OPTIMIZING MICROGRID PERFORMANCE USING TRANSIENT DROOP CONTROL

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***Abstract*— The adoption of microgrids as decentralized energy systems has gained substantial momentum in recent years due to their potential to enhance energy resilience, reduce carbon emissions, and improve grid reliability. Central to the successful operation of microgrids is the implementation of advanced control strategies, with droop control emerging as a key technology. This project's primary objective is to investigate and optimize microgrid performance by using droop control operations. The project explores how droop control can adapt to varying load conditions and grid disturbances, ensuring uninterrupted power supply and stability. By implementing and testing the optimized droop control system in a real-world microgrid environment, this project seeks to demonstrate tangible improvements in microgrid performance, energy efficiency, and the ability to integrate renewable resources seamlessly.**

Keywords*— Microgrid, Droop Control Operations, Renewable Resources.

I. INTRODUCTION

Droop control is a decentralized control strategy that is based on the drooping characteristic of traditional synchronous generators, which follow a linear relation between active power and frequency and reactive power and voltage. Droop control can be used to regulate the voltage and frequency of a microgrid, as well as to achieve proper power sharing among parallel-connected distributed units, without relying on communication channels. However, conventional droop control suffers from various drawbacks. To overcome these limitations, various improved droop control strategies have been proposed. The improved droop control methods aim to enhance the stability, reliability, efficiency, and power quality of microgrid

An effort is made in this work and the paper deals with the implementation of a mode to explore how droop control enhances microgrid performance by adjusting power output based on voltage or frequency changes by integrating solar panels (PV arrays). By teaming up droop control with PV arrays, we're aiming to show how these two works together to squeeze the most benefits out of renewable energy in microgrids.

II. REVIEW FROM THE LITERATURE

A hybrid bidirectional interlinking converter's feedback control technique for alternating current (AC)/direct current (DC) microgrids. A robust droop control technique is suggested to address the load variations-induced uncertain voltage and frequency droop. The electrical switching transients between AC/DC microgrids and the unmodeled load dynamics are considered by the suggested droop controller [1]. To ensure power stability under various operating situations, a sliding mode controller (SMC) and a conventional current controller are employed. Hard sliding-mode control, however, can cause unmodeled dynamics to be excited, loss of energy, damage to plants, and chattering.

To address the drawbacks of basic droop control in the primary control level, in which the droop curves are configured flexibly according to partitioned load regions, a family of distributed piecewise droop control strategies (DPDC) is derived in the paper [2]. As a result, both current sharing and voltage compensation will be enhanced simultaneously. A method for managing voltage and power flow in DC microgrids—networks of dispersed energy sources and loads that run on direct current—is called distributed piecewise droop control, or DPDC. However, DPDCs may result in significant voltage variations at lower frequencies, which may have an impact on the microgrid's stability and power quality.

The work presents a hierarchical control scheme for islanded microgrids, consisting of primary and secondary controllers [3]. To enable the linked Distributed Generation (DG) units to independently share the overall microgrid load in proportion to their capacity, each DG unit uses a generalized communication-less droop-based primary controller at the primary level. To improve performance, the droop controllers also use an innovative method that separates the active and reactive powers of each DG based on the line impedances of the DG. Furthermore, to rectify the droop-controls-caused deviation in the microgrid's voltage magnitude and frequency, a decentralized communication-based secondary controller is put into place. The hierarchical control technique that is provided is verified by implementing a test microgrid in PSCAD/EMTDC. The outcomes of the simulation demonstrate that the controllers that have been proposed are capable of accomplishing the control goals and preserving steady system performance in the face of different disruptions.

The voltage source converter bridging the DC microgrid and AC main network is a modular multilevel converter (a multi-level converter is a type of power converter that can generate high-voltage waveforms from lower-voltage components) [4]. A few issues with traditional droop control include DC voltage variation, irrational active power distribution, and the fixed droop coefficient's inability to achieve flexible system adjustment. The bus voltage active power (Udc -P) droop management approach is therefore employed in a multi-level converter control system. [4] The adaptive droop control system is used in the paper to automatically modify the droop coefficient based on voltage deviation. However, the need for numerous submodules in multimodular converters raises the size, cost, and complexity of the converter. Additionally, it has a significant capacitor voltage ripple at low frequencies, which could shorten the submodule lifetime and lower the quality of the output voltage.

