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MODELING AND SIMULATION OF GRID-CONNECTED PHOTOVOLTAIC DISTRIBUTED GENERATION SYSTEM

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ABSTRACT:

Paucity in the energy scenario had made conservation of energy an essential issue. Usage of Renewable energy sources (RES) is increasing in the present era, which calls for green and clean energy sources. RES includes various forms viz., solar energy, wind energy, geothermal energy etc. but the most favored are the solar and wind energy. Most RES are intermittent in nature. To integrate RES to a utility grid is a quite challenging task, to track the maximum power point (MPP) of a consistently irradiated PV system is important and is yet another challenge. Of all the available methods in the MPPT context the Perturb and observe (P & O) method and incremental conductance method are the widely used techniques. In this project the P & O method is implemented for tracking the MPP.

The tracking system conventionally is supplied the PV array voltage and cur- rent to track the MPP. In this thesis instead of having a sensor for measurement of the solar array current, it is estimated or observed with a sliding mode observer. The observer is based on sliding-mode and is constructed from the dynamic equations of the considered system viz. a single phase grid connected Photovoltaic system that has a Photovoltaic module and a single-phase H-bridge inverter. The solar array current is observed by the known values or measured values of the array voltage and inductor current. The current estimation is governed by the sliding mode observer gain, as we increase the value of the gain chattering problems come into being. The estimated value almost follows the original current and hence, is used to track the MPP. In this thesis at first the methodology of grid integration of distributed Photovoltaic systems are studied and simulated. And then an observer based on sliding-mode theory, the MPPT control was

developed.

KEYWORDS:-

MPPT, RENEWABLE ENERGY SOURCES, SLIDING MODE OBSERVER, PHOTOVOLTAIC SYSTEM

I. INTRODUCTION

Electrical energy that is distributed or connected to the grid from many de-centralized locations, viz. wind farms and PV panels is known as distributed generations. Paucity of most sources, depletion of fossils and threat to the envi- ronment has led us to the choice of switching to renewable energy sources (RES). It is not only abundant in its availability but is also pollution free and eco- friendly. Most of these energies are intermittent in nature, this makes it interesting and in- triguing to connect RES into the grid. Solar energy, wind energy and geothermal energy are some of the most booming renewable energy forms.

They are everywhere around us but they cant be used in their direct form. In this thesis PV systems are taken into account. For PV systems it is very important to track its maximum power point (MPP). A tracking strategy called the maximum power point tracking comes into play for keeping track of the MPP of a PV array. There are many MPPT techniques but the most common ones are incremental conductance (INC) and Perturb and observe (P and O) MPP tracking. Here in this thesis perturb and observe technique is used to track the MPP. In order to connect the PV system to the grid it is necessary to invert the solar DC power into AC. Hence, power stages come into being for converting DC into AC. Various topologies such as the single phase H-inverter are discussed in this thesis. An observer based on sliding mode is used to estimate the solar array current, which is fed to the MPPT for tracking the MPP of the PV array.

The increasing demand of non-conventional energy has made it an intriguing challenge to use this kind of energy at its best. The depletion of fossil fuels and environmental hazards are yet another reason for mankind to switch to a better option such as Renewable energy sources. Since the last decade Photo-voltaic sys- tems has

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been a necessary install for commercial and domestic usage. The best part of PV based systems is its Eco-friendly and pollution free nature. Although the initial investment on its installation is a bit high but has got no match to the after benefits.

As most of the renewable energies are intermittent in nature it is therefore very important to extract the maximum usable power. Photovoltaic cells have non-linear output characteristics because of the irregularity in the incident sun rays and thus calls for an effective system to keep track of the maximum oper- ating point or the maximum power point. The tracking system is called as the maximum power point tracking system, to this day there are various MPPT al- gorithms of which two methods i.e. the perturb and observe and the incremental conductance are widely used.

II. PHOTO-VOLTAIC ARRAY MODELING AND SIMULATION

2.1 MODELING OF PHOTO-VOLTAIC MODULE

The very fundamental unit of a solar array is the Photo-voltaic cell. A no of cells together forms a module these modules are then connected in series and/or parallel combinations, which finally results in a array. Typically a solar cell produces 2W amount of power but are modeled as per requirement of the user.

