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Voltage Stability and Loadability Improvement of DC Microgrid Connected with Static and Dynamic Loads

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Abstract: **This paper addresses, the improvement of DC (direct current) microgrid voltage stability and loadability. When the DC microgrid starts feeding the loads, the DC bus voltage drops. In presence of both static and dynamic loads with different loading conditions, the drop in voltage becomes significant. A solar photovoltaic (PV) fed DC microgrid is considered in this study. Both static load and dynamic load (DC motor) are considered to be connected in the DC microgrid. The effect of droop control and the conventional control in presence of both types of loads for constant solar insolation condition are compared to establish the effectiveness of the droop control technique. Two parallel connected PV modules and their corresponding controllers with variable load were modelled in PSCAD/EMTDC software.**

Keywords— DC microgrid, droop index control, voltage stability, dynamic load

I. INTRODUCTION

The concept of microgrid was introduced as a key to integrate distributed energy resources (DERs) for example solar, wind, energy storage etc. and supply the energy to remote areas [1]. Advantage of microgrid involves its ability to operate in islanded or grid connected mode [2]. In the past decade research on microgrids was mainly focused on conventional type AC systems. However, presently DC microgrid is an attractive and efficient choice to integrate different renewable energy sources and energy storage devices [3]. Due to better efficiency, interfacing of different type of renewable energy sources and energy storage units, better fulfillment of consumer electronic, DC microgrid has been documented as an improved alternative to AC microgrid [4]. To integrate DERs to an existing grid, different control strategies have been developed as well as implemented [5-6]. In DC microgrid, there are no issues with power quality, regulation of frequency and reactive power flow which results a prominently relatively simple control system [7-9]. The mathematical design is required to examine the non-linear behavior of the solar PV, advanced chopper circuits and DC motor with the ability to track the maximum power from different insolation levels [10]. The stability is usually obtained by controlling the bus voltage when sources are in parallel. The procedure to achieve this, when there is a virtual resistance on the power converter side, using a method known as droop control [11]. A shifted voltage method was developed in [12], to achieve equal share of load power to the rating of DERs based on the instantaneous power of distributed generators (DGs) and the power rating. Voltage compensation method was presented in [13] for analyzing the circulating current flowing through the DC-DC converters in parallel and also to analyze the effect of droop coefficient on bus voltage magnitude and on the load sharing [13].

Improvement in voltage stability of solar PV fed DC microgrid in presence of static and dynamic loads with different loading condition is a present day need. The main aim of this paper is to provide an improved voltage stability and loadability of solar PV fed DC microgrid when it is feeding both static and dynamic loads. The method adopted here is the well-established droop index method as conventional method was found to be ineffective to obtain a desired voltage profile for the system considered here. The DC microgrid, consisting of two parallel connected PV modules with their controllers and variable loads (static and dynamic), was modelled in PSCAD/EMTDC software. The simulation results are discussed for different loading conditions to show the effectiveness of droop control strategy used in DC microgrid.

II. MODELLING OF THE SYSTEM

The parallel connecting distributed generation sources in microgrid applications through power electronics modules gives many advantages when compared to the utilization of a single high power converter. Fig. 1 shows Solar PV fed DC microgrid integrated with static and dynamic loads.

A. Solar PV

PV cells are grouped together to form a PV module. The PV modules can generate direct current electricity when exposed to sunlight. Based on load requirement, the energy is transferred to load through DC-DC converter.

The terminal PV module current, 'i' is given by,

$$i = i_p - I_o\left(e^{\frac{V+iR_s}{nV_T}} - 1\right) - \left(\frac{V+iR_s}{R_{sh}}\right) \qquad (1)$$

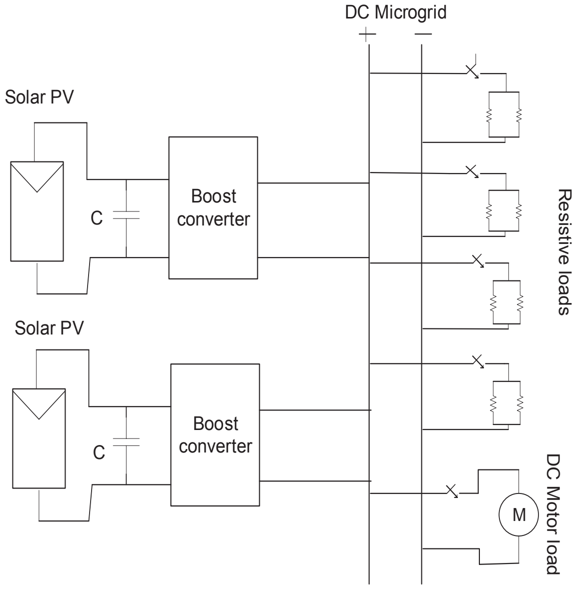

Fig.1 Solar PV fed DC microgrid integrated with static and dynamic loads

Where,

I_p –Photo-generated current
I_o – PV module saturation current
V – Module voltage,
V_T – Junction thermal voltage
R_s & R_{sh} – Series and parallel resistances of a PV module
n – Number of series connected cells

