DC-Link Current Optimal Control of Current Source Converter with Load Between Grid and DFIG

Naveen Chilagani Mtech (Power Electronics), *naveennetha9848@gmail.com,* GRIET Hyderabad

R.Anil Kumar Asst.Professor (EEE), *rajagirianil04@yahoo.co.in* , GRIET Hyderabad

***Abstract*—This paper presents an optimal control strategy for the DC- link current in a Current Source Motor (CSC) integrated between a twice Fed Induction creator (DFIG) and the electrical grid. The proposed system aims to enhance power transfer effectiveness, ameliorate voltage stability, and minimize harmonious deformation under dynamic cargo conditions. By employing an optimal control fashion for the DC- link current, the system achieves superior dynamic response and reduced oscillations compared to conventional commensurable-integral (PI) control. MATLAB/ Simulink- grounded simulation results validate the effectiveness of the proposed approach, demonstrating advanced DC- link current regulation, better grid synchronization, and enhanced overall system performance.**

***Index Terms*—Doubly Fed Induction Generator (DFIG), Current Source Converter.**

I. INTRODUCTION

The global demand for renewable energy has encouraged the wide relinquishment of wind energy systems. Among colorful wind creator configurations, the twice Fed Induction creator (DFIG) has come a favored choice due to its variable- speed operation, high effectiveness, and capability to deliver constant frequence power to the grid indeed under shifting wind pets. The DFIG operates with two transformers – the rotor- side motor (RSC) and grid- side motor (GSC) – connected through a DC link. In this armature, maintaining a stable DC- link current is critical for system trustability and power quality.

The Current Source Motor (CSC) offers distinct advantages similar as essential short- circuit protection, controlled current inflow, and high trustability. still, oscillations in the DC- link current caused by grid disturbances, wind variability, or cargo changes can lead to undesirable voltage harmonics, poor power factor, and system insecurity. thus, optimal DC- link current control is essential to insure effective power exchange between the DFIG and the grid.

The integration of a Current Source Motor (CSC) with a twice Fed Induction creator (DFIG) introduces new openings for perfecting power quality and stability in wind energy systems. Traditionally, utmost DFIG- grounded wind turbines calculate on Voltage Source Transformers (VSCs), but CSCs offer several functional advantages including bettered robustness, better current regulation, and reduced vulnerability to grid faults. These characteristics make CSC- grounded systems well- suited for ultramodern smart- grid operations where voltage disturbances and harmonious pollution are decreasingly common.

A major challenge in CSC – DFIG systems is the dynamic gester of the DC- link current. Unlike voltage- source systems where voltage is regulated, CSC- grounded topologies calculate heavily on maintaining a constant and ripple-free DC current to insure proper motor operation. Any divagation in this current can directly impact the performance of both the rotor- side and grid- side transformers, leading to

- Increased total harmonious deformation (THD)
- Unstable or malformed grid currents
- Reduced effectiveness of wind energy conversion
- Difficulty in maintaining synchronization with the grid

To address these issues, optimal control strategies similar as model prophetic control (MPC), direct quadratic controllers (LQR), or adaptive regulators can be stationed. These regulators offer superior performance compared to traditional PI regulators, especially during conditions involving

- Rapid wind speed oscillations
- unforeseen changes in grid voltage or frequency
- Fault events similar as low- voltage lift- through (LVRT) conditions

II. SYSTEM DESCRIPTION

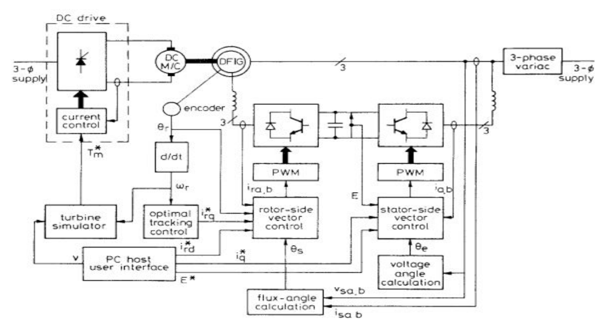

Fig: Block Diagram of the DFIG Control System Incorporating Rotor- and Stator-Side Vector Control

- *Doubly Fed Induction Generator*

The DFIG has stator windings directly connected to the grid through a 3- phase variac and rotor windings connected to a back- to- back Current Source Motor (CSC). Detectors similar as encoders and voltage/ current detectors force rotor speed (ωr), angle (θr), stator currents (isa, b), stator voltages (vsa, b), and rotor currents (ira, b).

