the impact of Photovoltaic Power Plants (PVPs) on system stability, particularly with a focus on voltage stability [25]. In a noteworthy study, the authors of [26] utilized the Nordic test system to investigate the influence of Large-Scale Photovoltaic Plants (LSPVPs) on Low-Tension (LT) voltage stability, taking into account voltage regulation at the plant level.

The investigators in [27] employed a meticulous methodology to analyze the impact of Photovoltaic (PV) systems on Low-Tension (LT) voltage stability. As posited by [28], enhanced controllers for Large-Scale

Photovoltaic Plants (LS-PVPs) have the potential to deliver superior dynamic reactive power responses, thereby bolstering LT voltage stability. Synthesizing the insights from these three antecedent studies, it is deduced that implementing plant-level voltage regulation for LS-PVPs contributes to augmenting LT voltage stability. Nevertheless, adopting a judicious approach to forestall voltage collapse is imperative. As a result, an advanced voltage management technique is required to avoid LT voltage instability.

Static compensators, or STATCOMs, serve as voltage regulation solutions by injecting reactive power at the load connection point [29]. This approach proves advantageous when deployed in transmission or distribution systems characterized by predominantly inductive line impedance. When applied specifically to distribution lines, these devices are called DSTATCOMs [30]. However, the efficacy of voltage regulation with DSTATCOM becomes compromised in low-voltage grids, primarily due to the substantial reactive power demands necessary to compensate for the elevated R/X line grid ratio prevalent in weak grids [31]. This component introduces two noteworthy challenges. Firstly, it requires a converter with an exceptionally high nominal power to ensure effective regulation. Secondly, it induces an excessive reactive power flow in the distribution transformer, potentially damaging equipment. In response to these challenges, [32] suggests a Minimum PowerPoint Tracking (MPPT) scheme. This approach enables the supply voltage to oscillate around the nominal voltage while adhering to local regulatory standards, effectively addressing the identified issues. Furthermore, [33] delves into a voltage-based storage control strategy for managing distributed solar Photovoltaic (PV) power in conjunction with battery systems. However, the paper acknowledges the need to confront practical challenges, including but not limited to limited Battery Energy Storage System (BESS) capacity and unexpected variations in PV generation, as highlighted in [34]. The study explores active and reactive power control measures to mitigate overvoltage limit violations by forecasting the curtailment threshold based on the past 15 seconds of PV output. Notably, the proposed control approach must exhibit more effectiveness when confronted with substantial changes in PV output. Reference [35] delves into peak shaving using Battery Energy Storage Systems (BESS), focusing on load data. On the other hand, [36] explores a load-shifting mechanism that leverages BESS to transition energy consumption from peak to off-peak hours. However, all approaches in [35,36] could be enhanced further by requiring a minimum voltage level on the distribution feeder to initiate peak shaving/load shifting. Some research has been done on the effect of PVPs on stability, precisely voltage stability [37-39]. Nonetheless, a method for mitigating the harmful impacts of PVPs on LT voltage stability has yet to be developed in these experiments. Historically, power quality issues, such as voltage swings in the LV grid, have occurred. Similarly, in [40], the authors propose a decentralized emergency control solution addressing Low-Tension (LT) voltage instability. Considering the on-load tap-altering capability, this controller monitors the generator's reactive powers and gearbox voltages. In response to the imperative of averting voltage collapse, the study devises a solution grounded in under-voltage load shedding. While Energy Storage Systems (ESS) stand out as versatile resources widely adopted in contemporary power systems globally, their optimal integration into transmission networks necessitates nuanced considerations. Challenges include determining the optimal position and capacity, alongside grappling with the associated investment expenses for maximizing the ESS's efficacy within the network.

3. Research gap from the literature review

The foremost objective of the studies in the literature review section was to reduce the voltage at PCC by voltage regulators, droop control, and on-load tap changers (OLTC) by renewable curtailment in power systems during unexpected load-changing situations. Some researchers also include STATCOM, some decentralized emergency control solutions, and several algorithm-based controllers for voltage control. Nonetheless, these voltage regulation methods are relatively inexpensive and require the replacement of a large number of LV cables; as a result, it is considered undesirable [15]. Also, no algorithm-based controller provides a better-controlled response. Therefore, a suitable controller with superior optimization is required to better control power systems during sudden load demand conditions or any variation in solar or distributed power generation. The CVC technique is easily implemented to solve voltage variation problems by controlling active and reactive powers.

