

Literature review paper on doubly fed induction generator wind turbine technology

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Abstract: The wind turbine technology is now a developed technology. Modern wind technology incorporates each aspect of grid integration, stability and power quality issues in the arena of reliable power production to user end or utility. The paper provides cumulative modernization of wind turbine technology through literature survey of wind turbine configurations followed by discussion of different control schemes mainly of doubly fed induction generator (DFIG) wind turbine. This paper gives proper understanding of conceptual experiments conducted with DFIG and control schemes along with their characteristics and limitations.

Keywords: Doubly fed induction generator, DFIG, Fixed speed wind turbine, Variable speed wind turbine, control schemes, SFO, SVO.

I. INTRODUCTION

Due to environmental concerns caused by excessive exploitation of conventional resources, now the focus is diverted to non renewable resources especially solar & wind as these are environmentally clean and eco-friendly. With the modern technology incorporated in the wind turbines, wind power generation limits have been uplifted to considerable level in the grid. Hence penetration level of wind power has become more significant and is leading to more complex, sophisticated and reliable interconnection requirements.

This paper objective is literature survey of topologies of WTs and methods of power control adopted to wind turbine systems mainly DFIG WT through different control schemes and different configurations of converter schemes with advancement in power extraction process. In the paper, FSWT characteristics, drawbacks and comparison to VSWT are discussed [1-8] and this is derived that VSWT compensates most of the shortcomings of previous WT and improves dynamic performance. VSWT configurations, working modes, power converter techniques model and their characteristics are discussed [9-21]. Later the influence of control strategies on WT performance are discussed [22-35] and it is followed by the comparison of control schemes [36-51]. The main control schemes discussed are SFO and SVO. The performance evaluation of control schemes and compatibility with the back to back converters are focussed.

II. INITIAL WIND TURBINE DEVELOPMENT TREND

In 1990s, the wind turbine generator systems employed were mostly fixed speed wind turbine squirrel-cage induction generators (FSWT - SCIGs) to generate wind power as these system are more simple and reliable [1]. But as they need fixed wind speed to operate so due to wind speed variation overall efficiency becomes poor. The major problems observed with the system are voltage fluctuation (flicker) & Low voltage ride through (LVRT), when they are connected to weak power grids where the wind power penetration levels are high [2]. As the available wind energy generation equipment is most often installed in remote, rural areas, and these remote areas usually have weak grids, often with voltage unbalances and under/overvoltage conditions [3-4]. Also it has one more disadvantage of requiring capacitors at the stator terminals to provide for the reactive power demand of the machine [5].

The system delivers the rated power only at a given wind speed, leading to low energy conversion efficiency (at other wind speeds). At different wind speeds, the generator speed varies within 1% of its rated speed [6]. Grid connected FSWT - SCIG WTs often produce active power with significant fluctuations due to wind speed variations, the wind gradient and the tower shadow effect [7]. If is connected to a weak power grid (during a grid fault), the over-speeding of the WTs cause voltage instability [8]. As a result, utilities typically disconnect the WTs immediately from the grid when such a contingency occurs.

With the tripping of certain WTs in a large wind farm, the overall power system stability becomes poor [2]. Due to above mentioned problems with traditional set up there was need of new system which could incorporate previous drawbacks. Therefore concept of variable speed wind turbine (VSWT) came in existence.

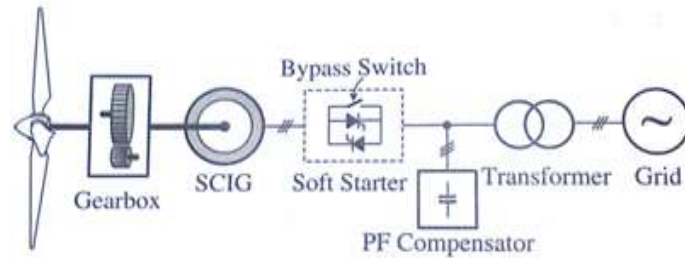


Figure 1: Fixed speed wind turbine - squirrel cage induction generators (FSWT - SCIGs)

The FSWTs have no speed control capability and cannot provide voltage or frequency support when connected to the power grid [2]. In case of variable speed systems, comparison shows that using a wound rotor induction machine (WRIM) of similar rating can significantly enhance energy capture [1]. It is possible to transfer maximum power to the network in a wide range of wind speeds without exceeding the ratings of the induction generator [5]. SCIG severely limits the energy output of a WT.