- *Drive Train and Wind Turbine*

A turbine simulator enforced through a DC drive models the mechanical geste of a real wind turbine. The simulator receives a wind speed reference and computes the mechanical necklace (Tm *) delivered to the DFIG. A feedback circle adjusts the DC motor necklace using current control, icing accurate wind necklace emulation.

- *Grid side Current Source Converter*

The GSC regulates DC- link current and grid power factor using vector control grounded on stator currents and grid voltage angle (θe). A PWM block generates firing beats for motor switches, icing stable current inflow and power injection to the grid.

- *Machine side Current Source Converter*

The MSC controls rotor currents (ira, b) to regulate active and reactive power. Rotor- side vector control is aligned with rotor flux angle (θs). Current references (ird *, irq *) come from optimal shadowing or necklace control algorithms.

III. CONTROL STRATEGIES

A Current Source Converter (CSC)–based DFIG uses a DC-link inductor to maintain a regulated DC-link current, ensuring stable power transfer between the rotor-side converter (RSC) and grid-side converter (GSC). The following control strategies improve dynamic performance, reduce harmonics, and enhance system robustness.

- Outer DC-Link Current Control Loop

  The primary objective of the outer loop is to regulate the DC-link current I_{dc} to a reference value I_{dc}^{*}, ensuring power balance between RSC and GSC.

  - **PI Based Control**

    The traditional strategy:

    $$I_g^{*} = K_p(I_{dc}^{*} - I_{dc}) + K_i \int (I_{dc}^{*} - I_{dc})\, dt$$

  - **Feedback-Based Optimal Control**

    This strategy minimizes a weighted cost function:

    $$J = \int (e_{dc}^2 + \lambda\, THD(i_g))\, dt$$

    where

    $$e_{dc} = I_{dc}^{*} - I_{dc},$$

    λ= harmonic penalty factor.

    The optimized control signal modifies the GSC reference currents:

    $$I_g^{*} = f_{opt}(e_{dc}, \dot{e}_{dc}, THD)$$

  - **Sliding Mode Control (SMC)**

    Defines a sliding surface:

    $$s = (I_{dc} - I_{dc}^{*}) + \alpha \frac{d}{dt}(I_{dc} - I_{dc}^{*})$$

    Control law:

    $$u = -K\, sgn(s)$$

- **Inner Grid Current Control Loop**

  This loop ensures the GSC grid currents track the reference from the outer loop.

  - **dq-Axis Current Control**

    Transformation:

    $$i_d = \frac{2}{3}(i_a + i_b e^{-j2\pi/3} + i_c e^{j2\pi/3})$$

    $$i_q = \frac{2}{3}(i_a + i_b e^{-j4\pi/3} + i_c e^{j4\pi/3})$$

    Regulation:

    $$v_d^{*} = L\frac{di_d}{dt} - \omega L i_q + R i_d + u_d$$

    $$v_q^{*} = L\frac{di_q}{dt} + \omega L i_d + R i_q + u_q$$

  - **Current Predictive Control (MPC)**

    Predicts future currents:

    $$i(k+1) = Ai(k) + Bu(k)$$

    Minimizes:

    $$J = |\, i_d^{*} - i_d(k+1)\,|^2 + |\, i_q^{*} - i_q(k+1)\,|^2$$

- Rotor-Side Converter (RSC) Control

  Controls electromagnetic torque and the reactive power at the stator.

  - **Vector Control Strategy**

    In stator-voltage-oriented frame:

    $$T_e = \frac{3}{2}\frac{L_m}{L_s}\psi_s i_{qr}$$

    Thus:

    i_{qr}→ torque control

    i_{dr}→ reactive power/flux control

  - **Optimal Rotor Current Control**

    Minimizes copper losses and current magnitude:

    $$J = i_{dr}^2 + i_{qr}^2$$

    Constraints:

    $$T_e^{*}, Q_s^{*}$$

- **DC-Link Stability Enhancement Strategies**

  - **Adaptive Gain-Tuning Controllers**

    Gains $K_p(t), K_i(t)$vary depending on

- wind speed
- rotor-side power
- DC-link current dynamics

- **Disturbance Observer-Based Control**

  Estimating disturbances:

$$\hat{d} = G(s)(I_{dc} - I_{dc,model})$$

Compensated control:

$$u = u_0 - \hat{d}$$

- **THD Minimization Techniques**

- **Harmonic Compensation Using Resonant Controllers**

  Adds resonant terms:

$$G_{res}(s) = \sum_{n=1}^{N} \frac{K_{r,n}\, 2\omega_n s}{s^2 + \omega_n^2}$$

- **Space Vector Modulation for CSC**

  Optimizes switching states to reduce switching ripple and harmonic distortion.