4. Changes in voltage caused by changes in solar output

The variation in voltage produced by the sharp changes in the PV inverter output is investigated using a PV system that is connected to a distribution system, as in Fig. 2. It is assumed in this section that the ESS still needs to be incorporated with the solar system.

The relationship between the quantity of change in the magnitude and angle of voltage in a distribution system caused by a change in active power (P) and reactive power (Q) is as follows:

$$\begin{bmatrix} \sigma_{P\delta} & \sigma_{P|V|} \\ \sigma_{Q\delta} & \sigma_{Q|V|} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta[V] \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (1)$$

Here, $\boldsymbol{\sigma_{P\delta}}$, $\boldsymbol{\sigma_{P|V|}}$, $\boldsymbol{\sigma_{Q\delta}}$, $\boldsymbol{\sigma_{Q|V|}}$ are the active and reactive power sensitivity matrices correspondingly concerning the magnitude and angle of voltage. The vector Δδ represents variations in voltage angles, while the vector Δ[V] signifies alterations in voltage magnitudes [ΔV]. The vectors ΔP and ΔQ denote net active and reactive power changes, respectively. Equation (1) may be interpreted as a system of linear equations akin to the form expressed in equation (2).

$$A * X = B \quad (2)$$

Here,

$$A = \begin{bmatrix} \sigma_{P\delta} & \sigma_{P|V|} \\ \sigma_{Q\delta} & \sigma_{Q|V|} \end{bmatrix} \quad (3)$$

$$X = \begin{bmatrix} \Delta\delta \\ \Delta[V] \end{bmatrix} \quad (4)$$

$$B = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (5)$$

Using equation (2), the change in the magnitude of voltage at the point of interconnection (PoI) of a PV system can be determined by using Cramer's rule as given in (6).

$$\Delta[V_i] = \frac{Det \begin{bmatrix} \sigma_{P\delta} & \Delta P \\ \sigma_{Q\delta} & \Delta Q \end{bmatrix}}{Det \begin{bmatrix} \sigma_{P\delta} & \sigma_{P|V|} \\ \sigma_{Q\delta} & \sigma_{Q|V|} \end{bmatrix}} \quad (6)$$

Where $\Delta[V_i]$ is the change of voltage at any i_{th} bus. In this case, that i_{th} bus is the point of common coupling, and Det means determinant. The variation in load demand and the output of the PV inverter will determine how much the active and reactive power changes.

5. Proposed Method

The microgrid being examined comprises a battery, photovoltaic (PV) panel, and constant and variable demands. The proposed corrective voltage control (CVC) scheme aims to reduce fluctuations induced by mismatches between solar PV output and load. The corrective Voltage Control (CVC) approach is employed to control and keep voltage levels within acceptable limits in a power system, especially in the presence of fluctuations in voltage or instability. The CVC scheme modifies the system's reactive power injection or absorption to fix voltage problems and restore stability. Fig. 1 displays the theoretical block diagram of a typical battery storage coupled to a photovoltaic system that will be examined in this work. The battery storage will be charged and discharged to reduce the erratic solar PV production at the PCC.

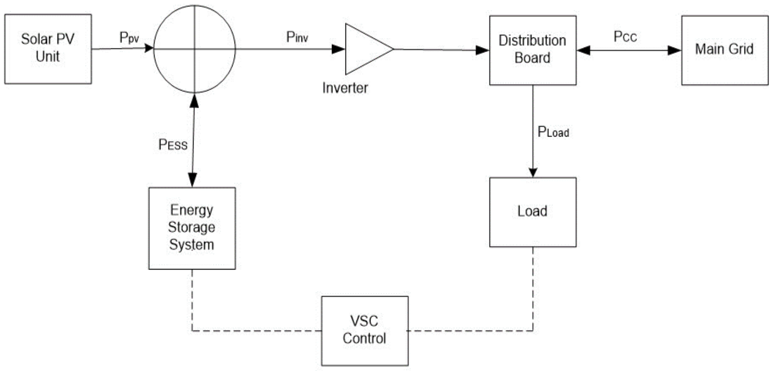

Figure 2. Schematic representation of the solar system connected with the battery

According to Fig. 2, an inverter connects the solar PV unit and the battery storage to the grid and the household load. As indicated by Eq. (1) below, the BESS output (P_{Bess}) and the load (P_{Load}), must be equal to the power output of the PV panel (P_{pv}) and the power absorption/injection from and to the grid.

$$P_{Grid} + P_{pv} = P_{Bess} + P_{Load} \quad (7)$$

Power absorption and injection from and to the grid P_{Grid} must be regulated by modifying the P_{Bess} to maintain the voltage characteristics of the linked power distribution feeder within the usual operating limits.

