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Fuzzy Based Smart PV Inverter PV-Statcom to Enhancement of Solar Farm Connectivity

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Abstract:

This paper presents a creative shrewd PV inverter control as STATCOM (PV-STATCOM) for preventing the requirement for a physically related STATCOM in a distribution network for controlling predictable state voltage and temporary over voltages (TOVs) happening in light of unsymmetrical issues. Two 10 MW PV close by planet groups are at this point related in the distribution feeder of a utility in Ontario, Canada. A STATCOM knows all about hinder the expected state voltage and TOV issues rising out of the relationship of a third 10 MW PV sunlight based ranch at same bus. It is exhibited from MATLAB that if the proposed PV-STATCOM control is finished on the approaching third 10 MW PV sunlight based ranch, all the above voltage issues are moderated acceptably exactly as expected by the utility Grid Code. This proposed quick inverter PV-STATCOM control therefore gets out the essential for the physical STATCOM, saving a colossal expense for utilities directing voltage rise and TOV issues with grid related PV systems utilizing cushy system. Such a control can really expand the Distributed Generator hosting cutoff of distribution feeders at in excess of a basic degree lower cost under comparative affiliation conditions utilizing cushy. Likewise, this one of a kind grid support worth can open new compensation making open doorways for PV sun powered ranches.

Keywords **— Put your keywords here, keywords are separated by comma.**

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1. INTRODUCTION

Dispersed Generators (DGs) pass a couple of advantages on to distribution affiliations. However, these advantages show up with new challenges. A piece of these challenges combine unsurprising state overvoltage, short lived overvoltage (TOV), unbalanced voltage, power quality issues such as harmonics, steady operation of conventional voltage controllers such as load tap changers and capacitor banks, changes in feeder power factor, and so forth. High penetration of sunlight based ranches is known to cause turn power streams achieving over voltages at PCC which possibly limit any future DG establishments. All around, shunt capacitor banks (SCs), on-load tap changers (OLTC) and step type voltage controllers (SVRs) are used for voltage control in the distribution systems. However, these devices are slow acting with a reaction time going from seconds to few moments. Furthermore, these devices such as OLTC and SVR work based on unidirectional development of power and can't work dependably during bidirectional power streams brought about by Distributed Generators for example sunlight based ranches. Adaptable AC Transmission Systems (FACTS) such as Static Var Compensator (SVC) and STATCOM are involved all around for voltage rule purposes in power systems. These devices can furnish voltage control with a reaction season of 1-3 cycles with STATCOM being much quicker than SVC. The Ontario Independent Electricity

System Operator (IESO) proposed the establishment of a - 33/+48 Mvar Static Var Compensator (SVC) to give the exceptional responsive power fundamental of the 100 MW PV sunlight based ranch at the Grand Renewable Energy Park (GREP) in Haldimand County, Nanticoke, Ontario. A SVC is proposed to hinder ascend in client voltage brought about by interconnection of PV nearby planet groups in a Japanese distribution feeder. Little size STATCOMs are besides proposed in Japan to soothe voltage rise issues because of excess power permeated by PV sunlight based ranches in distribution feeders. Examines up for closing ideal size and area of SVC for further making voltage rule at various working states of private PV planetary groups related in an Egyptian distribution feeder are depicted in.

A D-STATCOM is proposed to further encourage voltage rule because of change of power output from PV planetary groups in an Australian distribution affiliation. Four STATCOMs in the reach 1-2 Mvar have been genuinely introduced in Massachusetts, USA, at different districts to moderate feeder voltage rise and voltage changes in a distribution feeder brought about by changeability of power output from a bunch of 13 MW PV planetary groups.

Through and Dynamic Reactive Current Injection, and so on have been shown in field applications [20-21]. Grid Codes such as IEEE 1547 have been rethought meanwhile. The actually proposed unbelievable inverter limits as portrayed in the updated IEEE 1547 (2018) although give ride through limit yet not Temporary Overvoltage facilitating unequivocally. An uncommon control of PV sun based ranches as STATCOM during nighttime for furnishing different grid support limits with full inverter limit and for conveying equivalent advantages during daytime with PV inverter limit staying after authentic power generation was presented in 2009. The proposed control, named PV-STATCOM, was used for developing the openness of wind ranches and for further encouraging the power bandwidth. The above control however has a requirement of open responsive power limit particularly during the afternoon when the inverter is totally used for guaranteed power generation. The control of PV sun arranged ranches as a shrewd inverter PVSTATCOM was proposed in. The control introduced in this paper gave just unsurprising state voltage control in the grid by three-phase even authentic power generation by PV systems. However, the control system proposed in can't give moderation of Temporary Overvoltage (TOV) during unsymmetrical imperfections which is a basic issue in the integration of PV sun arranged ranches. For suppressing TOV, an altogether exceptional control is required, which is the vital obligation of this paper.