To enhance voltage quality for an AC microgrid, a synchronous rectifier-based droop management technique is implied [5]. Initially, a three-phase PWM rectifier is equipped with the virtual synchronous machine (VSM) technology, which gives it a droop mechanism and damping characteristic comparable to that of a synchronous machine. Second, the frequency droop control and voltage droop control techniques are made to reduce the frequency and voltage fluctuations of the AC bus that are brought on by changes in load in the AC microgrid, respectively, along with the synchronous machine's droop characteristics. There are several drawbacks. For example, if a three phase PWM rectifier is used with a VSM, it might not be able to manage the grid voltage and frequency because it only imitates synchronous machine behavior and has no direct control over the grid values.

The droop control approach is the foundation for the optimized micro-grid control strategy, which lowers frequency and voltage fluctuation and enhances the electric power quality of the micro-grid. To enhance the frequency consistency of the micro-grid, a frequency correction segment is introduced to the P-f control section, whereby the PID parameters can be modified [6]. To reduce the voltage fluctuation, a fuzzy self-adaptive PID controller is a kind of controller that combines the benefits of a fuzzy logic controller with a normal PID controller is added to the Q-U control section at the same time. A seamless and quick transition between grid-connected mode and islanded mode is intended to be accomplished through the phase synchronization and voltage amplitude adjustment (PSVAA) module. These methods do have certain drawbacks, though, such as the potential to produce coupling effects among the phase and amplitude loops, which might result in spurious transients and oscillations in the frequency and voltage of the output.

A unique automatic mode transition control approach is proposed in paper [7] to allow numerous inverters to function in both standalone and grid-connected modes. These inverters use the current control mode to deliver power to the grid when it is available. All inverters immediately switch to droop control mode during a grid failure to provide appropriate power sharing, and they return to current control mode as soon as the grid returns to normal. Novel state machines are used to synthesize dual structure control algorithms of different inverters. The purpose of these state machines is to enable the inverters to switch modes smoothly. In this manner, state machines unique to each inverter generate the control signals for mode transition. In contrast to current control techniques, the suggested approach requires no need for a dedicated storage facility or communication-based supervisory control of inverters in order to achieve a smooth mode transition.

When operating in grid-connected mode, distributed generators (DGs) use current control (CC) and when operating in islanded mode, they utilize droop control (DC). When there is an operational shift from the grid connected mode to the droop control mode and vice versa, a significant transient is seen[8]. It is necessary to create an appropriate control mechanism to reduce these transients. Four popular controller configurations are the conventional droop, generalized droop, conventional droop with virtual impedance (VI) based control, and the transient droop, which represent the variety of droop controllers used. The Paper [8] explores the transient power sharing performances on a two-inverter DG microgrid under different combinations of these droop controller topologies and discusses a state machine-based mode transition technique.

In the study [9], synchronous frame PLL is used to present a seamless transfer control approach or algorithm for single phase grid-tied inverters. A phase-locked loop (PLL) is a feedback mechanism that synchronizes a voltage-controlled oscillator's (VCO) output frequency with a reference signal's input frequency. For controlling active and reactive power in the grid-connected mode and output voltage in the islanded mode of operation, the inverter is operated using the Direct-Quadrature Synchronous Reference Frame Transformation. The suggested method determines the breaker state, which is in charge of switching between the two control modes. The seamless transfer algorithm checks the grid's frequency and PCC voltage on the grid side. It then determines what to do by analyzing if these two parameters fall within a certain range. The synchronization process is carried out by the SF-PLL, which, depending on the algorithm's output setting, uses either the grid or a constant d-q component of the voltage as its reference. The frequency and phase angle of the inverter plications will be determined from the SF-PLL's output. Even so, PLLs also have certain disadvantages, such as the potential for stability problems, excessive power consumption, and heat generation as a result of the phase detector and VCO operating continuously. Therefore, using it is not more reliable.

Evaluation is done on the circulating current between the parallel dc-dc converters in dc microgrids as well as the effects of the droop coefficient on bus voltage and load sharing. Based on the analytical results [10], a dynamic voltage compensation mechanism and variable droop coefficient are presented to respond to different scenarios and maintain a stable bus voltage. This is a simple and efficient solution, however the circulating currents can lead to a number of issues, such as decreased converter efficiency and reliability due to increased power losses and component thermal stress. It may also cause the microgrid's stability and power quality to decline as well.