Photo-voltaic Cell:- The very fundamental unit of a solar array is the Photo-voltaic cell. A no of cells together forms a module these modules are then connected in series and/or parallel combinations, which finally results in a array. Typically a solar cell produces 2W amount of power but are modeled as per requirement of the user.

Photo-voltaic Module:- Power generated by a single cell is very less so, in order to increase the generated power, a collection of PV cells are connected in series and together these cells are called as a solar module or PV module.

Photo-voltaic Array:- Sometimes, even solar modules do not suffice for some applications. To further improve the rating of a PV system, modules are connected in series or/and parallel to obtain a PV array. The formation of modules and then array from

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a number of solar cells connected in series and parallel arrangement is shown in figure 2.1.

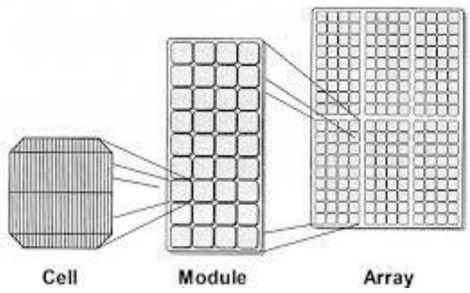

Figure 2.1: Figure showing PV cell,module and array

2.1.1 Impact of temperature and irradiation on the parameters of a Photo-voltaic cell

$$I_{pv} = (I_{pv,N} + K_I \delta_T)\frac{G}{G_N} \tag{2.3}$$

Where,

- $I_{pv,N}$ is the current generated by incident light under nominal conditions ($25 \deg\ C\ and\ 1000 Watt/m^2$)
- K_I is the temperature co-efficient of the short circuit current
- δ_T is the temperature difference of actual and nominal values ($T-T_N$)
- G is the light exposure or insolation
- G_N is the nominal value of insolation

2.1.2 Ratings of the solar module

The table shown below (Table 2.1) includes the parameter values for modeling of the required PV module. In this thesis KC200GT solar array is used and the respective ratings of the array are also included in the table. The following table gives the adjusted parameters of KC200GT under nominal conditions, it is to be noted that although the model is adjusted but the parameters closely resembles to the parameters of the actual model.

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Table 2.1: Ratings and parameters of the used solar module

Peak power of the module	189.3 W
Voltage at max. power	26.4 V
Current max. power	7.6 A
Assured minimum peak	185 W
I_{sc}, Short circuit current	8.21 A
V_{oc}, open circuit Voltage	32.9 V
R_{se} , series resistance	0.221 Ω
R_p, shunt resistance	415.405 Ω
K_I, temp. coefficient of I_{sc}	0.0032 A/K
K_V , temp. coefficient of V_{oc}	−0.1230 V/K
n, Diode ideality factor	1.3

2.2 SIMULATION RESULTS OF THE SOLAR MODULE

2.2.1 P-V characteristics

The simulation was carried out at 25° C temperature and irradiation of 1000 W/m^2. The maximum power point which is obtained by the product of the peak values of the current and voltage of the module is highlighted in the characteristic in Figure 2.3, 189.3 W.

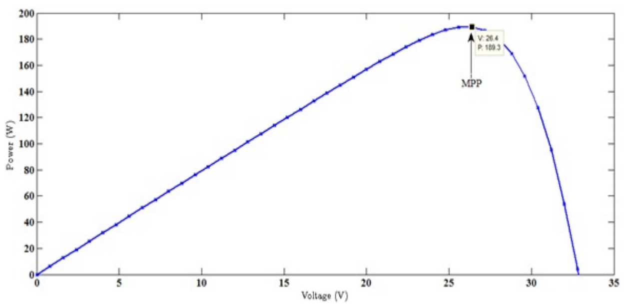

Figure 2.3: P-V characteristic of the module

2.2.2 I-V characteristics

The simulation was carried out for various insolation conditions and accordingly the behavior of the module characteristic to the variations was studied. The curve plots various voltage values for corresponding current as shown in Figure 2.4. It can be seen that the solar array short circuit current decreases as we gradually decrease the

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insolation. The open circuit voltage V_{oc} at the instant where solar array current I_{pv} is zero also decreases.It was further observed that on varying the temperature to higher values, the current remains almost the same but the open circuit voltage decreases as depicted in Figure 2.5.

