Photovoltaic Controller Design Based on Adaptive Volt/Var Algorithm to Stand the Impact of Load Increase in Grid Tied Microgrid System

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Abstract—**This paper presents an efficient design and real-time implementation of a controller for a large-scale grid-tied photovoltaic (PV) plant in a power system affected by disturbances. To direct the adequate amount of solar power, an Adaptive voltage and volt-ampere reactive (Volt-VAr) algorithm implemented in real-time using the Real Time Digital Simulator (RTDS) is proposed. An efficient and self-sufficient active and reactive *P-Q* power control scheme is proposed and implemented to transfer the generated power of the PV to the grid using a Voltage Source Converter (VSC). The proposed controller is implemented along with the PV system considered in RTDS to evaluate its effectiveness. By considering the impact of the disturbance caused by the load increase, the efficiency of the proposed power controller to transmit the generated power of the PV plant to the electrical grid system is investigated. It is observed that the hardware in the loop results verifies the advantage of the proposed method.**

Index Terms—**Adaptive voltage and volt-ampere reactive algorithm, microgrid integration impacts, Photovoltaic, real-time digital simulator, voltage stability control**

I. Introduction

The electrical power system is a real-time energy supply system designed to generate, transport, and supply power to the load. As a rule, the electrical power system is planned to operate in stable conditions and correct loading conditions [1]. However, these design expectations can be strained by disturbances [2].

Because of either the environmental concern or depletion of traditional energy source such as fossil fuels. The integration of Distributed Energy Resources (DER) in modern power grids have gained interest in the past years because of their not exhaustible nature. The availability of solar energy has established potential demand for the rapid growth of solar photovoltaic (PV) energy connection to existing power grids at transmission and distribution levels [3].

The integration of the microgrid photovoltaic system into the main utility grid is likely to bring some technical problems that request the upgrade of the traditional power system to a smarter energy supply system that handles the dynamic characteristics of the power system in various operating states. One of those challenges can be described as voltage stability [4].

Voltage instability is one of the disturbances that make the normal operations of the grid difficult. To achieve the safe operation of an electrical network, the stability of voltage needs to be monitored and attended to when there is case of voltage collapse [5]. With the integration of the microgrid in the power system, countless researchers have previously searched for and developed various algorithms for the safe addition of a microgrid system into the utility grid and their impact on the stability of voltage [5].

A more accurate trend called smart grid technology, brings control algorithms more accurate, especially when used in real-time. With modern technology, it is important and recommended to consider algorithms that can constantly monitor the grid vulnerability and propose fast voltage stability recovering margin to prevent the total collapse of the grid. Few of the algorithms proposed in the past investigated the voltage collapse in real-time simulation with regards to digital communication schemes as well as the possibility of combining different algorithms for better control of power flow in power systems, particularly those with microgrid-tied architectures.

The proposed controller design pattern based on the adaptive voltage and volt-ampere reactive (Volt-VAr) algorithm describes a better recovery method of voltage stability compared to other various methods used for voltage stability in power system [6].

The algorithm promotes comprehensive monitoring of the variability of the power on the grid side of the system. By considering the algorithm in a Real-Time Digital Simulation (RTDS), a more efficient adaptive Volt-VAr algorithm may produce a better result for voltage stability in the power system affected by disturbances.

In this paper, the impacts of connecting a photovoltaic system to existing grid are considered with emphasis on the IEEE 9 bus transmission network that is affected by dynamic load disturbance with a corresponding increase of 35% load consumption.

Developing a Real-time Digital Simulator Computer-Aided Design (RSCAD) model of the power network

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considering the disturbance caused by load increase, the implementation of an adaptive Volt-VAr algorithm, which considers the dynamic behaviour of the power system, is investigated using an efficient controller that monitors both the PV plant and the power system behaviours in an effort of restoring the voltage stability when the system generator fails.

The overall control strategy of the algorithm is to monitor the operation of the grid for any variations in power due to disturbance and be able to react instantly once the voltage in the transmission network or part of it drops beyond the permissible index of 0.95 p.u. The overall concept of the algorithm is based on the functionality of the adaptive Volt-VAr technology which consists of monitoring any variation of the magnitude of voltage between the voltage of the transmission network and the voltage set index by the controller [6].