III. DEVELOPED TECHNOLOGY ON VARIABLE SPEED WIND TURBINE

The main goal is to maximize the wind power capture at different wind speeds, which can be achieved by adjusting the turbine speed in such a way that the optimal tip speed ratio λ_{opt} is maintained constant.

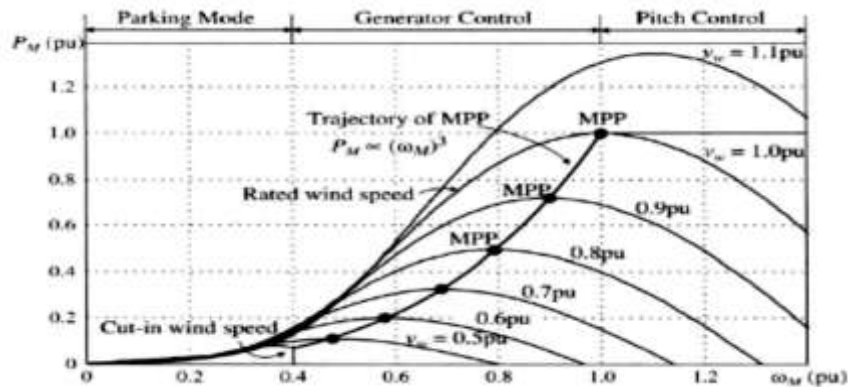


Figure 2: Maximum power tracking point for VSWT

For a given wind speed, each power curve has a maximum power point (MPP) at which the optimal tip speed ratio can be achieved. To obtain the maximum available power from the wind at different wind speeds, the turbine speed must be adjusted to ensure its operation at all the MPPs. The trajectory of MPPs represents a power curve.

Now the control mechanism/schemes ensure the adjustment in speed of turbine so as to maximise power extraction. This is concept of variable speed wind turbine set up. The proposed configurations of VSWT are reduced capacity and full capacity configuration. The reduced capacity configuration consists of processing of slip power of wound rotor induction machine. If the rotor resistance is connected to slip terminals, slip power got wasted and machine attains only about 10% of speed variation near to synchronous speed operating range whereas if slip power is feedback to the grid after processing through back to back converters (Kramer technique) then 30% of speed variation can be achieved within operating range.

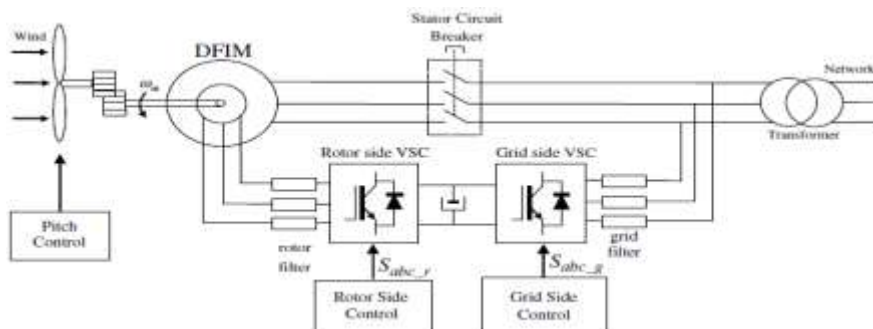


Figure 3: Variable speed with reduced capacity configuration

In full capacity, the back to back converters are directly connected from WRIM to grid. This needs converter switches to withstand rated voltage so configuration cost is relatively high.