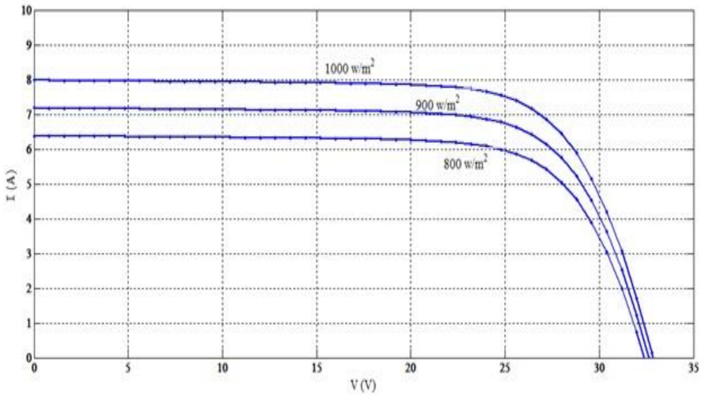

Figure 2.4: I-V characteristic of the module

III. SINGLE PHASE INVERTER

3.1 SINGLE-PHASE FULL BRIDGE INVERTER

Inverters are a group of power conversion circuits, which operates from DC source and converts it to symmetric AC voltage. In contrary to the converters which are used for conversion of ac power into dc, inverters works totally on the opposite principle of a converter. Usally as inputs inverters are fed with a dc source acquired from an ac source or a simple dc source.In practice, a battery bank or a PV array are the customary choices as sources for inverters. Voltage sources (magnitude) that are independent of the load are often called as stiff volt- age sources. An ideal inverter should produce sinusoidal output waveforms but practically this is not the case, waveforms are not sinusoidal and consist of harmonics content.

3.1.1 PULSE WIDTH MODULATION

Various analog circuits are controlled using the pulse width modulation (PWM) technique, these analog circuits are controlled using the digital output of a proces- sor. Applications of this technique range from measurement and communication to power conversion and control.In order to generate control signals for the inverter switches by

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this method requires a reference signal, which should be a sinusoidal l signal and a carrier signal usually a triangular wave, which controls the switching frequency. These two signals are then compared to obtain the pulses. There are two methods of switching with PWM viz. Unipolar method and bipolar method of switching. In unipolar strategy unlike bipolar method the output signal is either switched from low to zero or high to zero whereas in a bipolar method of switching the signal is switched from low to high or high to low. The switching control for a unipolar scheme is presented below:

- S_1 gets turned on when $V_{sin} > V_t$
- S_2 gets turned on when $-V_{sin} < V_t$
- S_3 gets turned on when $-V_{sin} > V_t$
- V_4 gets turned on when $V_{sin} < V_t$

3.2 CHOICE OF POWER DEVICES

The best of conventional bipolar transistors and FETs are merged together in an Insulated Gate Bipolar transistors (IGBT). Like FETs IGBTs, only a voltage across the base is required for conduction. They are also effective conductors of current through their emitters/collectors like the conventional bipolar junction transistors (BJT). A high base current is necessary in order to turn on a BJT, the turn-off charac- teristics of a BJT is relatively slow (current tail), and due to its negative temper- ature co-efficient it is liable for thermal runaway. To add, the conduction loss or the lowest attainable on-state voltage is controlled by the collector-emitter voltage at saturation.

However, MOSFETs are voltage controlled devices unlike BJTs. These have positive temperature coefficient, thus eliminating thermal runaway. As per the- ory, the on-state resistance has no restrictions. Hence, we can be further lower the on-state losses. The body to drain diode has a profound usage concerned to the limited freewheeling currents in a MOSFET. Looking at the benefits of the IGBT its an obvious to opt for IGBT as a switching device. Having the bests of both BJT and MOSFET has made IGBT an enhanced device in the power-electronics field.

