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Electric vehicle as a reactive power compensator and power oscillation damper in a DFIG based wind farm

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***Abstract*—Wind is one of renewable energy sources gaining popularity nowadays. Stable integration of wind energy requires voltage compensation and energy storage medium. Power electronic devices and huge storage devices are used so far for integration of wind power. Extensive use of power electronic devices and storage devices makes entire structure and control complex. Electric vehicle having bidirectional charger operating in the four quadrants of PQ plane can support grid integration of wind power by giving real and reactive power support.Real and reactive power modes of operations are independently controlled by controlling d and axis current of the bidirectional converter.**

***Keywords*—Doubly fed induction generator,Electric vehicle STATCOM,Wind energy conversion system**

I. Introduction

In recent years the penetration of electric vehicles has increased tremendously. New battery technologies and power electronic power converter have resulted in highly efficient vehicles. Electric vehicles are used only for small amount of time for transportation, for the remaining time they are parked in parking space. These vehicles while they are not used for transportation can provide many grid services[1],[2]. They can act as storage devices, and with suitable interconnections it can feed power back to grid especially during peak hours. Another service that can be provided by electric vehicle is that they can act as external storage devices for renewable sources. Electric vehicles have the potential of supplying both real and reactive power with the grid, inverter and dc to dc converter in vehicle can control the amount of real and reactive power exchanged with a vehicle side proper controller.

Electric vehicle's real power capability has been studied previously, but same vehicle can provide reactive power support, which in effect will not reducevehicle's battery's state of charge(SOC) when compared to real power exchange. Thereby electric vehicle can give voltage support for integration of renewable energy like wind and act as a virtual STATCOM. Utilization of Solar farm as a STATCOM during night time has been studied previously. Most of the wind energy systems uses doubly fed induction generator(DFIG).DFIG has the inherent capacity to provide necessary reactive power for its operation during normal operating conditions. During fault conditions it is a common practice to short the rotor side converter of DFIG using crow bars.DFIG with shorted rotor will act as simple induction generator[3].Reactive power for the induction generator has to be supplied by some external means. STATCOM is used for fast and reliable reactive power compensation and voltage support in doubly fed induction generator based wind farms, but their major drawback is their high cost. Electric vehicle connected to grid by bidirectional power converter can support DFIG based wind farms by supplying necessary reactive power. Decrease in the battery state of charge(SOC) is very less in this reactive power transfer. The vehicle charger can supply reactive power during charging and discharging. Different charger topologies have been discussed in [4].

Other than reactive power compensation, major problem associated with wind power integration is due to intermittency in wind power generations. Stability of grid gets affected due to transmission line outflows and power oscillations due to variations in wind velocity. Wind farms equipped with energy storage devices can effectively reduce stability issue. Super capacitors acting as energy storage devices for wind farm was studied in [5]. But when the wind farm is large, huge no of storage devices and converters are required, making entire structure and control complex. Electric vehicle can involve in active power transfer with the grid by making use of battery and bidirectional converter. Battery can store energy when there is excess wind power, and it can discharge sufficient amount power, when wind velocity is low, making grid power always constant.

Real and reactive mode of operations of electric vehicle are studied in this paper. Modeling of entire system consists of modeling of DFIG based wind farm and its controller, modelling of vehicle .Vehicle side controller is also modeled.Entire systemmodeling is done in MATLAB.

II. Electric Vehicle Modelling and Control

A. Electric vehicle model

Most of the electric vehicles in market are charged using unidirectional chargers that allow power to flow only from grid to the vehicle. In order to incorporate vehicle to grid interaction, it is necessary to use bidirectional charger. There are different types of charging topologies. Charger considered for the study in this paper is a bidirectional ac-dc full bridge converter [6].Bi directional ac-dc full bridge converter allows four quadrant operations in P-Q plane. Four operating regions of the bidirectional chargers are shown inFig. 1.Electric vehicle is modeled as dc source and a three phase bidirectional inverter. The inverter generates a three phase voltage which passes through a small inductance to smooth out the variations in power output of inverter as shown in Fig.2.V_C is the magnitude inverter output voltage and α is angle between inverter output voltage and grid voltage. V_{pcc} is the voltage at the point of coupling. When V_C lags behind V_{pcc} active power flows from grid to vehicle. When there is difference in magnitude of the voltages, there is reactive power flow between grid and vehicle. Since three phase bidirectional converter injects high frequency current to grid during power transfer, a filter is designed with a cut off frequency of 700Hz.Converter with a filter is shown inFig .3.Bidirectional flow of active and reactive power can be controlled using vehicle side controller.

