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Design and Implementation of Reactive Power with Multi Mode Control for Solar Photovoltaic Inverter in Low Voltage Distribution System

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Abstract – Small and medium scale solar photovoltaic inverters are interconnecting to the low voltage distribution system at a rapid growth. The grid connected solar photovoltaic inverters able to provide the reactive power to the low voltage distribution system. Reactive power capability of the solar photovoltaic inverter is depending upon the inverter's rating and the solar power generation. In this project focuses on the reactive power management for solar photovoltaic (PV) inverter in low voltage distribution system. This strategy can be applied for various solar power generating conditions (no solar power generation, low solar power generation, maximum solar power generation, cloud passing solar power generation). During no and low solar power generation, the inverter inject reactive power and support the voltage by using Dynamic VAR compensation mode. During maximum solar power generation, the inverter absorbs reactive power and there by mitigating voltage rise using Droop characteristics approach. During passing clouds, the inverter will inject reactive power and reduce the voltage fluctuation using Ramp rate control. The objective of the project is to maintain the constant voltage level and to provide the fast reactive power control in low voltage distribution system. The power system model conveyed in the project is established on the MATLAB / SIMULINK R 2009 b platform. The results show that the solar photovoltaic inverter can be used for reducing the voltage rise, voltage fluctuation and improve the voltage profile in various solar power generating conditions.

Index Terms—**Low voltage distribution system, PI controller, Reactive power management, Solar power generation, Solar PV inverter, Voltage control.**

1. INTRODUCTION

Recently, the grid connected solar photovoltaic inverter is used to manage the reactive power in low voltage distribution system & the focus was entirely on energy harvest and active power production of the solar PV system [1]-[6]. Reactive power capability of an inverter is limited by the current carrying capacity of semiconductor switches. When the real power injection is less than this inverter rated power, remaining capacity of power can be utilized for the reactive power supply / absorption [2].Several strategies have been proposed in the literature for reactive power management of PV inverters, such as Q-V droop [7], [8], [15], power factor control [8], [11], [15], and voltage control [8], [11], [18].The Q-V droop is a widely used strategy where the amount of reactive power consumption is determined from a droop characteristic between the point of common coupling (PCC) voltage and the PV inverter reactive power. In the power factor control approach, the reactive power output is determined using the active power output and the desired power factor of the inverter. A reactive power control strategy based on the inverter active power is used [17], [18] for voltage rise mitigation in coordination with an energy storage unit. A combination of voltage and active power generation based Q-V droop characteristic has been proposed [6] for the mitigation of voltage rise.

During cloud passing periods, the solar PV generation is subject to PV output fluctuations that cause rapid voltage variations [2], particularly in weak radial systems. A solar PV inverter is used to reduce the voltage fluctuation by using reactive power support. Steep voltage changes may create voltage flickers in distribution systems that can cause objectionable flicker in the illumination devices and may also cause hunting of upstream voltage control devices [10].The contribution of this paper is the development of a multimode reactive power control strategy that can provide an appropriate reactive power support to meet various conditions associated with solar power generation, including the absence of solar power generation in the night and the high ramp rate operation during passing cloud.

A dynamic reactive power control approach is proposed for reactive power support during no, low solar power generation depending on the power drawn from the grid by the loads. Instead of using a droop characteristics approach, a reverse power flow versus reactive power droop characteristic is proposed for voltage rise mitigation during the maximum solar power generation. A strategy based on PV output ramp-rate is proposed for reactive power control during the cloud passing solar power generation. A coordinated control strategy is developed for smooth mode transition [14] among the control modes, such as the transition from maximum PV power to low PV power during passing clouds, so that high and unwanted step changes in reactive power can be avoided. The proposed strategy will therefore provide a better performance under diverse conditions of solar power generation compared to other traditional strategies

2. SYSTEM ANALYSIS FOR REACTIVE POWER MANAGEMENT BASED SOLAR PV SYSTEM

The reactive power management capability of solar photovoltaic inverter is used for support the voltage in low voltage distribution system. It can be used as a fast acting static VAR (volt ampere reactive) compensator controlled through a voltage regulator [15]. The proposed reactive power controller will have three modes of operation. During no, low solar power generation, it will operate in Mode 1, which is a dynamic VAR control mode to provide voltage support in low voltage distribution system. The droop characteristics approach of Mode 2 will be used to mitigate voltage rise produced by reverse power flow during maximum solar power generation. If significant PV output fluctuations appear when the controller is in Mode 1or Mode 2 operation, a ramp-rate based voltage support will be provided using Mode 3 during cloud passing solar power generation. The amount of reactive power support during different modes of operation will depend on the available reactive power capacity of the inverter.

