JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
ISSN (Online) : 2454 -7190 www.journalimcms.org ISSN (Print) 0973-8975

J. Mech. Cont.& Math. Sci., Special Issue, No.-5, January (2020) pp 408-423

A UNIFIED DROOP CONTROL STRATEGY FOR DC BUS VOLTAGE REGULATION AND MPPT CONTROL OF MULTI INPUT BI-DIRECTIONAL DC-DC CONVERTER IN AC-DC-MICROGRID

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https://doi.org/10.26782/jmcms.spl.5/2020.01.00034

Abstract

Voltage regulation is vital in DC microgrids and the power generated at DC Bus of DC Microgrid is fed to AC side via. Interlinking converter in an AC-DC microgrid. Many Droop control techniques are used to efficiently control the voltage regulation at DC bus and sharing load demand among DGs (distributed generators) as per their individual droop characteristics in a decentralized manner. Low rating hybrid residential microgrids are eventually increasing popularity which are to be controlled to inject power into grid in grid-tied mode and to meet power balance in Islanded modes. The Proposed Unified dp / dv control strategy for a Multi-port DC-DC converter, not only improve transient performance of DC-DC converter in tracking MPP compared to other methods, but also improves DC bus voltage regulation and battery SOC control. This control eliminating the switching between MPPT and voltage regulation modes. This Multi input DC-DC converter fed by Solar PV wind Battery storage is feeding power to critical DC load and connected to AC side via. Interlinking converter. The proposed System is implemented in MATLAB/Simulink to verify the effectiveness of this control strategy.

Keywords: Droop Control; Hybrid Distributed Generator; Bi-directional DC-DC converter, current based MPPT, Low voltage AC-DC Microgrid

I. Introduction

Now a Days, Residential Microgrids are gaining popularity having two or more sources simultaneously along with storage. DC microgrids or in normal AC microgrids, Maintaining DC link voltage is very important. In case of PV source, both voltage regulation and MPPT control simultaneously cannot be achieved with normal MPPT control techniques and a change over control is used such that DC-DC converter will operate only in one mode at a time i.e., either voltage regulation mode or MPPT control mode ,thus a mode switching mechanism is to be provided. Coming Microgrid system control, it is categorized into Primary, Secondary and Tertiary controls. [I], [II], [III], [IV]. Primary control is current control and is localized to converter. In grid connected mode, DG may operate at MPPT or it may operate in power controlled mode based on requirement. In Islanded mode, it is operated in MPPT so that the remaining power after feeding load is fed to battery, if battery is fully charged, DG is forced operate at non-MPPT mode [V],. Transformer coupled half-bridge boost Converter with bidirectional dc-dc converter is considered with two DG sources and one storage is mentioned in [VI], [VII], [VIII] PV inductor current operates PV at MPPT as well as maintaining battery SOC, here DC-link voltage is taken care by battery and DC link capacitors when PV and wind are down, if battery is also down the DC link voltage falls below specified value. In [V], a small capacity multi- input converter is projected to cater the dc loads. Six-arm converter topology proposed in [IX], Wind, PV outputs are given to boost converter to maintain dc-bus voltage, and in [X] a multi input converter is proposed for decentralized control when more than two DGs are present. A nested power-current-voltage control scheme is introduced in [XI] for control of single phase power inverter, integrating small-scale renewable energy based power generator in a microgrid for both stand-alone and grid-connected modes, Here MPPT is controlled by inverter switching alone but to attain higher voltages rating of components and number of PV arrays to meet voltage rating are more .. A new droop based MPPT control technique for DC Microgrids is proposed in [XII], but, for battery SOC control separate strategy need to be used here. PV array and battery based converter based DC side droop control is discussed in [XIII], such that it tracks MPPT, maintains battery SOC and DC bus voltage regulation with unified control strategy. Wind MPPT control is proposed in [XIV],A solar wind Battery based AC-DC microgrid is proposed in [XV] where a separate converter is added for wind source to interface it into AC grid.

Proposed control strategy accommodates solar and wind energy sources with battery storage. Wind is controlled to operate at MPP, is fed through transformed coupled half bridge boost converter and MPPT control and battery SOC is achieved simultaneously by dual input bidirectional DC-DC converter, the control of this converter is modified in such a way that along with above two functions it regulates DC voltage by dp/dv based MPPT control proposed in [XII], [XIIIc] such that the DC link voltage variations due to changes in wind speed are counteracted by PV and battery control.