For any difference in the voltage set, the controller will send a signal command to the inverter through a proportional-integral controller to supply power from the PV gradually in line with the dynamic change of power consumed by the load. The controller regulates in stages, not at once the power flow from the PV to the power grid [7]. Hence it restores the voltage stability in the power system to an acceptable voltage magnitude of between 0.95 p.u. and 1.05 p.u. based on the maximum power point tracking.

The following is a short description of a few algorithms that were developed by previous researchers in the mitigation of voltage stability in power systems with integrated microgrid.

Reference [8] developed an adaptive control algorithm to maximise the extraction of the photovoltaic power. The algorithm design is based on the combination of pre-existing algorithms. The Modified Model Reference Adaptive Control (MMRAC) and the Incremental Conductance algorithm (IC) are combined to facilitate the maximum control law to rapidly accomplish the Maximum Power Point (MPP) under different variations of temperature and irradiance.

The new control strategy consists of using the efficiency of the MMRAC method to track the maximum power point and compare the result with Incremental Conductance (IC) algorithm applied to the proportional integrated controller.

Considering the role of the maximum power point tracking system to extract optimal power of the photovoltaic plant by means of adapting the internal impedance of the load to that of the photovoltaic power plant. The authors proposed a two-stage control algorithm for better voltage collapse recovery. The purpose of the first stage known as the incremental conductance algorithm is to set the photovoltaic reference voltage V_{ref} used fort photovoltaic power extraction. During the second stage the V_{ref} is used as an input for control mechanism. By decoupling the two stages of control, the power system can achieve maximum power point tracking necessary for the overall voltage stability of the power systems.

Based on the boost converter topology, the authors developed a Robust Direct Adaptive Controller algorithm (RDAC) for Maximum Power Point Tracking (MPPT). The controller is designed to adapt to different operational conditions of the photovoltaic power plant [9]. The simulation is implemented in MATLAB/Simulink considering the influence of the irradiance, the temperature factors, and other natural challenges on the efficiency of the solar modules.

To add to the use of boost, buck, and buck–boost converters in solar configuration; a mathematical model of an algorithm capable to extract the maximum power of the solar plant is also developed to improve the maximum power point by using a reference voltage set by the boost converter.

Technically, the reference voltage of the boost converter tracks the reference output power of the photovoltaic by means of adaptive gains. The simulation of the algorithm demonstrates that the adaptive law which allows the controller to perform excellent tracking by adapting to the varying conditions of the voltage stability is achievable.

In [10], Hosseinzadeh and Salmasi proposed a controller scheme for power management of an isolated hybrid Alternative Current-Direct Current (AC/DC) micro-grid with wind and diesel generators. For simulation purposes, the Alternative Current (AC) loads are tied to the Alternative Current (AC) micro-grid while the photovoltaic microgrid and the Direct Current (DC) loads are connected to the Direct Current (DC) micro-grid. The controller detects the operational mode of the hybrid micro-grid by fixing the reference values of the wind and solar subsystems as well as controlling the recharge cycle of the battery banks so that the load demand can be satisfied.

In practical when power from direct current microgrid is injected to alternative current micro-grid, the output alternative current power is obtained from both direct current and alternative current converters. On the other hand, when the alternative current microgrid injects power to the direct current microgrid; the utility converter will act as an Alternative Current-Direct Current (AC/DC) converter. The exchange of power between the two converters is used to monitor the grid for any divergences between the output voltages and independence of the converters.

By monitoring the power deviation between the converters, the proposed scheme determines a suitable power management approach that allows the equitable dispatch of power between the alternative current converter and the direct current converter or vice versa. Technically when the unexploited wind power is higher. or equal to the critical power of the wind turbine ($\Delta P_{\mathrm{WG}} \geq P_{\mathrm{Critical}}^{\mathrm{WG}}$) the suggestion is that the wind power is higher enough to be used. The transfer of power from alternative current to direct current is therefore effective. On other hand, when the unexploited power of photovoltaic is higher or equal to the critical power of the solar power ($\Delta P_{\mathrm{PV}} \geq P_{\mathrm{Critical}}^{\mathrm{PV}}$), the power transfer from the direct current to the alternative current micro-grid is allowed to operate at maximum solar power. The proposed method for power management increases the systems efficiency and improve the power quality.