A. Dynamic VAR Compensation Mode

When there is no voltage rise caused by a high PV output producing reverse power flow or no voltage fluctuation caused by PV output fluctuation, this strategy will operate in a dynamic VAR compensation mode. In this mode, the reactive power support will be provided if the voltage at the inverter connection point falls below a threshold. Fig 1 (a) shows that, the amount of reactive power support from the inverter (Q_{INV}) will dynamically vary depending on the power drawn by the customer from the grid. . The ratio of the voltage sensitivity with active power (σ_{vp}) to the voltage sensitivity with reactive power (σ_{Vq}) will be included in the reactive power control function to determine the appropriate amount of reactive power support to compensate for the voltage drop produced by drawing active power from the grid. The reactive power support function is developed to allow the user to control how much reactive power will be injected at the detection of low voltage using a parameter C1 and how the reactive power injection will vary during the peak load period, using a parameter C2.However, Q_{INV} increases at a high rate with increase of forward power, as indicated by the slopes in fig 1 (b) & (c).

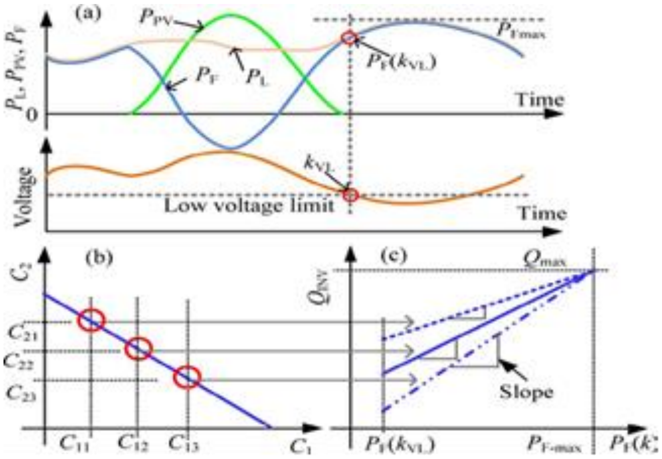

Fig 1. Dynamic VAR compensation mode for voltage supports (a) Historical forward power profile and voltage profile. (b) Relation between C1 and C2. (c) Relation between and under different selections of P_F and Q_{in} under different selections of C1 and C2

B. Droop Characteristics Approach

The cause of the voltage rise impact of solar PV is mainly the reverse power flow created by excess PV power at the PV connection point [6], [9]. Therefore, a reverse power flow based reactive power droop control method is used to mitigate the voltage rise.

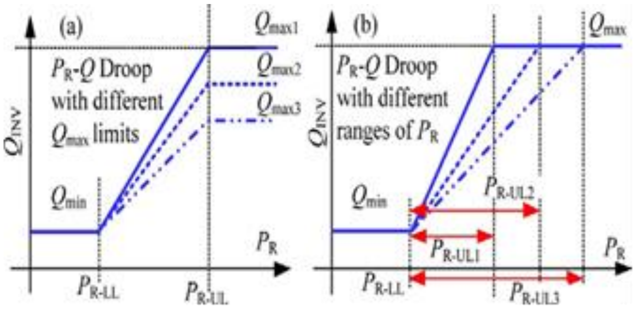

Fig 2.Reverse power flow based reactive power droop characteristics. (a) For different capacities of reactive power. (b) For different ranges of reverse power flow.

The design of mode 2 is based on the maximum solar power generation will create the voltage rise in low voltage distribution system. The solar photovoltaic inverter is used to absorb excess reactive power and mitigate the voltage rise. The Droop characteristics approach for reduce the voltage rise is shown in fig 2.

C. Ramp-Rate Control Mode

When the PV units experience shading effects due to passing clouds, PV power fluctuation may become severe and can create significant voltage fluctuations in weak radial feeders.

