Large Scale Integration of Renewable Sources with STATCOM for Reactive Power Compensation and Power Quality Improvement

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Abstract__ The force quality is impressively influenced by interconnection of environmentally friendly power sources to the network. During this project STATCOM (Static simultaneous Compensator) framework has been extended as a device for responsive force pay and as Power Quality improvement gadget while associated with Point of Common Coupling (PCC) of Large-Scale Renewable Energy Converters (RECs). Turbine (Doubly Feed Induction Generator-DFIG) and Solar PV converters are reenacted during this project. A hysteresis current control conspires, which has basic and hearty structure, is proposed. Utilizing this strategy STATCOM creates current wave con to the unsettling influence wave and subsequently repays the music delivered by huge scope RECs and functions as Active Power Filter. This presents the breaking point for measure of intensity age from RECs after which uphold from STATCOM become compulsory for additional RECs interconnection thinking about security of lattice. Reproduction controlled in MATLAB/Simulink approves the viability of the proposed methodology.

Keywords— Point of Common Coupling (PCC), Static Compensator (STATCOM), Hybrid Power System (HPS), Wind Energy Source (WES), Phase Lock Loop (PLL).

I. INTRODUCTION

Due to the environmental concerns, renewable energy sources such as wind or solar generation have gained the popularity in the recent years. Only the last decade alone, the total global installed capacity of wind energy, comprising of onshore and offshore wind, has increased by a factor of seven [1]. The fact that this high proportion of wind energy within the conventional generation mix challenges the network operator(s). One of the major challenges is that the wind farms are generally built in remote areas (i.e. offshore) and therefore, they are connected to weaker parts of the transmission system with relatively low short circuit level and short circuit ratio being less than 20 [2]. This makes the voltage magnitude at the point of common coupling (PCC) and at neighbouring points varies significantly with the change of active power injection from the wind farm since nature of wind speed to intermittent. This intermittency in the combination with the limited strength of the local network, moreover, can cause frequency instability and degrade power quality [3]. In various studies, it is observed that transient and steady-state stability can be improved by regulating the voltage at PCC of wind farms to the network [4]. The voltage at transmission and subtransmission level can be regulated by controlling reactive power transfer due to the high X/R ratio (i.e. mainly inductive) [5]. Since Flexible AC Transmission systems (FACTS) devices such as such as Static Var Compensator (SVC) or Static Synchronous Compensator (STATCOM) are capable of dynamic reactive power support, these devices can be used for maintaining the voltage at PCC within the required limits [6]. On the other hand, the most common types of wind generation technologies are based on induction generators. These generators lack the reactive power regulation capability (i.e. type A and type B wind turbines) or have limited reactive power generation (i.e. type C and type D wind turbines) by scarifying active power generation [7]. To fulfil the reactive power regulation functionality, these wind farms require a massive amount of reactive power compensation from a controllable capacitor at the point of common coupling, a nearby SVC or STATCOM [8]. Furthermore, type A and type B wind turbines require reactive power to operate (usually compensated through large capacitor banks) whereas this is not the case for type C and type D wind turbines [9]. Thanks to the cost-effective manner and the flexibility in operation and control, the partly-rated type C wind turbines using doubly-fed induction generators (DFIG) have become more common compared to full-rated type D turbine; however, the previous kind of turbine represents a restricted capacity of shortcoming ride through in basic conditions and the obliges of rotor appraisals in ordinary tasks [8]. Under any conditions, the Flexible AC Transmission system (FACTS) gadgets, particularly SVC and STATCOM, actually have a vital impact in the entire breeze ranch arrangement and they are impossible supplanted in the decade to come. In this manner, FACTS gadgets are equipped for further developing voltage also, recurrence security in the framework through responsive force control. The nearby measure of responsive force given by FACTS additionally diminishes the responsive force streams from up-stream and henceforth keeps the taking care of conductors from over-burdening. In any case, the cost of such FACTS gadgets is as yet a significant concern. In correlation with other receptive pay frameworks, for example, shunt capacitor, STATCOM is around multiple times more costly [10]. Since the speculation for a committed FACTS gadget is critical inside a breeze ranch project, this paper investigates the probability of using the close by sun oriented ranch DC

connection and inverter to fill in as a STATCOM. Possessing to the similitude of parts plan, exchanging gadgets setup and regulators among STATCOM and inverter-based sun oriented homestead [11], the activity standards of an inverter and STATCOM are cautiously thought of and altogether investigated in this work. The plausibility also, smooth transient of these modes are then mathematically checked utilizing DigSILENT/Power Factory stage.
The rest of this paper is arranged as follows: Section 2 describes the operationprinciple of an inverter and a STATCOM followed by validation of created models in Section 3 and conclusions are drawn in Section 4.