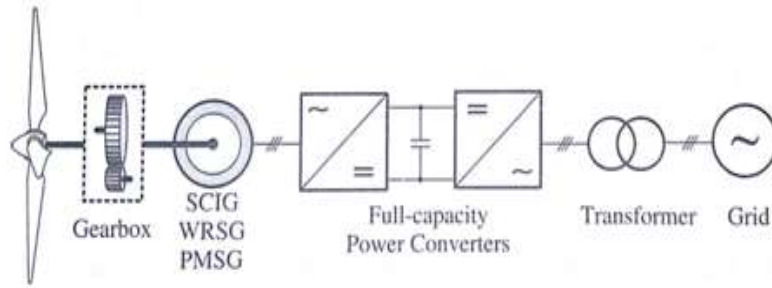


Figure 3: Variable speed with full capacity configuration

The doubly fed induction machine can be operated in generating mode in both sub-synchronous and super-synchronous modes [9]. The SCIG controlled over a range of sub-synchronous and super-synchronous speeds, using the novel secondary EMF signal generator, shows considerable advantage over sub-synchronous systems based on the Kramer technique [10] and does not have the stability problems normally associated with doubly fed machines [11]. The steady-state analysis of a wound-rotor induction generator operated at varying shaft speeds in the sub-synchronous and super-synchronous regions, by control of both the magnitude and direction of slip power is studied [12].

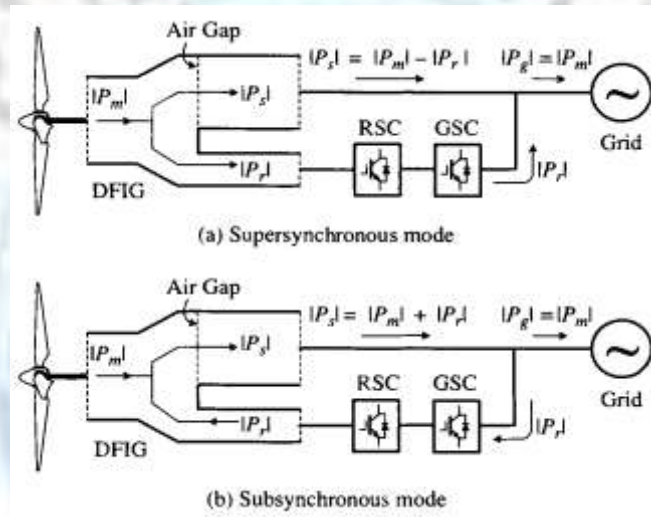


Figure 4: Operating modes of DFIG

The Kramer technique in reduced capacity provides better performance as compared to rotor resistance method, but its cost of converter switches and firing circuits is accounted more. Due to need of better operating systems which is assisted by reduced cost of converter switches in 2000s, the VAWT based system became popular. The rated speed settings, gearbox ratios, and machine and converter ratings were described for VSWT based DFIG [11] and this rating and data is considered as reference for developing wind turbine installation for higher power wind farms. With the Kramer technique based wound rotor configuration or DFIG WTs, decoupled active and reactive power control of the generator could be achieved, with more efficient energy production, improved power quality and improved dynamic performance [13, 14].

The concept of a variable speed wind turbine (VSWT) driving DFIG has received increasing attention because of its noticeable advantages over other Wind Turbine Generating systems [1, 8, 14, 15, 16, 17]. DFIG-based WT are more popular on account of their favourable cost/performance attribute resulting primarily from the need for a much smaller converter rating compared to the machine rating [13,18].

DFIGs are widely used in modern WTs due to their power control capability; variable speed operation, low converter cost, and reduced power loss and these characteristics are compared to fixed speed induction generators and fully rated converter systems [17]. The converter design and control technique using an ac/dc/ac converter in the rotor circuit of DFIM (Schrebius drive) is studied [19]. It was a standard drive option for high power applications involving a limited speed range.

