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REACTIVE POWER RECOMPENSE OF A SOLAR-BASED ENERGY GRID USING ACTUAL POWER AS A FUNCTION OF POWER FACTOR

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ABSTRACT
Solar energy is currently one of the most popular renewable energy sources. Solar inverters can only feed the load or inject active power into the grid at Unity Electricity Factor (UPF), depending on the requirements of the load. The whole amount of reactive power required by the load is met due to insufficient voltage control. There are numerous ways to control the flow of reactive power from the grid to the load and balance out reactive power at the load side, including the use of synchronous condensers, mechanically switched capacitors, and FACTS devices like STATCON, SSSC, and SVC, among others, which can reduce the amount of reactive power drawn from the grid by the load and enhance grid performance. But to get around some issues in these devices such as installation, maintenance, space requirements, overall life span, the cost of the equipment to be installed etc., a methodology is presented in this project the grid itself as the solar inverter do not contribute to reactive power requirement of the load. Due to this scenario at the grid side, the performance of the grid worsens because of poor power factor as a result of this the voltage profile of the grid will not be maintained properly, to control the reactive power flow from the grid side to load side by using a solar inverter which can provide reactive power along with the active power also. In this project, the solar inverter is programmed in simulation to provide reactive power injection in addition to active power generation. The methodologies for compensating the reactive power are developed using Matlab/ Simulink software and the results are presented.
KEY WORDS: Reactive power compensation, Solar Inverter, FACTS devices.

1. INTRODUCTION

Reactive power is an oscillating power that alternates between the source and the load. Reactive power exists in a network when the voltage and current are not in phase. The word "VAR" was first used in 1930 by a scientist by the name of Constant in Budeanu. The word "power factor" has also changed since reactive power results in a phase mismatch between voltage and current. With declining power factor angles and vice versa, reactive power requirements also decline.

Since the advent of power electronics, which offer benefits over mechanical ones in terms of running speed, little power loss, low maintenance costs, etc., power engineers began using electronic devices for compensating. Formerly, the reactive power compensation is of two types - series compensation and shunt compensation. In series compensation the capacitors are placed in series with the transmission line which improved the power transfer capability up to two times the original rating by decreasing the equivalent impedance of the line. The shunt compensation mainly focuses on the voltage profile of the line in which a capacitor is placed in shunt with the line improves the voltage regulation of the line. At the beginning, the thyristor family has been used for VAR compensation which is otherwise called as FACTS devices such as SSSC, SVC, SVS, STATCOM etc. These are having more advantages than the mechanically switched devices but the major disadvantages include the installation cost and allocation of the device.

To overcome the disadvantages of using FACTS devices, solar inverters are used as one of the solutions for compensating the reactive power as the inverter is also made of power electronic devices. Moreover, the solar inverter can be effectively used if reactive power provision is provided at lower solar insolation levels, thereby improving the utilization factor of the inverter also.

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2. METHODOLOGY

In most of the cases the shunt compensation is used rather than series compensation at grid side or at load centers. Up to late 1990s this is the method followed to compensate the reactive power and improve the power factor and performance of the system. But due to the disadvantages of FACTS devices mentioned in the above chapters, the usage of solar inverter as a VAR compensation device has been encouraged. These devices are previously used to convert DC to AC and inject only the active power to the load or grid depending on the requirement. Now a days these inverters are manufactured with a provision of providing the reactive power compensation also.

The inverters are basically current limited machines. There are two possibilities for manufacturing the inverters to provide the provision of reactive power compensation to it. One is to inject full capacity of current available for active power, the other is to hold the current capacity in reserve for the reactive power capability at its rated capacity. The above two possibilities mainly depend on some factors like voltage limit, current limit and the active power limit which will be discussed in this chapter.

2.1 VAR Capability Curve:

The ability of the machine to deliver the power to the load or vice versa without causing any damage or wear and tear to itself i.e., without crossing the threshold value of current limit of the machine is called the VAR capability of the machine. It is defined by a specific curve called D-curve. The curve is drawn to know the current and voltage limits of the machine and is drawn between the active power (P) and reactive power (Q) of the machine. There are three constraints on which the capability curve depend they are