II. OPERATIONAL PRINCIPLES OF INVERTER AND STATCOM AND THEIR SIMILARITIES

the activity standards of a sun oriented inverter and a

In this section, STATCOM are explored to decide the similitudes between the two and to investigate the plausibility to use the sun powered inverter as a STATCOM. The as a matter of first importance similitude of these two gear is the force gadgets based voltage source converter (VSC) and its control procedures for various activity modes.

2.1 VSC control strategy

the activity standards of a sun oriented inverter and a STATCOM are researched to decide the likenesses between the two and to dissect the possibility to use the sun based inverter as a STATCOM. The above all else similitude of these two hardware is the force gadgets based voltage source converter (VSC) and its control systems for various activity modes.

Regarding PCC voltage. While in the last mode, the dynamic what's more, responsive force are constrained by controlling VSC line current, stage and greatness, comparative with PCC voltage. Current-mode control is better than the voltage-mode control because of the way that current is firmly directed in the previous one and hence, the VSC can be secured against over-current flood and abrupt variety in framework boundaries [12]. Consequently, the current-mode control is considered in this paper. A common lattice associated two-level VSC with the DC interface capacitor is displayed in Fig. 1 and considering current course from the converter terminal to the network, the framework condition becomes:

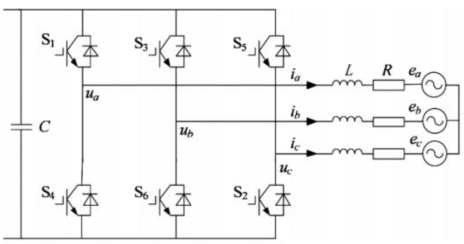

Fig. 1 *Grid connected VSC layout*

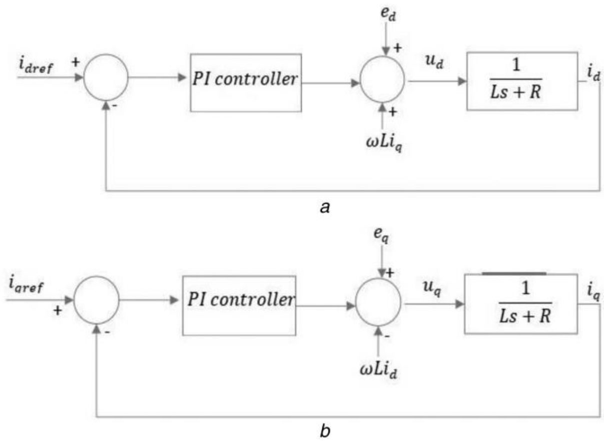

Fig. 2 *Inner-loop controllers*
(a) d-axis current, and *(b)* q-axis current

$$\mathbf{U} = R\mathbf{I} + L\frac{\mathrm{d}\mathbf{I}}{\mathrm{d}t} + \mathbf{E} \quad (1)$$