This paper is based on a patent-forthcoming technology for modulation of ensured and open power of PV sun arranged ranches. Execution of this control on a PV sun based ranch permits the sun powered homestead to give a regularly of the week helpfulness as a STATCOM with evaluated inverter limit both during nighttime and any time during the day reliant upon the circumstance by the grid, including full-afternoon. The interest of this paper is that another astonishing inverter PVSTATCOM game-plan is proposed for moderating unsurprising state voltage rise and, surprisingly, more on a very basic level Temporary Overvoltage brought about by high penetration of PV planetary groups. Generally, to decide these issues, dynamic responsive power compensators such as Static Var Compensator (SVC) and STATCOM, have not exclusively been proposed however really introduced in a couple of districts of the planet including Canada and USA. In this paper, the common sense of the PV-STATCOM technology has been shown on a sensible distribution feeder in Ontario where a confirmed STATCOM has been introduced for unsurprising state voltage control. It is shown that the proposed PV-STATCOM can give an equivalent helpfulness of dependable state voltage control furthermore give TOV moderation, thus killing the need of the introduced STATCOM. The PV-STATCOM game-plan is highly costeffective (multiple times cheaper) stood apart from authentic SVCs and STATCOMs as it uses the current electrical substation construction such as buswork, transformers, breakers, security systems, of the PV planetary group (which are very like those in real SVCs and STATCOM establishments). The PV-STATCOM technology can therefore get huge expense adventure resources for utilities that they should not present costly SVCs or STATCOMs. Furthermore, this exceptional grid support handiness can open new compensation making open entrances for PV sun arranged ranches.

This paper presents: a) control thought of the proposed PVSTATCOM, and b) EMTDC/PSCAD diversion of the PVSTATCOM technology on the third 10 MW PV sun powered inverter in [16] for consistent state voltage control. The proposed PVSTATCOM control further gives moderation of brief over voltage (TOV) which isn't viewed as in.

The genuine power generation from a sunlight based ranch on a bright day and the extra unutilized inverter limit more than a 24 hour time span is portrayed in Fig. 1. The working modes of the proposed PV-STATCOM are depicted beneath: I) Full PV mode: The PV sun based ranch works at determination power factor with no responsive power control. ii) Partial STATCOM Mode: quite far excess after extraordinary power creation is used for dynamic responsive power control as STATCOM. ii) Full STATCOM mode: During a power system disrupting effect or shortcoming in the day, when the essential for open power support is high, the sunlight based ranch for a brief time frame outline (for consistently under a second) decreases its confirmed power output to no by fluctuating the voltage across the sunlight based chargers. It further makes its whole inverter limit open for dynamic responsive power control as STATCOM. After the grid support need is satisfied, the sun based ranch gets back to its pre-disrupting influence power output. The Full STATCOM mode can be founded whenever during the day relying upon system need. For instance, this Full STATCOM mode is portrayed by the thin square shape around 8 am in Fig. 1. The width of the square shape is under a second yet is shown throughout a twisted timeframe of an hour, only for ease of understanding. This mode is comparably absolutely accessible during night.

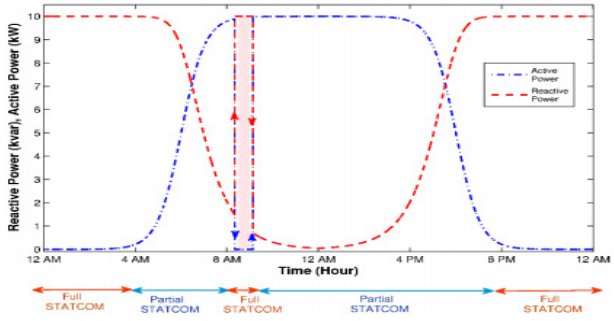

Fig. 1. Concept of smart PV inverter control as STATCOM (PV-STATCOM)