The power converters only need to handle the rotor side power (30% of rated). The power circuits and control system required for a rectifier are studied, and closed loop regulation through d.c. link voltage for four quadrant operation in order to control power feedback to the supply with desired power factor is achieved [20]. In [21] detailed design of the DFIG using back-to-back PWM voltage source converters in the rotor circuit is validated experimentally by considering a grid connected system. Also it was found DFIGs and a four-quadrant ac-to-ac converter connected to the rotor windings increases the transient stability margin of the electrical grids, when compared with the case where the fixed speed wind systems with cage generators are used [15].

IV. ROLE OF CONTROL STRATEGIES IN PERFORMANCE OF WIND TURBINE

Performance of DFIG WT depends not only on the type of generator but also on the control strategies implemented with different orientation frames. Various types of control designs have been proposed for studying the behaviour of DFIG based wind-turbine system during normal and faulty AC grid conditions [14, 21, 16, 22, 23, 24].

Vector control (VC) strategy is used for decoupled control of active and reactive power drawn from the supply [20]. Also the VC technique is used for the independent control of torque and excitation current [25]. The control schemes in reference to stationary and synchronous frames are developed. Also reference frame models have been developed for DFIM [26-27]. These methodologies are transformed into algorithms which relate firing sequence (for firing back to back converters) to DFIG output parameters such as active & reactive power via vector control strategy.

The control of reactive power flow in DFIG can be made independent to active power. For controlling reactive power flow, system constraints are considered due to variation of operating voltage, current and speed which arises because of changes in speed of turbine [13]. In [28, 29], similar approach is used in order to guarantee reactive power production during outages and unbalanced conditions. In [30] active and reactive power control in DFIG is proposed through state feedback method and is compared to PI controller method by simulation. Also active and reactive integral controllers with voltage and phase angles control loops are studied and sensitivity and stability aspects are also analysed [31]. Decoupled control of the electromagnetic torque and the reactive power using a sensor less scheme for the DFIG was proposed in [32]. Case studies on active and reactive power flow in wind farms were carried out in [33] using induction generators and in [34] using the DFIG. The recorded results pointed out the superior dynamics of the latter topology. It is inferred that PI controllers are effective in achieving better decoupled controlling of DFIG output parameters and with using sensor less scheme.

V. COMPARISON OF CONTROL SCHEMES (SFO/SVO/DTC)

The DFIG is controlled using VC [14, 25, 35], which decouples the rotor currents into active power (or torque) and reactive power (or flux) components and adjusts them separately in a reference frame fixed to either the stator flux or voltage. Current controllers are then utilized to regulate the rotor currents [17]. DFIGs are controlled using VC based on rotor current decoupling, which are either stator flux oriented (SFO) [25, 21] or stator voltage oriented / voltage oriented control (VOC) [14]

Most existing models widely use VC based on SFO. However, the existing control designs assume the stator voltage is ideal, i.e., the frequency and amplitude of the stator or grid voltage are constant and the dynamic characteristic of the stator magnetizing current is not considered [21, 23, 24] Such a system can provide good dynamic response during normal operating condition but the performance may be degraded during AC voltage disturbance. Therefore dq VC, stator-voltage-oriented can be called "grid flux oriented" control [36], the d -axis is aligned with the stator-voltage space vector in this scheme. The DFIG usually operates in VC mode based on the PI controllers in a synchronous reference frame either to the SFO or stator voltage oriented (or VOC) frames. The DFIG with PI controllers and its performance under normal operation conditions has been discussed [37, 35, 38, 17, 39] It is well known that the DFIG performance with PI controllers is excellent in normal grid conditions, allowing independent control of the grid active and reactive power [29, 40].

In [41, 31], the SFO frame is used to develop the DFIG wind power extraction mechanisms. Similarly, direct power control strategy is applied to DFIG WTs using the SFO frame [42], it has been proposed recently while VOC frame is normally not used for DFIG design. System based on VOC has also been used to control DFIG system [14, 43]. In [14], VOC was proposed for controlling DFIG system under normal operation, but no detailed design of decoupling circuit was given and a constant stator voltage was assumed. In [43], VOC control was used to investigate the fault current of DFIG. However, as no decoupling circuits were used, so that control response was inadequate during transient condition.