In [11], Munkhchuluun and Meegahapola described how the size and location of the photovoltaic plant can affect the operation of the power system. Bearing in mind that the penetration of solar power in a power system may increase the voltage stability of the grid, it is therefore critical to emphasize that connecting a photovoltaic plant can create unwanted situations like overvoltage, distribution losses, harmonics, and flickers appearing during the operation of the power system.

Analysing the influence of the solar power on the IEEE 14 bus system, the researchers demonstrated that the size of the solar plant in grid-tied mode may have the possibility of negatively influencing the parameter of the grid when not carefully regulated.

A downsized photovoltaic plant integrated into the grid may contribute to more overloading troubles, whereas an oversized photovoltaic plant supplying active and reactive power can negatively affect the operations of the grid by creating overvoltage and more instability. While the size matters, it is important to also consider the position of the solar plant since this may positively influence the magnitude of the voltage when placed closer to the problematic area of the network.

Isha and Jagatheeswari [12] developed an algorithm for the best allocation of distributed static compensator (DSTATCOM) and photovoltaic array in the distribution system. The fuzzy-lightning search algorithm is dealing with power losses that affect the operation of the power system. Fuzzy-lightning search algorithm focuses on the placement of the distributed static compensator (DSTATCOM) as Distributed Flexible Alternating Current Transmission System (DFACTS) device and the photovoltaic (PV) array unit as Distributed Generation (DG).

The algorithm proceeds by performing a load flow analysis using the Newton-Raphson method. Data from the load flow are used to determine the base case values of active and reactive as well as the bus voltage values of the entire power system. From the result of the load flow analysis where the best case has been revealed, the optimal location of the distributed static compensator (DSTATCOM) and the photovoltaic system can be obtained.

The placement of the static compensator (STATCOM), as well as that of the photovoltaic system, are load flow analysis's results dependent. The Fuzzy logic algorithm as presented reduces the power loss in the power system, assists in voltage recovery after disturbance, and increases the voltage stability value of the power system.

The disadvantages of the current literature in voltage stability study are that the authors focused on the theory and static simulations but ignore the designing and digital simulation in real time to prepare for the practical implementations of the system. Modern utilities prefer to go with probability study in real time to end up with a sufficient investigation through accurate testing of voltage deviation and recovery and implementation of confirmed simulation results.

The paper is structured as follows: Section II presents a review on voltage stability and the application of the adaptive Volt-VAr algorithm in power system. Section III presents the integration of photovoltaic in power system. Section IV elaborates the design of the proposed controller based on the adaptive Volt-VAr algorithm, Section V presents the case study to be investigated, Section VI presents the impact of the PV power on the voltage profile considering the disturbance and Section VII concludes the paper.

II. Theorical Basis

A. Voltage Stability

Voltage stability in an electrical power system refers to the stable operation of the electric power grid, which operates within the acceptable limit of voltage magnitude. The acceptable index of voltage stability is generally endorsed by the power utility. The stability of the voltage normally raises concern after the grid is subject to disturbance either by a fault in the system, an increase in load demand, or loss of generation [6, 13]. The electric power system is said to be unstable when the voltage magnitude and the reactive power at a given bus decrease or increase beyond the threshold percentage of 0.5% to 1 p.u. index [14]. The stability of the power grid depends on the capability of the power grid to restore and maintain the balance between the load and the electricity supplied by the generator [15]. The voltage instability may happen in form of a progressive drop or rise of voltages at some buses in the electrical system [13].

A possible scenario that follows voltage instability is either a loss of load in a specific area or again tripping of other equipment such as transmission lines at a large scale [16]. The Voltage Stability Margin (VSM) of a power system can be calculated using Eq. (1):

$$\text{VSM} = \frac{V_{\text{initial}} - V_{\text{critical}}}{V_{\text{critical}}} \quad (1)$$

where V_{initial} is the bus voltage at normal operating system conditions and V_{critical} is the bus voltage when the voltage collapses due to disturbance.

Voltage stability is generally classified into two subcategories as follows:

- Large-disturbance voltage stability relates to the electrical system's capability to keep adequate voltages following great disturbances. This is usually caused by loss of generation and circuit contingencies like unplanned excessive load increase. The large disturbance is usually determined by the interaction of both discrete and continuous controls and the protection of the load and the generation unit [17].
- Small-disturbance voltage stability relates to the system's capability to keep steady voltages when minor trouble occurs in the operational state of the power grid. This type of stability is caused by the characteristic of the load and the generator at a given time of the operation of the grid [17].