B. DC-DC Boost converter

The DC-DC boost converter is a non-isolated DC-DC converter. It is used to step up unregulated DC voltage to regulated DC voltage required by DC loads. The average output voltage is given by,

$$V_o = \frac{1}{1-D} * V_i \quad (2)$$

The inductance of boost converter is given by,

$$L = \frac{D*V_i}{f*\Delta I_L} \quad (3)$$

The capacitance of boost converter is given by,

$$C = \frac{D*I_0}{\Delta V_C*f} \quad (4)$$

Where,
V_i – Source voltage to converter
D – Duty ratio
I_o – Converter output current
ΔV_c – Ripple voltage
ΔI_c – Ripple current
f – Switching frequency

Table I shows, the nominal parameters of DC-DC boost converter.

TABLE I: PARAMETERS OF BOOST CONVERTER

Parameters	Symbol	Value
Output voltage	V_{dc}	120V
On state resistance of IGBT	r_{CE}	0.5mΩ
On state resistance of diode	r_f	0.5mΩ
Filter inductor	L	0.12H
ESR (filter inductor)	r_L	0.03Ω
Filter capacitor	C	100μF
ESR (filter capacitor)	r_C	0.05Ω
Switching frequency	f	10KHz

C. Dynamic load

DC Shunt motor modelling:

For operating equipment and machinery in a broad variety of applications and industries, DC motors are usually used because of certain advantages. They are simple, wide, precise, having lower cost and where controllers can be easily implemented.
Speed (ω_r) response of DC shunt motor due to change in load torque (T_L) is given by,

$$\frac{\omega_r(s)}{T_L(s)} = \frac{\frac{-1}{J}\left(s+\frac{1}{\tau_a}\right)}{s^2+s\left(\frac{1}{\tau_a}+\frac{1}{\tau_m}\right)+\frac{1}{\tau_a}\left(\frac{1}{\tau_{in}}+\frac{1}{\tau_m}\right)} \quad (5)$$

Where,

$\tau_a = \frac{L_a}{R_a}$ – Electrical time constant
$\tau_m = \frac{J}{B}$ – Mechanical time constant
$\tau_{in} = \frac{JR_a}{K_V{}^2}$ – Inertia time constant
R_a – Armature resistance
R_f – Field resistance
L_a – Armature inductance
K_v – Back emf constant
J – Inertia constant
B – Damping constant

From equation (5), S-domain equivalent block diagram of DC shunt motor is presented in Fig. 2. Table II shows, the DC shunt motor specifications.

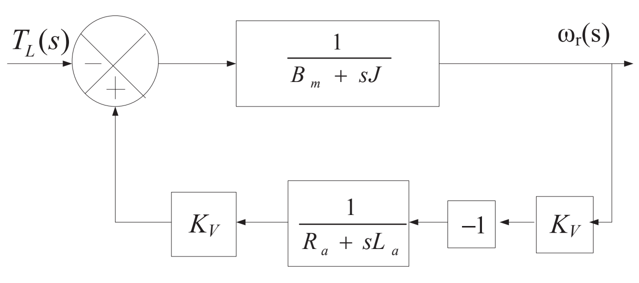

Fig.2 S-domain equivalent block diagram of DC shunt motor

TABLE II: DC SHUNT MOTOR SPECIFICATIONS

Symbol	Parameter	Value
R_a	Armature resistance	1.5 Ω
R_f	Field resistance	100 Ω
L_a	Armature inductance	0.02 mH
K_v	Back emf constant	0.676 V/rad/sec
J	Moment of inertia	0.02365 Kg.m^2
B_m	Viscous friction coefficient	0.00025 N.m/rad/sec
V_a	Armature voltage	120V
I_a	Armature current	2.5A
I_f	Field current	1.2A

III. CONTROLLERS

Whenever there is a variation in load current, the DC microgrid voltage varies. To maintain the voltage at its rated value, it is required to control the converter output voltage. This cannot be achieved by conventional method. Droop control may fulfill this requirement.