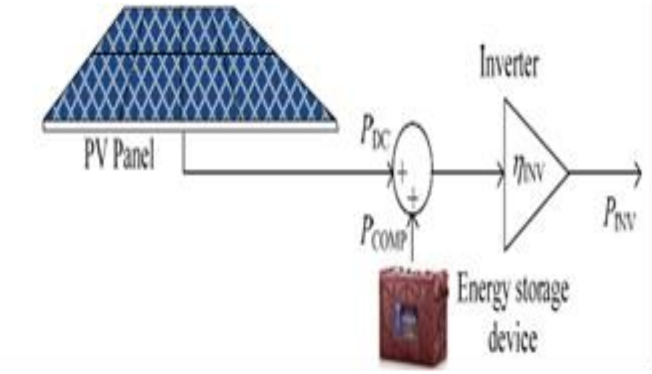

Fig 3.Conceptual schematic of the proposed ramp-rate control strategy

During such power and voltage fluctuations, the reactive power of the PV inverter will be controlled using the ramp- rate of the PV panel power P_{DC} to provide fast and appropriate reactive power support. In this ramp-rate control strategy, a compensation power will be added with the PV panel DC power to control the ramp-rate of the PV inverter output within a desired level at any instant of time. The basic concept of ramp-rate control strategy is explained in fig 3.The PV inverter real power output P_{INV} depends on the PV panel DC power P_{DC} and the compensation power P_{COMP} [2], [12].

3. MODES OF OPERATION

Fig 4. Block diagram of reactive power management based solar photovoltaic inverter

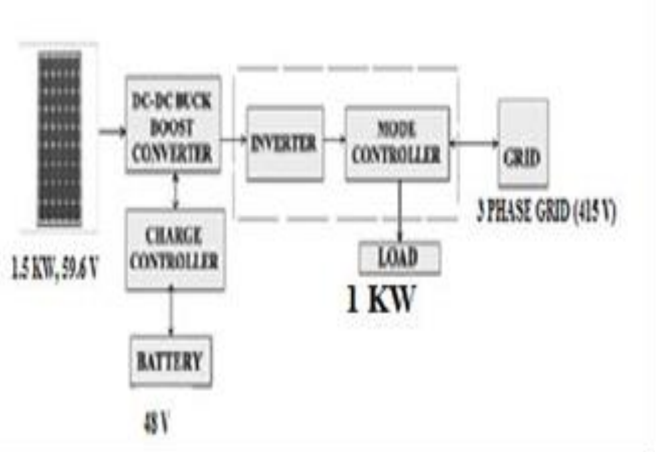

Fig 4.shows the block diagram of reactive power management based solar photovoltaic system. It consist of 1 KW solar panel generates electricity in DC form, and the DC– DC converter is used for convert unregulated DC input voltage into a regulated DC output voltage [13]. It can also be converted as switched mode regulator and 48 V batteries are used to store the DC electricity. . But many appliances need AC power for their operation. Therefore the inverter is used to convert DC to AC electricity. The reactive power capability the solar photovoltaic inverter is used to maintain the constant voltage level and provide the fast reactive power control under various solar power generating conditions (no solar power generation, low solar power generation, maximum solar power generation and cloud passing solar power generation)[16].The mode controller (proportional integral controller) is used to compare reference reactive power value and actual reactive power value there by provides accurate result. This solar power system is synchronized to the three phase grid by using the phase locked loop (PLL).

A. Mode 1: Dynamic VAR compensation mode(No low Solar Power Generation)

This mode will include the conditions of no, low solar power generation. In this mode, the inverter will inject the reactive power and support the low voltage distribution system with the help of battery

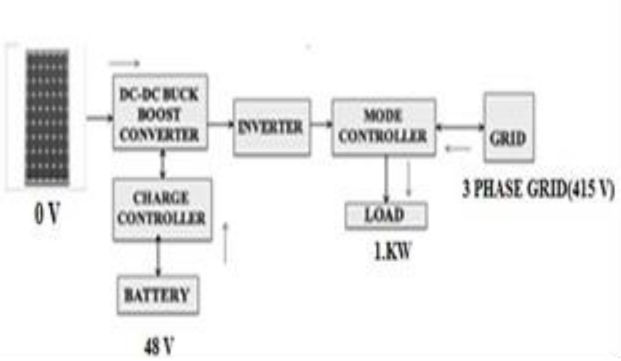

Fig 5.Block diagram of solar photovoltaic inverter for Mode 1 operation (no solar power generation)

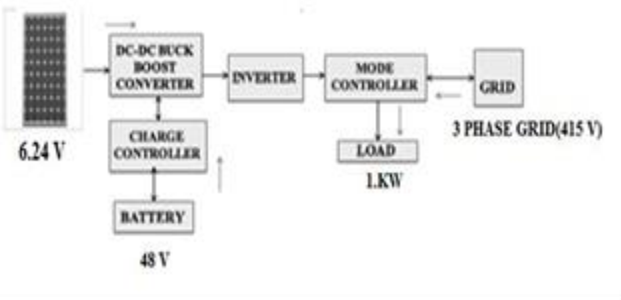

Fig 6. Block diagram of solar photovoltaic inverter for Mode 1 operation (low solar power generation)

In no solar power generation, the solar panel produces 0Vand the low solar power generation, the panel produces 6.24V. In low, no solar power generation, the load creates voltage drop in the low voltage distribution system, because less amount of power is available on the solar power generation.