1. Voltage limits
2. Current limits
3. Real power from the solar generator.

Voltage Limits

The voltage limits are imposed on the inverter at the input side where DC voltage may vary depending on the conditions to extract maximum power from the PV panel. According to the variation in the DC voltage at the input side of the inverter also will have certain limitations on the voltage parameters. The minimum value of the voltage at the input side of the inverter terminal that will allow the AC voltage value to be inside the permissible value according to the grid code requirements are given below

$$Vmin = 2\sqrt{2} * V$$

$$Gmin = \left(\frac{Vdcmin - Vocstc}{Kv} + 25 - Ta\right) * \frac{800}{Noct - 20}$$

$$Vocmax = Vocstc + Kv * \left(Tamin + Gmin * \frac{Noct - 20}{800} - 25\right)$$

$$Vmax = Vocmax * Nser$$

$$P^2 + (Q + \frac{Vg^2}{X})^2 = \frac{Vg\,.Vi}{X}$$

In case the PV inverter is working at MPP, the minimum solar irradiance accepted to keep the voltage above the minimum acceptable range of voltage is determined by the equations mentioned above. After determining the minimum range of voltage, the maximum voltage should also be considered which depends on the open circuit voltage of the PV panel. If the DC voltage is greater than the maximum PV voltage then the power supplied from the PV panel is zero.

2.1.1 Current Limits:

The current from the PV panel depends on the irradiance level of the solar rays falling on the PV panel which will be varying throughout the day. The current injection into the inverter is done depending on the irradiance level. So, the maximum amount of the current injected into the inverter at the maximum irradiance condition imposes the limitation on the inverter power delivery capacity. This limit is determined by the circle equation given below.

$$P^2 + Q^2 = (Vg * Ii)^2$$

$$Ii = \frac{\sqrt{P^2 + Q^2}}{\mathrm{Vg}}$$

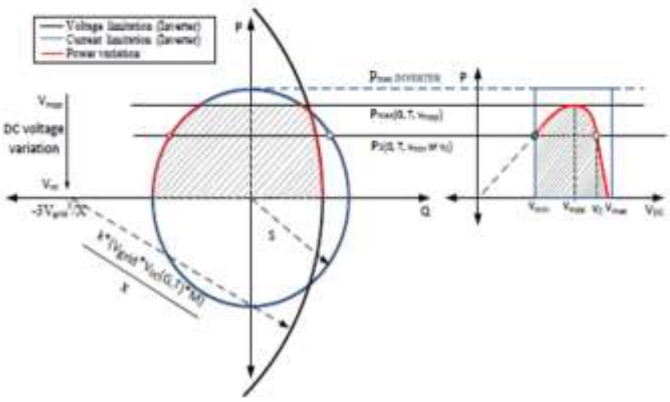
$$P^2 + (Q + Vgrid)^2/X = \frac{(Vgrid\,.Vconv)^2}{X}$$

$$Q = \frac{Vgrid.Vdc.M}{\mathrm{X}}$$

$$Qmpp(G,T,Vdc) = \frac{Vgrid.Vmpp(G,T).M}{\mathrm{X}}$$

2.1.2 Active Power Limit:

It is the maximum power that can be obtained from a PV panel which is 1 pu at its highest irradiance level. The capability curve is shown in the below Fig.2.1 with all the constraints discussed above.



2.2 Prosumers:

There is a concept called prosumers where an active part of interaction with electricity is taken place where they produce electricity and consume electricity, vary their demand pattern and provide ancillary services to the network, if needed. In this case the PV operator may be considered as a prosumer. They can help mitigate some problems at the grid side through a series of strategies including the active power curtailment and reactive power injection using solar PV system.

The reactive power requirements of grid or the load are met by the inverter through some appropriate control methods which are discussed below.

1. Constant Reactive Power method
2. Constant Power Factor method
3. Power Factor as a function of Active power
4. Voltage as a function of Reactive Power
5. Load Compensation

All the methods are explained in detail and the simulation work is also presented in the results section.

3. SYSTEM DESCRIPTION AND CONTROL CIRCUITE DESIGN

Three phase inverter model was selected for application ofreactive power compensation techniques. The configuration of inverter along with the synchronous reference frame theory (SRF) which is also called as dq0 transformations used as a control strategy applied to them are discussed in this chapter.