II. System Operation

The proposed system consists of a PV and wind generating sources and a battery for storage, a bidirectional DC-DC converter to accommodate PV source, battery and is cascaded with transformer coupled half bridge boost converter which is fed by wind generator. Section 2 discusses about converter working and section 3 Illustrates existing and proposed control strategies.Fig.1 shows the block diagram of proposed system.

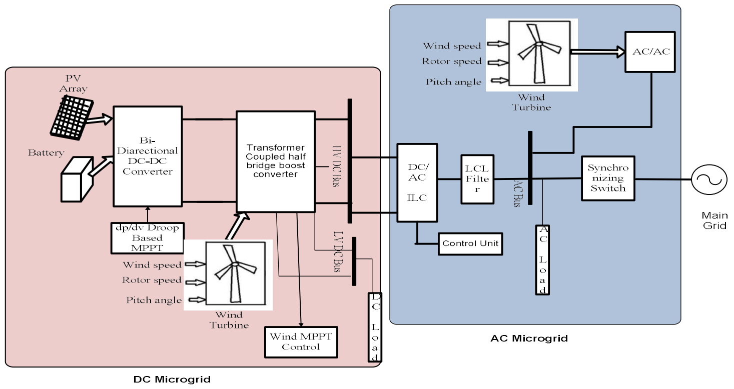


Fig.1 Block Diagram of Proposed AC-DC Microgrid Structure

Converter Operation

A cascaded combination of dual input bi-directional buck-boost converter with transformer coupled half bridge boost converter detailed operation in given in [VII] , Fig.2 shows the circuit diagram of DC-DC converter, with Solar, and battery as inputs buck-boost converter and wind source as input to boost converter and its working is explained as below.

Maximum power point tracking from wind is achieved by pitch angle control unit, which generates gating pulses to SW3 and SW4. PV MPP and battery SOC simultaneously achieved by controlling inductor current in bi-directional buck-boost converter using switches SW1 and SW2 and wind turbine MPP is controlled by switches SW3 and SW4. The voltage across capacitors C1 and C2 shown in fig.2 are V_{c1} and V_{c2} respectively, thus the dc bus voltage at the transformer primary side is (V_{c1}+V_{c2}) which is equal to (V_{pv}+ V_{batt}.). It infers that this dc bus voltage rely on the magnitude of PV output voltage, V_{pv} and battery voltage V_{batt} and also wind output voltage. During the ON/OFF operation of switches S3 and S4 each of the capacitors, C1 and C2, appear across the transformer primary winding, i.e. when S3 is ON PV and battery voltage appears across primary, if S4 ON wind voltage appears across the high frequency transformer primary. The transformer is modified such that secondary winding is split into two to form two DC buses of different voltage levels, one with voltage V_{dc1} is interfacing with high voltage interlink converter to feed power to AC load/grid, another with voltage V_{dc2} is to feed low voltage DC bus to feed critical DC loads to form a DC microgrid.

Thus the two DC bus voltages Vdci in terms of PV, battery and wind output voltages for i=1, 2 is obtained as

$$v_{dci} = n_i(v_{pv} + v_{batt}) = n_i(v_{c1} + v_{c2}) = \frac{n_i v_{pv}}{1 - D_{wind}} \tag{1}$$

Where,

$$v_{batt} = \frac{D_{pv}}{1-D_{pv}}$$

Here Dw and D_{pv} are duty cycle of switches SW1-SW2 and SW3-SW4 respectively, as shown in Fig.2. This DC link voltage for interlinking converter is considered as, transformer secondary voltage in (1) is for i=1,i.e., V_{dc1} and primary side dc-voltage can be controlled based maximum power point tracking of PV fed bidirectional buck-boost converter and wind fed half bridge boost converter . The dedicated low voltage DC bus which forms a DC Microgrid voltage in (1) is for i=2,i.e V_{dc2} and this is also influenced by battery and PV outputs, Thus battery is considered in such a way that it should cater critical DC load irrespective of PV and wind outputs.