Where U and E are VSC terminal and framework voltage separately, I indicates the line current, and R and L are comparable inductance what's more, obstruction seen from Bus 38. The regulators for current-mode control can be planned in abc, αβ or dq-outlines [13]. Contrasted with abc-outline, controlled boundaries are diminished to three-two in αβ or dq-outlines thinking about the equilibrium framework. Moreover, every one of the signs (for example criticism, feedforward, control and so on) are sinusoidal in αβ-outline while these amounts are DC in dq-outline. In this manner, zerosteady state mistake can promptly be accomplished with a straightforward PI regulator in dq-outline making regulator plan and tuning very basic as control signals are DC in amounts [12]. In mechanical applications, along these lines, PI regulators have gotten the most mainstream for converter control because of their activity dependability and sending straightforwardness. The normal strategy for this control approach is the transformation of three stage voltages and flows in the time space into invariant signs in simultaneous dq reference outline utilizing the joined Clarke and Park changes. The changes are communicated as in (2) and if the framework isadjusted, then, at that point the Io term would vanish. Along these lines, the three-stage amounts in (1) can be addressed as (3) in dq-outline. The definite deduction can be found in [14]. Also, the dynamic and receptive power at the PCC are as in (4) and it is obvious that, they can't be controlled freely. It is qualified to note in these changes, the stage point (θ) is a vital factor and it is gotten from a high precision Phase locked circle (PLL) segment also, in consistent express the space-vector is lined up with d-hub making
eq =0 [12]. This improves (4) to (5), and dynamic and responsive force
can be controlled autonomously by controlling id what's more, intelligence level
individually.

$$\begin{bmatrix} I_d \\ I_q \\ I_e \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2)$$

$$u_d = Ri_d + L\frac{di_d}{dt} - \omega L i_q + e_d$$
$$u_q = Ri_q + L\frac{di_q}{dt} + \omega L i_d + e_q \quad (3)$$

$$P = \frac{3}{2}(e_d i_d + e_q i_q)$$
$$Q = \frac{3}{2}(-e_d i_q + e_q i_d) \quad (4)$$

$$P = \frac{3}{2}e_d i_d$$
$$Q = -\frac{3}{2}e_d i_d \quad (5)$$

Where ud also, uq are VSC terminal, ed also, eq are framework voltage, id
also, level of intelligence are line current in d and q-hub separately, P and Q are dynamic and receptive force from VSC to the framework.

2.2 Controllers for PV inverter

As can be seen from (5), receptive and dynamic forces are totally decayed in various tomahawks, in which id is accountable for controlling dynamic force while level of intelligence is responsible for controlling receptive force. Since the organization voltage is generally powerful in the transmission organization, ed also, eq can be considered as steady. The control targets are presently to track down the reasonable yield voltages, ud and uq in (3) to effectively direct id furthermore, level of intelligence in d and q-pivot separately and ultimately the dynamic and receptive forces of PV inverter to wanted qualities. Since these signs are DC amounts in consistent state, PI regulators are utilized to control id also, level of intelligenceby following the d and q tomahawks current reference esteems for example idref and iqref. Moreover, to decouple the elements of id also, level of intelligence because of ωL term in (3), decoupling feed-forward terms are utilized. These establish the inward current circle of the PV inverter control framework as displayed in block graphs in Fig. 2. Thusly, these activities require an external circle to give the reference esteems to the internal circle. In the event that reference upsides of dynamic and receptive force are given, then, at that point current reference esteems can be discovered utilizing (4). This is plausible when the DC terminal is associated to a consistent DC voltage source. In any case, in PV application DC side voltage is anything but a consistent DC voltage source, rather the DC terminal is associated with PV modules and convey capacity to the AC lattice. Along these lines, the DC transport voltage should be managed [12]. The thought is the point at which the delivered power is more (or not exactly) moved power, the voltage at the DC transport increments (or diminishes). Consequently, by controlling DC transport voltage, moved dynamic force is directed what's more, this gives the d-pivot current reference esteem, idref. The DC transport voltage can again be followed to its reference esteem utilizing a basic PI regulator. In PV inverter activity, it is a typical practice that current is infused to the network with solidarity power factor (for example Qref = iqref = 0). Then again, if the PV framework is needed to infuse sure about of receptive capacity to the framework, iqref can be discovered utilizing (5). On the off chance that the PV inverter, in any case, is needed to imitate the customary nuclear energy generators with voltage control

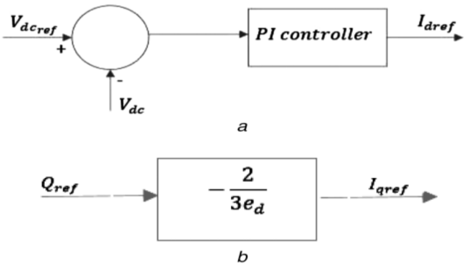

Fig. 3 *Outer-loop controllers for PV inverter*
(a) DC voltage, and *(b)* Reactive power