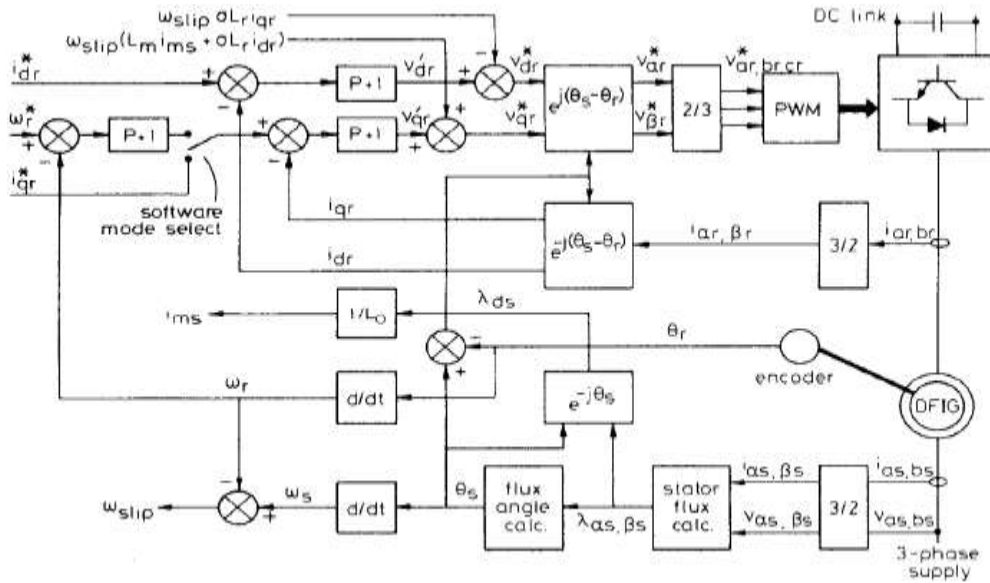


Figure 5: Stator flux oriented control scheme

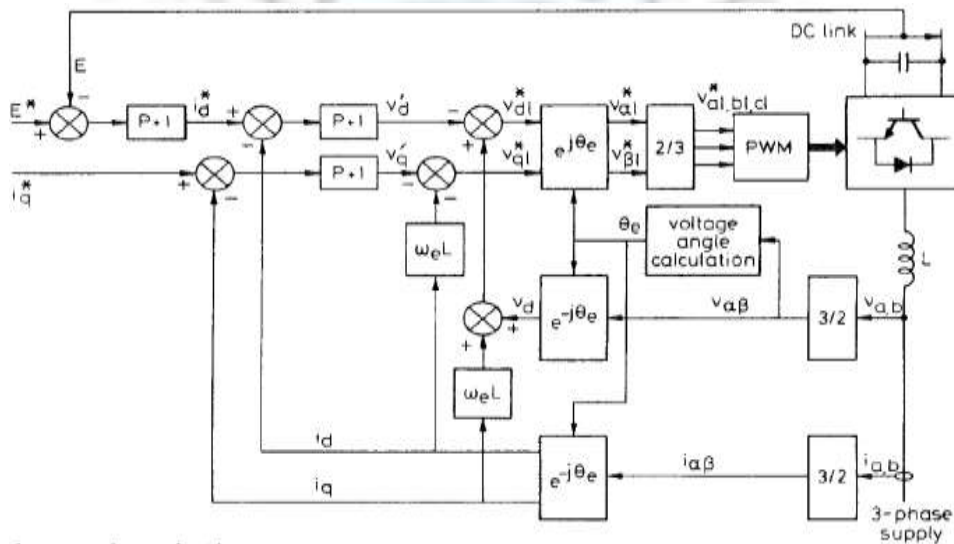


Figure 6: Voltage oriented control scheme

SFO method only utilizes the estimated stator flux so as to remove the difficulties associated with rotor flux estimation. The method selects appropriate voltage vectors based on the stator flux position and active and reactive power errors. Thus, the difficulties associated with the rotor flux estimation are removed [44]. There is special approach to improve DFIG stability under unbalanced conditions using the VOC frame [45, 46]. In [45] an analysis and control design of a DFIG based wind generation system operating under unbalanced network conditions is studied, a DFIG system model in the positive and negative synchronous reference frames is presented to enhance the stability of the DFIG under unbalanced voltage supply. In [46], it is shown that a DFIG control strategy can enhance the standard speed and reactive power control with controllers that can compensate for the problems caused by an unbalanced grid by balancing the stator currents and eliminating torque and reactive power pulsations. Doubly fed machines, naturally, have a pair of poorly damped poles near the grid frequency. Fast inner current loops have a fast response time, but also tend to push the poorly damped system poles toward the right half plane [36]. When the stator phase voltages supplied by the grid are unbalanced, the torque produced by the induction generator is not constant. Instead, the torque has periodic pulsations at twice the grid frequency, which can result in acoustic noise at low levels and at high levels can damage the rotor shaft, gearbox, or blade assembly [47].

DFIG-based WTs can be well explained [14, 48, 21, 49]. DFIG systems are conventionally controlled using stator VOC [14], [48] or SFO [21], [49] controls based on d-q decoupling. In [50], a rotor position phase locked loop (PLL) is used which acquires the rotor position and rotor speed simultaneously for the implementation of the decoupled P-Q control in the DFIG. The rotor position PLL is designed to operate without the knowledge of any parameter of the DFIG except the magnetization reactance.

VI. DRAWBACKS OF DISCUSSED CONTROL SCHEMES

In [51], comparison between SFO and VOC reference frames is done and it is shown that the performance of DFIG wind power extraction is similar to using both VOC and SFO frames. But, it is found that a conventional wind power extraction approach using the SFO frame could deteriorate the power quality of the DFIG system while it is more stable to estimate the position of the stator-flux space vector by simply adding -90 degree to the stator-voltage space vector.