STUDY SYSTEM

Fig. 2 shows a 44 kV feeder in a utility distribution network in Ontario, Canada (name and locale withheld for request reasons) [16]. The overview feeder system coordinates three 10 MW PV systems with a full scale limitation of 30 MW related around 35 km away from the utility transformer station (TS). The 30 MW PV plants are connected with the distribution system through a 30 MVA interface transformer, although each 10 MW PV system utilizes a broadly engaging transformer earlier the affiliation point transformer. Two planetary groups with 10 MW generation are currently associated with the PCC. Relationship of 10 extra MW PV system causes broadened turn power stream during light load conditions achieving solid state over voltages. A 3.5 Mvar STATCOM is familiar at PCC with moderate consistent state overvoltages. The TOV is furthermore seen to beat very far during single line to ground insufficiencies (SLGF) or line to line ground (L-G) shortcoming conditions. As exhibited by an Ontario utility fundamental [29] the TOV brought about by a DG office should be under 1.25 p.u. what's more, in no situation beat 1.30 p.u.

IV. MODELING OF THE STUDY SYSTEM

This part presents the modeling of various bits of the study system in EMTDC/PSCAD programming. The model of the review system is portrayed in Fig. 3. The substation system is tended to as an identical voltage source with 1.05 p.u. voltage to supply the 44 kV feeder. The 35 km line from substation to PCC is tended to by a π model in which the shunt assent (for example line charging) is disregarded. In Fig. 3, Rg and Lg address the line deterrent and inductance, independently. The electrical load is viewed as a constantpower static RL load. At clear voltage of 44 kVL-L, the all out load is viewed as 30 MVA. The rush hour dynamic and open loads are viewed as 27 MW and 6 Mvar, only, whereas during off-top hours, these loads are 6 MW and 1.5 Mvar, freely. Each of the three PV systems are used with 10 MVA two-level six-pulse IGBT-based voltage source inverters (VSI). The switching rehash is chosen to be 4 kHz to limit the switching losses. For each PV system, a LCL filter is used to lessen the harmonics brought about by the switching rehash. The LCL filter includes a series inductor (Lf), shunt capacitor (Cf) with series damping resistor (Rd) and another series inductor (Lt) standing out from the transformer inductance. The mix of shunt capacitor in series in with damping resistor is connected in delta configuration. The filter inductor is chosen between 0.1 to 0.25 pu [30]. How much responsive power generated by the filter capacitor furthermore impacts the open power pay by the VSI. Hence, the filter capacitor respect is supposed to restrict the responsive power exchange beneath 0.05 pu of the inverter power rate. To stay away from reverberation between filter capacitor and inductor, a damping resistor is added to filter capacitor in series [31].

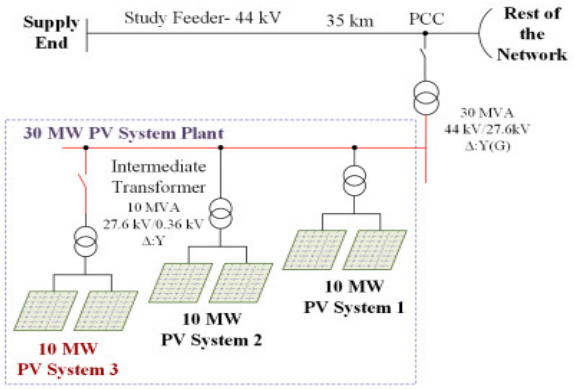

Fig. 2. Single line diagram of the study system

V. CONTROLLER DESIGN This paper suggests that the extra (third) 10 MW PV system be furnished with the proposed patent-forthcoming splendid PV inverter PV-STATCOM control [28]. The other two PV systems use simply conventional controllers to generate authentic power at fortitude power factor. Fig. 3 outlines the schematic of the splendid PV inverter controller. The controller is arranged in d-q frame and consolidates abc/dq change block, PLL, DC controller, current controllers, AC voltage controller, TOV identifier unit and PWM unit. The PLL unit eliminates the phase point of PCC voltage for changing currents and voltages from abc-packaging to dq-edge or the other strategy for getting around [32]. The DC controller, to oversee DC interface voltage at the reference regard, generates the reference current for d-part of inverter current which tends to the powerful current part. In this manner, the current controller in d-hub deals with the unique current part to its reference regard [32]. During daytime, the shrewd PV control functions as a conventional PV system i.e., in Full PV mode. Accepting that reliable state voltage control is normal in all of the three phases, together with authentic power generation, Partial STATCOM mode is established. In FullSTATCOM mode, the MPPT mode is crippled and the certifiable power generation is made zero by making the voltage across PV board identical to its open circuit voltage. The whole inverter limit is then used to hold responsive power to reduce the phase voltage. After the TOV is lightened, power creation from the sunlight based chargers is empowered and control mode is switched to Partial STATCOM mode.

