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Parallel Operation of DC Converters in Isolated PV-Wind DC Microgrid Using Droop

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Abstract— **With the increasing consumer loads operated by DC voltage, DC micro-grids are becoming popular in terms of reliability and efficiency. In DC micro-grids, a conventional droop control method has been used to share the load proportionally to their capacity; however, it led to the reduction of reference bus voltage. This paper presents an adaptive droop controller designed to mitigate the trade-off between current sharing and voltage regulation of the DC micro-grid. To simulate and evaluate the suggested control approach, isolated dc-dc converters are used. The proposed scheme is simulated using MATLAB Simulink and the simulation results show that the control logic for adaptive droop control works satisfactorily.**

Keywords - DC Micro-grid, parallel operated inverters, droop control, load sharing

I. INTRODUCTION

The need for energy is growing, and distributed power production systems-which include tiny generation and storage units-are becoming increasingly widespread. Low distribution losses, high dependability, fewer blackouts are likely, it's simple to scale, and remote electrification are some of the main benefits of dispersed systems.

The DC micro-grid was developed to fix the AC micro-grid's flaws while also offering other advantages including frequency synchronization, reactive power regulation, skin effect, power quality problems, etc. These days, many consumer products, like computers, battery chargers, LED bulbs, etc., work on DC voltage. Currently, AC to DC converters built within the load devices themselves are used to power these loads from AC mains. The cost and losses associated with AC to DC converters can be reduced if DC micro-grids are able to power this equipment.

One of the most important issues in DC micro-grids with parallel-connected sources is accurate current sharing [1]. In addition to achieving the required goals (proportional load sharing and voltage regulation within limitations), an acceptable control approach should be able to preserve the system's stability. In order to accomplish precise load sharing across parallel-connected converters, certain research items modify the droop controllers in unique ways. They either modify the droop value or set up a secondary controller to stop the current from flowing.

In [2] an approach for decoupling droop control that takes into account both line resistances and load characteristics is suggested. For adjusting the virtual resistance of the droop controller, a generalized technique of particle swarm optimization is presented in [3]. This method shares the current using heuristic techniques rather than calculating line impedance. The droop parameters in [4] are computed using a suggested indicator termed the droop index. Although this strategy produces precise load sharing, it is hindered by significant computational work. The power of the converter is sent through a low pass filter by the authors of [5] to create a new virtual parameter. A low pass filter adds complexity and delay to the design phase. The addition of the voltage observer and the frequency controller leads to the proposal of a precise power-sharing mechanism [6]. To ensure precise power sharing, this approach needs high-speed communication lines, nevertheless.

The initial step toward current sharing accuracy in the dc micro grid was the centralized droop control approach [7]. Due to insufficient voltage regulation, inadequate current sharing, and problems with the secondary controller, this system is not particularly successful. Droop control is restricted to the one- source, one-load scheme in [8]. As a result, it does not illustrate the impact of uneven load sharing in the distributed generating system.

II. PROPOSED SCHEME

Adaptive droop control logic can be used to share power according to their capacities while improving DC bus voltage regulation, parallel operated converters in a DC micro-grid. Here, the controller is designed to change droop by itself according to the amount of change in load.

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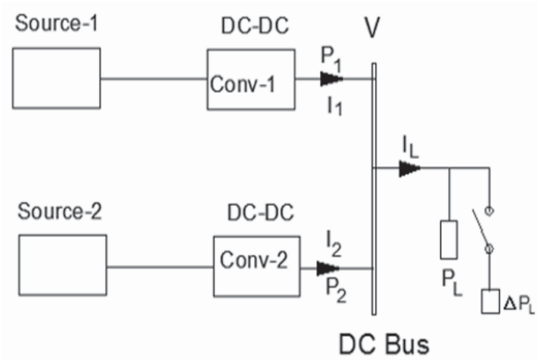


Figure1: Parallel connection of two sources with their respective converters supplying a common load

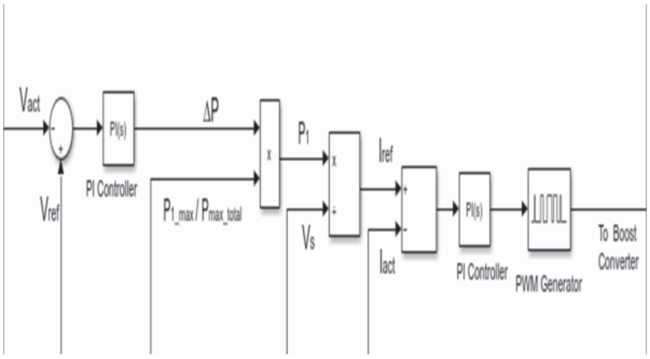


Figure2. Diagram of proposed scheme

In this scheme, the error in the voltage signal is fed to the PI controller, whose output is multiplied by the ratio of the source's maximum capacity (P max) to the combined maximum capacity of both sources (P total max), to obtain the necessary power needed by that source for sharing the load proportionately to their capacity. The acquired power is then transformed into current, and the difference between the actual current and the reference current is determined. This error is then sent through the IGBT diode's gate using a PWM generator.

