Reactive Power Compensation and Optimization of Integrated Grid Tied Cascaded Hybrid System

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Abstract-**Cascaded multilevel converter structure can be fascinating for high-power solar photovoltaic (PV) systems due to its interchangeability, extensible, and dispensable maximum power point tracking (MPPT). Though, the power divergence in cascaded unitary PV transmute modules can cause unstable voltage and system operation. This paper highlights the concern, inspects the consequences of reactive power compensation and optimization on system security and power characteristics, and suggests synchronized active and reactive power distribution at the grid to diminish this instability. Also a wind energy system is connected parallel to the PV system to increase the system's reliability. Additionally, an expansive control system with the reactive power compensation algorithm (RPCA) is suggested to acquire intense voltage regulation and competent power distribution.**

Keywords: **Cascaded photovoltaic (PV) system, grid tied, power–voltage distribution, reactive power compensation, hybrid power system, unsymmetrical active power.**

I. INTRODUCTION

Worldwide renewable energy resources, especially solar energy, are growing dramatically in view of energy shortage and environmental concerns. Largescale solar photovoltaic (PV) systems are typically connected to medium voltage distribution grids, where power converters are required to convert solar energy into electricity in such a grid-interactive PV system. To achieve direct medium-voltage grid access without using bulky medium-voltage transformer, cascaded multilevel converters are attracting more and more attraction due to their unique advantages such as enhanced energy harvesting capability implemented by distributed maximum power point tracking (MPPT), improved energy efficiency, lower cost, higher power density, scalability and modularity, Plug-N-power operation, etc.

Motivations are toward addressing the aforementioned issues and approaching to mitigate the negative effect of active power mismatch. MPPT is achieved for each module in these approaches to enhance energy harvesting. However, only unity power factor control was considered and the inherent reactive power compensation capability of the cascaded PV system is ignored. It is recognized that reactive power compensation is able to provide strong voltage support in a wide range. Proper reactive power compensation can significantly improve the system reliability, and in the meantime help the MPPT implementation for the cascaded module under unsymmetrical condition as well as comply with the system voltage requirement simultaneously. All of these have spurred growing interest in reactive power compensation for the cascaded PV system.

Although cascaded multilevel converters have been successfully introduced in medium- to high-voltage applications such as large motor drives, dynamic voltage restorers, reactive power compensations, and flexible ac transformation system devices, their applications in PV systems still face tough

challenges because of solar power variability and the mismatch of maximum power point from each converter module due to manufacturing tolerances, partial shading, dirt, thermal gradients, etc. In a cascaded PV the output voltage from each converter module in one phase leg, which must fulfill grid codes or requirements, synthesizes system the total ac output voltage. Ideally, each converter module delivers the same active power to grid; hence, symmetrical voltage is distributed among these modules. In serious scenario, the synthesized output voltage may not be enough to meet the system requirement.

As a result, the active power mismatch may not only result in losses in energy harvesting but also system instability and unreliability due to the inadequate output voltage or over modulation issues.

II.   LITERATURE SURVEY

Jie Liu et al.[1] presented a vector diagram derived to help illustrate the principle of active and reactive power distribution between each module. Correspondingly, the relationship between power and output voltage for each module is analyzed under different condition. A reactive power compensation algorithm (RPCA), which is inherently suitable for different type of cascaded PV system, is developed to improve system operation performance in view of point of common coupling (PCC) voltage range and MPPT implementation. Accordingly, a control system with the proposed RPCA is designed to achieve dynamic voltage regulation and optimized power distribution. The proposed reactive power compensation method is implemented in the MATLAB/Simulink and PSIM co-simulation platform and a 10kVA grid-interactive laboratory prototype.

Md. Rabiul Islam et al. [3] evaluated that in solid-state semiconductors have led to the development of medium-voltage power converters, which could obviate the need for the step-up transformers of renewable power generation systems. The modular multi- level cascaded converters have been deemed as strong contenders for the development of medium-voltage converters, but the converters require multiple isolated and balanced dc supplies. Here a high-frequency link multilevel-cascaded medium-voltage converter is proposed. It is expected that the proposed new technology will have great potential for future renewable generation systems and smart grid applications. Quan Li and Peter Wolfs evaluated that the annual world photovoltaic (PV) cell/module production is growing at almost an exponential rate and has reached 1727 MW in 2005. Building integrated PV (BIPV) projects are emerging as the strongest part of the PV market and grid interactive inverters are a key component in determining the total system cost.