The paper [11] examines power coupling problems in low-voltage AC microgrids generated by several parallel inverters. Analysis is done on how control settings affect the system's equivalent output impedance under the conditions of classic droop control. According to these constraints, a droop control technique based on virtual impedance is used, which illustrates how the virtual impedance value affects the properties of the output impedance. An enhanced control approach based on PI controller is proposed to compensate for the voltage drop caused by virtual impedance. This method can provide load power distribution based on the capacity of the inverters while preserving the stability of the AC bus voltage.

A unique operational method for PV-storage independent microgrids is proposed in the paper [12]. PVs function as current controlled voltage sources (CCVS). To clarify the suggested operation mode, a droop control technique based on maximum power point tracking (MPPT) is presented. In order to maximize the use of renewable energy sources, PVs can provide an additional service of frequency regulation in this mode.

III. PROBLEM DEFINITION

The stability and effectiveness of the system may be in risk when a microgrid operates without a droop control plan, which can lead to a number of serious problems. Uncertainty in both frequency and voltage is one of the main problems, as it can cause interruptions in the electrical supply and possibly harm expensive devices. Without droop control, load balancing becomes an extremely difficult process that increases the risk of overloads and reduces the reliability of the distribution of electrical loads throughout the microgrid. Moreover, the lack of droop control makes grid disconnection more difficult and unreliable during emergencies or service disruptions.

Each of these issues add up to unstable operations, problems in integrating renewable resources into the microgrid, and inefficiencies in operation. Droop control implementation therefore becomes essential for addressing these issues and maximizing microgrid performance. Droop control is essential for improving stability, encouraging effective allocation of resources, and enabling smooth grid disconnection if required since it adjusts power output according to system conditions. Droop control must be implemented in order to ensure a consistent and robust energy supply for microgrids due to its complex connections to a number of loads and renewable energy sources. Conventional droop control struggles with modern grid demands, so adopting a Transient droop offers faster response, dynamic stability, and tighter frequency regulation, crucial for microgrids and distributed energy.

IV. METHODOLOGY

Droop control can be implemented for both active (real) and reactive power. This is crucial for maintaining voltage stability. Feasible solutions involve setting the appropriate droop coefficients for active and reactive power to balance the load effectively such that the generators generate the power to the loads according to their respective ratings maintaining the standard frequency and voltage achieving droop control. The solar power sources are connected to the load via an inverter and control system to generate power to the loads efficiently by using the droop control technique. The most common type of droop control is conventional droop control. In conventional droop control, frequency and voltage vary linearly for active and reactive power, respectively as shown in Fig 1, Fig 2.