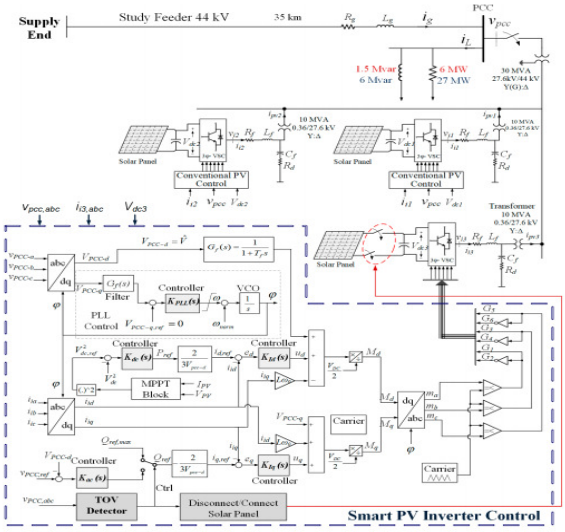

Fig. 3. Modeling of the study system and control components

The PCC voltage is controlled by the AC voltage controller. Therefore, either by and large unbelievable open current or output of the AC voltage controller characterizes the reference worth of responsive current control circle. The current controller in q-hub manages the open current to its reference respect. It is seen that the TOV Detector unit switches between voltage control mode and TOV facilitating mode. Additionally, this unit generates the solicitation to empower or handicap the power creation from PV sunlight based chargers. The outputs of the controller are modulation records in d-q outline, which are in the end changed over absolutely to abc-outline utilizing the phase point of PCC voltage. The modulation records in abcframe are showed up contrastingly according to carrier signal with generate doorway pulses for the VSC switches [30], [32].

A. Operation Mode Selector

Fig. 4 shows the flowchart of the marvelous PV inverter control to choose the operation mode. During daytime, the voltages in three phases are surveyed. Assuming any phase voltage beats very far while the voltages in other phase/phases decline essentially, the output of TOV Detector unit is trigged "ON", and Full STATCOM mode is established. The controller keeps the inverter current release the inverter voltage by 90 degrees (for example continues to adapt open power) to diminish TOV until the phase voltages reach a palatable worth. After the shortcoming is cleared all the phase voltages will move to their standard characteristics. The controller thus sees that TOV is moderated. It therefore empowers power generation from the sunlight based

chargers and switches to Partial STATCOM mode for steadystate voltage control. In fragmentary STATCOM mode, the controller manages the PCC voltage with Qrem, which is beyond what many would consider possible leftover after authentic power generation. During nighttime, the PV nearby planet group works in Full STATCOM mode to control either the consistent state voltage or TOV. The awe inspiring PV inverter control thus independently chooses its operation mode and spotlights on between novel power generation and responsive power exchange based on the system prerequisites, nature of transient/disrupting effect, time and remaining inverter limit.

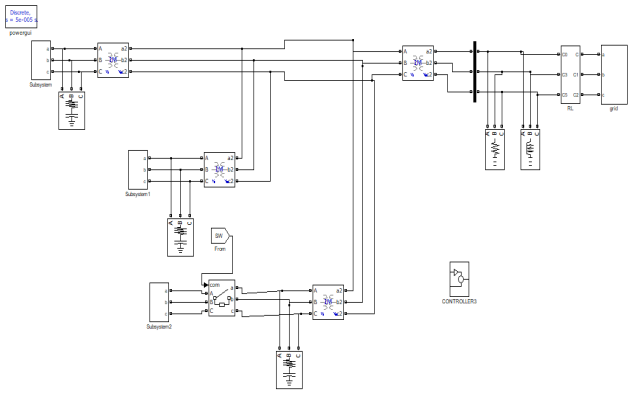

Fig: Proposed Simulation diagram

Reproduction STUDIES

The exhibition of the breathtaking PV inverter PV-STATCOM while satisfying two control targets, voltage control and TOV reduction, are introduced in this part. In this multitude of studies, (almost nothing) load is characterized as 6 MW and 2 Mvar, whereas a heavy (huge) load is viewed as 27 MW and 9 Mvar. The three sun arranged ranches are all viewed as conveying 7 MW each during light load conditions, i.e., a measure of 21 MW power.