A. PV System:

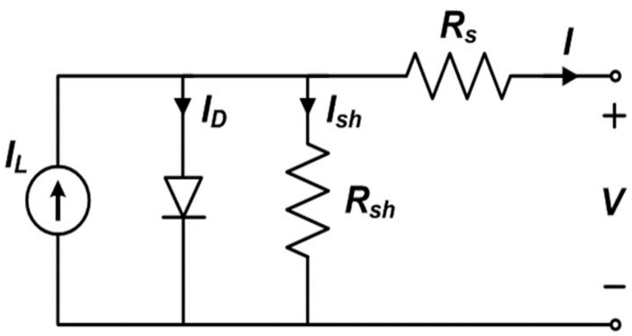


Figure3: Solar Cell Model using single diode along with series and shunt resistances

The Sun, the never ending source of energy on this planet, is the central part of a PV system. A PV system converts sunlight directly into electrical energy based on photovoltaic effect. When a PV cell is placed in the sun, the radiant energy energizes the free electrons and if a circuit is made, electrons flow from the n-layer to the p-layer, producing electricity. PV cells when grouped together form modules or panels. These series or parallel connected PV modules form PV arrays for the production of the required energy.

The model of a PV cell can be defined using the following equation:

$$I=N_P I_L - N_S I_D \left[\exp \{q (V+IR_S)/ N_S * nkT\} - 1\right] - \{V + (IR_S)\}/R_{sh}$$

Where;

k= the Boltzmann constant (1.38 *10-23) JK^{-1}

q= the electronic charge (1.602 * 10-19) C

T= the cell temperature (K)

n= the diode ideality factor

R_S= the series resistance (Ω)

R_{Sh}= the shunt resistance (Ω)

N_S= the number of cells connected in series

N_P= the number of cells connected in parallel

I_L=the photocurrent in (A)

T= Module operating temperature in Kelvin

I= the output current of the photovoltaic cell

I_D= the diode saturation current

PV cells generate voltage at around 0.4v to 0.8v depending upon the semiconductor material and the built-up technology. As a result, PV cells are linked in series to create a module. And strings are created by connecting these modules in a succession. In aseries connection like this, the voltage is increased while the current stays constant. Solar arrays are created by joining these strings in parallel. This parallel connection adds current while keeping the voltage constant.

The output from the PV system depends upon irradiance and temperature. This effect can be illustrated with the help of P-V and I-V characteristics curve of PV system as follows:

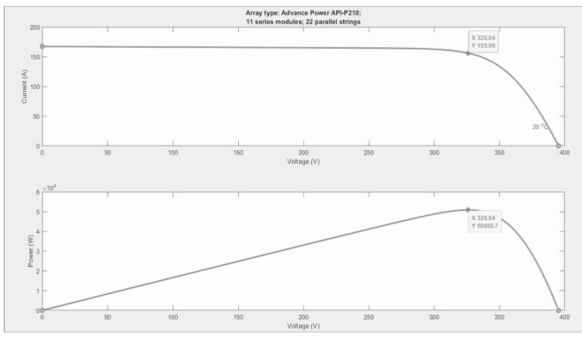


Figure 4: P-V and I-V characteristics of solar cell

Thus, in order to produce the maximum power of 50.8 kW at standard temperature and irradiance (250C and 1000 W/m^2), we simulate the solar cells. Voltage and current at maximum power point are 326v and 156A, respectively.

B. WIND SYSTEM:

Wind turbines utilize the kinetic energy of the wind to produce electricity. Airfoil-shaped blades are turned by the wind passing over them. The shaft that powers the generator, which creates electricity, is attached to the blades. Wind turbines function by first transforming wind's kinetic energy into mechanical energy, which is then used by wind generators to create electricity. The amount of energy that can be converted in WECs primarily depends on the wind speed and the turbine's swept area.