5.1 Principle of Operation and Control

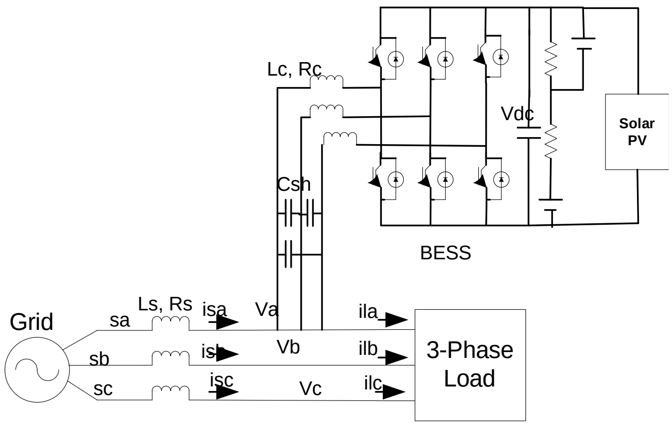

Figure 3. System configuration

The system configuration is illustrated in Fig. 3, and Fig. 4 illustrates the algorithm for the control scheme. The proposed microgrid system, comprising conventional power sources, renewable energy generation, and energy storage, represents a holistic approach to power system design. By seamlessly blending these components, the system ensures a stable and reliable power supply and minimizes environmental impact and resource dependency. This innovative solution marks a significant step forward in the quest for sustainable and resilient power systems capable of meeting the evolving needs of consumers, especially during critical load scenarios. In this scheme, the three-phase reference source currents comprise two key components: an in-phase component and a quadrature component relative to the phase voltages. The in-phase component of the reference source current ($I^*_{sad}, I^*_{sbd}, I^*_{scd}$) charges the BESS battery and supplies active power to the load. This active power component can be regulated to maintain a constant power output at the point of common coupling (PCC), ensuring stable power generation. The amplitude I^*_{smd} is multiplied by the in-phase unit vectors (U_a , U_b , U_c), which are calculated by dividing the AC voltages (V_a, V_b, V_c) by their amplitude (V_m), resulting in the in-phase components of the reference currents ($I^*_{sad}, I^*_{sbd}, I^*_{scd}$). The quadrature components of the reference source currents ($I^*_{saq}, I^*_{sbq}, I^*_{scq}$) are required to regulate the AC voltage at the point of common coupling (PCC). These quadrature unit vectors are derived from the in-phase unit vectors. The AC voltage (V_m), at the PCC, is measured and compared with a reference voltage, with the resulting voltage error processed by a proportional-integral (PI) controller. The PI controller's output I^*_{smq} establishes the amplitude of the reactive current required by the system, which the BESS supplies. By multiplying the quadrature unit vectors W_a , W_b , W_c *with* I^*_{smq} quadrature components of the reference source currents ($I^*_{saq}, I^*_{sbq}, I^*_{scq}$) are generated. The total reference source currents ($I^*_{sa}, I^*_{sb}, I^*_{sc}$) are obtained by summing the in-phase and quadrature components. A PWM-based current controller then ensures that the BESS currents accurately follow the reference source currents.

5.2 Control Scheme

The various components of the proposed system are modeled and integrated to form a comprehensive system model. The control scheme, illustrated in Fig. 4, is primarily employed to derive the reference source currents, which are then utilized in the PWM current controller of the BESS's voltage source inverter (VSI).