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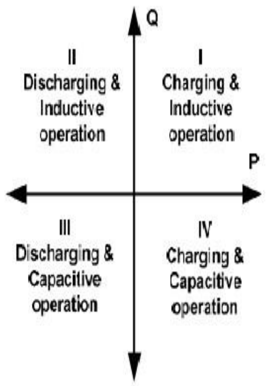

Fig. 1. Operating modes of bidireectional charger

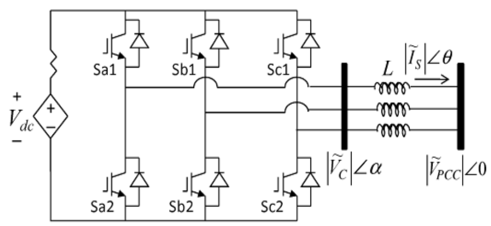

Fig. 2. Electric vehicle representation

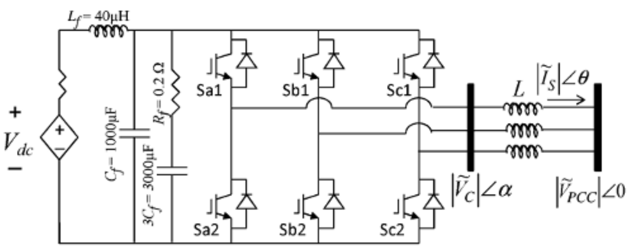

Fig. 3. Converter with filter

B. Controller for electric vehicle

The vehicle side controller generates the control pulses for inverter and controls the real and reactive power exchange with the grid. Real power output and reactive power of inverter is developed in dq0 reference frame. Usually currents and voltages are expressed in abc reference, but analysis is complex in abc reference frame due to variability in time frame.

Active and reactive power output of the 3 phase inverter can be developed in the dq0 reference frame as shown below [7].

$$P=\frac{3}{2}(v_d i_d+v_q i_q) \qquad (1)$$

$$Q=\frac{3}{2}(v_q i_d+v_d i_q) \qquad (2)$$

Where P and Q are the real and reactive power output of the inverter and v_d and i_d are d axis components of voltage and current, where $v_q$and i_q are q axis component of voltage and current.For simplification reference frame is chosen such that the d axis aligned with grid voltage, q axis component of voltage will become zero. When v_q becomes zero in the above equation, real power depends only on i_d and reactive power depends on i_q thus decoupled control of active and reactive power is achieved. Vehicle side controller generates the d and q axis reference current, from the demanded real and reactive power output. Equations for reference current are as follows

$$i_d^*=\frac{2}{3}\left\{\frac{P^*}{v_d}\right\}+\frac{k_i}{S}\{P-P^*\} \qquad (3)$$

$$i_q^*=\frac{2}{3}\left\{\frac{Q^*}{v_q}\right\}+\frac{k_i}{S}\{Q-Q^*\} \qquad (4)$$

Reference currents from controller arecompared with actual currents of inverter to generate control pulses.$P^*$and$Q^*$are the reference real and reactive power. Whenvehicle acts as STATCOM real power reference $P^*$of controller is made zero. Vehicle supplies only the reactive power demand from grid. When electric vehicle act as storage or supplier ofreal power,reactive power referenceQ^* is set to zero and vehicle act as a real power flow controller. Two operating modes of electric vehicle is considered in this paper, i.e. real power mode and reactive power mode. Independent control of real and reactive power is possible with the vehicle side controller. Block diagram of the vehicle side controller is shown in Fig .4.

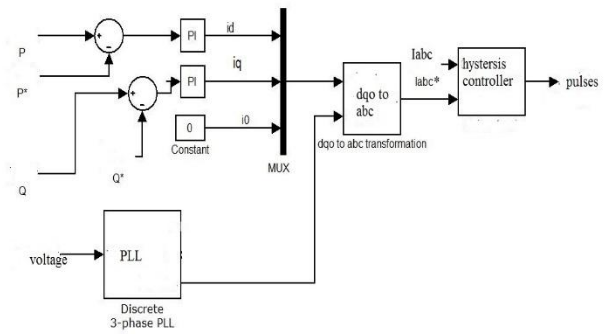

Fig. 4. Electric vehiclesidecontroller

III. INTGRATION OF WIND ENERGY TO GRID

A. DFIG for wind engery conversion

Doubly fed induction generators (DFIG) is the most popular wind energy generator because of its various advantages over fixed speed induction generator. Main advantage of DFIG is frequency of output voltage of DFIG is independent of variations in the wind velocity. Rotating magnetic field created in DFIG depends not only on mechanical speed of rotor, but also on the frequency ac currents fed into the rotor ,making frequency of voltage generated constant. Basic block diagram for DFIG based wind energy conversion system is shown in Fig. 5. In DFIG there are two converters connected back to back i.e. grid side converter (GSC) and rotor side converter (RSC). Two converters are connected in rotor side, so converters are required to handle only slip power which is 30% of generator rating. It is capable of efficient operation under varying wind speed.