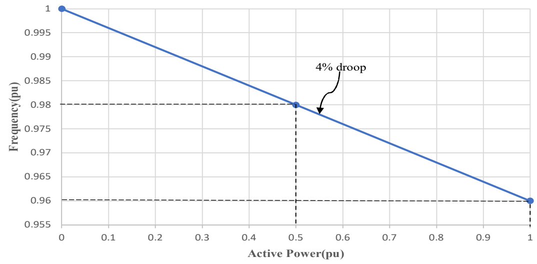

Figure. 1: Active Power vs Frequency Curve

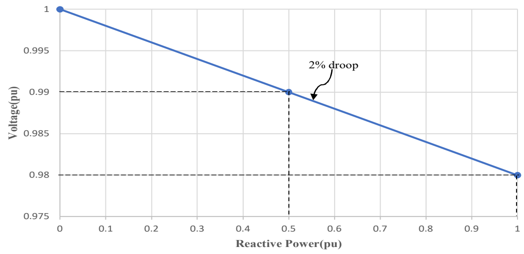

Figure. 2: Reactive Power vs Voltage Curve

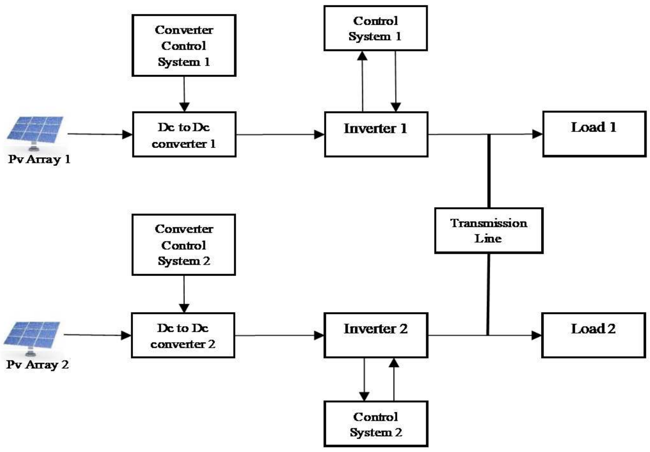

Figure. 3. Block diagram of three phase solar powered microgrid with droop control

The PV arrays 1 and 2 generate the photovoltaic energy, which produces DC energy, and this DC energy is boosted using a boost converter so that the desired energy is obtained for power generation and fed to the inverter 1 and inverter 2 having LCL filters to reduce harmonics, These inverters converts the DC energy into AC energy, and the droop control methodology is implemented in the system to generate the energy from each solar power generator to the loads connected to the grid through a transmission line based on the ratings of the generators such that the accurate and efficient generation of energy from the microgrid to the loads is possible while maintaining the standard frequency and output voltage via controlling the amount of energy delivered from each generator to the connected loads as shown in Fig. 3.

In this paper, both generators are rated equally and connected with loads of 7 KW and 3 KW, resulting in a total load of 10 KW. So, the droop control technique is used such that the control system generates the pulses as outputs, which govern the action of switches in the inverter to produce 5 kilowatts of power from each generator as they are rated equally to meet the load demand of 10 KW. In the droop control, the frequency is considered as one of the main variables along with the voltage. With this control, the relationship between both the active power and reactive power and the voltage and frequency are given by:

$$\text{Frequency(f)} = \frac{\omega_n - m_p P}{2\Pi} \tag{1}$$

$$\text{Vod}\_ref = V_n - n_q Q \tag{2}$$

The term "transient droop" typically refers to a temporary decrease in voltage or frequency in an electrical system. This can occur due to sudden changes in load or other disturbances, the voltage, Frequency, and load transient droop equations are given as:

$$V(t) = V_0 - \Delta V.e^{-t/\tau} \tag{3}$$

$$f(t) = f_0 - \Delta f.e^{-t}/_T \tag{4}$$

$$P(t) = P_0 - \Delta P.e^{-t}/_T \tag{5}$$

These equations offer a fundamental insight into how voltage, frequency, or load can fluctuate over time during transient occurrences within a power system. They provide a foundational understanding of the dynamic behavior exhibited by these parameters during the events.

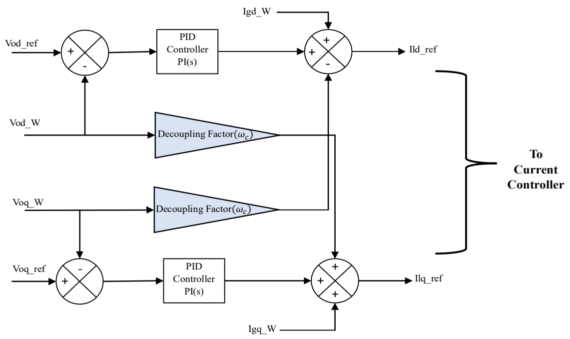

Figure. 4: Outer Voltage Controller loop

In droop control, the outer voltage control loop regulates the voltage by comparing the actual voltages (Vod_W, Voq_W) with desired references (Vod_ref, Voq_ref). This comparison generates an error signal. The error signal is then processed by a proportional and Integral (PI) controller, which determines the necessary adjustment to the output current of the power source and is given to the Current Controller. If the sensed voltage is below the desired level, the controller increases the output current to raise the voltage. Conversely, if the sensed voltage exceeds the desired level, the controller decreases the output current to lower the voltage. This continuous feedback loop ensures that the system maintains stable voltage levels, compensating for fluctuations in load or other operating conditions as shown in Fig. 4.