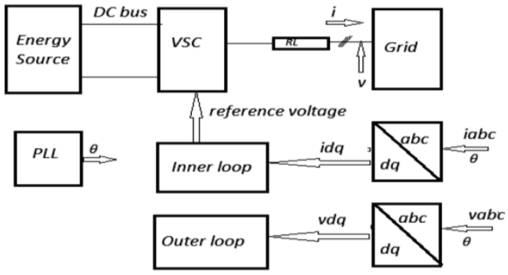

Fig. 4 *Overall PV inverter control scheme*

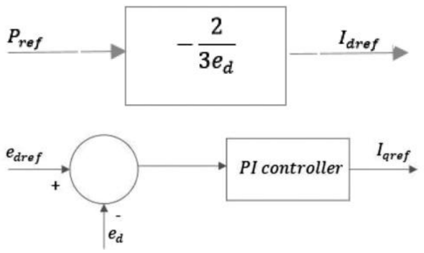

Fig. 5 Outer-loop controllers for STATCOM
(a) active power, and **(b)** voltage at PCC

Controllers' parameters

- equivalent system parameters L = 500μH; τi = 0.5 ms
- inner-control loop parameterskp = 1;
  ki = 2
- outer-control loop parameters kp = 5;
  ki = 500

controlled. As clarified before AC voltage can be constrained by directing receptive force move in transmission and sub transmission framework. In this manner following the voltage at PCC would give q-hub current reference, iqref and is clarified in subtleties in Segment 2.3. The square graph of inverter external circle is displayed in Fig. 3 considering PV inverter is creating a predefined receptive power. Along these lines, the PV inverter control framework has two control circles: external voltage and inward current control circle. Controlled boundaries for example, DC transport voltage and predefine receptive force are contributions to the external control circle. The yields of the external circle regulators are taken care of into internal current circle regulators to make reference voltage to the exchanging adjustment unit. An outline of the inverter control framework in entire is displayed in Fig. 4.

2.3 Controllers for STATCOM

IEEE characterizes STATCOM as a static compensator associated in equal whose yield current can be controlled freely of the AC voltage at the PCC [3]. STATCOM is a VSC based frameworkwhose primary target is to trade responsive force at PCC [15].

VSC framework in Fig. 1 can likewise be utilized as STATCOM. In contrast to PV inverter framework where the DC transport is controlled to move dynamic capacity to the matrix, it is utilized primarily for moving responsive force among VSC and the matrix. At the point when the PLL is in consistent state, eq = 0 and in this manner, making ed = Vac, pinnacle of the AC stage voltage. This worth can measure up to the reference stage voltage esteem edref utilizing a PI regulator and the yield would give the q-pivot current reference. Moreover, generally there is no fuel source at the DC terminal of STATCOM furthermore, in this manner, Pref = idref = 0. Practically speaking, a modest quantity of dynamic force is attracted from the framework to keep the DC transport voltage steady and all things considered this worth can be given as Pref and idref is found utilizing (5) (however with a negative sign as the force would move from the network to the DC transport).

2.4 Tuning the controllers

The PI controllers in the inner current-loop are tuned according to [12]. From Fig. 2, the open loop gain is:

$$G_o(s) = \left(\frac{k_p}{Ls}\right)\frac{s + k_i/k_p}{s + R/L} \qquad (6)$$

The zero proportion (R/L) is moderately little and the post (s = −R/L) is near the beginning. Subsequently, the zero (s = −ki/kp) is picked with the end goal that the circle acquire doesn't fall excessively fast at a low recurrence. The open circle acquire becomes as in (7) and the shut circle move work is an in (8) if

kp = L/τi

what's more, ki = R/τi

This τi

is a plan decision and is generally picked between 0.5–5 ms. External circle regulators are tuned with experimentation measure until good outcomes are accomplished.