The power extracted from the rotor blades is given by,

Where,

$P_{Blade} = 1/2*\rho*A* v3 * C_p(\lambda, \beta)$

ρ= Density of air = 1.225 kg/m

$A=\pi*r^2$

$C_p(\lambda,\beta)= (C_1*(C_2*1/y - C_3*\beta - C_4*\beta_x - C_5)\ e^{((-C6)/y)}$

Where,

Gamma(y) is given by,

$1/y = 1/ (\lambda+0.08\beta) - 0.035/ (1+ \beta_3)$

Where, C_1–C_6 are the aerodynamic coefficients given as;

C_1 is 0.5176; C_2 is 116; C_3 is 0.4; C_4 is 5; C_5 is 21;

and C_6 is 0.0068.

The rotor torque is therefore defined as, $T_w =$

P_{Blade} / w_m

Where, w_m= Angular velocity of rotor

$$T_w = 1/2*\rho*A* v^3 * Cp(\lambda,\beta) /w_m$$

C. DC CHOPPER:

A boost or step-up DC-DC converter is a power converter that raises the source voltage, or creates an output voltage greater than its input voltage. It often consists of an energy storage component like a capacitor, an inductor, or both, as well as two nearly perfect semiconductor switches (such as a diode and a transistor/metal-oxide semiconductor field effect transistor (MOSFET)). To lessen output voltage ripple, filters built of capacitors are typically added to the converter's output (occasionally in conjunction with inductors or resistors). These converters' output current is less than their input current because power is conserved. A boost DC-DC converter's configuration is shown in the figure below.

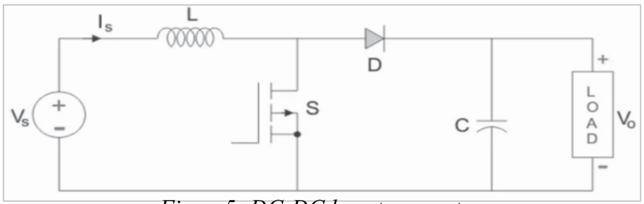
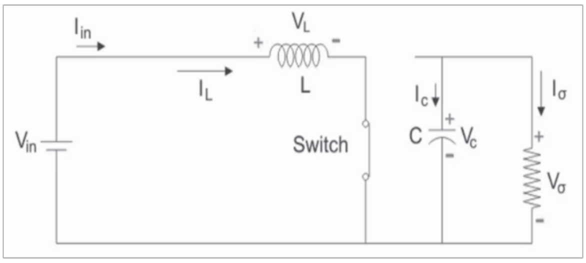


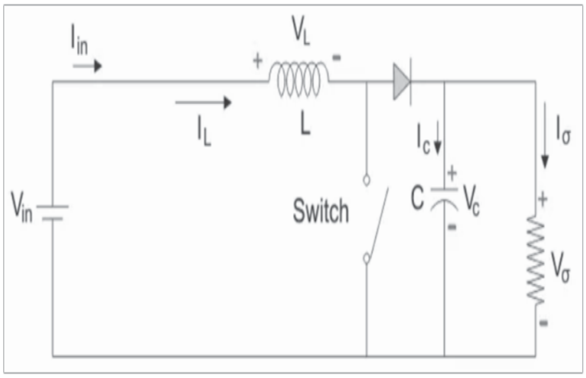
Figure5: DC-DC boost converter

I. When switch is closed



As seen in fig , when the switch is closed, the inductor experiences clockwise current flow and stores some energy by producing a magnetic field.

II. When switch is open



The inductor's polarity is reversed in this mode. The inductor's energy is released and eventually dissipated in the load resistance, which aids in maintaining the direction of the current through the load and stepping up the output voltage because the inductor is now also serving as a source in addition to the input source.

D. DROOP CONTROL:

I. Fixed Droop Control Method

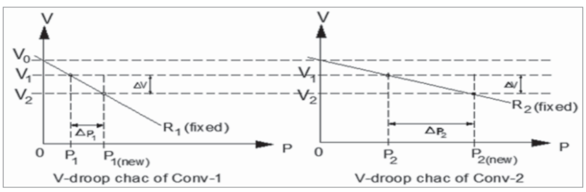


Figure6: P-V curve for fixed droop control method

Fig. shows the voltage droop curves with fixed slopes for two parallel operated DC-DC Converters. When the common load is P_L, they operate at a common DC bus voltage of

V_1. The Conv-1 supplies P_1 and Conv-2 supplies P_2 and corresponding converters currents are I_1 and I_2 respectively.

When load is increased by ΔP_L, the conv-1 and conv-2 shall supply more power to fulfill the increased load demand.