A. Conventional controllers

The schematic representation of the conventional control is shown in Fig. 3. The triggering pulses for the power semiconductor devices in power converter are generated at the points of intersection of the carrier and reference signal wave. The firing pulses so generated turn on the switching device so that output voltage is available during the interval carrier (triangular) wave exceeds the reference wave.

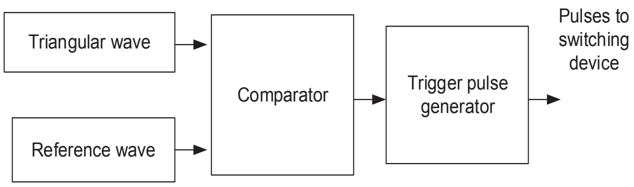

Fig. 3 Schematic representation of conventional control

B. Droop index control

The controller, which uses droop index method, is an autonomous controller [14]. The reference voltage ($V_{dc,ref}$) is compared with the product of droop co-efficient (R_{droop}) and DC-DC boost converter output current (I_{dc}) to generate a new reference V^*_{dc}, which is then compared with the actual output voltage of converter. The comparator gives error signal which passes through the PI controller. The signal coming from PI controller output is compared with load current. These error signal again passes through the inner loop PI controller. The output of this PI controller is then used to generate triggering pulses which is given to the respective power semiconductor device of each power converter through a signal driver circuit. The schematic representation of droop index control diagram is shown in Fig. 4.

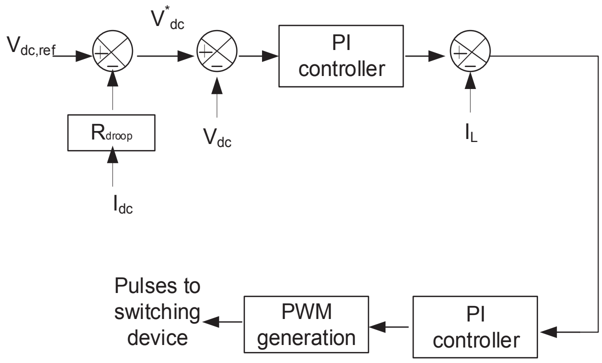

Fig. 4 Droop index control diagram

IV. RESULT AND ANALYSIS

In this section, the performance of DC microgrid is evaluated by connecting static (resistive) and dynamic (DC shunt motor) loads, with conventional and droop index methods in presence of constant solar insolation. In this study, two different loading conditions are considered.

Case I: Continuous dynamic and static intermittent load – In this case the DC shunt motor is considered to be connected throughout the simulation time period. The static resistive loads are intermittent in nature.

Case II: Continuous static and intermittent dynamic load – In this case one static resistive load is considered to be connected throughout the simulation time period. The DC shunt motor load is intermittent in nature.

Case I: Continuous dynamic and static intermittent load

The simulation is carried out for 2s. The DC motor is connected from 0 to 2s continuously. During time period 0-0.4s, 0.5-0.9s, 1-1.4s and 1.5-1.9s resistive load is connected to the DC microgrid. For these load connection, DC bus voltage is found to 101.5V when conventional control technique is applied. Whereas, the voltage improved to 114.05V with droop index method with a droop coefficient value as 0.15 Ω. Fig. 5 shows, the converter output voltage, V_{dc} with continuous dynamic and static intermittent load.

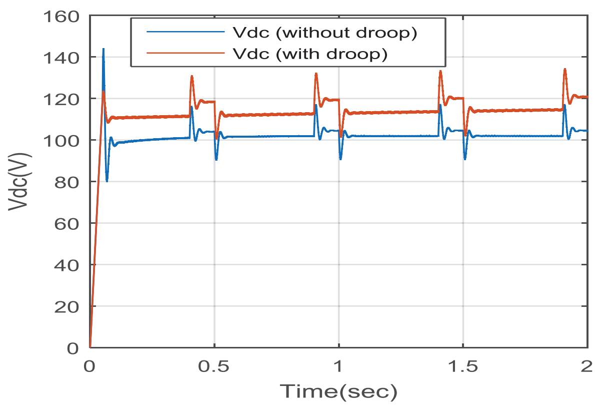

Fig. 5 Converter output voltage, V_{dc} with continuous dynamic and static intermittent load

It may observed from the figure that the DC bus voltage profile has improved with droop index method when compared to conventional method in *Case I*. With the load connection as of *Case-I*, the total load current is increased from about 2.67 A to 3.78 A with droop index method compared to conventional method. Fig. 6 shows the load current, I_L with continuous dynamic and static intermittent load. In absence of static load, the load current is increased from about 2.1 A to 3.2 A with droop. Hence the loadability of DC microgrid has improved with droop with respect to conventional method.

