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Droop Control With Improved Disturbance Adaption for FACTS Based PV System With Two Power Conversion Stages

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Abstract :*Droop control has commonly been used with distributed generators for relating their terminal parameters with power generation. The generators have also been assumed to have enough capacities for supplying the required power. This is however not always true, especially with renewable sources with no or insufficient storage for cushioning climatic changes. In addition, most droop-controlled literatures have assumed a single dc-ac inverter with its input dc source fixed. Front-end dc-dc converter added to a two-stage photovoltaic (PV) system has therefore usually been ignored. To address these unresolved issues, an improved droop scheme for a two-stage PV system has been developed in the paper. The Proposed scheme uses the STATCOM control structure in both grid-connected and islanded modes, which together with properly tuned synchronizers, and mitigates the harmonics, by providing Reactive power and Load current Subsequently the proposed scheme adapts well with internal PV and external grid fluctuations, and is hence more precise with its tracking, as compared with the traditional droop scheme. Simulation and experimental results are obtained using MATLAB Simulink.*
Keywords: *Droop Control, Photovoltaic, STATCOM.*

I. INTRODUCTION

Droop control is a control strategy commonly applied to generators for primary frequency control (and occasioallyvoltaqe control) to allow parallel generator operation

II. CONTROL SYSTEM

Another well-received approach is indirect current control, where the grid current has been controlled by regulating magnitude and phase of the ac filter capacitor voltage [6]. Its design is however complex because of nonlinear factors, and sine and cosine tables included in the control. A simplification has subsequently been developed in [7] without the sine and cosine tables. The controller can then be designed using classical control techniques. Despite that, the load voltage waveform may still be distorted since it is not regulated directly by a voltage control loop. A further improvement can be found in [8], where the control system has been enhanced by connecting a local load to the filter capacitor, before feeding back the capacitor current for control. The method works fine, but its dc-link dynamic has not been addressed.

The next voltage-controlled technique proposed is the droop method, which in effect, has mapped the generator terminal parameters with its active and reactive power generations [9]-[11]. The droop concept has been commonly used with [12] presenting a droop controller for DG that can guarantee zero steady-state error for its output reactive power. Its output active power may however deviate from the desired reference value. To solve the problem, integral terms have been added to the conventional droop scheme for forcing the DG active and reactive powers to track their references closely [13]. The droop principle has also been recommended by the Consortium for Electric Reliability Technology Solutions (CERTS) for regulating photovoltaic (PV) inverters with a stable bus voltage, even during load transient [14].

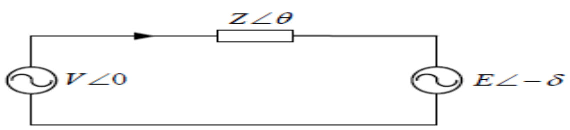


Fig. 1. Simplified circuit for illustrating power transfer.

More recently, a universal controller has been proposed in [15], where maximum-power-point-tracking (MPPT), droop control and dc-link voltage regulation have been managed simultaneously without major control reconfiguration. The limitation introduced is other non-renewable sources or storage units must be present for balancing supply and demand, which if not catered, will severely narrow variation range of the loads

Despite these differences, the studies in [12] to [15] have not considered possible fluctuations of the dc source connected to the inverter. Such consideration is relevant to renewable sources like PV, where variations may be unintentionally caused by changes of irradiation or intentionally activated by the MPPT scheme. In addition, the studies have only focused on single-stage converters, which make them not directly applicable to two-stage converters used with some PV systems.