1.1 System and its control strategy:

A 50 KW solar panel is used as energy source input to the inverter and the inverter type is three phase, H-bridge configuration which allows the bidirectional flow i.e., from source to load as well as from load to source. In this model, a dc-dc converter is used at the input side of the inverter which steps up the voltage to the required level. The dc link capacitor is used to maintain the dc voltage as per the reference mentioned in the control strategy. The synchronous reference frame method which is also called as park's transformation method is used for the control of active and reactive power. The components in the synchronous reference frame are also called dc components or rotational reference components. The voltage and current signals are transformed to dq0 components directly by using Clarke and Park's transformations. The equations (4.1) to (4.4) determine the Clarke transformation otherwise known as stationary reference quantities.

$$V\alpha = \frac{2}{3}(Va) - \frac{1}{3}(Vb - Vc)$$

$$V\beta = \frac{2}{\sqrt{3}}(Vb - Vc)$$

Where, V_a, V_b, V_c are three phase quantities

V_α and V_β are stationary orthogonal reference frame quantities

When V_α is superposed with Va and Va+Vb+Vc = 0, Va, Vb, Vc can be transformed into V_α V_β as given below

$$V\alpha = Va$$

$$V\beta = \frac{1}{\sqrt{3}}(Va + 2Vb)$$

Where $V_a+V_b+V_c = 0$.

The Clarke Transformation is then converted into Parks transformation using the following equations (4.5), (4.6)

$$Vd = V\alpha * Cos(\theta) + V\beta * Sin(\theta)$$

$$Vq = V\beta * Cos(\theta) - V\alpha * Sin(\theta)$$

Where V_d&V_q are the rotating reference frame quantities

V_α and V_β are stationary orthogonal reference frame quantities

Θ is the rotating angle

The converted dq0 components are the actual measured components of the system and are compared with the reference values of I_d and I_q which further generate the references for the voltage for pulse generation.

The I_{dref} is generated by comparing the actual value of DC voltage and the reference to which it must be regulated and the generated error for the comparison is fed to a PID controller such that it generates appropriate reference for I_d. The reactive power reference is generated by using several methods discussed above in chapter 3. The generated I_d and I_q reference values are compared with the actual values of the current component in dq0 reference frame to produce the reference voltage values of pulse generation. The MatLab and Simulink diagram is shown in the next section.

2. SIMULATION RESULTS AND DISCUSSIONS

The simulation is carried out for a three-phase inverter circuit in which the input power source is a solar panel of 50 KW capacity and a DC-DC converter is used here to boost the voltage to the required level, a DC link capacitor is used for coupling purpose at which the DC link voltage is maintained constant (i.e., 500V) using appropriate control strategy.

2.1 Simulation Circuit and result discussion for three phase system:

The simulation circuit and the respective waveforms for the three phase 50 KW grid tied solar inverter model is shown below. For this model all the reactive power compensation techniques are applied which are discussed in chapter 2. The aim of all the methods involved is same ie., to control the reactive power flow at the grid side and maintain a flat voltage profile throughout the transmission line so that the power factor of

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the grid will be in limits.

The simulation circuit of a three-phase grid tied solar inverter is shown in the below Fig.4.1 along with the performance characteristics and the solar array data shown in the Fig.4.2.and Fig. 4.3. The load is connected at the point of common coupling (PCC) with an active power demand of 30 KW and 30 KVAR initially. An L-C type filter circuit is used to smoothen the output of the inverter. The simulation circuits for the methods applied for reactive power compensation are also shown in the below fig. along with their waveforms.

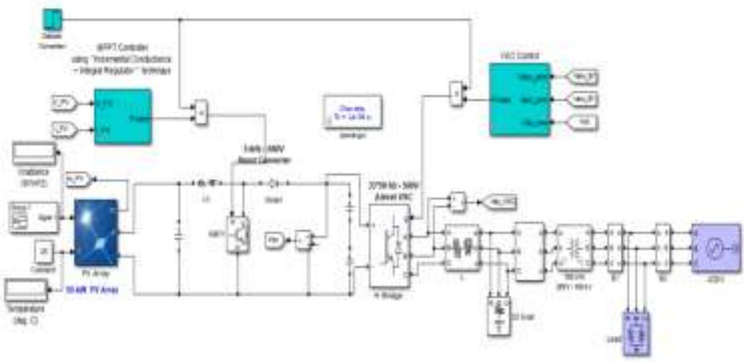

Fig.4.1 simulation circuit of a three-phase grid tied PV solar Inverter.

2.1.1 Only Active power injected:

The Fig.5.4 below shows there is no control strategy implemented to inject the reactive power, as the reference for generating the reactive power is kept at zero. In this mode of operation only active power will be injected and there will be no reactive power provision to provide reactive power as per the requirement of load. All the reactive power demanded by the load is met by the grid itself and some part of the active power requirement is met by the inverter as it is capable of delivering real power depending on panel's generating capacity. The connected load at the PCC terminals is 30 KW resistive load and 30 KVAR inductive load.

