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# AC Phase-Shift Control and Traditional Interleaving PWM Control to Design Two-Phase Interleaved Boost Converter



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***Abstract:***

***The proposed inverter is placed betweenthe wind turbine and the grid, same as a regular WEI, and isable to regulate active and reactive power transferred to the grid.The goal of this paper is to introduce newways to increase the penetration of renewable energy systemsinto the distribution systems. This will encourage the utilities andcustomers to act not only as a consumer, but also as a supplier ofenergy. Moreover, using the new types of converters with FACTScapabilities will significantly reduce the total cost of the renewableenergy application.The proposed control strategy regulates the activeand reactive power using power angle and modulation index,respectively. The function of the proposed inverter is to transferactive power to the grid as well as keeping the PF of the localpower lines constant at a target PF regardless of the incomingactive power from the wind turbine. The simulations for an11-level inverter have been done in MATLAB/Simulink.***

## INTRODUCTION

The power electronicdevices are usually used to convert the nonconventionalforms of energy to the suitable energy for power grids,in terms of voltage and frequency. In permanent magnet(PM) wind applications, a back-to-back converter is normallyutilized to connect the generator to the grid. A rectifierequipped with a maximum power point tracker (MPPT),converts the output power of the wind turbine to a dc power.The dc power is then converted to the desired ac powerfor power lines using an inverter and a transformer.

Thereare a lot of single-phase lines in the United States, whichpower small farms or remote houses [1], [2]. Such customershave the potential to produce their required energy using asmall-to-medium-size wind turbine. Increasing the number ofsmall-to-medium wind turbines will make several troublesfor local utilities such as harmonics or power factor (PF)issues.It is often desirable to adjust the PF of a system to near1.0. When reactive elements supply or absorb reactive powernear the load, the apparent power is reduced. In other words,the current drawn by the load is reduced, which decreases thepower losses. Therefore, the voltage regulation is improvedif the reactive power compensation is performed near largeloads.

The D-STATCOMs are normallyplaced in parallel with the distributed generation systems aswell as the power systems to operate as a source or sink ofreactive power to increase the power quality issues of thepower lines. Using regular STATCOMs for small-to-mediumsizesingle-phase wind applications does not make economicsense and increase the cost of the system significantly. This iswhere the idea of using smarter

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WEIs with FACTS capabilitiesshows itself as a new idea to meet the targets of beingcost-effective as well as compatible with IEEE standards.The proposed inverter in this paper is equipped with aD-STATCOM option to regulate the reactive power of the localdistribution lines and can be placed between the wind turbineand the grid, same as a regular WEI without any additionalcost. The function of the proposed inverter is not only toconvert dc power coming from dc link to a suitable ac powerfor the main grid, but also to fix the PF of the local grid at atarget PF by injecting enough reactive power to the grid. In theproposed control strategy, the concepts of the inverter and theD-STATCOM have been combined to make a new inverter,which possesses FACTS capability with no additional cost.

The proposed control strategy allows the inverter to act as aninverter with D-STATCOM option when there is enough windto produce active power, and to act as a D-STATCOM whenthere is no wind.The authorscalled their proposed system PV-STATCOM. Similar to windfarms (when there is no wind), solar farms are idle duringnights. We proposed a control strategy that makes the solarfarms to act as STATCOMs during night when they arenot able to produce active power. The main purpose of thePV-STATCOM system is to improve the voltage control andthe PF correction on three-phase transmission systems.