The instability phenomenon of concern is the voltage stability as indicated in Fig. 1 [18].

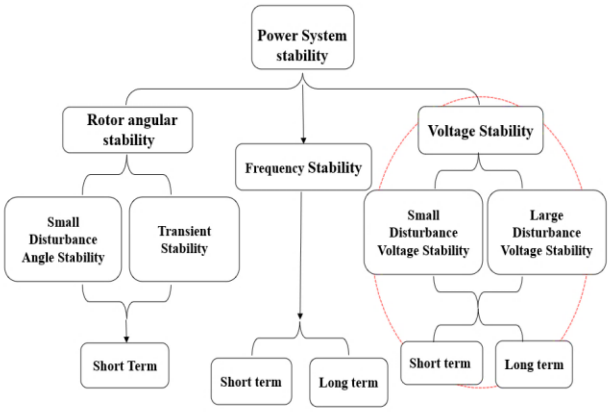

Fig. 1. Classification of power system stability according to the IEEE/CIGRE joint task force on stability terms and definition.

B. AdaptiveVoltage and Volt-Ampere Reactive Algorithm

The integration of large-size photovoltaic systems into the power system requests the application of an adequate controller to manage the output power of the PV plant. Thus, the amount of active and reactive power needs to be monitored in line with the requirement of the grid code for PV integration.

The proposed controller is defined to keep adequate power within the grid by considering the characteristics of the PV as well as the demand for power needed by the power system [7]. Photovoltaic adaptive Volt-VAr control scheme delivers reactive power output to the power system as a response to voltage measurements index [8].

The capability function of Volt-Var control scheme depends on the inverter's reactive power (Q) available to be injected into the power system. The relation including the injected reactive power and the available inverter capability is described in Eq. (2):

$$Q_{\text{inv}}^{\max} = \sqrt{S_{\text{inv}}^2 - P_{\text{inv}}^2(t)} \quad (2)$$

where S_{inv}^2 is the inverter-rated power, P_{inv}^2 implies the inverter-generated power and $Q_{\text{inv}}^{\max}$ represents the reactive power limit of the inverter when supplying active power.

Eq. (2) proves that the Volt-VAr function is used to keep the injection of the power from the inverter in line with the required power of the power system.

The controller guides the inverter to respond to voltage variation at the point of common coupling. By doing so, the inverter of the PV responds to the command of the adaptive Volt-VAr control setpoints as predefined by the utility in line with the grid code, which is expected to keep the voltage of the grid within the threshold of ±5% of the p.u. value [19]. For a given voltage index setpoint, the inverter will deliver extra reactive power or absorb the extra power depending on the prospective difference at the point of common coupling.

The control function of Volt-VAr algorithm regulates the inverter output power needed to improve the stability and reliability of the level of voltage in the power system. The overall operational function mode of Volt-VAr controller is based on the electrical grid characteristics [19]. A power meter is set on the grid side to sense the variation in voltage magnitude. The control algorithm has a unique optimization mode that considers the magnitude of the deviation of the voltage and lines current at the point of common coupling. Consequently, sending an order to the inverter to provide an adequate amount of power needed for voltage stability on the grid side [6].

By solving the two nonlinear load flow in Eq. (3) and Eq. (4), we can obtain the voltage sensitivity analysis, given as a mathematic matrix Eq. (5). This is used as a representation of an approximation of the grid's topology and reactive power dispatch [20].

$$Q_i = U_i \sum_{j=1}^{n} U_j \left(G_{i,j} \sin(\theta_i - \theta_j) + B_{i,j} \cos(\theta_i - \theta_j) \right) \quad (3)$$

$$P_i = U_i \sum_{j=1}^{n} U_j \left(G_{i,j} \cos(\theta_i - \theta_j) + B_{i,j} \sin(\theta_i - \theta_j) \right) \quad (4)$$

$$\begin{bmatrix} \Delta\theta \\ \Delta U \end{bmatrix} = \begin{bmatrix} S_{\theta_P} & S_{\theta_Q} \\ S_{U_P} & S_{U_Q} \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (5)$$

where P_i, Q_i, and U_i represent the active, reactive, and voltage as seen at node i by the controller set level, $G_{i,j}$ represents the real part of the admittance of the line connecting node i to node j, $B_{i,j}$ is the imaginary part of the admittance, θ_i is the voltage phase of node i.