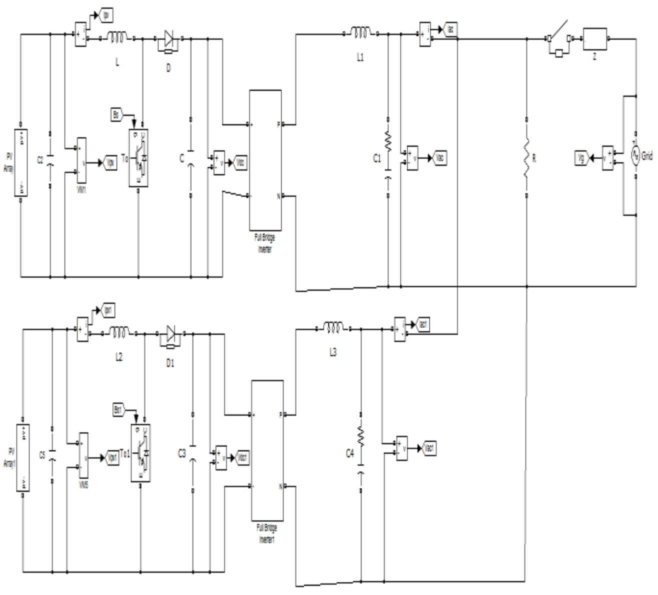


Figure 2. Simulation 1

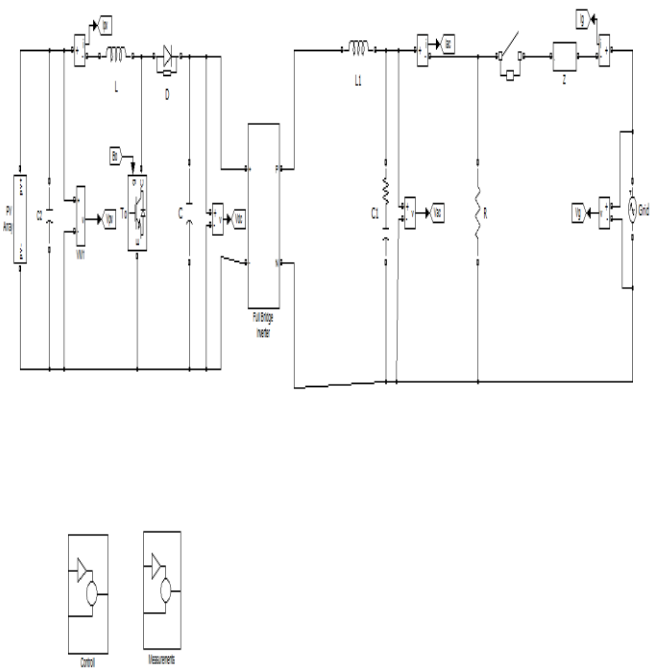


Figure 3.Simulation with feedback.