The average value of inductor current in terms of PV and battery current over a switching cycle is expressed as

$$I_L = I_{pv} + I_{batt} \tag{2}$$

It is apparent that I_{batt} and I_{pv} can be controlled by regulating I_L. Therefore, the MPP operation is assured by controlling I_L while preserving a proper battery charge level. $I_{bmax}$and I_{bmin} along with I_{pv} forms upper and lower limits for $I_{L,}$ and is used as inner control loop parameter for better dynamic response while, capacitor voltage across PV is used formaintaining MPP voltage forms an outer control. Perturb and Observe (P&O) Algorithmis used for maximum power point tracking and maximum point current i.e. modified dp/dv based MPPT is used for PV and Battery operating point control, and wind MPP is used

Power management in DC-DC converter

High frequency Transformer coupled multi input DC-DC converter is designed to feed a DC critical load and to feed AC loads through interlinking converter with two dedicated DC buses with two different voltage levels. The power balance equation for the above converter is as below,

$$V_{pv} I_{pv} + V_w I_w = V_{batt} I_{batt} + V_{grid} I_{grid} \tag{3}$$

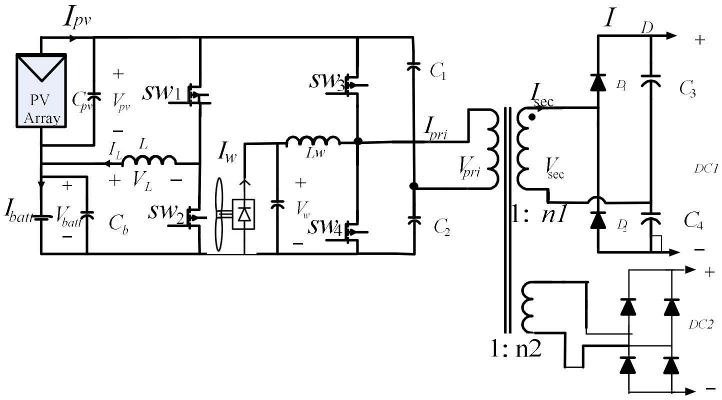


Fig 2. Circuit Diagram for multi-input DC-DC converter

Where, Vpv, Ipv, Vw, Iw, Vbatt, Ibatt, and Vgrid, Igrid are PV, wind, battery, load/grid voltage and currents respectively. The converter operation is explained in the following:

Islanded Mode:

In Islanded mode DC bus voltage regulation is taken care by bidirectional DC-DC converter.

Mode1: In this mode PV and wind are working in MPPT until Pdc+Pac+Pbatt < Ppv+Pwind, PV and wind are operated at MPP and power is fed to load and remaining is used to charge the battery

Mode2: when battery becomes fully charged, and Pdc+Pac+Pbatt<Ppv+Pwind, PV is forced to operate in non-MPPT mode, battery is idle.

Mode3: when Pdc+Pac>Ppv+Pwind+Pbatt ,then battery starts discharging along with PV and wind which are operating at their MPP region.

Mode4: when Pdc+Pac>Ppv+Pwind+Pbattery,and battery become fully discharged, then converter control strategy identifies and withdraw switching pulses, thus system is in shut down mode.

Grid Connected Mode:

In grid connected mode, power is fed o grid in non-dispatched power mode (DGs operate in MPP) or dispatched power mode. In dispatched power mode DC bus voltage regulation is taken care by two ways

i) Interlinking converter (ILC) is operating DC bus voltage regulation mode and DGs on AC bus in coordination with DC bus are for providing dispatched power by power balancing. DC-DC converter operates PV and wind sources at MPP in normal mode and power flow control mode, Battery is getting charged from grid and it discharges as and when required i.e., when power generated by PV and wind is less than demanded power from grid side ii) DGs connected to AC bus and interlinking converter is operating in power flow control mode and DGs connected to DC bus are responsible for DC link voltage regulation. Power fed to grid can be controlled by controlling phase angle and magnitude of fundamental of converter voltage with respect to grid.it is said to be dispatched power mode in grid connection.

III. Control Strategy

Control Strategy is categorized as DC microgrid and AC microgrid control DC microgrid control take care of voltage regulation and load sharing in Islanding mode, whereas AC control strategy is realized to achieve power flow injections into grid in grid connected mode

Droop control strategy For MPP tracking and DC-Bus voltage Regulation in Islanding Mode:

DC side control strategy consists of two controllers, one for controlling a transformer coupled boost converter to track MPP of wind using Pitch angle control, and other is a bi-directional buck boost converter to track MPP and to maintain SOC, in addition these, it also maintain DC bus voltage regulation and load sharing if two or more similar systems of this kind, feeding common load, in Islanded mode, and send maximum power to grid in grid connected mode. DC bus voltage regulation is taken care by inverter in grid connected operation. Block diagram for the Proposed Control strategy is shown in Fig.3(c). Battery SOC is maintained by taking battery maximum and minimum currents, i.e., Ibmax and Ibmin representing over charging and deep discharging currents respectively PV MPPT is achieved by dp/dv MPP tracker in which dp/dvref obtained from droop controller, which is responsible to maintain DC bus voltage regulation, and dp/dv output of droop generator, [XII], [XIII] is obtained from PV source voltage and current inputs Here PI-controller1 generates IL* which is the current to be allowed in inductor of buck-boost converter. If this current is more than Ibmax+IPV .then ILref=Ibmax+Ipv which limits the charging current in battery, similarly if the current less than Ibmin+Ipv then pulses to the converter are withdrawn in order to not to allow the battery to deep discharge, otherwise ILref=IL*.Duty cycle to the buck boost converter is obtained by feeding error of inductor current ILref and IL to PI – Controller2.DC bus voltage regulation in voltage and current based control strategies are taken care by battery, When PV current become low, in Islanded mode. Here there is a need of mode shifting from MPPT to voltage regulation mode. But, when battery is discharged, this affects the DC bus voltage regulation. In the proposed control strategy, DC bus voltage regulation is integrated in MPP tracking thus, this control simultaneously achieve voltage regulation, Battery SOC control and MPP tracking without and mode shifting. Voltage regulation is achieved by droop control and droop coefficient ‘m’, when a similar system is running in parallel with this system, then this droop parameter is used for load sharing between the systems proportional to its individual droop coefficients [XIII]. Whereas this coefficient is responsible to not to allow the DC bus voltage goes beyond reference value.

The expression for the droop coefficient is obtained as,

$$I_{pv} = \left\{ N_p I_{ph} - N_p I_{rs} \left\{ \exp\left(q \frac{v_{dc}}{AKT} \left(v_{dc} + \frac{N_s R_{se} I_{pv}}{N_p} \right) \right) \right\} \right\} - I_{rsh} \tag{4}$$

Where

$$I_{ph} = \left[I_{scr} + k_v \left(v - v_r \right) \right] \frac{S}{1000}$$

$$p_{pv} = v_{pv} i_{pv} \tag{5}$$

$$y\left(v_{pv}\right) = \frac{dp_{pv}}{dv_{pv}} = i_{pv} + v_{pv} \frac{di_{pv}}{dv_{pv}} \tag{6}$$

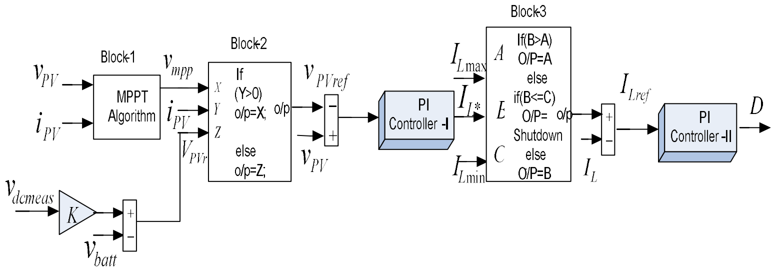
$$y\left(v_{pvoc}\right) = N_p I_{sc,n} \left(\frac{G}{G_n} - 1 - \frac{v_{oc,n}}{\alpha v_t} \right) \tag{7}$$

Where I_{scr} is the short-circuit current of one PV cell at the reference temperature and irradiation level, v_r is the reference cell temperature, and K_v is a temperature coefficient. v_{dc} is PV arrays voltage, N_p and N_s are the number of PV cells connected in parallel and in series respectively, I_{ph} is the photo-current of a single solar module which is proportional to both illumination and surface area, I_{rs} is the saturation current of diode. R_s is series resistance of the single solar module, and I_{rsh} is the current flowing through the shunt resistance

Droop coefficient for proposed control strategy is given as

$$m = \frac{y\left(v_{pvoc}\right)}{v_{dc\max} - v_{dcref}} \tag{8}$$

y(Vpvoc), is the value of dp/dv when PV voltage reaches its nominal open circuit -value, i.e., Vpv =Voc,n , where suffix ‘n’ represents nominal value.This is achieved by regulating PV output. Using dp/dv droop control of PV and battery, transient response of MPPT and DC bus voltage regulation can also be improved compared to other control techniques.P-V and dp/dv –P characteristics of PV array are clearly described in [XIII]