Liming Liu et al. [4] developed a single-phase photovoltaic (PV) system integrating segmented energy storages (SES) using cascaded multilevel inverter. The system is designed to coordinate power allocation among PV, SES, and utility grid, mitigate the overvoltage at the point of common coupling (PCC), and achieve wide range reactive power compensation. The power allocation principle between PV and SES is described by a vector diagram, a sophisticated power allocation strategy is developed to allocate power between PV and SES based on a novel discrete Fourier transforms (DFT) phase-locked loop (PLL) method.

III.   COMPARATIVE STUDY
1.   Existing Method

A high voltage high power grid connected PV system with cascaded multilevel inverter has advantages as for sectional PV modules individual MPPT, reduced electro-magnetic interference, lower power rating devices utilization, transformer less topology, etc.

2.   Proposed Version

The existing work consists of solar power system. In the proposed version we are going to hybridize the PV energy system with the wind energy system. The system has the advantage of improved reliability. The Perturb and Observe (P&O) MPPT algorithm is applied to each inverter module so that individual tracking/controlling can be achieved.

Fig.1: Architecture of the existing system.On the grid side reactive power is controlled by means of FACTS devices (like: IPFC, UPFC), and controlling algorithms will be applied to them so that the reactive power resulted in the system can match the same at the end terminal.

3. Methodology

The electric system that incorporate solar energy and wind energy is known as hybrid power system, which propounds various advantages over either single system.

Just like the Sun rays, the wind is also available throughout the Earth's surface. The difference in air pressure causes wind to blow. Wind power is regenerative, abundant, thoroughly available and uncontaminated. It doesn't produce any harmful gases, requires no water and can be structured up on a small area.

The wind turbines convert the kinetic energy of the wind into mechanical energy by means of wind turbines. This mechanical energy is converter into electrical energy via generator. The wind turbines may be horizontal or vertical in axis. They can either be fixed speed turbines or variable speed turbines.

The combined wind and solar power system, known as hybrid power system has various benefits as compared to either of the power system working solely. During summer, the wind is low while the Sun is at its brightest glow and in winters, heavy wind blow but the sunlight is low. Thus wind-solar energy system results in all time available electricity.

a. Conversion/ Controller stage:

Among the two sources of power; solar energy gives the DC voltage at the output and Wind energy gives AC voltage at the output. So at the conversion stage Wind energy is converted to DC. This combined output is given to the controller stage which controls the input voltage and gives the constant voltage at output side.

b.   Distribution Stage:

This is the last stage in which the energy is distributed to the houses, industries for the actual use.

This electrical energy can be directly supplied to the grid or stored in the batteries.
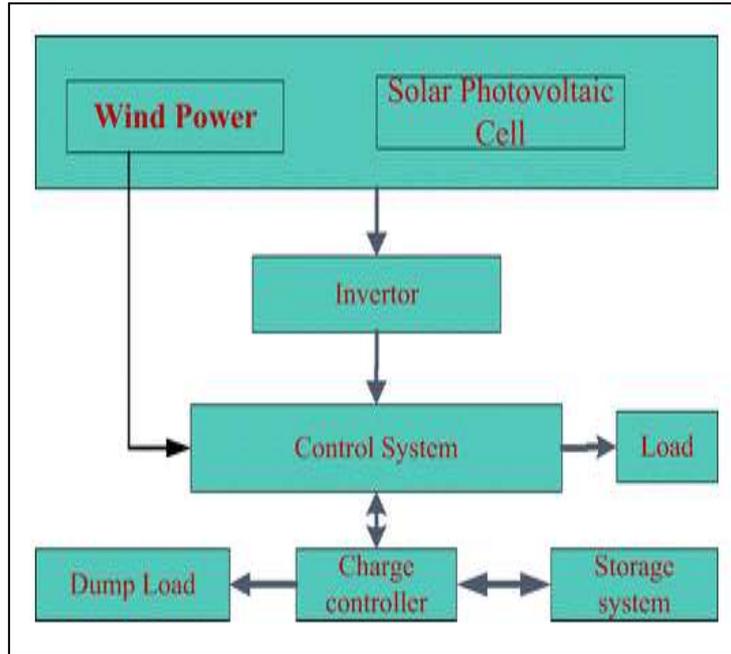