Here, ΔP_1 = additional power supplied by Conv-1

ΔP_2 = additional power supplied by Conv-2

And, $\Delta P_1 + \Delta P_2 = \Delta P_L$

ΔP_1 and ΔP_2 are proportional to the capacities of Conv-1 and conv-2 respectively. In order to supply additional p o w e r , the common DC bus voltage decreases to V_2 . If the change in load is large, ΔV will be large, resulting in poor voltage regulation. This is the disadvantage of the fixed voltage droop method.

II. Adaptive Droop Control Method

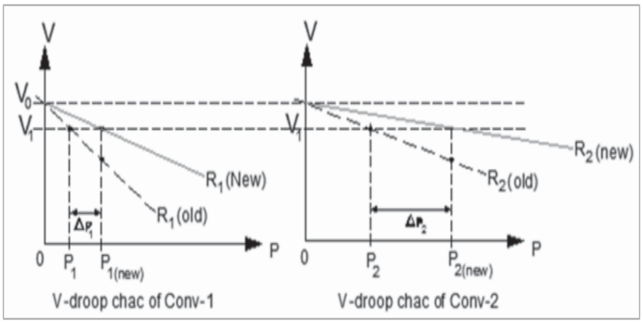


Figure7: P-V curve of Adaptive droop control method

Fig. shows the voltage droop curves with adaptive slopes for two parallel operated DC-DC Converters.

When Load = P_L, slope of droop curve of con-1 is $R_{1\,(old)}$ and slope of droop curve of con-2 is $R_{2\,(old)}$. P1 is the load shared by conv-1 and P2 is the load shared by conv-2 so that $P_1 + P_2 = P_L$ and bus voltage = V_1.

When the load increases by ΔP_L, ΔP_1 and ΔP_2 are additional power supplied by conv-1 and Conv-2 in proportional their capacities. In order to keep bus voltage constant at V1, the slopes of the droop curve of Conv-1 and Conv-2 need to be changed to new values $R_{1\,(New)}$ and $R_{2\,(New)}$.

If the controller is designed to change these slopes by itself according to the amount of change in load, such a controller is known as an adaptive droop controller.

III. SIMULATION RESULTS

Fig.8 represents the complete model that has been simulated in the MATLAB/Simulink R2021a environment. It consists of PV and wind generator as DC voltage sources at 326.04V and 350 V respectively which are supplied to the respective dc- dc boost converters connected to the dc bus, which has a common load. The adaptive droop controller varies the value of droop coefficient whenever there is change in load maintaining the constant DC bus voltage of 400V.

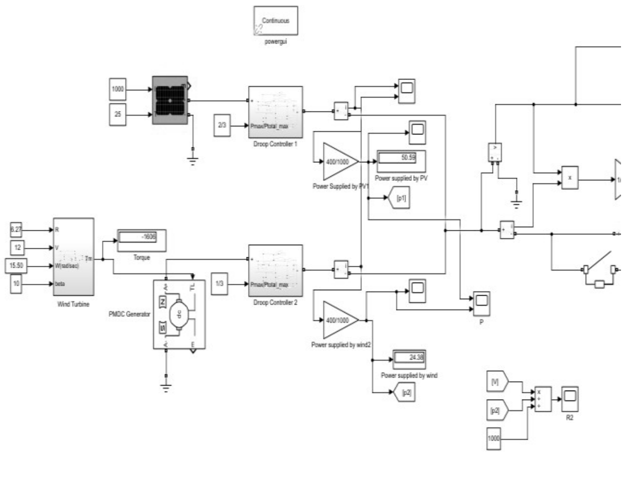


Figure8: Simulation model of parallel connected PV and Wind generator with respective dc-dc converter with fixed V-droop characteristics