$$G_o(s) = \left(\frac{k_p}{Ls}\right) \qquad (7)$$

$$G_c(s) = \frac{1}{\tau_i s + 1} \qquad (8)$$

III. CASE STUDY

To show the viability of the proposed approach in this work, the IEEE 39 transport New England framework is received as a benchmarking contextual analysis as it is a notable framework in thewriting. Also, the framework addresses the electric high voltage (EHV) transmission framework (345 kV) with a high voltage (HV) sub-transmission (138 kV) framework. The framework has adaptable age blend, for example, hydro, coal, atomic and so on with a automatic voltage controller (AVR) and lead representatives introduced, separately, for voltage and recurrence guideline. Subsequently, this framework is an ideal possibility to distinguish the effect of huge scope wind power into the electrical lattice. The breeze and sun oriented homestead are introduced at transport 38 as a enormous thermal energy station was at first associated with that transport. Besides, this transport is an optimal contender for voltage security examination since it is associated with the remainder of the organization by a transformer through a twofold line circuit. The breeze ranch is reproduced by a nonexclusive static generator while a definite model of the sun powered ranch is utilized. The introduced limit of the breeze ranch is 1500 MW furthermore, the sun oriented ranch is 250 MW (top).

3.1 Solar farm modelling

As the PV module can be modelled as a current source [16], an Identical current source is utilized to imitate the PV modules associated at the DC transport. The inverter is reenacted by PWM converter (.ElmVSC) with a rating of 300 MVA. The inside current regulators of PWM converter are utilized as inward control circle regulators while the external voltage control circle is displayed in DIgSILENT Simulation Language (DSL). The boundaries for regulators are given in Table 1 where comparable L is found byfiguring short out power at transport 38 and the same

obstruction is thought to be 1mω. The DC transport voltage of the inverter terminal is chosen to be 1.5 kV because of the more extensive transport reach and benefits like low copper and switchgear costs, high energy extraction in high and low temperature as clarified in [17]. The AC transport voltage is chosen as common 0.4 kV and a move forward transformer is utilized to interface it to the MV transport of 16.5 kV (transport 38). The in general sun oriented homestead framework associated at transport 38 as in Fig. 6.

3.2 PV-STATCOM modelling

During the STATCOM activity, PV modules are detached from the DC transport and an enormous DC capacitor is associated at the DC transport [11]. This DC capacitor is utilized to keep the DC transport voltage steady. A similar PWM converter alongside its regulators with a similar transfer speed is utilized. The DC and AC terminal of the converter has a similar worth as in the sunlight based ranch model. The stepup transformer is utilized as the coupling transformer for the STATCOM. The framework is portrayed in Fig. 7.

3.3 Simulation results with solar and wind farm

During the STATCOM activity, PV modules are detached from the DC transport and an enormous DC capacitor is associated at the DC transport [11]. This DC capacitor is utilized to keep the DC transport voltage steady. A similar PWM converter alongside its regulators with a similar transfer speed is utilized. The DC and AC terminal of the converter has a similar worth as in the sunlight based ranch model. The stepup transformer is utilized as the coupling transformer for the STATCOM. The framework is portrayed in Fig. 7.

3.4 Simulation results with wind farm and PV STATCOM

Now, the PV-STATCOM is utilized to control the voltage at the PCC of the breeze ranch. Fig. 11 shows the correlation of the voltage at the PCC while the breeze ranch is working alone without any STATCOM (dark bars) and with STATCOM (sangria red). It is seen that when the infused dynamic force surpasses 1100 MW, the voltage at the PCC plunges past as far as possible without the STATCOM (for example recreation doesn't meet) while the voltage is inside acknowledged breaking point with STATCOM. Indeed, even with the same dynamic force infusion, the PCC voltage would differ without STATCOM as found in Fig. 11. With a similar dynamic force (1050 MW), the transport voltage differs somewhere in the range of 1pu and 9pu. This is expected to the way that the voltage at PCC differ essentially with the infused
dynamic force contingent upon the strength and framework working state of the lattice by then of the organization as portrayed previously while the variety is a lot more modest with STATCOM.