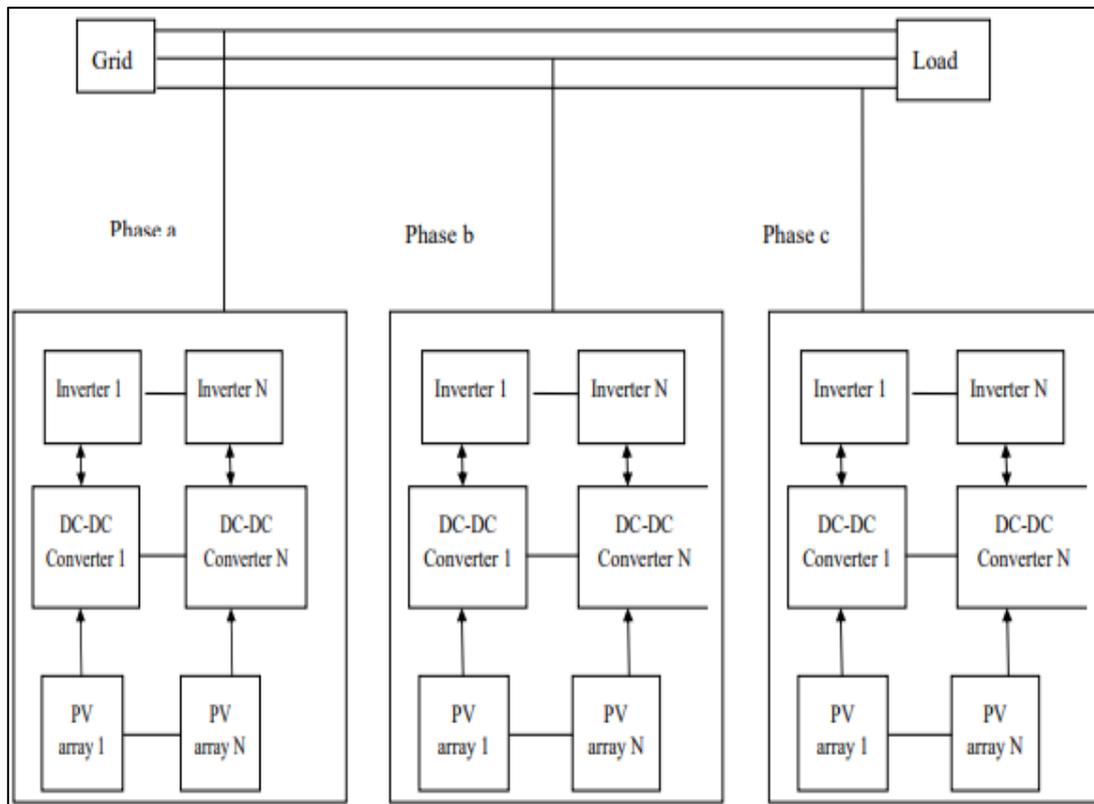**Fig.2: Architecture of PV–wind hybrid system**

Fig.3: Block diagram of Grid-connected PV system with Cascaded PV inverters.

The PV system shown in Fig.3, includes n cascaded multilevel inverter modules for each phase, where each inverter module is connected to one unique dc-dc converter with high voltage insulation. The dc-dc converter is interfaced with individual PV arrays and therefore the independent MPPT can be achieved. Moreover, it is immune to double-line-frequency power ripple propagation into PV arrays. It can also solve the ground leakage current and PV insulation issues. The detailed dc-dc converter design with wide range input range would be presented. Here focused on the active and reactive control of the cascaded multilevel PV inverters. The selected PV application is a 3MW/12kV PV system. The n is selected to be 4 considering the trade off among the cost, lifetime, capacitors and switching devicesselection, switching frequency, and power quality. As a result, power rating of each inverter module is 250kW.

IV. MAXIMUM POWER POINT TRACKING

It is a DC-DC converter that boosts the compatibility between a PV cell and a battery or receiver. It converts the DC voltage of high value from a PV array to a voltage lower in value required at the end terminal. Normally, the conversion of power is never 100% and without MPPT around 35% energy is lost while being stored in a battery. MPPT can upturn this storage process to 15% in winter and 35% in summer. Grid connected systems comprising MPPT have competence of 94% to 97%. Although the payoff lean greatly upon the atmospheric conditions, temperature, battery position, etc.