A. Conventional PV System without Smart Inverter Control

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Amusement STUDIES

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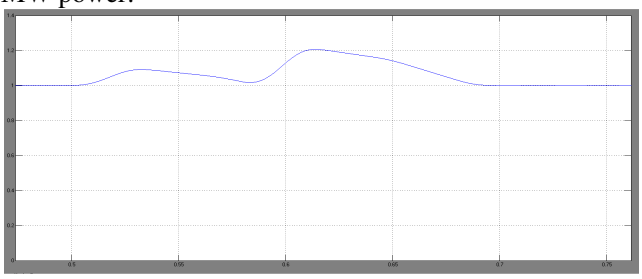

Fig:Pcc Voltage in PU

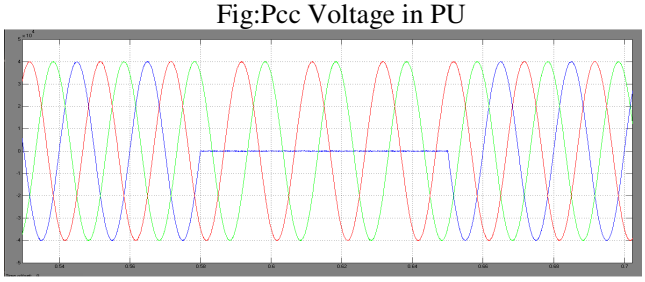

Fig:Pcc Voltage

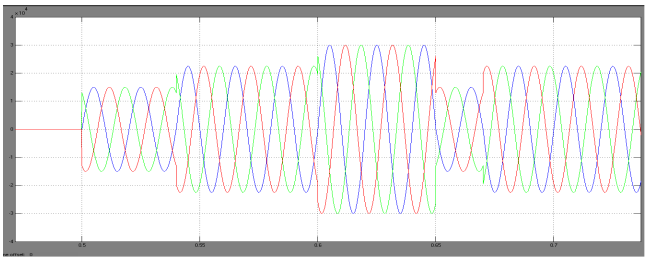

Fig: Smart PV Current

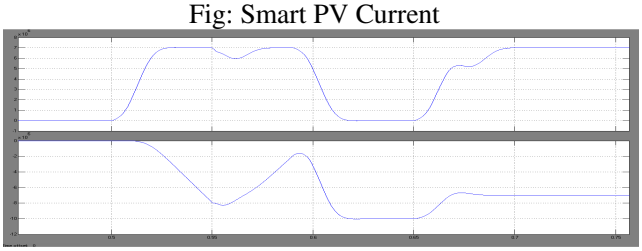

Fig: Active and reactive powers of Smart PV

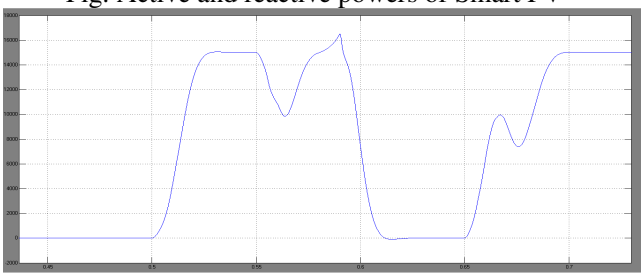

Fig: Active current

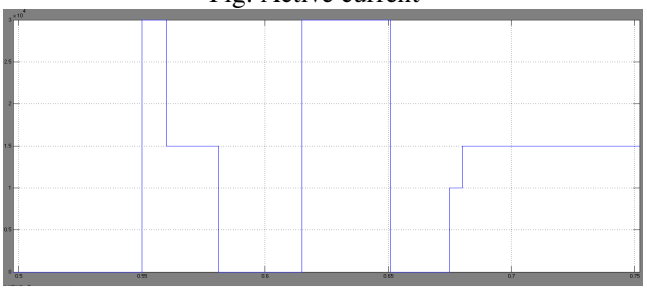

Fig:Reactive Current

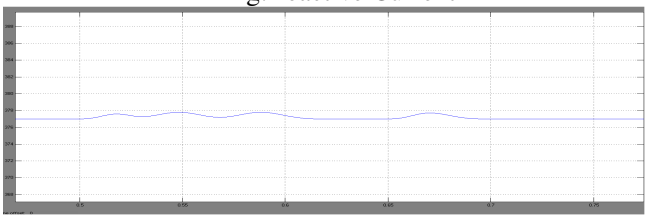

Fig:Anugular Frequency

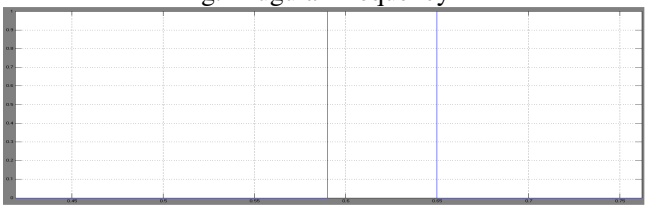

Fig: TOV Flag

Fig. 8. Execution of the third 10 MW PV system as PV-STATCOM, together with two conventional PV systems, during little load and SLG shortcoming a) PCC voltage (pu) b) PCC voltage c) Smart PV current d) Active and responsive powers e) Reactive current f) Active current g) DC partner voltage h) Angular rehash of PCC voltage I) Angle output of PLL j) TOV standard status

mode for voltage control to Full STATCOM mode for TOV reduction. In this current circumstance, the controller changes the DC partner voltage of the inverter to a worth equivalent to the open circuit voltage of the sunlight powered chargers (Fig. 8 (g)). It thusly holds responsive power with full limitation of the inverter to diminish the voltages of phase "B" and phase "C". On separating and