4 Simulation Results

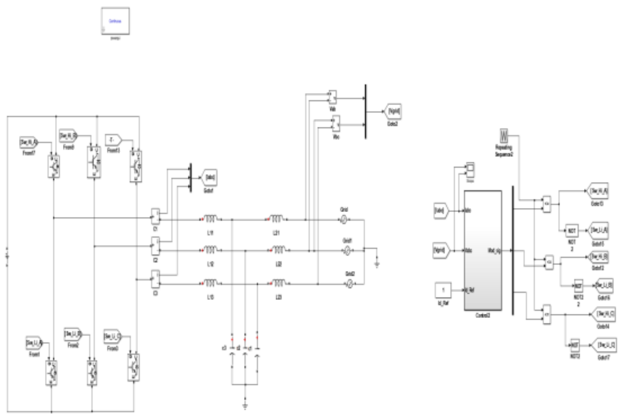

Fig 6: Simulink of VSC into a Grid

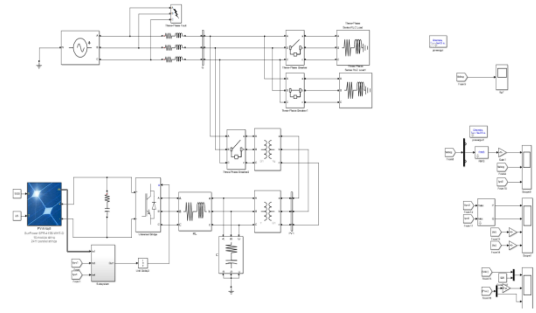

Fig 7 SIMULINK DESIGN OF PV-STATCOM

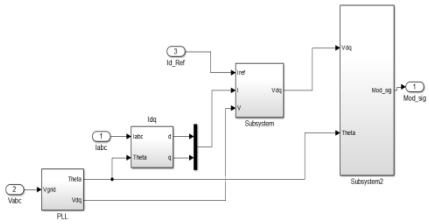

Fig 8: Control Design of Grid Connected VSC

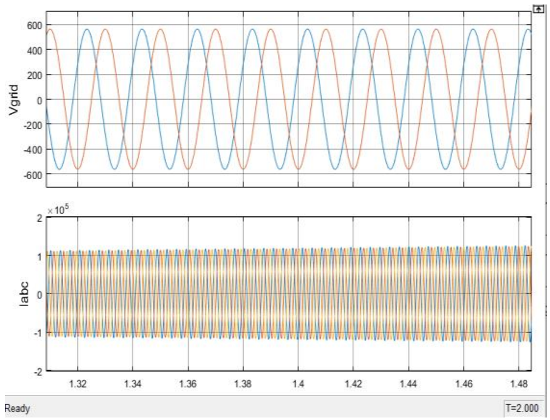

Fig 4.3) i)VGrid ii) Iabc

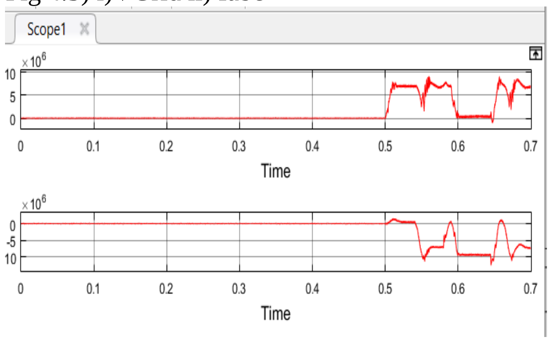

Fig 10: Active Power and Reactive Power

IV. CONCLUSION

Reconciliation of huge scope wind ranches into the lattice achieves new difficulties for the activity of intensity frameworks. it's discovered that the heft of these difficulties are regularly illuminated by limiting the voltage at the PCC change radically with the difference in dynamic force age by the breeze ranches. this is frequently regularly for the most part through with the assistance of FACTS gadgets like SVC or STATCOM. Since both PV inverter and STATCOM are VSC-based framework, and have comparable control technique, associated PV inverter at PCC assists with residual the voltage inside acknowledged cutoff points. this might be accomplished even there is no dynamic force age from PV framework for example around evening time. this is frequently prepared to lessen the value identified with devoted FACTS gadgets for wind ranch network joining and furthermore increment the convenience of PV inverter.

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