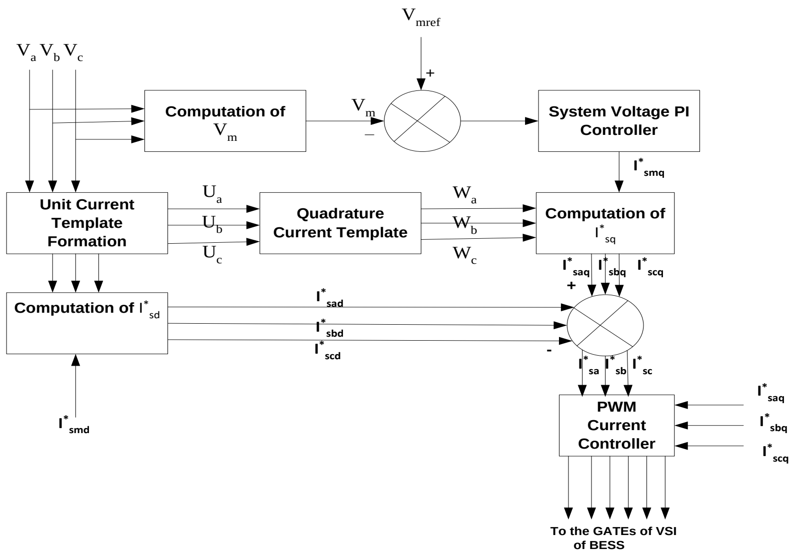

Figure 4. Algorithm of controller

These reference source currents consist of an in-phase and quadrature components, which are determined sequentially, as outlined in the following section.

The unit vectors in phase with Va, Vb, and Vc are derived as in equation 10:

$$U_a = \frac{V_a}{V_m}; \qquad U_b = \frac{V_b}{V_m}; \qquad U_c = \frac{V_c}{V_m} \tag{10}$$

Where V_m is the amplitude of the AC terminal voltage at the PCC and can be calculated as;

$$V_m = \frac{2}{3}\sqrt{(V_a{}^2 + V_b{}^2 + V_c{}^2)} \tag{11}$$

Where V_a, V_b, and V_c are the instantaneous voltages at PCC and can be derived as:

$$V_a = V_{san} - R_s i_{sa} - L_s P i_{sa},\ V_b = V_{sbn} - R_s i_{sb} - L_s P i_{sb},\ V_c = V_{scn} - R_s i_{sc} - L_s P i_{sc} \tag{12}$$

Where P represents the time differential operator (d/dt) and L_s and R_s are per phase source inductance and resistance, respectively. V_{san}, V_{sbn} *and* V_{scn} are the three-phase instantaneous input supply voltages at PCC and are expressed as:

$$V_{san} = V_m \sin(\omega t); \quad V_{sbn} = V_m \sin(\omega t - 2\pi/3); \quad V_{scn} = V_m \sin(\omega t + 2\pi/3) \quad (13)$$

The peak value, denoted as *Vm*, and the angular frequency (ω=2πf) of the power supply are established parameters in this context. The derivation of unit vectors orthogonal to *Va*, *Vb*, and *Vc* involves implementing a quadrature transformation on the in-phase unit vectors *Ua*, *Ub*, and *Uc* as,

$$W_a = -U_b / \sqrt{3} + U_c / \sqrt{3} \quad (14)$$

$$W_b = \sqrt{3}\, U_a /2 + (U_b - U_c)/(2\sqrt{3}) \quad (15)$$

$$W_c = -\sqrt{3}\, U_a /2 + (U_b - U_c)/(2\sqrt{3}) \quad (16)$$

The quadrature component of the reference source currents is computed as:
The voltage error V_{er} at PCC at the nth sampling instant is as:

$$V_{er(n)} = V_{ref(n)} - V_{m(n)} \quad (17)$$

The output of the PI controller at the nth sampling instant is expressed as;

$$I^*_{smq(n)} = I^*_{smq(n-1)} + K_P\{V_{er(n)} - V_{er(n-1)}\} + K_i V_{er(n)} \quad (18)$$

Where K_P and K_i are the proportional and integral constants of the PI controller, respectively, and the subscript (*) represents the reference quantity.
The quadrature components of the reference source currents are estimated as,

$$I^*_{saq} = I^*_{smq} W_a \quad I^*_{sbq} = I^*_{smq} W_b \quad I^*_{scq} = I^*_{smq} W_c \quad (19)$$

In-phase components of the reference source currents are estimated as

$$I^*_{sad} = I^*_{smd} U_a \quad I^*_{sbd} = I^*_{smd} U_b \quad I^*_{scd} = I^*_{smd} U_c \quad (20)$$

Where I^*_{smd} is considered as the fixed value corresponding to the constant source current.
The total reference source currents are the sum of the in phase components and quadrature components of the reference source currents and are given as:

$$I^*_{sa} = I^*_{saq} + I^*_{sad} \quad I^*_{sb} = I^*_{sbq} + I^*_{sbd} \quad I^*_{sc} = I^*_{scq} + I^*_{scd} \quad (21)$$

The in-phase component of the reference source current ($I^*_{sad}, I^*_{sbd}, I^*_{scd}$) charges the BESS battery and supplies active power to the load.