III. Photovoltaic Integration

The integration of PV into power systems is generally a major concern for the various power utility. Connecting distributed generation to the power system brings some challenges that need to be addressed for the safe operation of the electric grid [7, 21, 22]. One of those challenges is described as voltage stability, which is defined in the power system as the potential of the electric grid to re-establish the initial working voltage level after being exposed to a disturbance [23]. The integration of the photovoltaic (PV) as microgrid into the transmission network require adequate control strategy to assure that the operation of the grid remains safe and the quality of the power increase to the permissible index for stability as per grid code. An adequate voltage drop versus reactive power controller for the safe operation of the microgrid is required.

IV. Proposed Adaptive Voltage and Volt-Amper Reactive Algorithm

The added value of going from a mathematical model to a real-time simulation is demonstrated in Fig. 2 [24], which focuses on the design of the adaptive Volt-VAr algorithm controller in Real-Time Digital Simulations (RTDS).

By tracking the voltage and the angle of the grid side using a Phase-Locked Loop (PPL) mechanism at the point of common coupling, which is bus 5. A transformer angle "angPLL8" is obtained and used to transform the output AC voltage and current from the inverter to dq reference frame. The decoupled current controllers are used to provide a modulation signal (mdA8 and mqA8) as output. These reference outputs are transformed to three-phase sinusoidal signals ES2Va8, ES2Vb8 and ES2Vc8 using a dq/abc transformation block and serve as the modulation waveform in the (SPWM) control block. Thus, the Sinusoidal pulse width modulation (SPWM) control block generates the firing pulse of the voltage source converter (VSC) valves. The signal of the valve to allow the transfer of power from the PV to the grid is controlled by a second Proportional Integral Derivative (PID) controller block.

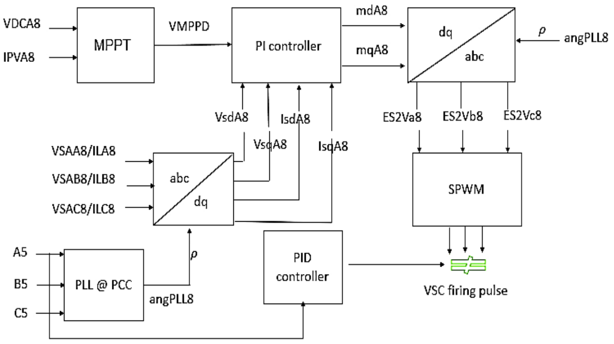

Fig. 2. Modified block design of the proposed controller for PV integration into the transmission power system.

The related equation of the PI control algorithm is presented in Eq. (5):

$$u = k_p e + k_i \int_0^t e(\tau)d\tau = k_p \left[e + \frac{1}{T_i} \int_0^t e(\tau)d\tau \right] \qquad (6)$$

where k_p represents the proportional gain constant, k_i signifies the integral gain constant, and $e(t)$ represents the error from the actual set point. The integral time or time constant T_i, is also used as the integral gain. These gain put together a substantial impact on the performance of the controller.

The basic control model of the PI controller describes in Fig. 3 presents the control diagram as designed in the real time digital simulator based on the adaptive Volt-VAr control algorithm.

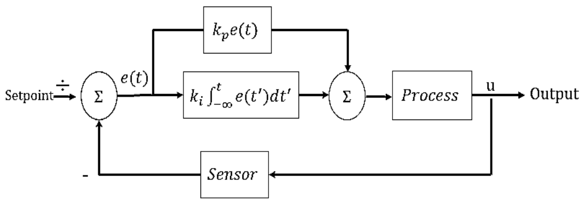

Fig. 3. Typical PI controller structure for process control

The very same mathematical system is designed in RTDS where the controller Fig. 4 and Fig. 5 consists of the following control modules:

- A measurement unit to regulate the voltage at bus 5 in a normal operating state and under disturbance.
- A voltage regulator unit, which compares the measuring unit of bus 5 to the reference set by the utility.
- A Synchronization unit with a signal generator to the firing pulse unit.
- A PI controller to set the ON/OFF state of the inverter valves for power transfer.

Fig. 4 represents the RTDS control block used to monitor the performance of voltage at bus 5, compares it to the reference voltage, and issues an error, which will be used as a measurement unit for the percentage of power to be delivered to the grid [19, 25].