IV. SINGLE-PHASE GRID INTEGRATION OF PV SYSTEM AND SIMULATION

4.1 INTRODUCTION

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Extracting the maximum power of a PV system is a prime concern so as to feed it into the utility. So, tracking the maximum power point as well as optimization of the energy conversion are the main modeling issues for grid integration.However, power quality, synchronization with the grid, protection of the system and reliabil- ity are some of the other vital issues that require special attention while connecting PV systems to the grid. Voltage rise effect is yet another challenge which limits the integration.distributed generation (DG) units when connected to the feeder may lead to improper voltage control of the system. If the power fed to the grid by the DG units is less than or equal to the feeder load but if this is not the case voltage rise occurs as an effect of reverse power flow which gets stronger when DG interject reactive power as well; dependent on $\frac{X}{R}$ ratio. Harmonic content and transient voltage variation are the two important and usually considered aspects under power quality in general. For instance if we consider a case of a PV array exposed to an irradiation level of 600 W/m^2 and suddenly the insolation level changes to 900 W/m^2 which leads to variations in the output of the array and can lead to a voltage transient. Addition of generation and increasing the fault level of the network oftentimes improves the power quality. As far protection of DG integrated systems usually are provided with a elementary over current protection strategy. Connection of DG units give rise to various sources of fault current.

4.2 TOPOLOGIES FOR GRID CONNECTED PV SYSTEMS

Organization of PV systems can be done in various possible ways that has direct impact on the structure as well as the topology of the converter. Conventionally the low voltage of the solar panel is boosted through a dc-dc converter and as the panel is to be connected to the utility grid it also requires a dc-ac converter or simply an inverter to convert the dc power into ac for injection into the grid. The whole configuration including the converter circuit and the panel regulates the cost,operation and its efficiency.

4.2.1 Centralized configuration

As the name suggests this topology has a central power conversion system. A mul- tiple number of PV panels are connected together in series and parallel to form an array, this topology is suitable for PV plants having nominal power greater than

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10 KW. Each string of this configuration is provided with a blocking diode to forbid energy reversal due to operation of strings at different insolation level and included energy storage systems

4.2.2 String Configuration

PV panels are connected in a number of strings and each string is provided with an inverter for converting dc into ac. This topology is an easy and modified version of the centralized topology. Many a times the voltage generated by these strings are not sufficient for particular applications and needs to be boosted which is done either by a dc-dc boost converter or a step-up transformer.

4.3 Simulation of single-phase grid connection of PV module

A very conventional simulation for the purpose of getting a clear picture of inte- gration of PV array with the grid is performed. The overall configuration is shown below in Figure 4.6, the switching signals for the inverter switches were generated by implementation of hysteresis current control.

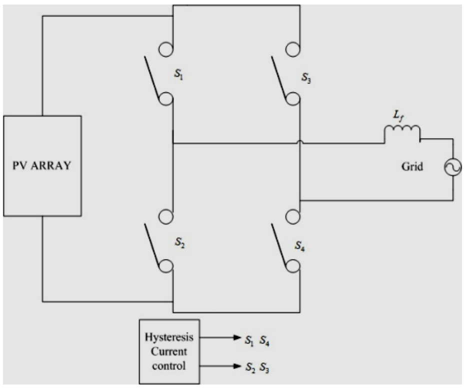

Figure 4.6: PV array integration with the grid

The grid voltage is set to a peak value of 325 volt, the PV array is consid- ered under uniform insolation condition. The first pair S_1, S_4 are turned on for the positive half cycle and the pair S_2, S_3 is kept on for the negative half cycle. The control signals are provided using hysteresis current control method for the simulation.

The voltage and current obtained during the simulation are shown in

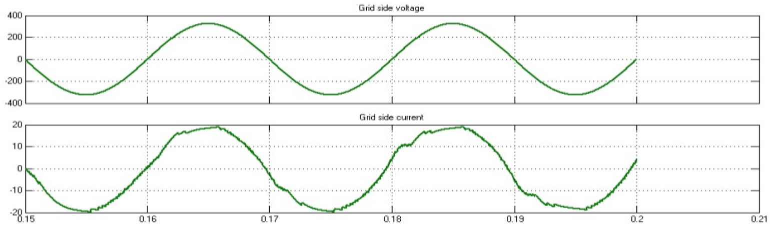

Figure 4.7: Grid voltage and grid current

Figure 4.7, It can be seen that the voltage and current are in phase, although the current has some ripple content it is nearly sinusoidal in appearance. For a better picture both the current and the voltage are shown together in Figure 4.8.