6. Results and Discussion

The design of a Simulink model for Peak PowerPoint Tracking involves the utilization of 100 KW at 1000 W/m^2 PVAs. Each of the 66 parallel strings (5 modules SunPower SPR-305E-WHT-U connected in series) comprises the system's 100.735 KW (66 × 305.226 × 5). The temperature and solar irradiance evaluation units are degrees Celsius and W/m², respectively. The PV array block is equipped with two inputs, which accommodate fluctuations in the sun's temperature and irradiance. The PV array's output is linked to DC-to-DC boost converters with input frequencies of 5 KHz. The outputs are connected to the DC bus of the 3-phase, three-level Pulse Width Modulation Voltage Source Converter. The tracking system generates the intended voltage by manipulating the duty cycle. At the same time, peak power is measured from the PVA terminals using the incremental conductance (IC) method, also called the maximum power point tracking strategy. The VSC has both internal and external control capabilities. The internal portion of the PWM-VSC regulates the quadrature current components (I_d, I_q), which represent the active and reactive components, respectively. The external portion of the PWM-VSC regulates the DC link voltage. It is worth noting that the PWM-VSC is maintained at a 20% higher level than the solar farm's rating. The voltage output of the PVA is increased from 272 VDC to 640 VDC via the boost converter. The PWM-VSC utilizes modulating reference voltage signals (V_{abcref}) that have been converted from the current controller's output voltage (V_d) and (V_q), which are typically 540 V_{dc} to 600 Vac at the common point. A filter circuitry has been coupled to the network to remove any distortion produced by the PWM-VSC. The design network in MATLAB/SIMULINK is simulated.

This session presents the findings of an investigation conducted to ascertain the impact of load fluctuations on the performance of a rated solar farm, with the power of the PVAs maintained at their rated capacity. There is an unacceptable voltage at the point of common coupling because it exceeds 10 percent of its rated value. This investigation examined three distinct scenarios involving variable load. In this study, the load varies gradually, and, in the case where the solar generation is more than the demand of load, a reverse current starts flowing. It is evident from the results (Fig. 5 and Fig. 6) that solar power generation remains constant under constant temperature and irradiance conditions. However, the fluctuations in PCC voltage and DC-link voltage are caused by this variation. A corrective voltage control (CVC) scheme is proposed to put these values in a permissible range.