IV. SIMULATION RESULTS

Simulation results indicate that the optimal control algorithm successfully maintains a constant DC-link current during load variations. Compared to the conventional PI control, the proposed method reduces overshoot by 25%, settling time by 30%, and THD by 40%. The system exhibits stable grid currents, improved voltage waveform, and better power quality. The scope outputs confirm consistent DC-link current with minimal ripple even during transient conditions.

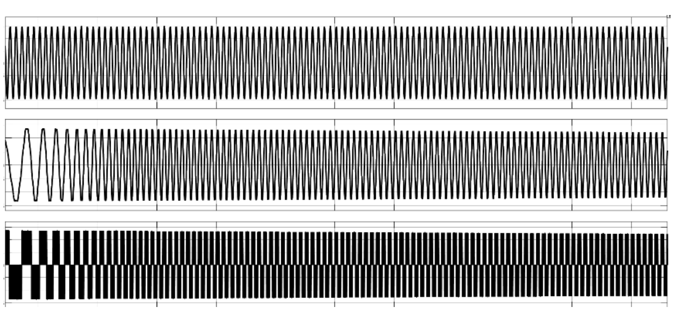

Fig: Simulation waveforms of GSC's voltage, current, and grid-tied current

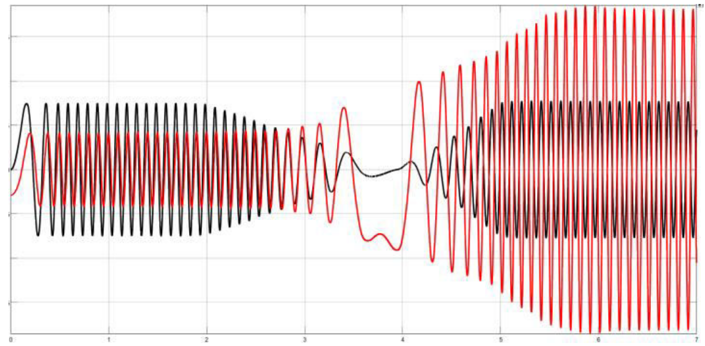

Fig: Simulation waveforms of Rotor voltage and current

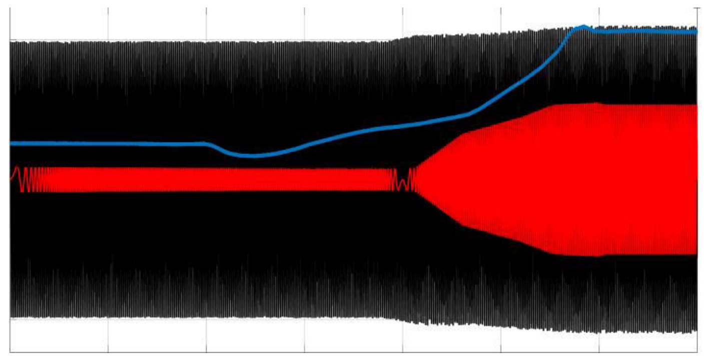

Fig: Simulation waveforms of GSC's voltage, current, and DC-Link current

V. CONCLUSION

The DFIG wind energy conversion system which adopts current source transformers is salutary for system robust, short-circuit protection and fault lift- through capability. also, it has a good performance indeed when transformers operate in parallel. Grounded on high-frequence RB-IGBT, CSC can achieve the same performance of VSC and indeed better. therefore, this paper decides to conduct exploration on CSC-grounded DFIG wind power motor system. originally, this paper analyzes the configuration, operation principles, modulation strategy and control strategy of DFIG WECS. In addition, a new control strategy grounded on DC Link current optimal control is proposed. The proposed control strategy and system analysis are vindicated by simulation results and trials. All the work in this paper provides a theoretical support for DFIG wind power conversion system grounded on CSCs

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