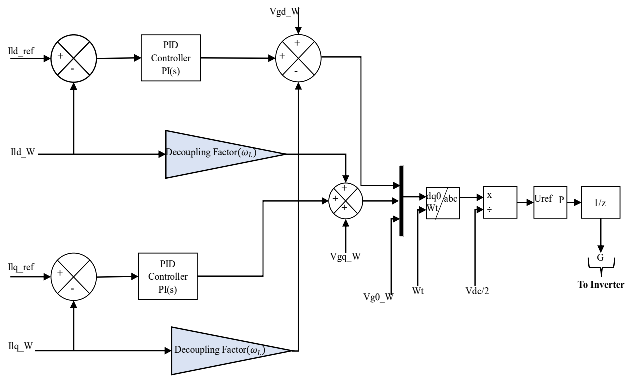

Figure. 5: Inner Current Controller loop

The inner current controller loop regulates the output current of the power inverter to match the desired current reference. This loop typically operates using a proportional-integral (PI) controller. First, the actual current measured (Ild_W, Ilq_W) is compared with the desired current reference (Ild_ref, Ilq_ref) value. The error signal resulting from this comparison is fed into the PI controller. The controller calculates the required adjustments to the gate pulse signals sent to the inverter's switching devices (such as transistors or IGBTs). The generated gate pulse signals control the switching of the inverter's devices, regulating the flow of power from the source to the load as shown in Fig. 5.

Table 1: Pv Array Block Parameters

Description	Symbol	Value/Unit
Sun irradiance	Ir	1000W/m2
Temperature	T	25°C
Parallel strings	Np	5
Series-connected modules per string	Ns	10
Maximum Power	Pmax	200W
Cells per module	Ncell	5.8Ncell
Open circuit voltage	Voc	41V
Short-circuit current	Isc	6A
Voltage at the maximum power point	Vmp	40V
Current at the maximum power point	Imp	5A

In the context of a solar energy system, several key parameters define the operating conditions and performance characteristics of the solar modules. The sun irradiance (Ir) is specified at 1000W/m2, representing the intensity of sunlight falling on the modules. The operating temperature (T) is set at 25°C. The system configuration includes 5 parallel strings, with each string consisting of 10 series-connected modules. The maximum power output (Pmax) of a single module is defined as 200W. Each module comprises 5.8 cells (Ncell). The open circuit voltage (Voc) across the module is 41V, and the short-circuit current (Isc) is measured at 6A. At the maximum power point, the voltage (Vmp) is set at 40V, and the corresponding current (Imp) is 5A. These parameters collectively provide a comprehensive overview of the solar modules' characteristics, offering insights into their efficiency and performance under varying environmental conditions Understanding these characteristics enables optimization of system design and operation, ensuring maximum energy generation and reliability (Table 1).

Table 2: DC to DC Block Parameters

Description	Symbol	Value/Unit
Ripple Capacitance	Cripple	0.006F
Inductance	L	0.000349H
Snubber resistance	Rs	1e5
Snubber capacitance	Cs	infF
Diode Resistance	Ron	0.001Ohms
Diode Inductance	Lon	0H
Diode Forward voltage	Vf	0.8V
Diode Snubber resistance	Rs	500Ohms
Diode Snubber capacitance	Cs	250e-9F
Switching frequency	Freq	20000Hz
Branch Capacitance	C	0.000000207F

The ripple capacitance (Cripple) is denoted as 0.006F, representing the capacitance associated with the circuit's ripple. The inductance (L) is specified as 0.000349H, indicating the measure of the circuit's inductive property. The internal resistance (Ron) is noted as 1e-3 Ohms. The snubber resistance (Rs) is defined as 1e5 Ohms, and the snubber capacitance (Cs) is labeled as infF, indicating an infinite capacitance value, The diode in the circuit has an internal resistance (Ron) of 0.001 Ohms, diode resistance (Rs) of 500 Ohms, and diode snubber capacitance (Cs) of 250e-9F. The diode is characterized by a diode inductance (Lon) of 0H, a forward voltage (Vf) of 0.8V, and an initial current (Ic) of 0A, the switching frequency (Freq) of the circuit is specified at 20000Hz. Additionally, the branch capacitance (C) is denoted as 0.000000207F, representing the capacitance within a specific branch of the circuit (Table 2).