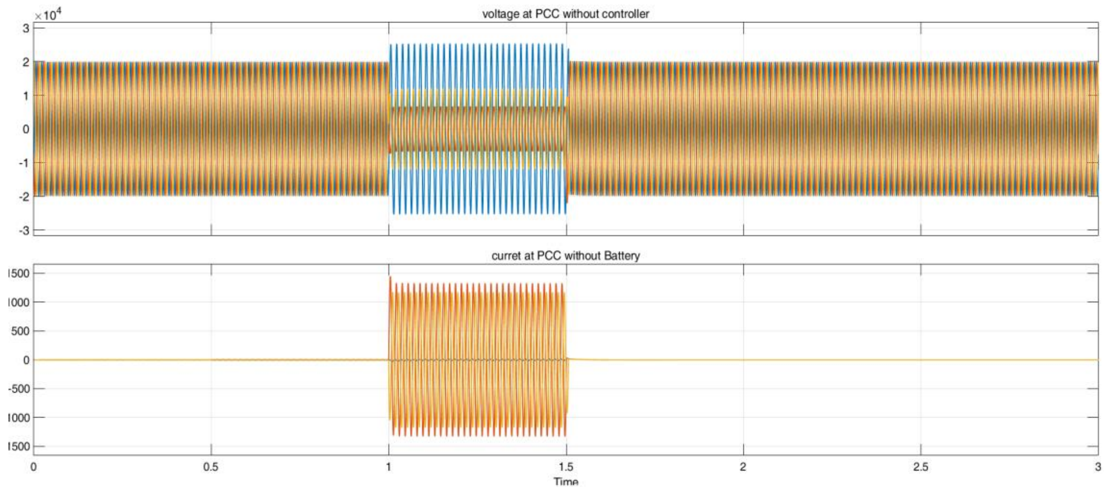

Figure 5. Variation of voltage at PCC without controller

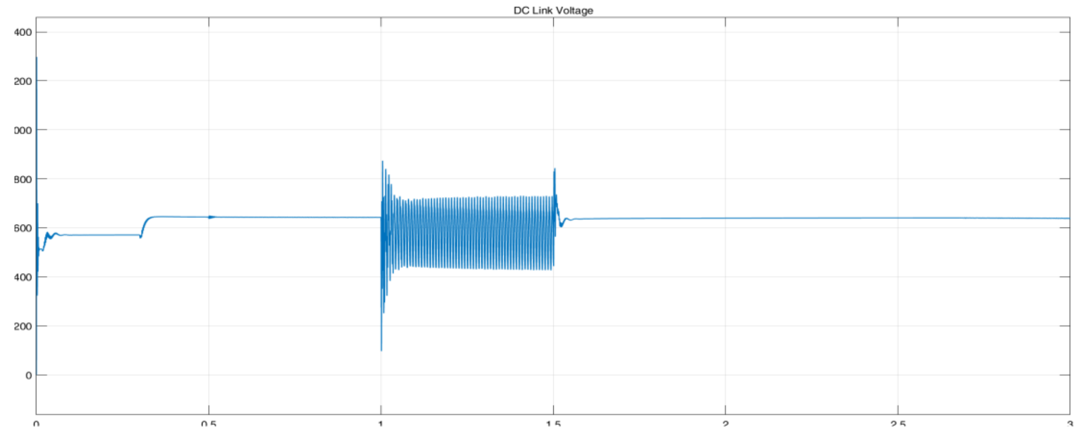

Figure 6. Variation of DC link voltage without controller

Specifications for battery and solar PV are shown in Fig 7 and 8, respectively. Fig. 9, Fig. 10, and Fig. 11 show the voltage at PCC, DC link voltage, and the power-sharing of solar, grid, and load.