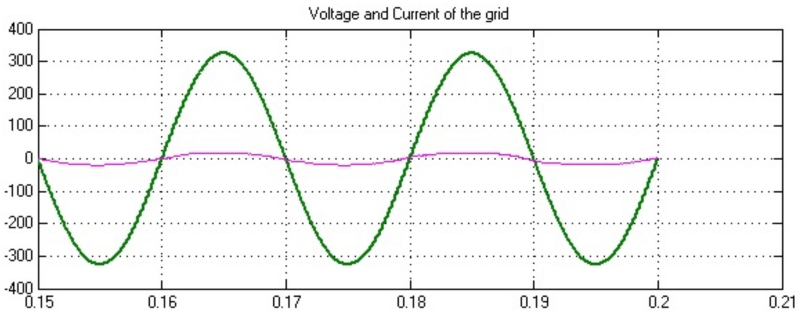

Figure 4.8: Voltage and Current of the grid

V. SLIDING-MODE OBSERVER DESIGN AND SIMULATIONS

5.1 OBSERVER

In the context of multivariable systems, lots of controllers are usually of the linear or non-linear state feedback type and they ask for the complete info about the states of the plant whenever they are to be implemented. However, it is either unfitting or not possible to measure all the state variables due to some limitations in practical. The solution to this very problem is to introduce an observer. An observer can be taken as an ancillary dynamic system, which is driven by the available inputs and outputs of a system yielding the original state vector with some structural supposals made on the system ensuring limitations.

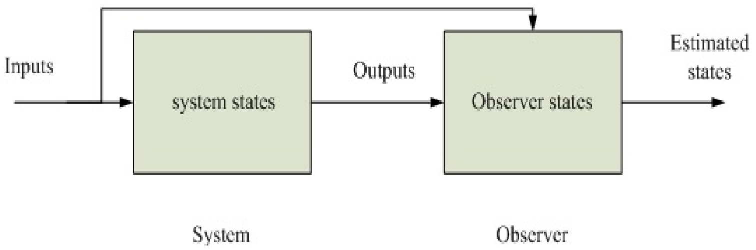

Figure 5.1: Open loop observer

5.1.1 Asymptotic Observers

Let us consider the continuous-time system,

$$\dot{X} = Ax + Bu$$
$$y = Cx \qquad (5.1)$$

Where $x \in R^n, u \in R^p, y \in R^m$ and A,B and C are constant matrices of proper dimensions. These matrices are known. The pair is assumed to be observable and it is also assumed that the matrix has full rank without losing generality. The plant states are unknown; nevertheless the linear combination of the plant states forms the output vector or we can say that the output vector is a linear composition of the states of the plant and is measurable. Hence, it all narrows down to the possibility of designing a new dynamic system, which probably estimates the original state vector by just using the output and the input vectors of the system.

5.2 SLIDING-MODE OBSERVER

We have seen that the state estimation is done asymptotically, the Eigen values related to the error dynamics can be chosen very far away from the jw-axis in the urge to increase the decay rate, however the tendency of a Luenberger observer to converge asymptotically cannot be removed totally. The same system in (5.1) is reconsidered. To at least reconstruct the states asymptotically, with only the input and output vectors of the considered system an observer can be proposed in the following manner,

$$\dot{\hat{x}} = A\hat{x} + Bu + L\,sgn(y - \hat{y}) \qquad (5.10)$$

5.2.2 Average Values of estimated and actual PV array current

In order to avoid errors while tracking MPP of the solar array it had been

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already assumed that the tracking system uses the average current instead its instantaneous value, provided the switching frequency is high. It was also mention earlier in this writing that the current of the PV array oscillates at twice the grid frequency, here 100Hz (2×50) imposed due to the sinusoidal inductor current. It was also assumed in (5.23) that the derivative of the PV array current is equal to zero.As the array current itself contains ripple components, it is obvious that the current error e_i also contains ripple components. In order to eliminate these ripple components the average of current error over the half cycle of the grid frequency is considered. The following deduction leads to the derived legitimacy of the averages of estimated and actual values of the current.

5.2.3 Range of Observer Gain

The stability and magnitude of chattering is governed by the observer gains L_1 and L_2. Although sliding mode observer is known for its robustness against disturbances, it does have a limitation on this property. The sliding-mode based observer is developed by the equations of the system and the switching gains L_A and L_B can be assigned arbitrarily to achieve robustness in presence of disturbances. However, the limitation associated with the observer gains comes in from the qualification that the observer is stable[22]. The range of L_A depends on the maximum value of the PV array current and the quantity of uncertainties. The estimation error of the PV array current is bounded by the product of number of cells connected in parallel and current generated by sunlight $N_p . I_{pv}$ and corresponds to the short circuit current of the PV array. It is already stated in the second chapter that the short circuit current depends on the temperature and insolation level.