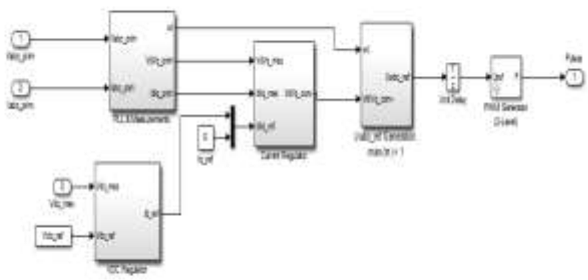

Fig.4.2.1 Control Circuit for the active power injection

The results can be observed from the Fig.4.2.2-4.2.3 that no reactive power supply is carried out by the inverter.

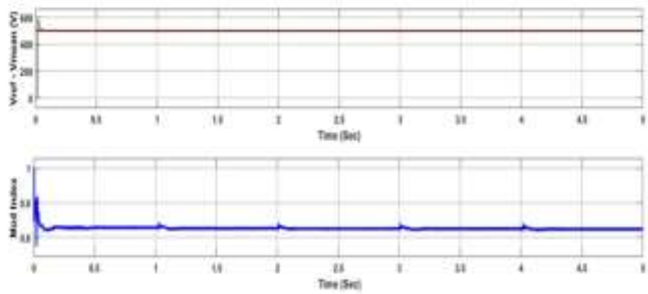

Fig.4.2.3 wave forms of DC voltage and Modulation Index of the inverter

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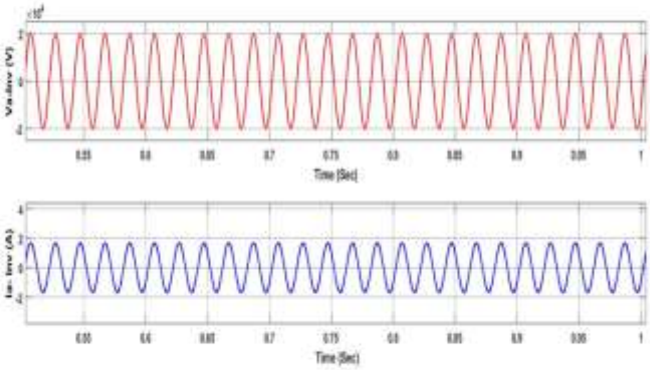

Fig.4.2.3 wave forms of Inverter Voltage and Current

2.2 Constant Reactive power method

In this mode of operation, there is a provision of reactive power injection provided to the inverter by setting a constant value other than zero at the reference value which is responsible for generating reactive power. In this mode, the load reactive power requirement is met fully or partially by the inverter depending on the set parameter of reactive power generation. This method is affected only by the rating of the inverter. The Fig.5.6 below shows the control strategy of constant reactive power along with the waveforms in Fig.5.7(a)-5.7(c). The load connected at PCC is 30 KW and 30 KVAR resistive and inductive loads respectively. In this method, the reactive power injection to the load can be limited by the operated by using a saturator such that the reactive power injection does not go beyond the set limit. The wave forms of the active and reactive power injection in the below figure suggests us that the inverter is able to meet the full load demand as the saturation point kept is 30 KVAR and the load demand is also 30 KVAR. The compensation of reactive power starts after 1sec of time period as the inverter delivers its full rated power at the highest irradiance i.e., 1000w/m^2. Up to 1 sec the load demand is met by the grid.