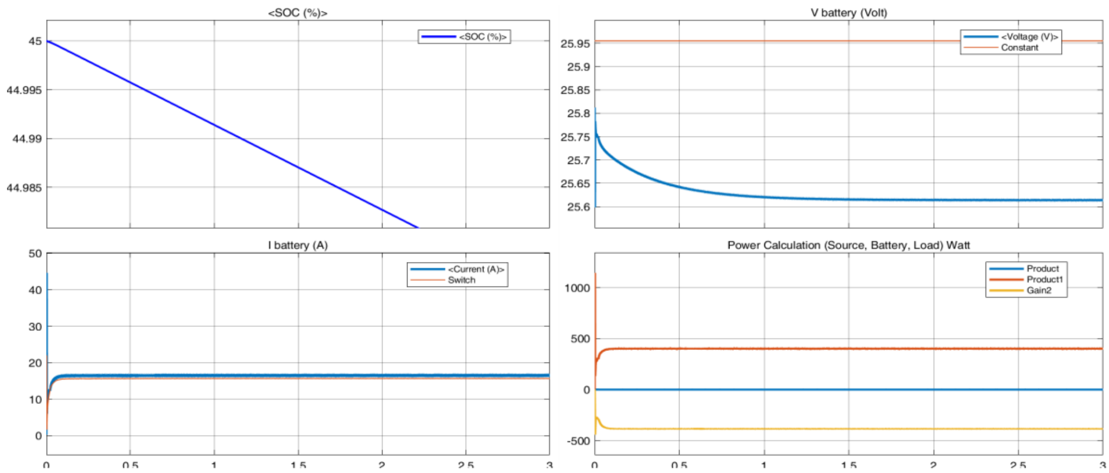

Figure 7. Specifications of battery

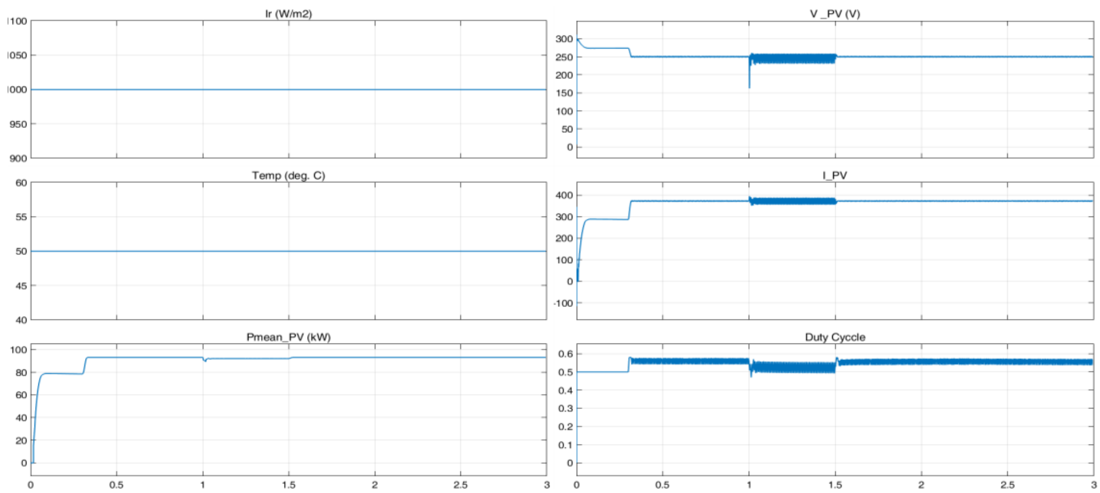

Figure 8. Specifications of solar

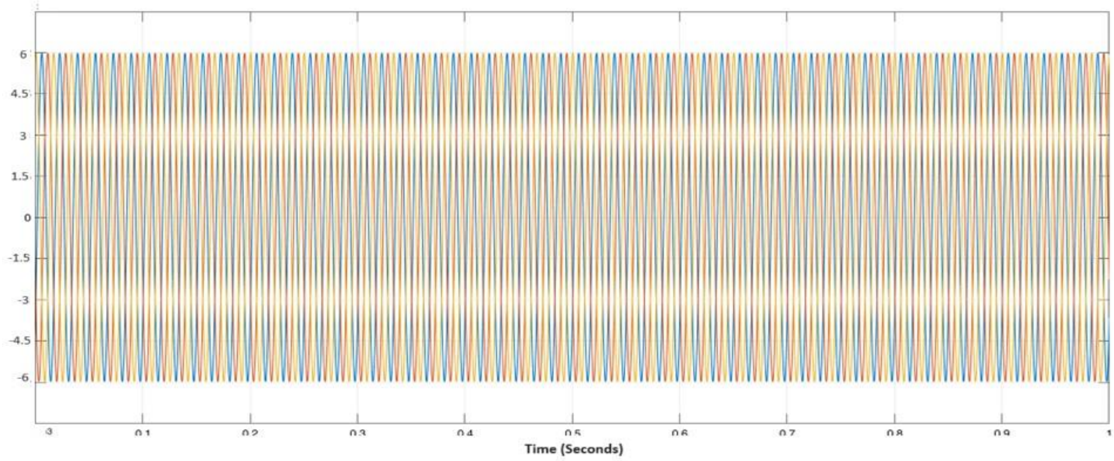

Figure 9. Voltage at PCC with controller

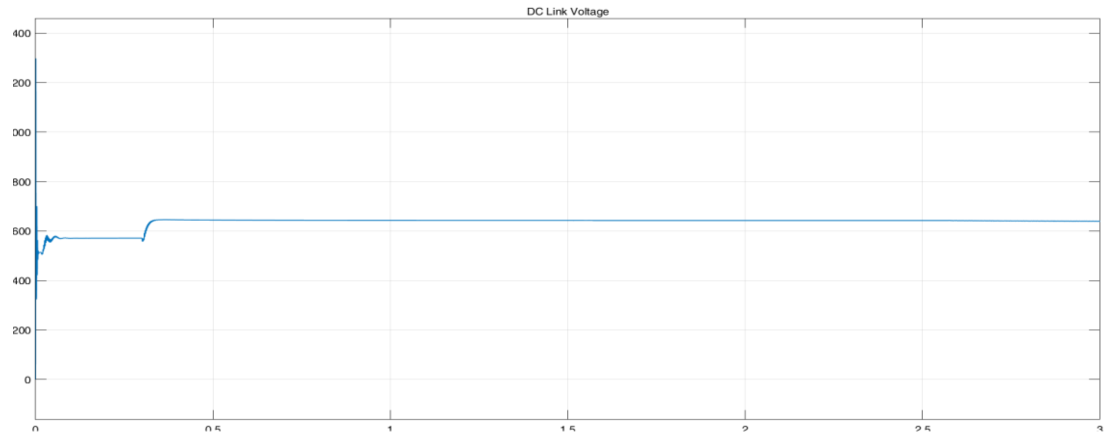

Figure 10. DC link voltage with a controller

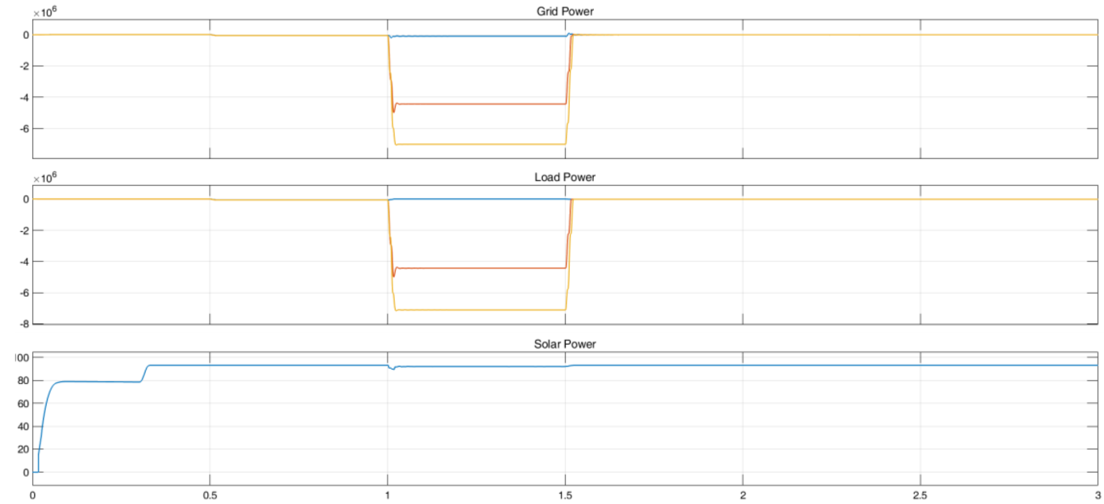

Figure 11. power sharing of the solar grid and load

7. Conclusion

The stability improvement of microgrid systems is a crucial aspect of their successful operation. Voltage has been one of the leading causes of voltage collapse and blackouts, so it's essential to have a system that is safe from a voltage stability point of view and less likely to collapse. This research article examines the voltage stability for a varying load system. It proposes an optimal improvement strategy by utilizing a control scheme to optimize controlling a BESS's real and reactive power output. A system with a PV generator, a grid, a storage system, and a load built into a microgrid is being studied. This paper describes a novel corrective voltage control (CVC) method that checks the terminal voltage to keep it from dropping and rising. Both grid-on and islanding modes operate the CVC and converter control. We can exchange electricity with the grid because of the DC-AC bi-directional converter. The interlinking converter in grid-connected mode operates in converter/inverter mode based on the load need. The energy storage system helps regulate the microgrid's voltage level and provides a constant power supply. PV power and stored energy meet the load requirement when the system is in grid-off mode. The suggested scheme allows us to regularly exchange electricity between all sources and loads. Simulations are used to examine the primary goals of the recommended strategy, which include preserving the PCC voltage and quickly restoring the DC bus voltage in the event of a disruption. The CVC scheme effectively maintains the desired control over the DC bus and PCC voltage, whether in the islanded or grid-on modes.

8. Future Directions

Finally, further research from this study could look into several ways to improve the use of energy storage systems in MGs with DERs. First, including more complicated MG configurations and large-scale models would help us learn how to improve things and scale them up in different situations. Adding advanced machine learning methods or artificial intelligence algorithms could also improve the controllers' adaptation. Lastly, looking into regulatory and economic frameworks that encourage advanced control strategies in MGs could make it easier for them to be widely used and have a bigger effect on grid resilience and the integration of green energy.

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