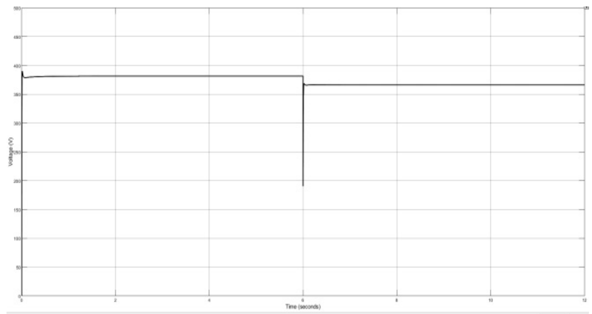


Figure 9: Plot of output voltage in fixed droop control

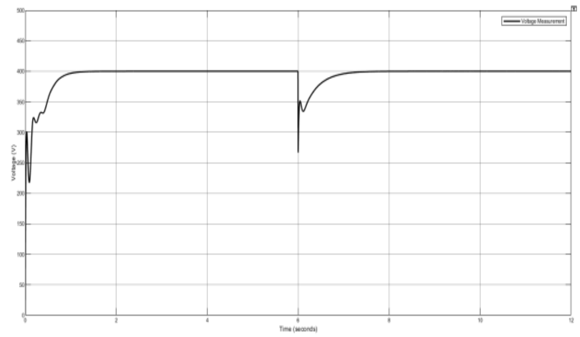


Figure10: Plot of output voltage in adaptive droop control

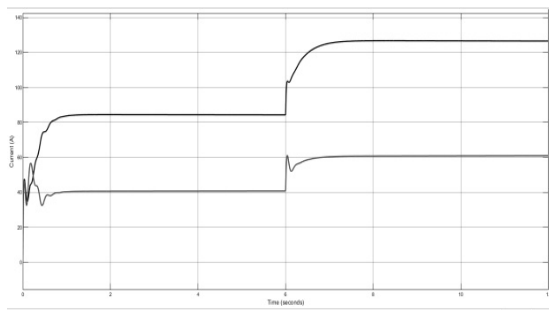


Figure11: Plot of load current from two converters in adaptive droop control

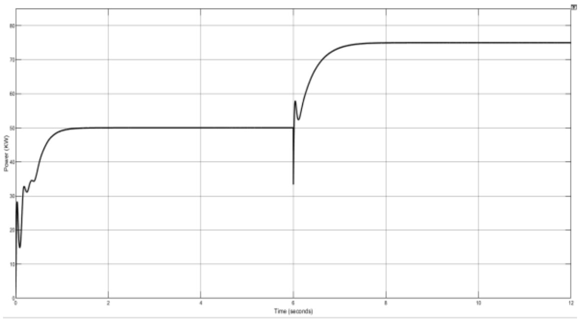


Figure12: Total power across load in adaptive droop control

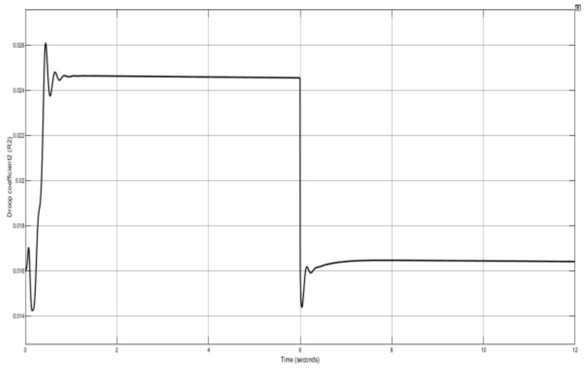


Figure13: Varying droop coefficient in conv-1 and conv-2 with varying load

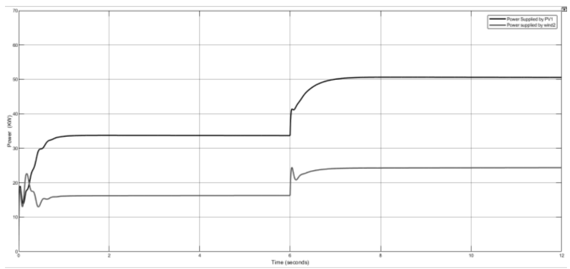


Fig.14: Power shared by PV and Wind for different loads in adaptive droop control

Initially, (upto 6 sec) when the total load was 50 KW, conv-1 was supplying 33.4 KW and conv-2 was supplying 16.6 KW to the load. When the total load was 75 KW after 6 sec (addition of 25 KW), conv-1 was supplying 50.6 KW and conv-2 was supplying 24.4 KW.

IV. CONCLUSION

When the load was 50KW the droop coefficient of conv-1 was 0.01195 and the droop coefficient of conv-2 was 0.0246 which changed to 0.008 and 0.0163 respectively when 25 KW load was added to make the total load of 75 KW.

The change in droop with varying load can be seen from the curve shown in fig.13.

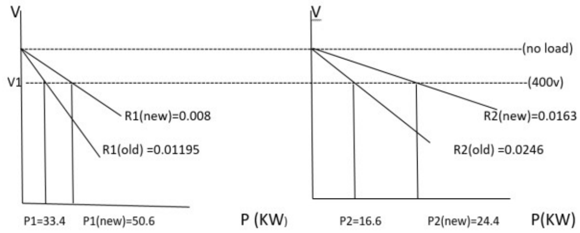


Fig.15: P-V droop curve of adaptive droop control method

V. REFERENCES

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