Both solar power generation and the battery is not sufficient to supply the load. Therefore the remaining amount of power is drawn from the grid to load is shown in fig 5 and fig 6.In this mode the inverter is used to maintain the constant voltage in low voltage distribution system.

B. Mode 2: Droop Characteristic Approach(Maximum Solar Power Generation)

This mode will include the condition of maximum solar power generation. In this mode, the inverter will absorb the excess reactive power and mitigate the voltage rise in low voltage distribution system. If the solar power generation is maximum, compared to the load and it will create the voltage rise. Therefore the solar power generation is supply to the load and charge the battery. The arrow marks indicate the solar panel provides the power to load

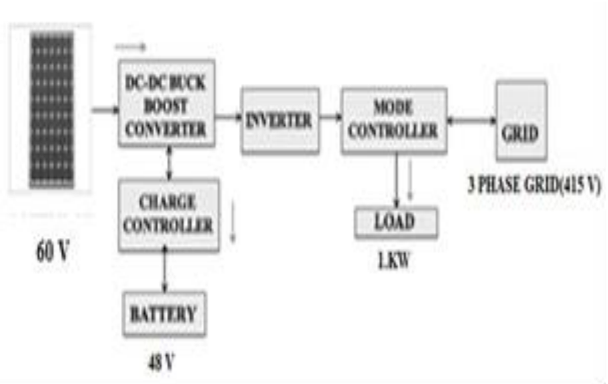

Fig7.Block diagram of solar photovoltaic inverter for Mode operation (Maximum solar power generation).

C. Mode 3: Ramp Rate Control (Cloud Passing Solar Power Generation)

This mode will include the condition of cloud passing solar power generation. In this mode, the inverter will inject the reactive power and reduce the voltage fluctuation in low voltage distribution system with the help of battery.

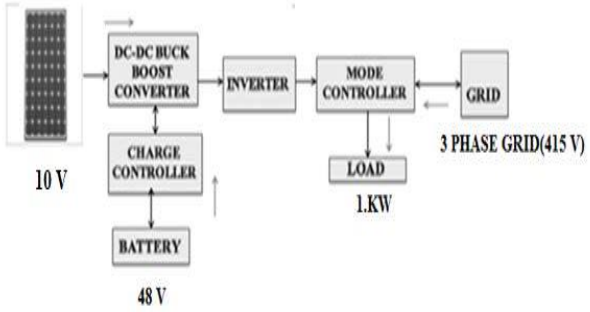

Fig 8 Block diagram of solar photovoltaic inverter for Mode 3 operation (Cloud passing solar power generation).

If the cloud passing solar power generation, will create voltage fluctuation in the low voltage distribution system. Both the solar power generation and battery is not sufficient to supply the load (due to cloud passing solar power generation). Therefore the remaining amount of power is drawn from the grid to load is shown in fig 8. In this case the battery is used to reduce the voltage fluctuation.

4. RESULT ANALYSIS OF REACTIVE POWER MANAGEMENT BASED SOLAR PHOTOVOLTAIC INVERTER

In this method the reactive power management based solar photovoltaic inverter has been modeled in MATLAB R 2009b. The solar PV inverter is running below its rated output current when converting DC solar power to AC active power. The unused capacity of the inverter can then be put to use to produce reactive power. The output of a solar PV inverter has both reactive and active AC currents that add to the apparent power which will be limited by the current rating of the inverter. Active power control is tied to controlling grid frequency, whereas reactive power control is linked with controlling the grid voltage [14].

Output Voltage Waveforms of Low Voltage Distribution System

A. *Output voltage waveform of without compensation for mode1 operation (no and low solar power operation)*

Scale

X axis 1 unit=0.01sec

Y axis 1 unit= 100 V.

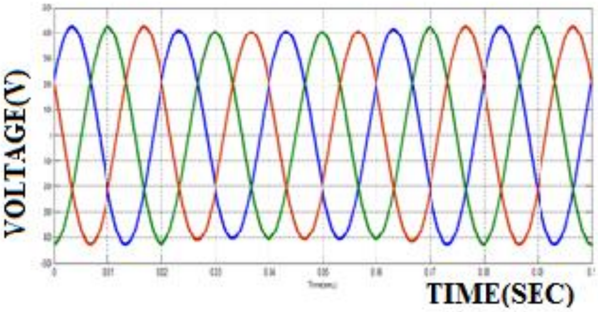

Fig 9. Output voltage waveform of without compensation for mode 1 operation. (No, low solar power generation)

B .Output voltage waveform of without compensation for mode 2 operation (maximum solar power generation)

Scale

X axis 1 unit =0.01sec

Y axis 1 unit= 100 V.