Fig. 8 (a), it is revealed that the proposed mind blowing PV inverter control diminishes the PCC voltage from 1.35 pu to 1.23 pu which is beneath not completely gotten comfortable [29]. Fig. 8 (d) approaches that novel power output reaches zero and the whole furthest reaches of the inverter is utilized for responsive power upkeep. t=0.63 sec: SLG shortcoming cleared: the issue is cleared and the controller gets back to Partial STATCOM mode for voltage control while making dynamic power. The PCC voltage is controlled to an OK level (1.03 pu) by utilizing the extra furthest reaches of the inverter.

2) Line to Line to Ground (LLG) Fault

The presentation of the proposed unbelievable inverter controller during a LLG shortcoming is shown in Fig. 9. As in the previous instance of SLG issue, the shrewd PV inverter controls the PCC voltage to its reference respect during consistent state. t=0.58 sec: LLG shortcoming started: the voltages of two phases phase "A" and phase "B" tumble to nothing and a TOV is caused in phase "C" because of LLG issue. The TOV affirmation unit sets off the TOV flag and the controller changes its mode from Partial STATCOM mode for voltage control to Full STATCOM mode for TOV reduction. This savvy inverter control genuinely diminishes the TOV in the healthy phase to a decent worth of 1.22 pu in about a cycle. It is seen that the organized PLL acts in a reliable way both during unsurprising state and during SLG and LLG blemishes.