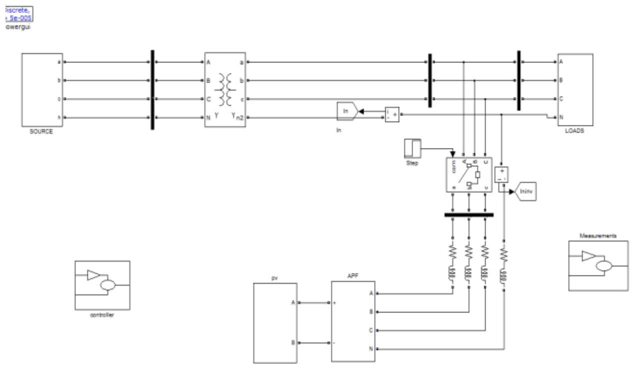


Figure 4.Simulation with STATCOM

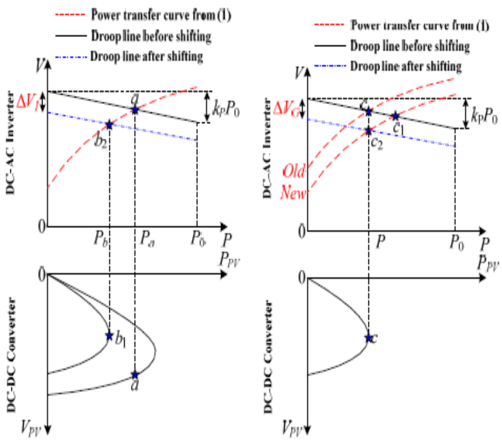
Beginning with active power transfer represented by (1), a *P-V* curve can be plotted, as shown in Fig. 2(a). This curve will shift when *E* and / or *Z* vary, as understood from (1). Regardless of that, the *P-V* curve alone is not sufficient for defining a specific operating point for the network. To mark out this stable operating point, the PV system must be controlled to add a second *P-V* curve to Fig. 2(a), which conventionally, has assumed the linear droop characteristic

$$V=Vo-Kp(P-Po)$$

$$F=fo+Kq(Q-Qo)$$

where*f* and *f*0 are the measured and rated freq where *f* and *f*0 are the measured and rated frequencies of the PV system, *V* and *V*0 are the measured and rated output voltage amplitudes, *P*0 and *Q*0 are the rated active and reactive powers, and *kp*and *kq*are the active and reactive droop coefficients, respectively. An intersection at point *a* is thus created, whose corresponding operating point on the PV curve is also marked with the same notation of *a*. In the steady state, both operating points must have the same power value *Pa*, in order to keep the dc-link voltage stabilized.

The same reasoning can be applied to reactive power transfer,



(a) (b)

Fig. 5. *P-V* interactions during changes of (a) PV power and (b) grid voltage.

which then necessitates the *Q-f* droop expression in (4) for controlling the PV system. It is however not possible to draw (2) and (4) on a single diagram because of their differences in one of the parameters (δ and *f*, where $\delta = 2ft + \delta 0$, and $\delta 0$ is the initial power angle). Implementation of (3) and (4) then results in a control scheme similar to that shown in Fig. 3 for a two-stage PV system when in its islanded mode. The only difference is Fig. 3 includes a modified active power droop expression, instead of (3). The modified droop expression will be explained later. Regardless of that, Fig. 3 shows the output voltage *vac*and current *iac*of the rear-end inverter being measured for computing *P* and *Q*.

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The active and reactive droop expressions can then be used for mapping out the desired *V* and *f*, from which the demanded voltage reference *vref*is computed for tracking by the usual double-loop controller. On the other hand, the front-end boost converter is controlled by a single-loop voltage converter notated as *GB*(*s*). Input to *GB*(*s*) is the difference between the measured dc-link voltage *VDC* and its reference *VDCref*. To nullify this difference, *GB*(*s*) is usually a proportional-integral (PI) controller, which may not be necessary for the proposed scheme because of reasons explained next.

As described earlier, the *P-V* curve and line in Fig. 2(a) help to define a common operating point with *P* = *Pa*. In the literature, this active power has always been assumed as supplied by the DG without difficulty [11]. Such assumption is however true only when a large reserve of fuel or storage is available for cushioning variations of parameters, which for a PV system, are its irradiation and temperature. Assuming now that the reserve is not catered and the PV maximum power *PPVmax*has been reduced such that *PPVmax*<*Pa* in Fig. 2(a) (see point *b*1), power delivered to the dc-link by the boost converter will then be lesser than power drawn out from it by the inverter.

The dc-link voltage will therefore drop until the inverter power is reduced to *P* = *Pb*= *PPVmax*, which in Fig. 2(a), is achieved by lowering the droop line by *VI* (see point *b*2).