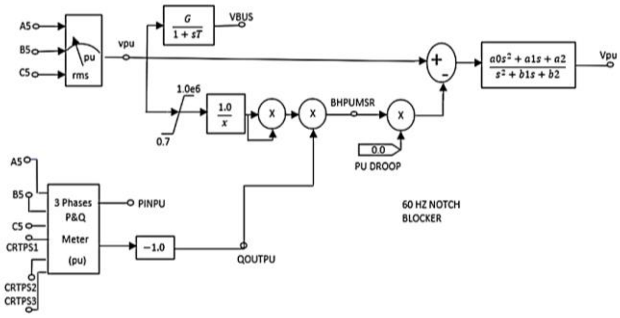

Fig. 4. Logic control for voltage monitoring at point of common coupling in RTDS.

The bus 5 RMS voltage per unit is processed through a filter circuit to obtain a clear input voltage per unit (VPU). With an input (VBUS) through a real pole function which computes the positive sequence of the voltage on the transmission side at a constant time set between 1μs to 5 μs. The voltage per unit (VPU) can be reset to a specified value at any instance of the power system operation. The current of the output side of the delta-wye transformer is also measured in per unit value together with bus 5 voltage to obtain the reactive output power (QOUTPU) through a gain device. This is multiplied to the input (VBUS) to obtain a susceptance (BHPUMSR). BHPUMSR and the clear value of the bus 5 per unit voltage (VPU) are sent via a second order polynomial method used as filtering technique to smooth-out their summation resulting to an accurate per unit voltage stability (V_{pu}) at bus 5 of the power system. The operation of the voltage logic controller plays a vital role in the steady-state and dynamic performance of the power system. The logic is automatically operational and self-coordinated to react to different types of variation within the operation of the transmission network.

In Fig. 5, the voltage, V_{pu} is compared to the reference voltage (V_{SET1}) to obtain an error for further processing. The error is processed through a PI controller to obtain the susceptance (V_{setref}). The susceptance gained from the voltage monitor is used to differentiate the ON state from the OFF state of the inverter.

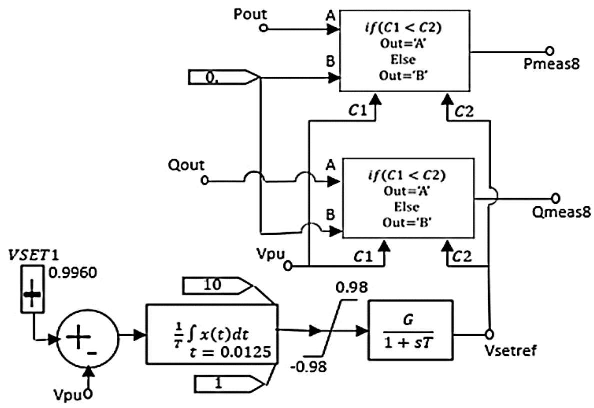

Fig. 5. PID controller design in RTDS.

By comparing the susceptance value to the pre-set V_{SET1} value, the PI controller will then send a control command to the inverter to allow the flow of power to the grid. For a V_{SET1} less than the susceptance the valves of the inverter will operate in an ON state for the power to flow. For a V_{SET1} greater than the susceptance, meaning the voltage at bus 5 is within the acceptable range of safe operation of the grid, the valve of the inverter will remain in the OFF state. Therefore, no power will be injected into the electrical grid.

The presence of these control modules in the modern power system constitutes the main task of the system operator to properly monitor and operate the Photovoltaic system to respond to the voltage stability in the grid considering the disturbance caused by the increase in load consumption. By implementing the control algorithm, the utility power is able not only to monitor the variation of voltage magnitude at the point of coupling but also be able to command appropriate action to the inverter once the voltage at bus bar 5 fails beyond the fixed threshold of 0.95 p.u [19, 26].

The function of the proportional-integral controller is dynamic and adapts to voltage variation at point of common coupling. The Photovoltaic power response to voltage variation is expected to follow the decreased patten of voltage at the point of common coupling. Hence it restores the voltage stability in the power system to an acceptable voltage magnitude.