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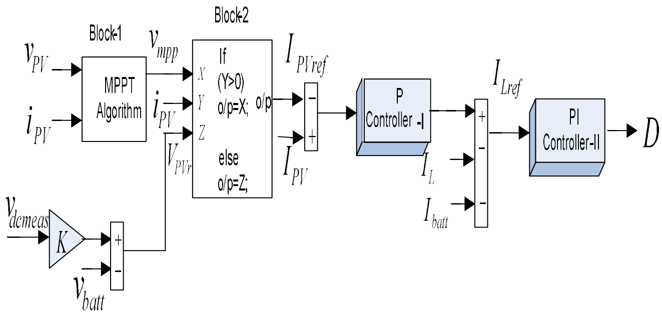

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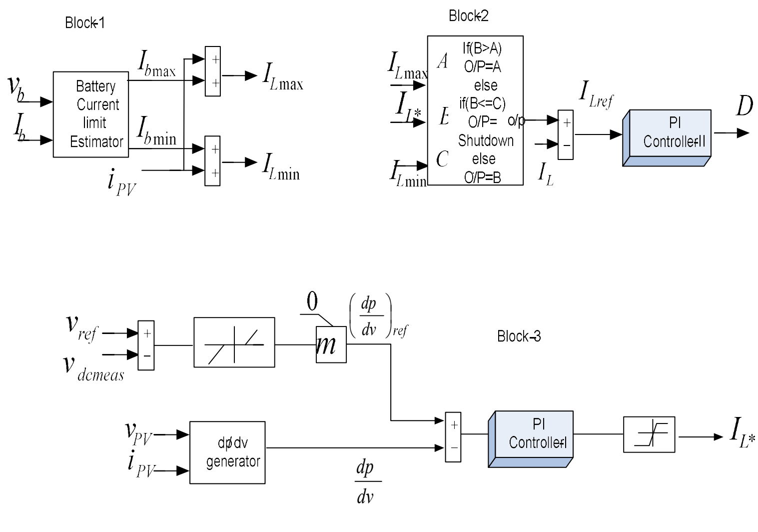


(c)

Fig. 3Block diagram for existing control strategies, a) Voltage based MPP tracking b) Current Based MPP tracking and Modified control strategy c) dp/dv based MPP tracking.

AC side Power flow Control in Islanded mode:

In order to achieve power demand on ac side, a Proportional resonant controller is used, thus eliminate complex single phase to dq transformation and number of controllers to be used also reduced. Iref, and fed to PR-controller, to generate duty cycle for single phase inverter. The transfer function of PR- Controller is shown in (9).Where ωb is said to be band width, and Kpr and Kir the controller gains on AC side Power flow control in Islanded case by droop control is achieved by droop equations used for X>>R case, which are usually followed for HV as well as LV Islanded microgrids, i.e., active power is achieved by frequency and reactive power control is achieved by voltage control respectively.

$$G_{PR}(s) = \frac{(K_{pr}S^2 + 2\omega_b S(K_{pr} + K_{ir}) + K_{pr})\omega_0^{\,2}}{S^2 + 2\omega_b S + \omega_0^{\,2}} \tag{9}$$

Power control is accomplished by ac side droop control in Islanded mode as shown in Fig 6.Power flow control equations for active and reactive power flow control scheme in Fig 4 are:

$$\begin{aligned} f &= f_0 + m_p(P - P_0) \\ V_{ac} &= V_{0,ac} - m_q(Q - Q_0) \end{aligned} \tag{10}$$

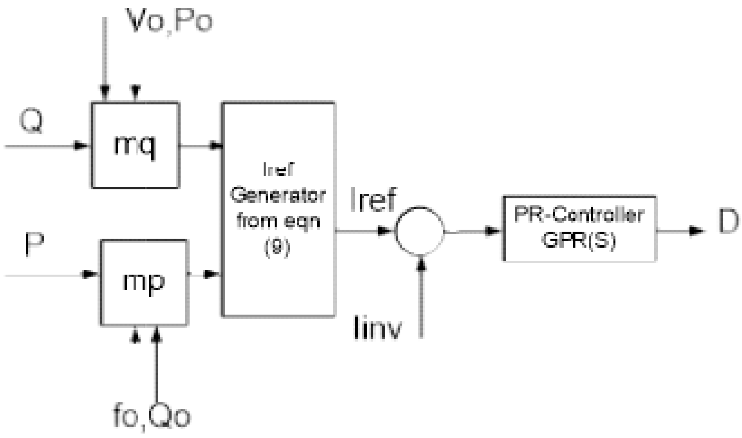


Fig. 4AC side Power flow control using droop mechanism in Islanded Microgrid.