The challenge is finding the value for *VI*, which the simplest method is to compute it using a PI controller. Input to the PI controller can be the difference between power delivered by the dc-dc converter to the dc-link capacitor and power extracted from the same capacitor by the inverter. However, in the steady

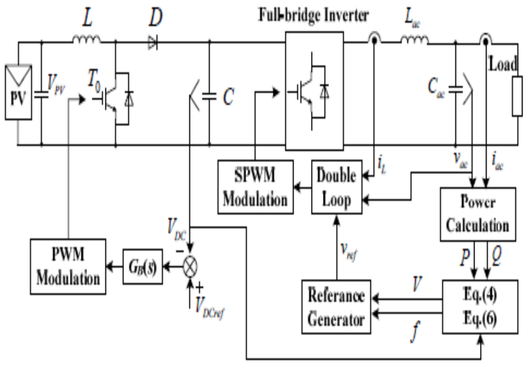


Fig. 6. Control scheme for two-stage PV system in islanded mode (transformer used in practice and experiment not shown for conciseness).

state, this power imbalance will reduce to zero (ignoring losses) before the dc-link capacitor voltage can stabilize. Despite that, the integral term of the PI controller will still output a finite *VI* for lowering the droop line in Fig. 2(a). Value of the PI controller output is however not specific, because of its single-to-multiple mapping characteristic, which is usually not encouraged when multiple converters are connected in parallel. Because of that, the proportional droop scheme without any integral term is used instead for finding *VI*.

III. REACTIVE POWER COMPENSATION FOR STATCOM

The STATCOM is a shunt connected reactive power compensation device. It is capable of generating or absorbing reactive power. The output voltage of the ST A TCOM can be varied to control the specific parameters of an electrical power system. The voltage source inverter is employed turn off capability semiconductor switches. It is an important part in the STATCOM because it can operate at high switching frequencies.The main reason for reactive power compensation in a system: 1) the voltage regulation; 2) increased system stability; 3) better utilization of machines connected to the system; 4) reducing losses associated with the system; 5) to prevent voltage collapse as well as voltage sag. The impedance of transmission lines and the need for lagging V AR by most machines in a generating system results in the consumption of reactive power [3][4]. The unnecessary voltage drops lead to increased losses which need to be supplied by the source

IV. SIMULATION RESULTS

Two similarly rated PV systems, tied to a LV distribution network, have been simulated in Matlab/Simulink using parameters listed in Table I for each system. Results obtained from them are described below. Fig. 10 shows the results of the two islanded PV systems when controlled by the improved droop scheme. Before 0.1s the two systems are assumed to have the same maximum rating of 1kW. They should hence share the active load demand evenly with their respective dc-link voltages kept at 400V (nominal value read from Table I). After 0.1s, the maximum power of one system has been reduced from 1kW to 60W, while that of the others remains unchanged. The compromised system, being unable to provide sufficient active power, will then have its dc-link voltage pulled down. The drop causes the droop line of the compromised system to be shifted down, like in Fig. 2. The droop-demanded output active power of the

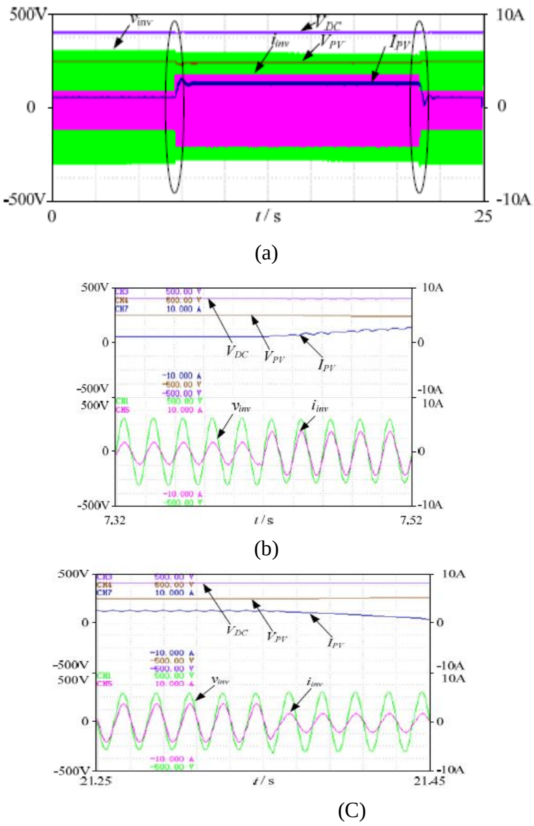


Fig.7 . Experimental results with load change. (a) Full view, (b) increasing load, and (c) decreasing load.