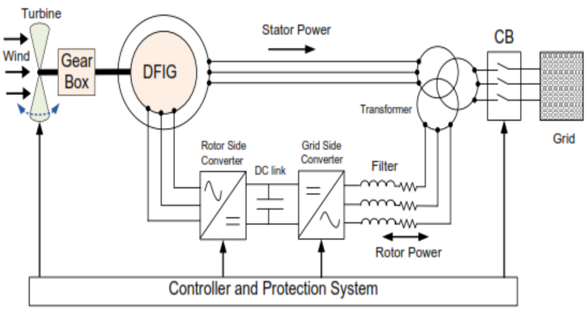

Fig. 5. Doubly fed induction generator based wind energy conversion.

B. *Modelling and control DFIG*

DFIG make use of two converters, rotor side and grid side converter.Since two converters are connected in rotor side, power handled by the converters is less. During super synchronous operation,power flows from rotor to dc link capacitance, and tends to increase the dc link voltage. During sub synchronous operation dc link voltage decreases.Grid side converter keeps the dc link voltage constant by proper interaction with the grid.Rotor side converter controls active and reactive power from stator. Stator flux oriented control method is used for control of DFIG[8].Stator flux oriented control block diagram is shown in Fig. 6.It is a vector control method with d axis oriented along the stator flux. Stator flux oriented control makes the control of active and reactive power independent. Rotor q axis current controls the active power, and rotor d axis current stator reactive power. Active power command for rotor is generated by maximum power point tracking.

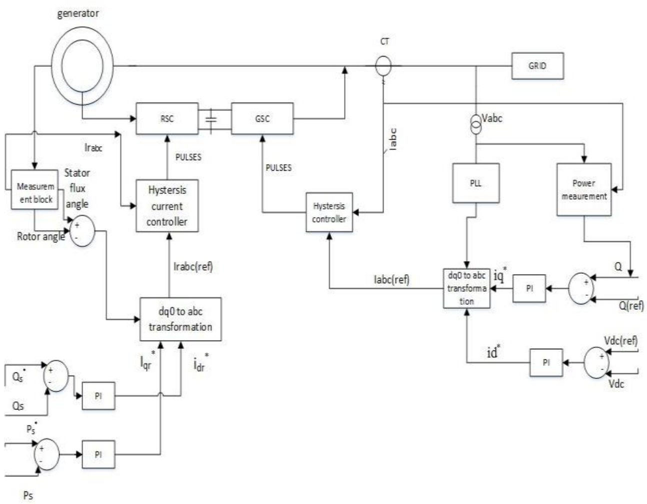

Fig. 6. Statorflux oriented control of DFIG

IV. SIMULATION MODEL AND RESULTS

Entire simulation is done using MATLAB.Two modes of operations of electric vehicle are considered,i.e. electric vehicle as a voltage compensator and power oscillation damperDFIG connected grid.

A. *Simulink model*

Simulink model of the system is shown in Fig.7. Simulink model consists of model of electric vehicle, and its controller, and model of DFIG based wind farm.

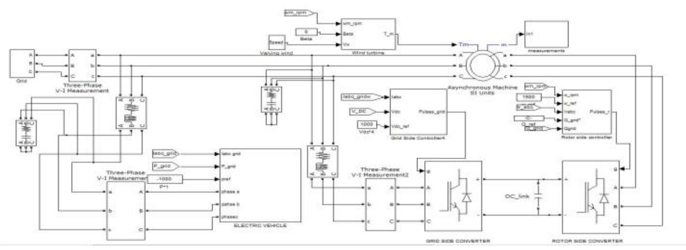

Fig. 7. Simulink model

B. *Electric vehicle as reactive power compensator*

Electric vehicle can be operated in reactive power mode or as a voltage compensator, by keeping real power reference of vehicle side controller to zero. Reference currents are generated from the vehicle side controller and compared with actual current using hysteresis controller and control pulses are generated.The waveforms of reactive power of grid are analyzed with and without using electric vehicle. It can be seen thatreactive power of grid was 850kVAR without electric vehicle. With the use of electric vehicle reactive power supplied from grid can be made almost zero. The wave forms are shown in Fig. 8 and Fig .9.