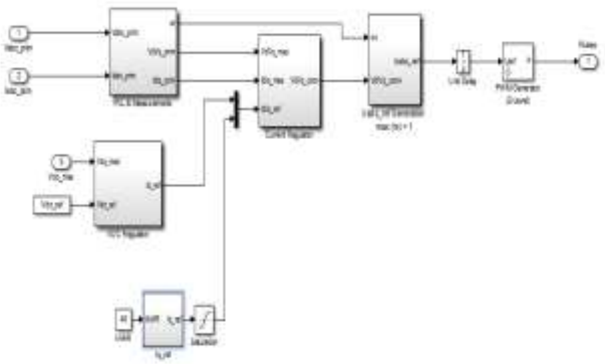

Fig.4.2.1 control circuit diagram for constant reactive power method

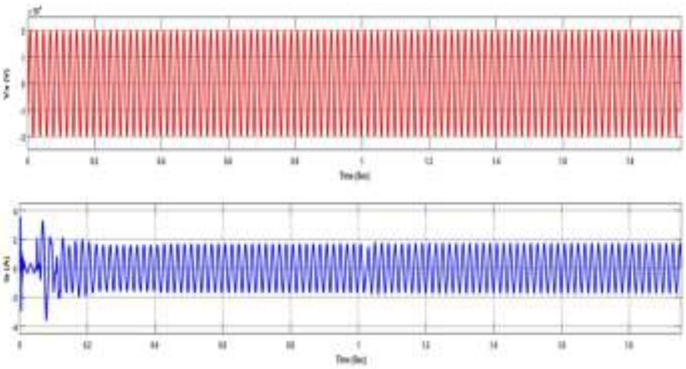

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Fig.5.7(a) wave forms for Inverter Voltage and Current

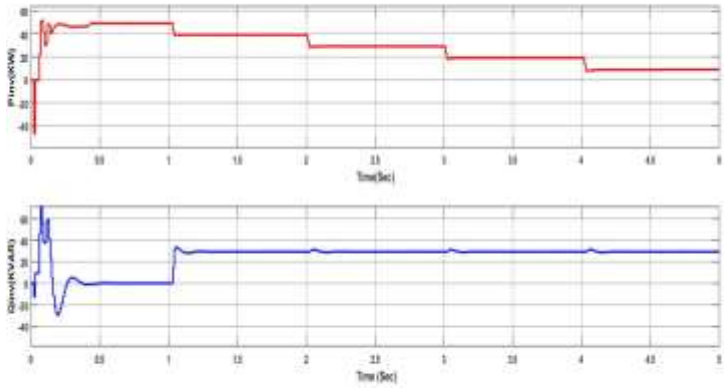

Fig.4.2.3 Wave forms for active and reactive power at inverter

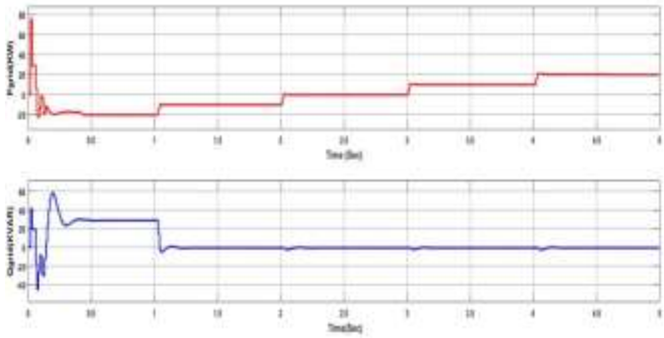

Fig.4.2.4 Wave forms for active and reactive power at grid

CONCLUSION

Instead of employing FACTS devices like STATCOM or SVC, the power engineers built a provision for reactive power compensation for a solar inverter in order to achieve reactive power curtailment/compensation in an economically feasible manner. Several advantages resulted from this choice, including the effective use of solar inverters in low-irradiance and partially shaded environments. Several reactive power compensation algorithms are simulated for a three-phase grid-tied solar inverter. The examination of the capability curve provides further detail on the restrictions put on the inverter during power injection to the grid and establishes control logic for reactive power management. They can be used to enhance the grid's efficiency in terms of voltage control and power factor. The MATLAB/Simulink tool is used to validate the system for various modes of control.

FUTURE SCOPE

In the present work, although this research has covered some of the interesting issues and challenges in reactive power control and compensation and several aspects like integrating the solar inverter to the grid for the effective use, there are certain aspects that might be interesting to take up for the future investigation and research which are listed below:

- Due to excessive usage of semiconductor devices and passive components, a fault protection scheme to enhance the ride through capability in various fault conditions remains to be a major challenge.
- In the investigation of interface topology, the DC link was assumed to be charged to a voltage not greater than the DC side voltage of VSC. It might be valuable to investigate the charging of DC link to a higher extent and related issues of protection at the DC side of VSC.
- Changes can be brought in the control logic implementation of controller (such as usage of PR controller instead of PID controller) in order to obtain the high speed of response.

- The inverter topology may also be changed as MLIs (Multi level Inverters) can be worked out for reactive power compensation which has its own advantage.

Hard ware implementation of the solar inverter with the provision of providing the reactive power compensation may be done in order to observe the effects of load and grid on the solar inverter under low solar isolation conditions.

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