For Grid Connected case is concerned, Unlike High voltage grids in which X>>R, Low voltage grids has R>>X, Where R and X are resistance and reactance of transmission line between converter and grid, thus normal active power frequency reactive power voltage does not holds good thus the LV microgrid droop equations are modified as in Eq.(11),

$$f = f_0 + m_q(Q - Q_0)$$
$$V_{ac} = V_{0,ac} - m_p(P - P_0) \quad (11)$$

Where,P0 and Q0 are active and reactive power references and Q are instantaneous active and reactive powers respectively.mp and mq represents its corresponding droop coefficients, inverter current 'Iinv' is compared with current reference generator value

III. Results & Discussion

The proposed system is simulated in MATLAB/SIMULINK.Table1 characterizes AC Microgrid and DC Microgrid using Table2.A solar array, wind and battery forms DC microgrid and a wind generator whose ratings are same as in DC side one, is considered as source in AC microgrid and its ratings are mentioned in Table1 and Table2 respectively

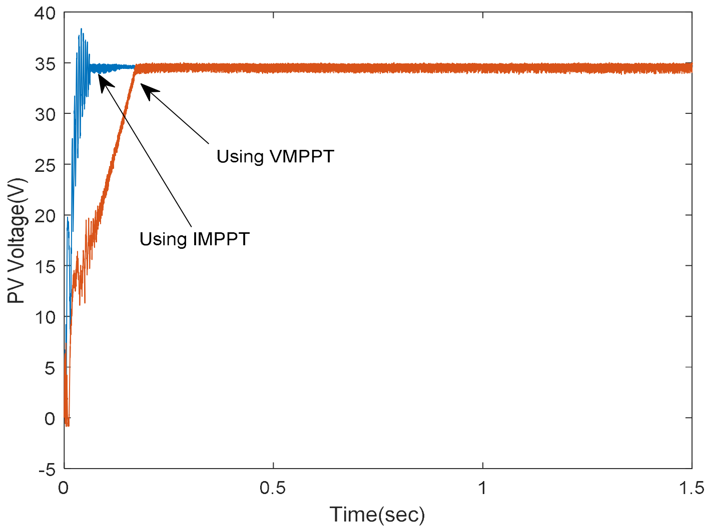
Table 1:Table1 AC Side System Parameters

Inverter Parameters	
DC link Voltage	380V
DC link Capacitor	Ca=Cb=1000 µF
Sinusoidal PWM Switching Frequency	1650Hz
LCL Filter Parameters	
Grid side Inductor Converter side Inductor filter capacitor dynamic resistor	Lg=0.0203H, Li= 0.0102H, Cf= 2.4069 µF Rd= 17.686Ω
Active power droop Coefficient Reactive power droop Coefficient	mp=0.08 mq=0.0012
PR Controller Parameters	
Band width,	ω_b =1 rad/sec
Natural frequency ,	ω_0 =314 rad/sec.
Kpr and Kir	0.4, 0.8889
Total Load Parameters DC Load ACMG Load Load on ILC	 50w PL=184w,QL=138w PL=787.5w,QL=590w

Fig 5. Illustrates a brief comparison performed among voltage, current and dp/dv based MPP control strategies and shown that dp/dv achieve MPP fast compared to other counterparts.

A 50w critical DC load is added on the DC microgrid low voltage, i.e. 48V DC bus, and 230V, 3.18A RL Load with power factor 0.75, is as AC Load.

Droop coefficient considered for dp/dv based droop controller in DC microgrid for PV source MPP Tracking is m=100, and on AC side droop coefficients for droop control of active and reactive powers is mp=0.08,mq=0.0012.



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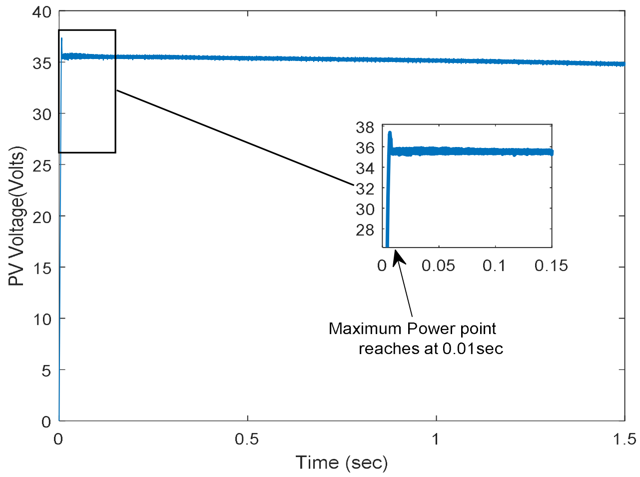


(b)

Fig. 5 (a) Response of MPPT of PV output Voltage for existing and (b) proposed control strategies.