Table 3: Inverter System Block Parameters

Description	Symbol	Value/Unit
Inverter Side Inductance	RL	0.2Ohms,2e-3H
Filter Capacitor	RC	5Ohms,15e-6F
Grid Side Inductance	RL	0.2Ohms,1e-3H
Snubber resistance	Rs	1e5Ohms
Inverter Side Resistance	Ron	1e-3Ohms
Snubber capacitance	Cs	infF
Number of bridge arms	Nb	3

The inverter side inductance (RL) is characterized by a resistance of 0.2 Ohms and an inductance of 2e-3H, signifying the impedance and inductive property of the inverter side. The filter capacitor (RC) is designated with a resistance of 5 Ohms and a capacitance of 15e-6F, outlining its role in filtering and smoothing the electrical signals within the system, On the grid side, the inductance (RL) is once again represented with a resistance of 0.2 Ohms and a reduced inductance of 1e-3H, indicating the characteristics specific to the grid connection. Additionally, a snubber resistance (Rs) is specified with a value of 1e5 Ohms, illustrating the presence of a snubber component designed to mitigate unwanted voltage spikes or transients within the system (Table 3).

Table 4: Control System Block Parameters

Description	Symbol	Value/Unit
Outer Voltage Controller Proportional (P)Value	Kp	2P
Outer Voltage Controller Integral (I)Value	Ki	10I
Inner Current Controller Proportional (P)Value	Kp	20P
Inner Current Controller Integral (I)Values	Ki	400I

The outer voltage controller is characterized by proportional (Kp) and integral (Ki) values denoted as 2P and 10I, respectively. These values signify the proportional and integral components of the Proportional-Integral (PI) controller used to regulate the outer voltage in the system, Similarly, the inner current controller is described by proportional (Kp) and integral (Ki) values, with 20P and 400I, respectively. These values represent the proportional and integral components of the Proportional-Integral (PI) controller dedicated to regulating the inner current within the system (Table 4).

Table 5: Comparison of transient and regular droop control

Aspect	Transient Droop Control	Regular Droop Control
Response Time	Very fast, typically within milliseconds or microseconds	Slower, adjusts power output gradually
Application	Addresses transient disturbances such as faults or load variations	Maintains stability during normal operation
Example	Quickly counteracting sudden load changes	Adjusting generator output to match load demand
Advantages	Rapid response prevents system instability during transients	Smooth adjustments promote stable long-term operation
Disadvantages	Requires careful tuning to avoid overcompensation	Less effective in addressing rapid changes or disturbances

The two kinds of droop control that are utilized in electrical systems are transient droop control and regular droop control, each with unique properties and uses. This is how the two are compared (Table 5).

V. Results

1) *Active Power on the Generation Side:*

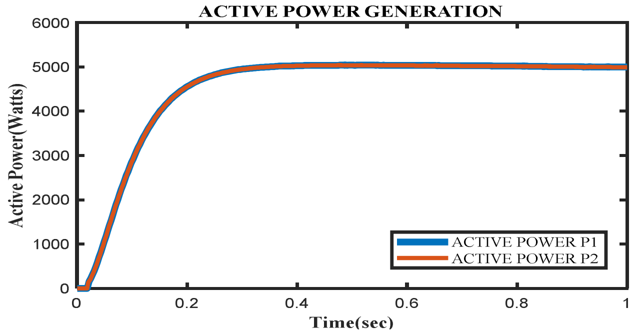

Figure. 6 Active Power on Generation Side

In above Fig. 6, The PV array1 and PV array2 generate photovoltaic energy, which produces DC energies and is further converted to AC energies, Where the Active power P1 and P2 Starting from 0Watts to a maximum of 5000Watts from both the sources are given simultaneously by the droop action to the Load accordingly.

2) *Reactive Power on the Generation Side:*

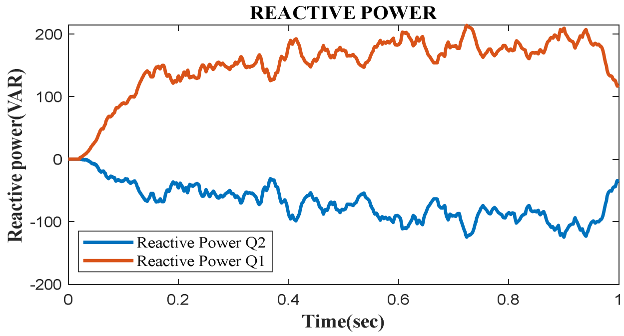

Figure.7 Reactive Power on the Generation Side

In the above Fig. 7, The PV array1 and PV array2 generate photovoltaic energy, which produces DC energies and is further converted to AC energies, Where the Reactive power Q1 and Q2 of both generations are almost equal to zero.