The overall controller configuration for the inverter is given below in Figure 5.3. The PLL (Phase lock loop) is used in order to match the phase of the injected current with the grid voltage. The PI controller takes the error of actual voltage of the solar array and the reference voltage generated by the MPPT system.

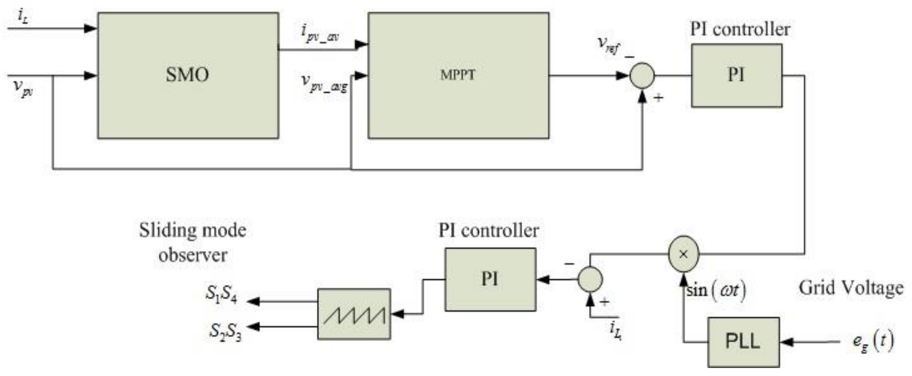

Figure 5.3: Overall Controller configuration

5.3 SIMULATION RESULTS WITH THE SMO

The values of the parameters associated with the SMO and the inverter for performing the simulation are presented in table 5.1.

Table 5.1: Values of parameters for simulation

Capacitor, C_1	1000 µF
Inductor , L_1	5 mH
Observer gain, L_B	0.5
Observer gain, L_A	1000
Grid voltage	25 V_m, 50 Hz
Sampling frequency, f_s	10kHz

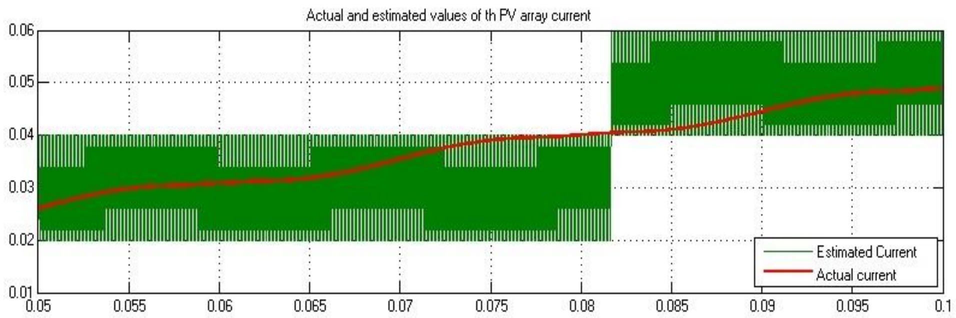

Figure 5.4: Estimated and actual state of PV array current

Fig 5.4 shows the estimated state of solar array current, for a capacitor value of 1000µF and $I_{pv=8.214}$ the value of L comes around 8000 from (5.34). The observer gain

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L_A takes a value of 0.5. It is already been stated in this chapter that the magnitude of chattering depends on the selection of observer gain in order to attain stability though they can be assigned with any random values but still restricted and this restriction is governed by (5.34).In Figure 5.4 we can see that the magnitude of chattering is high but sure is, following the actual current.

VI. CONCLUSION

The current estimation of the PV array current has been done using a sliding mode observer, which was constructed from the dynamics of the grid connected PV system. The average value of the estimated current was fed along with the array voltage to the MPP tracker, which generates a reference signal and was utilized to generate control signals for the inverter. It was also deduced that the average values of the estimated and actual current are equal.

A PV array of suitable ratings along with an H-bride inverter and a filter inductor was connected to the grid for performing simulations. Various waveforms with variations has been obtained to legitimatize the robust nature of the sliding mode observer.The average value of estimated current over half cycle of the grid voltage coincide with the actual value.

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