V. Case Study

The photovoltaic microgrid with the specification given in Table I is designed using 258 series and 780 parallel connected modules. For the standard solar intensity of 1000 W/m^2 and 25 °C. The expected operating voltage and output power of the PV are respectively 11 KV and 85 MW. The power system grid on other hand is a traditional IEEE 9 bus made of 9 buses, six lines, three generators, three loads, and three transformers. The related nominal voltage of the power system is 230 KV for a frequency of 60Hz and the total active power generation capacity of 319.63 MW [15]. The initial consumption of the loads is reported in Table II. Fig. 6 displays the comprehensive RTDS model of the grid-tied PV system under investigation in this paper.

Voltage stability is investigated using a disturbance describes as a load event, where the demand of the load has been increased from the initial value by 35% in the step of 5%. The result of load events following the disturbance in the power system is presented in Table III for the load increase and Fig. 7 and Fig. 8 below for the voltage drop.

TABLE I: PV Microgrid Design Specification

Description	Specification	Unit (s)
Modules type	Monocrystalline	201240
Voltage at P_{max} (V_m)	37.2	Volts
Current at P_{max} (I_m)	9.41	Amps
Open circuit voltage (V_{oc})	45.3	Volts
Short circuit current (I_{SCref})	10.15	Amps

TABLE II: Initial Power Consumption Per Load

Load range	Load 5 (MW)	Load 6 (MW)	Load 8 (MW)
Maximum	125.00	90.00	100.00
Minimum	31.00	27.00	14.00

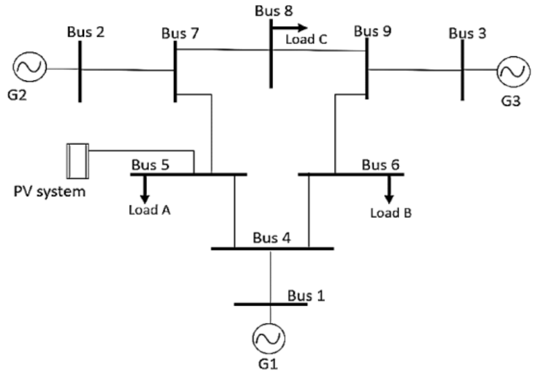

Fig. 6. IEEE 9 bus grid-tied system for simulation in RTDS.

TABLE III: Load Conditions After Disturbance

Load range	Load 5 (MW)	Load 6 (MW)	Load 8 (MW)
Initial	125	90	100
Overloading	168.8	135	121.6

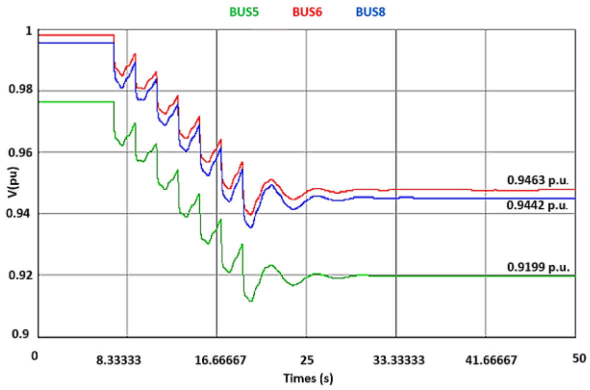

Fig. 7. Voltage drops at buses 5.6 and 8 due to a 35% increase in load consumption.

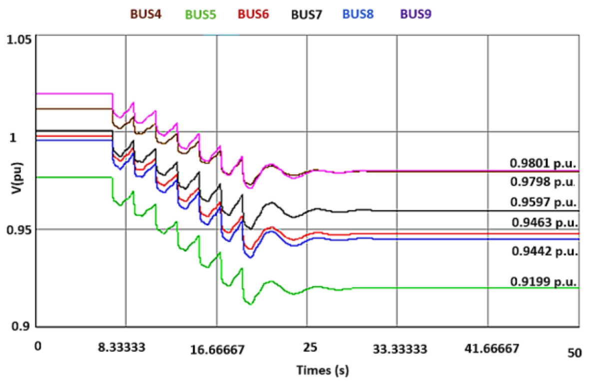

Fig. 8. Overview of the voltage drop of the entire system after disturbance.

VI. Power System Response

The response of the power system for the integration of the PV versus the applied disturbance is shown in Fig. 9 and Fig. 10.

The purpose of the proposed controller topology based on the adaptive Volt-VAr algorithm scheme in power system is proving to be efficient as it managed to monitor and regulate the high penetration of photovoltaic power in the transmission network. The results obtained demonstrate in Fig. 9 and Fig. 10 that the controller implemented in RTDS has managed to regulate the voltage versus power boundary when the power from the photovoltaic system is injected into an electrical grid considering the disturbance.