The Power Point Tracker is a high-frequency DC to DC converter. They take the DC input from the solar panels (or AC from the wind turbines), change it to high-frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the grid voltage. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high-frequency circuits is that they can be designed with very high-efficiency transformers and small components. The design of high-frequency circuits can be very tricky because of the problems with portions of the circuit "broadcasting" just like a radio transmitter causing radio and TV interference. Noise isolation and suppression becomes very important.

There are a few non-digital (that is, linear) MPPT's charge controls around. These are much easier and cheaper to build and design than the digital ones. They do improve efficiency somewhat, but overall the efficiency can vary a lot - and we have seen a few lose their "tracking point" and actually get worse. That can happen occasionally if a cloud passed over the panel - the linear circuit searches for the next best point but then gets too far out on the deep end to find it again when the sun comes out. Thankfully, not many of these around anymore.

The power point tracking technology is employed in power electronics converter to converts the DC input, changes it to AC, by a transformer (usually a toroid) and then convert it back to DC by a rectifier, and fed the output to a regulator. Usually MPPT is an electronic process. Recently microcontroller based MPPT controllers are designed to set the output to battery by observing the battery and the PV cell, by regulating its input to produce required output voltage.

V. PROPOSED WORK

The system stability and reliability issue caused by unsymmetrical active power was specifically analyzed in the paper we have chosen specifically in solar power system. Reactive power compensation and distribution was introduced to mitigate this issue. An optimized RPCA was proposed considering the MPPT implementation, grid voltage and over-modulation. Moreover, the RPAC was eligible to be integrated into different types of cascaded PV system.

While modeling the PV system, following equations are considered:

Cell series resistance (R_s) is connected in series with parallel combination of cell photocurrent (I_{ph}), exponential diode (D), and shunt resistance (R_{sh}).

I_{pv} and V_{pv} are the cells current and voltage respectively.It can be expressed as:

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$$

Where:

I_{ph} - Solar-induced current

I_s - Diode saturation current

q   - Electron charge (1.6e-l9C)

K   - Boltzmann constant (1.38e-23J/K)
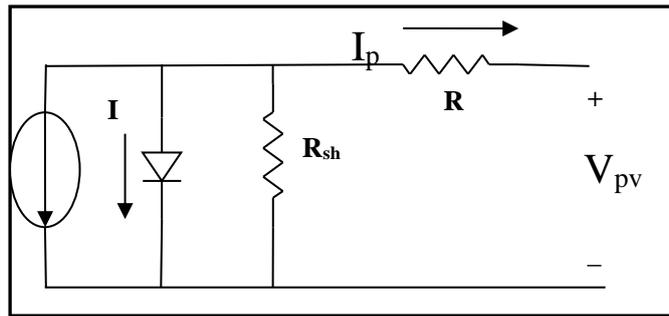
n   - Ideality factor (l~2)

T   - Temperature 0°K

Fig.4: Equivalent Circuit of Solar PV Cell

The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000}$$

Where:

I_{sc} - Short-circuit current of cell at STC

k_i - Cell short-circuit current/temperature coefficient (A/K)

I_r - Irradiance in w/m

T_c - Cell working temperature at STC

T_r - Cell reference temperature at STC

A PV cell has an exponential relationship between current and voltage and the maximum power point (MPP) occur at the knee of the curve as shown in the fig.6
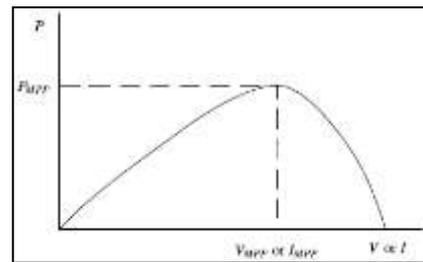
Fig.5: Characteristic PV Array Power Curve ₂