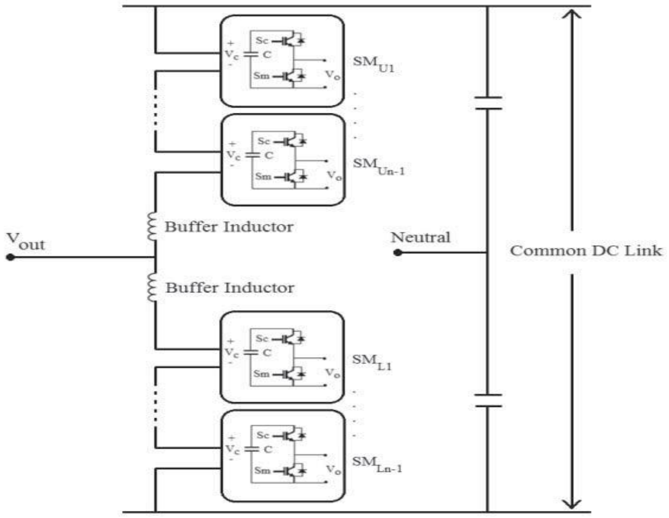

Fig 1: Structure of a single-phase MMC inverter structure

## MMC TOPOLOGY

MMC has gained increasing attention recently. A number ofpapers were published on the structure, control, and applicationof this topology, but none has suggested the useof that for inverter + D-STATCOM application. This topologyconsists of several half-bridge (HB) submodules (SMs) pereach phase, which are connected in series. An n-level single-phaseMMC consists of a series connection of 2(n−1)basic SMs and two buffer inductors. Each SM possessestwo semiconductor switches, which operate in complementarymode, and one capacitor. The exclusive structure of MMCbecomes it an ideal candidate for medium-to-high-voltageapplications such as wind energy applications. Moreover, thistopology needs only one dc source, which is a key point forwind applications. MMC requires large capacitors which mayincrease the cost of the systems; however, this problem is offsetby the lack of need for any snubber circuit.

The output voltage of each SM (vo) is either equal to itscapacitor voltage (vc) or zero, depending on the switchingstates. The buffer inductors must provide current control ineach phase arm and limit the fault currents. To describe theoperation of MMC, each SM can be considered as a two-poleswitch. If Sui, which is defined as the status of theith sub-module in the upper arm, is equal to unity, then theoutput of the ith SM is equal to the corresponding capacitorvoltage; otherwise it is zero. Likewise, if Sli which is definedas the status of the ith submodule in the lower arm, isequal to unity, then the output of the ith lower SM is equalto the corresponding capacitor voltage; otherwise it is zero.Generally, when Sui or Sli is equal to unity, the ith upper orlower SM is ON; otherwise it is OFF. Therefore, the upper andlower arm voltages of the MMC are as follows:

$$v_{\mathrm{upperArm}} = \sum_{i=1}^{n-1} (S_{\mathrm{ui}} v_{\mathrm{ci}}) + v_{11}$$

$$v_{\mathrm{lowerArm}} = \sum_{i=1}^{n-1} (S_{\mathrm{li}} v_{\mathrm{ci}}) + v_{12}$$

The dc and ac voltages of the 11-levelMMC are described by

$$v_{\mathrm{DC}} = v_{\mathrm{upperArm}} + v_{\mathrm{lowerArm}}$$
$$= \sum_{i=1}^{10} (S_{\mathrm{ui}} v_{\mathrm{ci}}) + \sum_{i=1}^{10} (S_{\mathrm{ui}} v_{\mathrm{ci}}) + (v_{11} + v_{12})$$
$$v_{\mathrm{out}} = \frac{v_{\mathrm{DC}}}{2} - v_{\mathrm{upperArm}} = -\frac{v_{\mathrm{DC}}}{2} + v_{\mathrm{lowerArm}}.$$

## CONTROL STRATEGY

The aim of the designed inverter is to transfer active powercoming from the wind turbine as well as to provide utilitieswith distributive control of volt-ampere reactive (VAR) compensationand PF correction of feeder lines. The applicationof the proposed inverter requires active and reactive power tobe controlled fully independent, so that if wind is blowing, thedevice should be working as a normal inverter plus being ableto fix the PF of the local grid at a target PF (D-STATCOMoption), and if there is no wind, the device should be onlyoperating as a D-STATCOM (or capacitor bank) to regulate PFof the local grid. This translates to two modes of operation:1) when wind is blowing and active power is coming fromthe wind turbine: the inverter plus D-STATCOM mode.