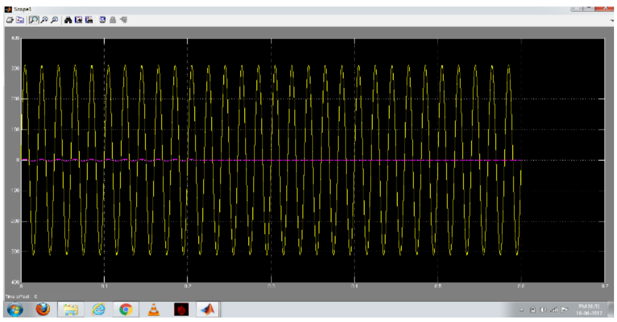
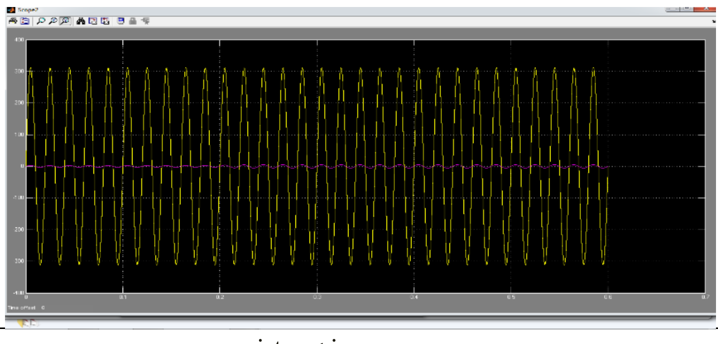
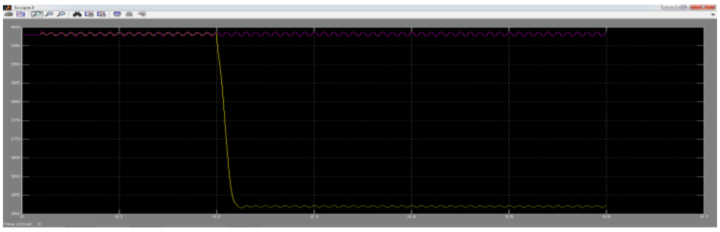


Figure 10. System without feedback

(a)

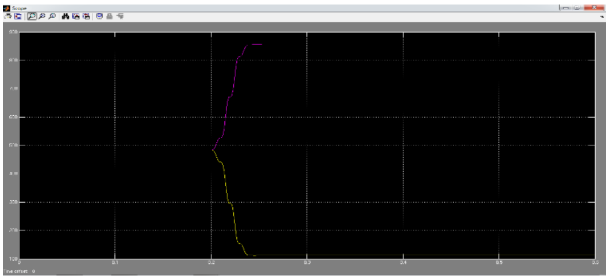


(b)

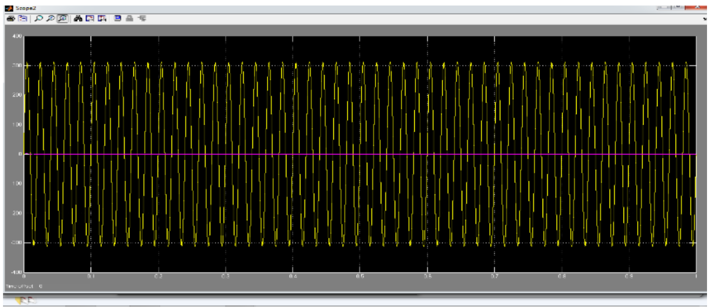


(c)