For the survey for other control schemes, the direct to power scheme decouples DFIG rotor current into two parts representing active and reactive power separately. The control of machine active and reactive power is achieved by adjusting these two rotor currents using PI controllers. One main drawback for Direct Power Control scheme is that system performance highly depends on accurate machine parameters such as stator, rotor resistances and inductance. Thus performance degrades when actual machine parameters depart from values used in the control system due to saturation, temperature variation etc [42].

The main drawback for SFO-VC is its linear nature which does not consider the discrete operation of power electronics converter [17]. Thus, in order to maintain system stability over the whole operation range and adequate dynamic response under both normal and abnormal conditions, the current controller and its control parameters must be carefully tuned [35]. This effectively reduces the VC's control bandwidth and robustness during changing operation.

VII. CONCLUSION

Above discussed control system can be implemented successfully but needs proper tuning parameters to achieve decoupling. It often happens that if one current loop parameter varies, other loop output also varies and proper tuning is not achieved. In other words it is time consuming task to define proper tuning parameters. This problem occurs frequently in SFO control scheme. The PI controllers help in proper tracking of reference parameter which is generated according to the loading bus conditions. Also in fault/abnormal conditions or during wind speed variation, the output should be in stability limits. The nonlinear relations of active and reactive power flow are simplified and under certain assumptions and constraints they are related to the operating voltage, current and phase angles. In all above discussed control schemes, current loop and voltage loop exist and the effect of phase angle is considered in stationary to synchronous frame and vice-versa. The parameters to be controlled in stationary frame are controlled in synchronous frame in the form of steady state or d.c. values of dq axis. At last the control techniques are effective for better performance of DFIG WT systems and the applied control system needs to be stabilizing for the given constraints.

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