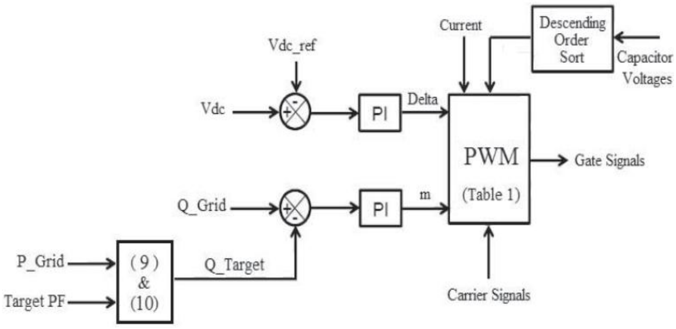

Fig 2: Schematic of the proposed controller system

In thismode, the device is working as a regular inverter to transferactive power from the renewable energy source to the gridas well as working as a normal D-STATCOM to regulate thereactive power of the grid in order to control the PF of the gridand 2) when wind speed is zero or too low to generate activepower: the D-STATCOM mode. In this case, the inverter isacting only as a source of reactive power to control the PFof the grid, as a D-STATCOM. This option eliminates theuse of additional capacitor banks or external STATCOMs toregulate the PF of the distribution feeder lines. Obviously, thedevice is capable of outputting up to its rated maximum realpower and/or reactive power, and will always output all realpower generated by the wind turbine to the grid. The amountof reactive power, up to the design maximum, is dependentonly on what the utility asks the device to produce.

In the proposed control strategy, active and reactive powertransferred between the inverter and the distribution grid iscontrolled by selecting both the voltage level of the inverterand the angle δ between the voltages of inverter and grid,respectively. The amplitude of the inverter voltage is regulatedby changing the modulation index m and the angle δ by addinga delay to the firing signals which concludes

$$P_S = -\frac{m E_S E_L}{X} \sin\delta$$
$$Q_S = -\frac{m E_S E_L \cos\delta - E_L^2}{X}$$

Several assumptions should be considered for the proposedcontrollers which are as: 1) the load on the feeder line shouldbe considered fixed for a small window of time and there isno change in the load during a cycle of the grid frequency;2) the feeder line can be accurately modeled as a constant P,Q load. This means that the power produced by a wind turbinewill displace other power on the feeder line and not add toit; and 3) although making a change in m or δ has effect onboth (7) and (8), it is assumed that a change in the modulationindex will predominantly affect Q, while a change in delta willpredominantly affect P. Any effect on Q from a small changein delta is thus ignored.

In an 11-level CPWM technique, ten carrier signals arecompared with a reference sinusoidal signal, basedon the phase of the reference signal (vr ), there are 11 operatingregions where each region defines a voltage level in the output

$$n_{\mathrm{upperArm}} + n_{\mathrm{lowerArm}} = 10$$

In an 11-level MMC inverter, there are ten upper andten lower SMs where each SM has a capacitor. For instance,in voltage level 1 of Table I, all the upper SMs should beOFF and all the lower SMs should be ON, which translates tothe fact that the main switches Sm of all upper SMs and theauxiliary switches (Sc) of all lower SMs have to be ON andall the other switches have to be OFF.

The most critical issue to control MMC is to maintainthe voltage balance across all the capacitors. Therefore, theSMs' voltages are measured and sorted in descending orderduring each cycle. If the current flowing through the switchesis positive, so that capacitors are being charged, n-upperArmand n-upperArm and of the SMs in upper arm and lower armwith the lowest voltages are selected, respectively. As a result,ten capacitors with lowest voltages are chosen to be charged.Likewise, if the current flowing through the switches isnegative, so that capacitors are being discharged, n-upperArmand n-upperArm of the SMs in upper arm and lower armwith highest voltages are selected, respectively. As a result,ten capacitors with highest voltages are chosen to be discharged.Consequently, the voltages of the SMs' capacitorsare balanced. Considering Table I and based on thedirection of the current flowing through the switches, theproper algorithm will be selected to maintain capacitorbalance.

## SIMULATION RESULTS

The design of an 11-level MMC inverter was carried out in MATLAB/Simulink.Before t = 6 s, there is no wind to power the wind turbine;therefore, the dc link is open-circuited. At t = 6 s, the inputpower of the inverter is ramped up to 12 kW in 5 s, and thenramped down to 3.5 kW 4 s later.