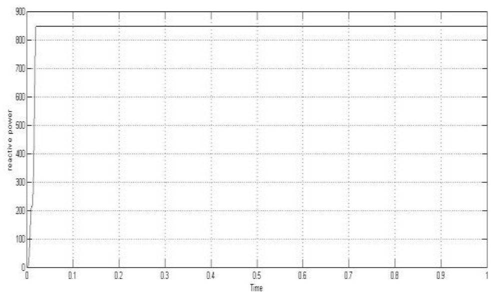

Fig. 8 Reactive power of grid without electric vehicle

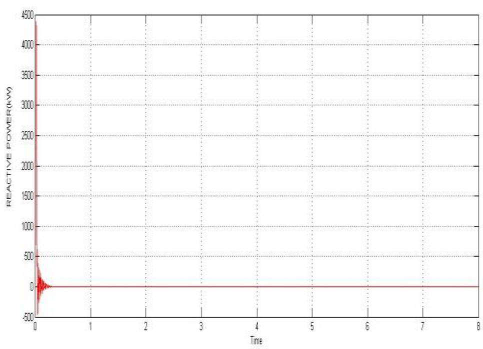

Fig. 9. Reactive power of grid with electric vehicle

C. Electric vehicle as a power oscillation damper

Performance of DFIG under varying speed with and without electric vehicle connected to it are analysed. Varying wind speed is simulated by using step inputs.Wind velocity varies from 12 to 8 m/s.Variation in wind velocity and rotor speed and gnerated power with electric vehicle connected is shown in Fig. 10.It can be seen that when electric vehicle is connected, power flowing from DFIG to grid is almost constant even though wind velocity changes.Electric vehicle act as variable load which absorps real power when wind velocity increses and it act as source of real power hen wind velocity decreaes.Grid side converter of DFIG makes dc link voltage constant irrespective direction of power from rotor.Dc link voltage is shownin Fig .11.

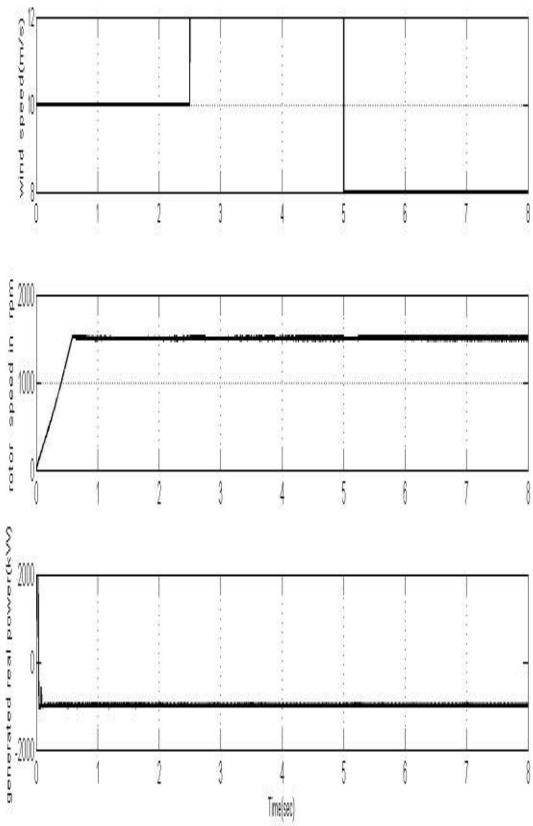

Fig. 10. Waveforms with electric vehicle connected

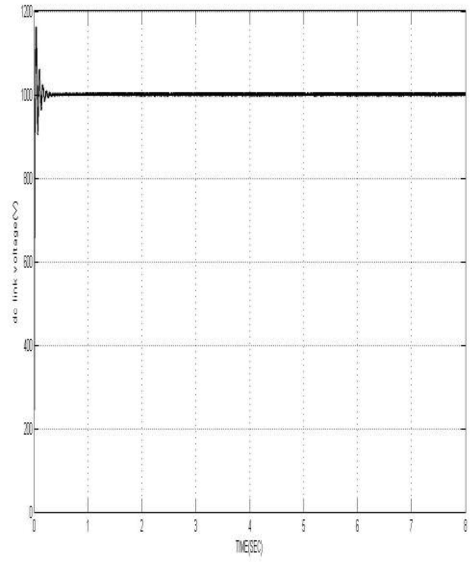

Fig. 11. Dc link voltage

V CONCLUSION

A novel idea is implemented which uses real and reactive power capabilities of electric vehicle. Two modes of operation electric vehicle are analyzed, i.e. electric vehicle as a reactive power compensator and power oscillation damper.A number of electric vehicles in a parking lot can effectively eliminate the requirement of STATCOM and other storage devices in a wind farm making structure and control simple. Real and reactive power control is made independent by using vehicle side controller.

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