Applied Algorithm: The perturb and observe (P&O) method is employed to track the maximum power point (MPP) by repeatedly increasing or decreasing the output voltage at the MPPT of the Photovoltaic.
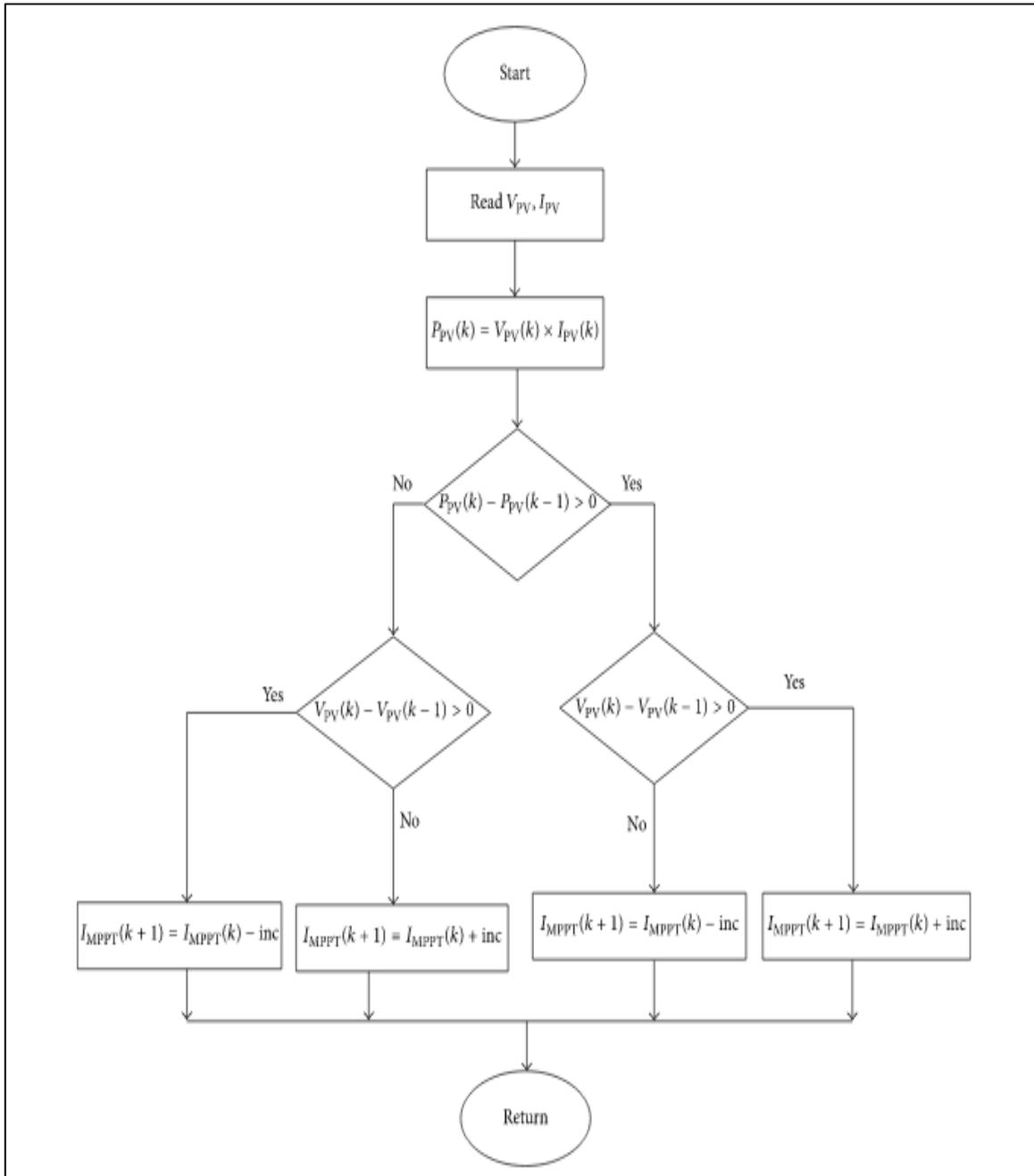
**Fig.6: Flowchart of P&O Algorithm**

The implementation of the method is relatively simple, but it cannot track the MPPT when the irradiance varies quickly with time. In addition, it may cause system oscillation around the peak power points due to the effect of measurement noise. The assumptions for model derivation are that the ideal current source can be presented as the PVs behavior. In addition, all power converters are operated under the continuous conduction mode (CCM) and the harmonics are also ignored. Also the inverter control algorithms can be modified for a better outcome and efficient system response.