3) *Active and Reactive Power of Load 1*

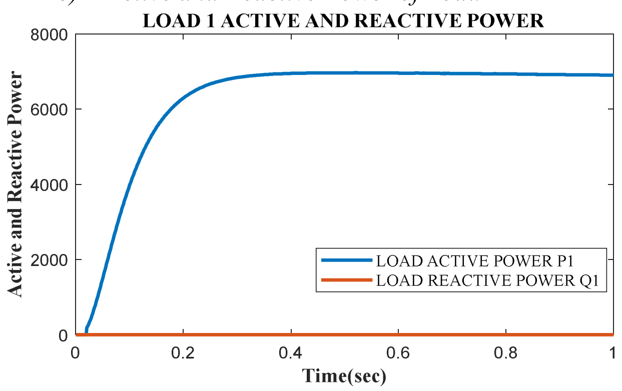

Figure.8 Active and Reactive Power of Load 1

In the above Fig.8, Load 1 consumes an Active Power P1 of 7000Watts constantly starting from 0 Watts after the droop action is completed and Reactive Power Q1 is equal to zero from 0 seconds to 1second.

4) *Active and Reactive Power of Load 2*

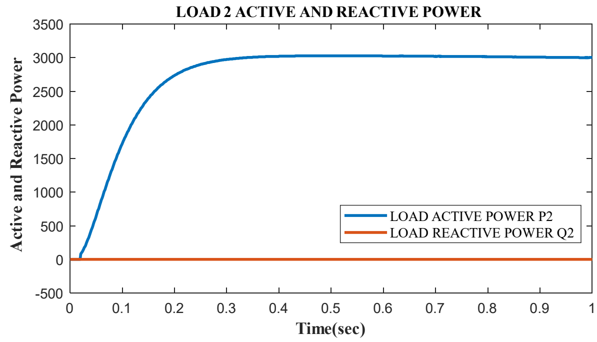

Figure.9 Active and Reactive Power of Load 2

In above Fig. 9, Load 2 consumes an Active Power P2 of 3000Watts constantly starting from 0 Watts after the droop action is completed and Reactive Power Q2 is equal to zero from 0 seconds to 1 second.

5) *Active and Reactive Power of Transmission Line*

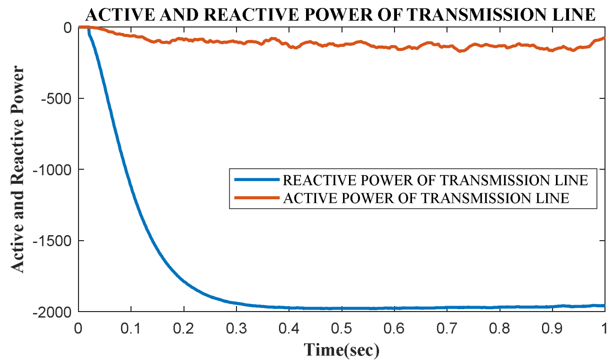

Figure. 10 Active and Reactive Powers of Transmission Line

In the provided Fig, 10, the Transmission Line exhibits near-zero Active Power (Pt), indicating minimal power transfer. Additionally, the Reactive Power (Qt) tends towards negative values, suggesting a tendency for the transmission line to absorb reactive power rather than generate it.

VI. Conclusion

The implementation of droop control in a solar PV system with two loads offers a highly efficient and reliable solution for power distribution and load sharing. This control strategy not only optimizes energy utilization but also ensures voltage stability and real-time adaptability to varying conditions. With its simplicity, scalability, and cost-effectiveness, droop control proves to be a superior choice for effectively harnessing solar energy and providing a consistent power supply to multiple loads. In summary, the use of droop control in such systems stands as a robust and economically viable approach to maximize the benefits of solar energy generation, so transient droop offers superior performance compared to normal droop in voltage regulation systems. Its ability to swiftly respond to dynamic load changes ensures stability during transient events, minimizing voltage deviation. This makes transient droop preferable for applications

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