To show the effectiveness of the PR controller in controlling the load demand, a sudden load current change from 3.18A to 2.60A with power factor 0.75 is considered and results are shown in Fig.6.Along with active and reactive power, it also shows power and DC load power.

DC bus voltage of interlinking converter (ILC) is shown in Fig.7,its change in voltage due to change in load is shows the effective ness of dp/dv controller not only tracking MPP of PV source but also to maintain voltage regulation in Islanded operation of hybrid ac-dc microgrid.

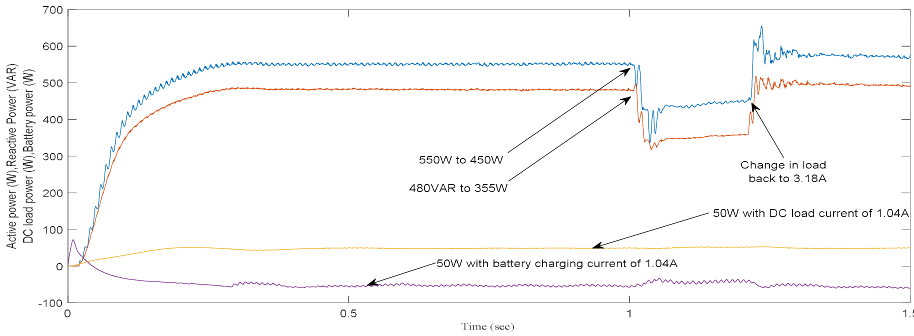


Fig.6 Active and reactive Load with change in load between 1sec and 1.2sec, DC load and battery powers when AC Microgrid is not connected to ILC AC BUS

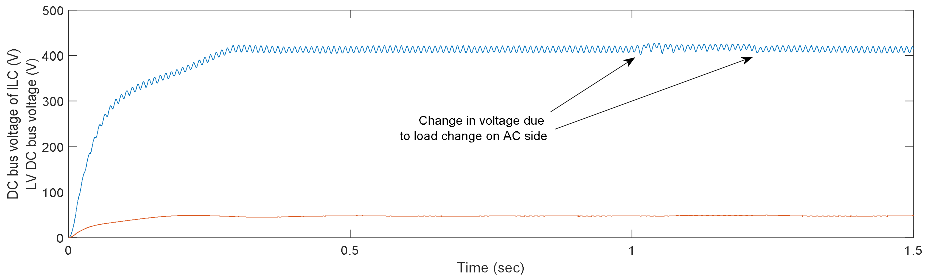
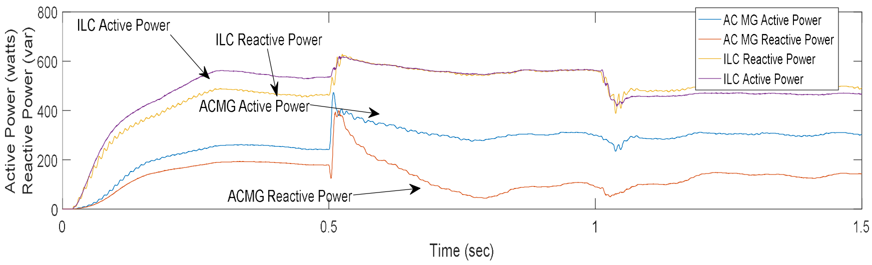


Fig.7 interlinking converter DC Bus and LV DC bus Voltages for given change in Load when AC Microgrid is not connected to ILC AC BUS



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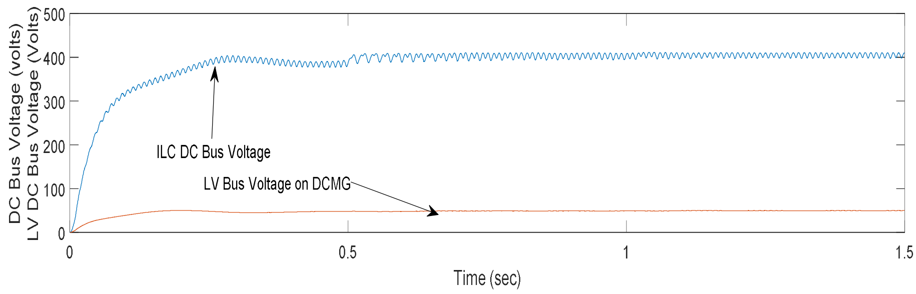