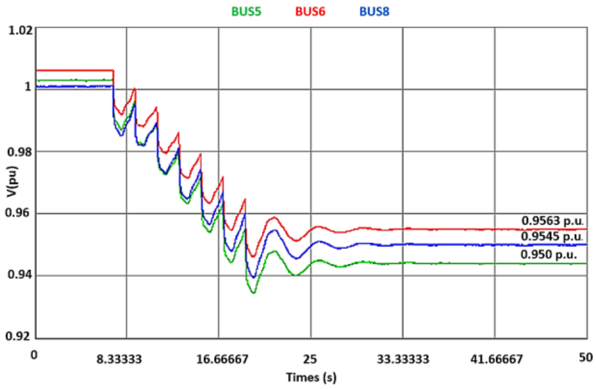

Fig. 9. Bus 5, 6 and 8 voltage response due to PV integration.

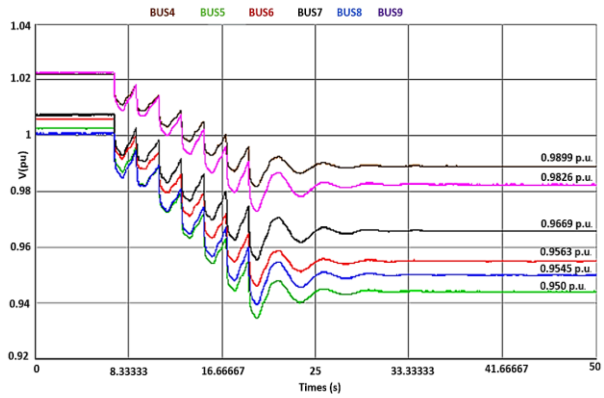

Fig. 10. Voltage recovery of all buses due to PV penetration.

The complete focus of the controller structure of the voltage and volt-ampere reactive manages initially to constantly monitor the behaviour of the voltage and secondly to restore and keep the profile of the system voltage within an acceptable range of stability. The controller based on the algorithm also proves it ability to respond gradually to the dynamic change of the voltage magnitude at the point of common coupling when the electrical grid is subject to disturbance.

VII. Results and Discussion

The result presents the contribution of the "adaptive Volt-VAr control" algorithm in the smart grid for the voltage stability study. The results show that the implementation of the controller in RTDS supports the algorithm because the voltage versus power relation has been well supervised in supporting the transmission network to keep its voltage between the permissible magnitude for the safe operation of the grid. The contribution of the adaptive Volt-VAr control scheme has improved the voltage stability of the grid after disturbance from dropping from 0.9199 p.u to 0.950 p.u. for bus 5, 0.9463 p.u. to 0.9563 for bus 6, and 0.9442 p.u. to 0.9545 for bus 8.

The controller helps to monitor the transmission network performance, to regulate the power delivered by the microgrid photovoltaic system (PV) and to restore the voltage stability by minimising the cost of power loss. To achieve the control efficiency, a logic control for voltage regulation at a point of common coupling together with the proportional-integral-derivative controller (PID) were designed and simulated as regulator modules in RTDS. The proposed controller replaces the old fashion control switches such as capacitors or STATCOM and other devices used in voltage stability control.

The controller keeps the inverter response dependent on the instability of voltage caused by the disturbance. The gradual and dynamic response of the inverter also corresponds to the dynamic impact of the disturbance in the power system [7]. The adaptative Volt-VAr control algorithm scheme is ideal for voltage control in a smart grid.

VIII. Conclusion

The results obtained show that the control implemented in RTDS fully controls the voltage versus power curve when a power system is affected by disturbance. The complete Volt-VAr control task is concerned with keeping the system voltage profile within a preferred range and minimizing system losses by monitoring the reactive power flow between the microgrid PV and the Transmission network. The inverter function in accordance with the function of the adaptive Volt-VAr algorithm responded gradually to the signal command received from the controller.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Sampi Denis Lumina conceptualized the research, performed the analysis, and wrote the paper. Mkhululi E. S. Mnguni and Yohan Darcy Mfoumboulou fully supervised the research, and reviewed, and edited the paper. All authors have approved the final version.

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