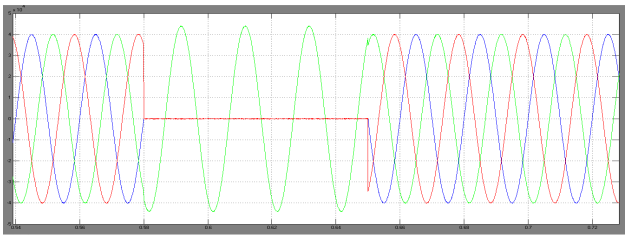

Fig:PCC Voltage

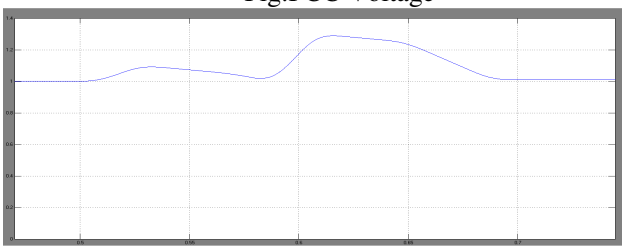

Fig:PCC voltage in PU

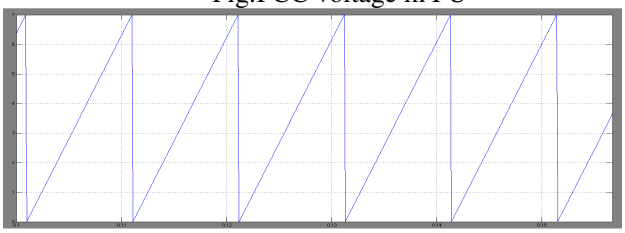

Fig: PLL Angle

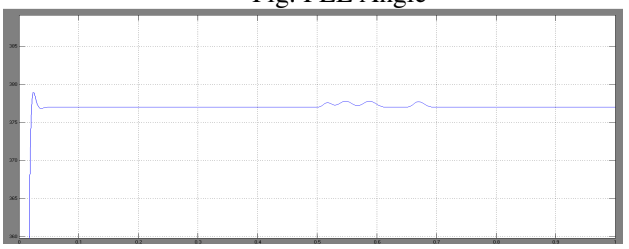

Fig:Angular frequency

Fig. 9. Execution of one PV system with proposed sharp inverter control, together with two conventional PV systems, during little load and LLG shortcoming a) PCC voltage (pu) b) Instantaneous PCC voltage c) Angular rehash of PCC voltage d) Angle output of PLL

This is in light of the way that basically the extra PVSTATCOM control with its associated control and appraisal circuitry, and security should be introduced on the current inverters of the PV sun powered ranch. The whole existing electrical (and common) substation design of the PV sunlight based ranch including the transformers, bus-work, circuit breakers, lines and associations, and so on is used for doing the overall STATCOM. Accepting another SVC or STATCOM should be charged, the full scale substation should be gathered everywhere, and new inverter should be gotten. These expenses are obviously kept away from with PV-STATCOM. This paper considers a single comparative inverter for a whole PV sun powered homestead to show another control thought, whereas a guaranteed sun based ranch might have multiple inverters including plant controls and correspondence delays, and so on. In such a circumstance, some PV inverters being used as PV-STATCOMs might have to sidestep the plant controls and answer quickly to TOVs in the grid. Such controls are being made and will be addressed in a future paper.

Table I. Comparison of different devices for voltage control

Devices / Features	*Conven – tional PV System*	*STATCOM with Voltage Control*	*STATCOM with Voltage and TOV Controls*	***PV-STATCOM with Voltage and TOV Controls***
Capacity	30 MW 0 Mvar	3.5 Mvar	10 Mvar	**10 MW/ 10 Mvar**
TOV Magnitude	1.35 pu	1.43 pu	1.24 pu	**1.22 pu**
Steady State Voltage	1.10 pu	1.02 pu	1.02 pu	**1.02 pu**
Response Time	----	Half Cycle	Half Cycle	**Half Cycle**
External Devices	----	Yes	Yes	**No**
Steady-State Voltage Test	Fail	Pass	Pass	**Pass**
TOV Test	Fail	Fail	Pass	**Pass**
Cost	----	~$5 Millions	~$ 8 Millions	**~$ 0.2 Million**

CONCLUSIONS

This thesis presents an innovative smart PV inverter control as STATCOM, named PV-STATCOM, for controlling the dependable state overvoltage and, surprisingly, more basically, moderation of Temporary Overvoltages (TOV) with delicate system. This keen control in Partial STATCOM mode manages the anticipated state over voltage to the ideal reference respect within one and half cycle. Further, this stunning inverter control in Full STATCOM mode really diminishes the TOV caused during both single line to ground shortcoming and line to line to ground issue to within utility tasteful characteristics within one cycle utilizing cushy. The PV-STATCOM thus gives the full limit of a STATCOM for voltage control on a the whole day premise. For the zeroed in on genuine distribution system the proposed PVSTATCOM control can help coordinate the third 10 MW PV sun powered ranch thereby disposing of the essential for the really introduced STATCOM for a tantamount clarification. The proposed PVSTATCOM control is supposed to be something

like multiple times cheaper than a conventional STATCOM. This control can therefore carry a huge setting something to the side for the concerned utility. Such a control can also help in becoming the hosting furthest reaches of PV sun based ranches on distribution systems which might be bound because of voltage issues. This control might possibly open another compensation making open entrance for the sun powered ranches for giving the STATCOM administration.

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