(b)

Fig.8 (a) Active and reactive loadings on AC side and (b) interlinking converter (ILC) DC bus ,LV DC bus Voltages for given change in Load when AC Microgrid is not connected to ILC AC BUS

In Fig 8(a), a load change from 4.28A to 3.28A (RMS) at a power factor of 0.8 is considered at 1 sec at ILC AC bus in AC-DC microgrid (ACMG) having a total capacity of 800W solar wind battery based DCMG and 300W wind generating ACMG and a local load of 1A at same 0.8 power factor is considered on ACMG side.ACMG is added to ILC AC bus at 0.5sec, and its effect on DC link Voltage is shown in fig 8(b), thus the corresponding change in load power and PV, battery power in DCMG are shown below in fig 9.

As Load is less than generation after adding the ACMG to ILC AC bus, dp/dv controller comes into action, As DC link voltage increases due to excess of generation at ILC, in order to regulate the DC link voltage, charging current to battery should be increased thus operating in MPPT. But as the battery is reaching upper charging limit I_{bmax}, PV is operating in Non-MPPT by reducing its power from 500 to 380w, now a reduction of load from 4.28A to 3.28A at 1 sec, PV output in DC MG is further reduced to 320w, and this can be clearly observed to maintain voltage regulation at ILC and LV DC buses in AC-DC-MG.

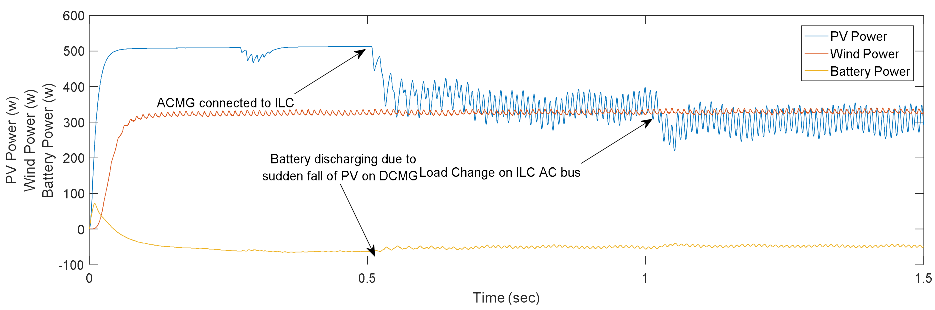

Fig. 9: Output Powers of solar wind and battery in DCMG.

Table 2:DC Side System Parameters

PV Generator Parameters		Wind Generator Parameters	
N	28	P_{W_MPP}	300W
N_s, N_p	1,2	Rotor speed	16rad/sec
V_{MPP},I_{MPP}	34.5V, 7.4A	Transformer Coupled DC-DC Converter Parameters	
P_{PV_MPP}	525W	Inductors	Lw=1 mH
V_{OC},I_{SC}	40V, 8.7A	Capacitors	C1=500 µF, C2 = 500 µF
Battery Parameters		High-Frequency Transformer Parameters	
Rating	34V,7Ah	power rating	1000VA
Buck-boost Converter Parameters		Transformer turns ratio, n	6
Capacitors	Cpv=2000 µF, Cb = 1000 µF	Frequency	15000Hz
Inductors	Lb=1 mH,, L =3 mH,	Primary voltage Secondary Voltage	70V 420V

Table 3:Comparison between Existing and Modified Control Strategies

	Existing Control Strategies		Modified Control Strategy
PV Voltage Specifications	Voltage based MPPT	Current Based MPPT	dp/dv based MPPT
Raise time settling time	120 msec 200 msec	40 msec 60 msec	7 msec 10 msec

V. Conclusion

A multi-input Solar, Wind and Battery based Transformer fed bidirectional DC-DC converter is considered, PV voltage transient response is improved and reach MPPT rapidly compared with existing strategies, thus DC bus voltage response and MPPT simultaneously achieved. Future scope of this work to develop a cost based droop control strategy with droop coefficients optimized using heuristic methods.

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