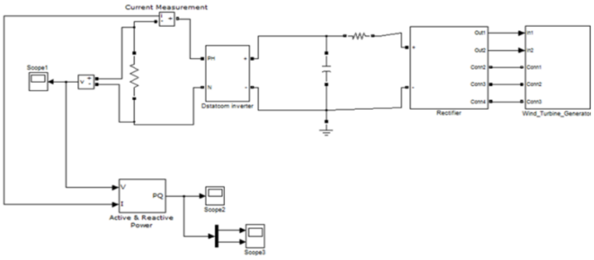

Fig 3: Simulation circuit of proposed converter

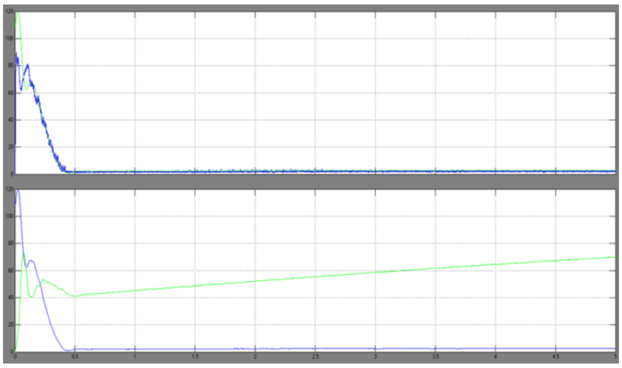

Fig 4: Torque of the Wind turbine Generator

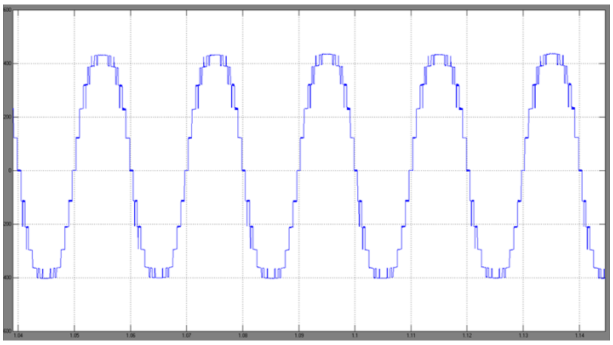

Fig 5: Output voltage of the proposed 11-level inverter

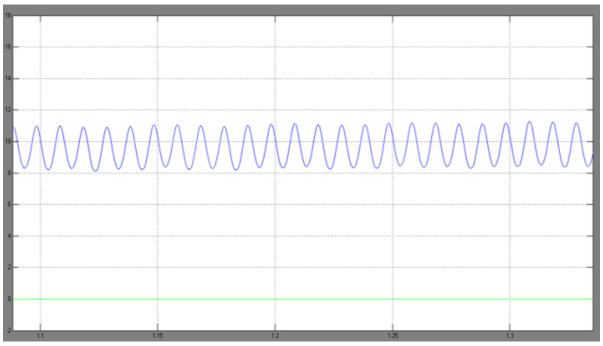

Fig 6: Active power

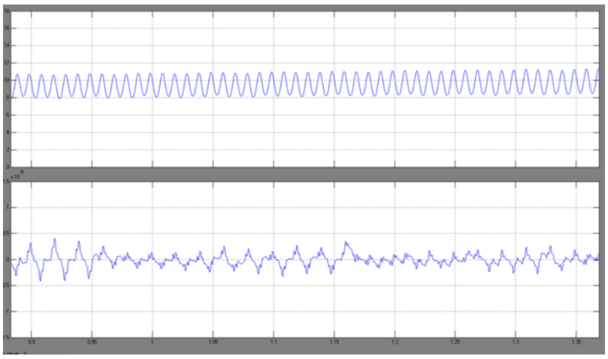

Fig 7: Active and reactive power

## CONCLUSION

Replacing the traditional renewableenergy inverters with the proposed inverter will eliminatethe need of any external STATCOM devices to regulate the PFof the grid. Clearly, depending on the size of the compensation,multiple inverters may be needed to reach the desired PF. Thisshows a new way in which distributed renewable sources canbe used to provide control and support in distribution systems.The proposed controller system adjusts the active power bychanging the power angle (delta) and the reactive power iscontrollable by the modulation index m. The simulation resultsfor an 11-level inverter are presented in MATLAB/Simulink.

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