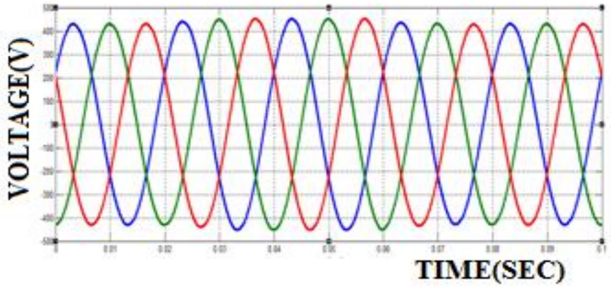

Fig 10.Output voltage waveform of without compensation for mode 2 operation (maximum solar power operation).

In fig 10 shows the output voltage wave form for mode 2 operation (maximum solar power operation). The voltage waveform is increased from nominal three phase voltage 415 V to 430 V due to the voltage rise at a particular time of 0.02 to 0.06 sec.

C. Output voltage waveform of without compensation for mode 3 operation (cloud passing solar power operation)

Scale

X axis 1 unit =0.01sec

Y axis 1 unit= 100 V.

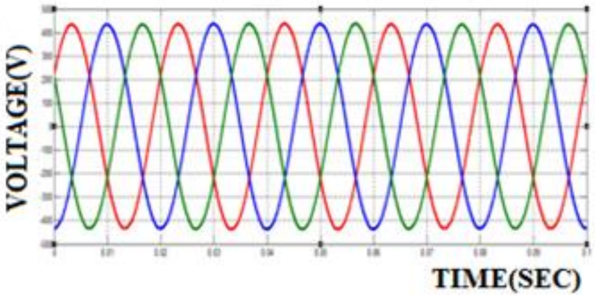

Fig 11. Output voltage waveform of without compensation for mode 3 operation (cloud passing solar power generation).In fig 11 shows the output voltage wave form for mode 3 operation (cloud passing solar power operation). The voltage waveform is reduced from nominal three phase voltage 415 V to 400 V due to solar power is fluctuates at a particular time of 0.03 to 0.06 sec.

D. Output voltage waveform of with compensation for 3 modes of operation.

Scale

X axis 1 unit =0.01sec

Y axis 1 unit= 100 V.

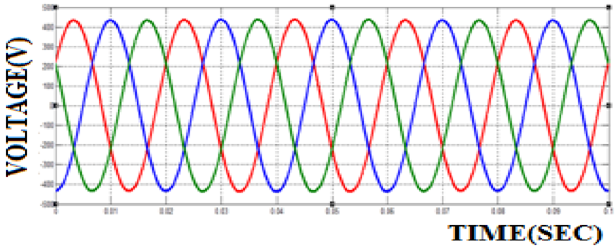

Fig.12.Outputvoltage waveform of with compensation for 3 modes of operation.

In fig 12 shows the output voltage waveform for 3 modes of operation. In this voltage wave form is maintained to nominal three phase voltage of 415 V. Because the inverter provides the fast reactive power control and maintain the constant voltage in low voltage distribution system. Thus the results concluded that, the system of reactive power management of solar photovoltaic inverter is well suited for real time application. The solar photovoltaic inverter can be used to control the reactive power and maintain the constant voltage profile in low voltage distribution system [19]. This strategy will provide a better performance under diverse conditions of solar power generation compared to other traditional strategies [20].

5. CONCLUSION

In this project, a solar photovoltaic inverter based reactive power management system has been implemented to the low voltage distribution system under various solar power generating conditions (no solar power generation, low solar power generation, maximum solar power generation, cloud passing solar power generation). The simulation results demonstrate the assessed in terms of their contributions towards regulating the voltage in low voltage distribution system. Investigations are carried out to this approach for capable of regulating the voltage during various solar power generating conditions. The solar photovoltaic inverter can be used to manage the reactive power and maintain the distribution system voltage.

The solar photovoltaic inverter which is used to manage the reactive power to the low voltage distribution system during various solar power generating conditions and regulating voltage at the Point of Common Coupling (PCC) are investigated. The system operation is supervised by a reactive power management strategy based on the dynamic control of inverter while a PI controller is also implemented to reduce voltage variations at PCC.

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