RESULT

The system stability and reliability issue caused by unsymmetrical active power was specifically analyzed in the paper. We have particularly chosen solar power system for Reactive power compensation and distribution to reduce problems related to unsymmetrical power distribution. An optimized RPCA is proposed considering the MPPT implementation, grid voltage and over-modulation. Moreover, the RPCA is eligible to be integrated into different types of cascaded PV system. It has resulted in following out comes:
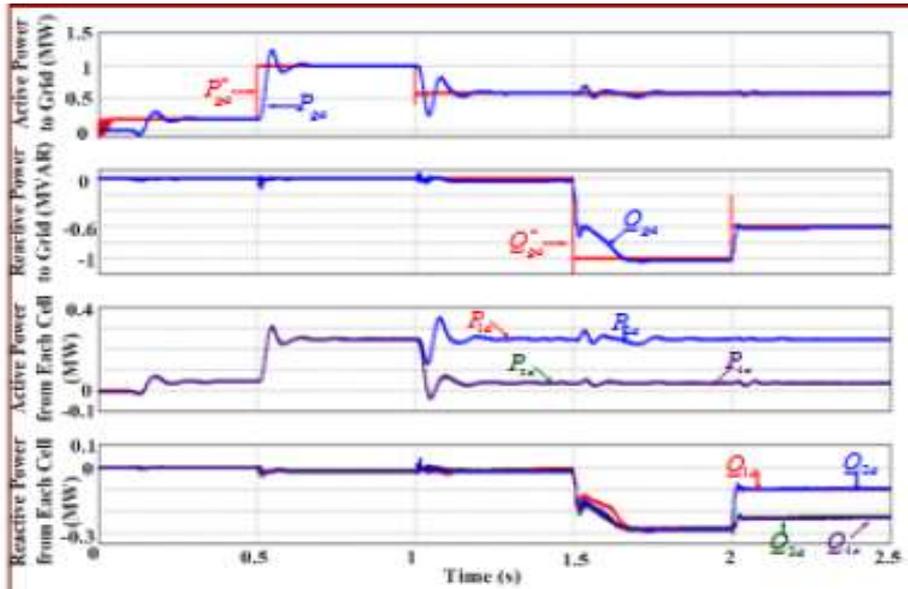
Active and reactive power distribution
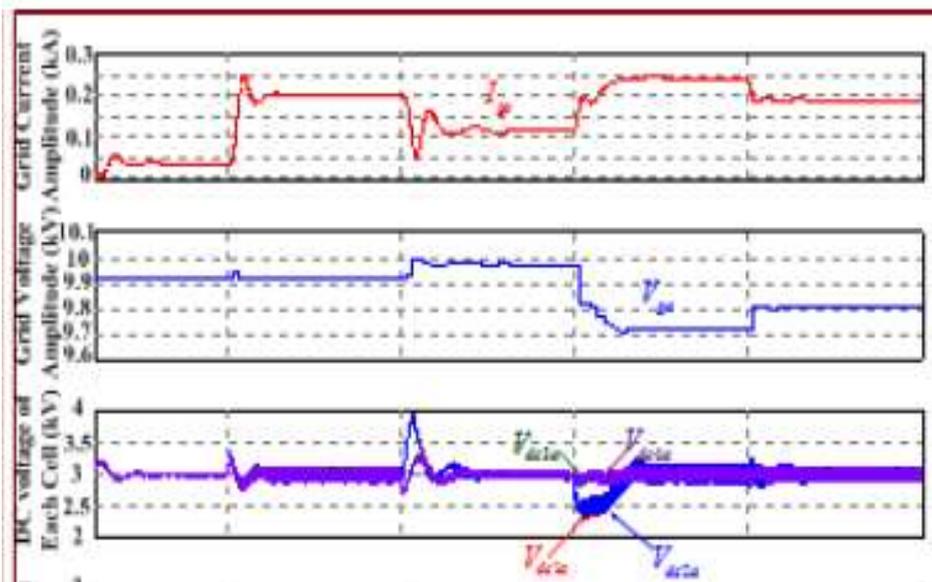
Voltage and current changes

In our work we will be focusing the reactive power compensation on grid side for a hybrid power system. The methodology may include several facts devices like UPFC, SVC etc. with their optimal control algorithms. There are many artificial intelligence based techniques for controlling the devices which can lead to a better outcome. Also the inverter control algorithms can be modified for a better outcome and efficient system response better than the above

CONCLUSION

This paper discussed the effect of reactive power on the grid interactive solar and wind power hybrid system with cascaded inverters. The wind power system is connected in parallel to the PV system to ensure power continuity and the DC-DC boost converter is used to obtain smooth output. The voltage from each PV array is controlled individually by MPPT algorithm. Furthermore, on the grid side, unified power flow controller (UPFC) is used to compensate the reactive power. The effect was analyzed and an optimizing method was suggested to improve the power quality and the system's reliability. The approach to improve the overall system stability and dynamic response is demonstrated.

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