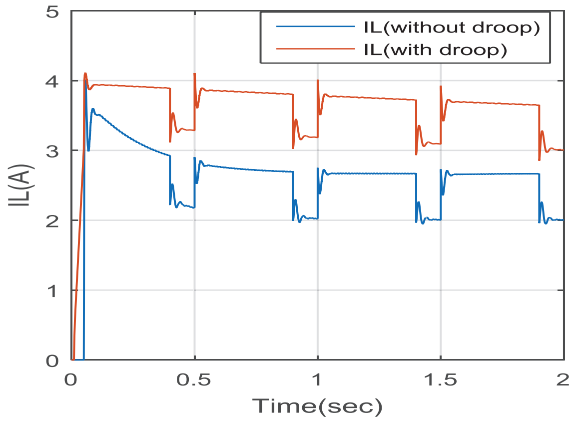

Fig. 6 Load current, I_L with continuous dynamic and static intermittent load

Case II: Continuous static and intermittent dynamic load

The simulation is again carried out for 2s. The resistive load is connected from 0 to 2s continuously and DC motor load as an intermittent. The DC motor load has connected from 0.5s to 1 sec. During these 0.5s to 1s period the DC bus voltage is 103.4V with conventional method and with droop method the DC bus voltage is 112.3V. In absence of dynamic load, the DC bus voltage is 107.8V with conventional and with droop the dc bus voltage is 118.2V.

Fig. 7 shows converter output voltage, V_{dc} with continuous static and intermittent dynamic load. The DC bus voltage profile has improved with droop method when compared to conventional method by choosing droop coefficient value as 0.15 Ω.

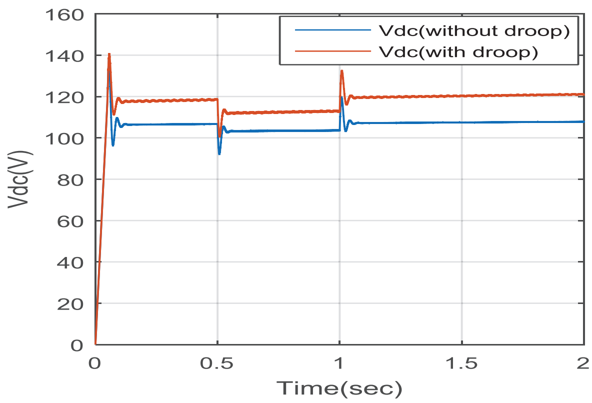

Fig. 7 Converter output voltage, V_{dc} with continuous static and intermittent dynamic load.

For feeding the dynamic load, the load current is increased from about 3.5A to 3.8A with droop method compared to conventional method. In absence of dynamic load, the load current is improved from about 2.8A to 3.1A using droop. Fig. 8 shows the load current, I_L with continuous static and intermittent dynamic load.

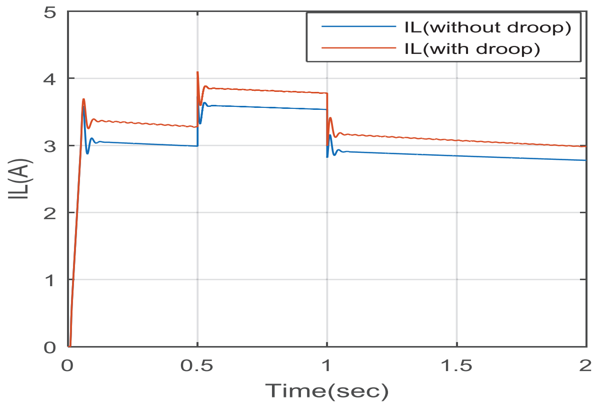

Fig. 8 Load current, I_L with continuous static and intermittent dynamic load

V. Conclusions

This paper shows that, droop index method gives improved voltage stability and loadability of DC bus in presence of static and dynamic loads with different loading conditions with respect to conventional method. DC microgrid is connected with solar PV of constant solar insolation. In droop index method by choosing the proper value of drooping coefficient, a better performance of DC bus voltage profile is achieved. The value of drooping coefficient depends on the variation of converter output voltage. The effectiveness of droop control method is established for two cases, viz. continuous dynamic load with intermittent static load and continuous static load with intermittent dynamic load.

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