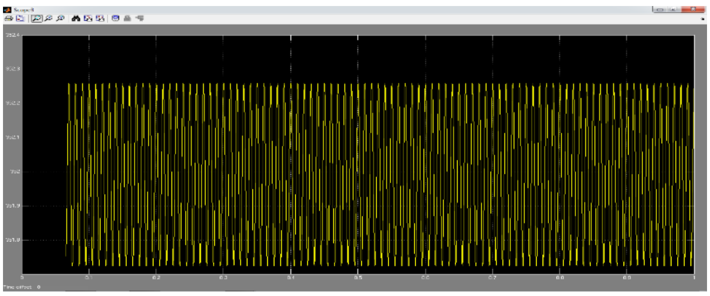
Fig 8: (a), (b), (c) Droop control system



(e)

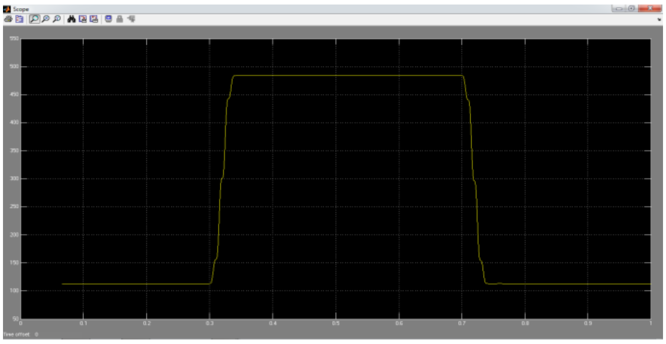


(f)

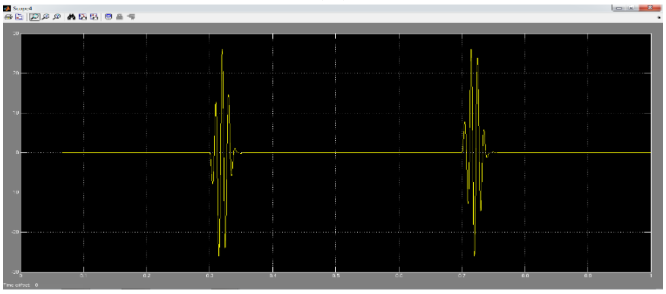


(g)

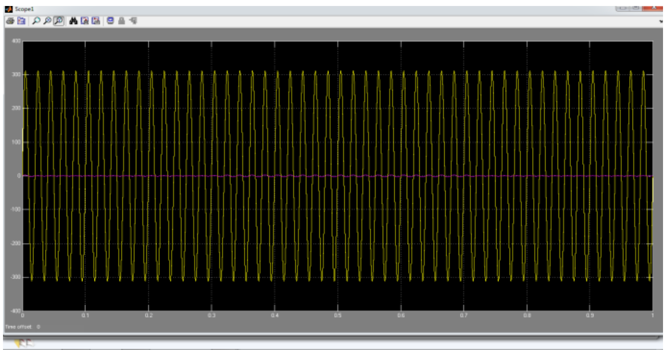
Fig 9: (e), (f), (g) Proportional Droop control system



(h)



(i)



(j)

Fig 10: (h), (i), (j) STATCOM integrated to Droop control

V.CONCLUSION

An improved droop scheme has been proposed in the paper for a PV system connected to a resistive LV distribution network. The approach is developed for a two-stage PV system, permitting it to transfer seamlessly between the islanded and grid-connected modes, after ensuring proper synchronization. It also allows the PV system to generate maximum active power, while remain not affected by power fluctuations, and other grid voltage and frequency disturbances when in the grid-connected mode. The Proposed scheme uses the STATCOM control structure in both grid-connected and islanded modes, which together with properly tuned synchronizers, and mitigates the harmonics, by providing Reactive power and Load current Subsequently the proposed scheme adapts well with internal PV and external grid fluctuations, and is hence more precise with its tracking, as compared with the traditional droop scheme.

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