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Control and maximum power tracking operation of hybrid excited variable speed induction generator

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ABSTRACT

This paper describes a method of voltage regulation, maximum power extraction and power transfer operation in a variable speed wind-driven Induction Generator (IG) feeding DC micro grid (DCM). The IG is self-excited in a hybrid manner with fixed capacitor and a current controlled, voltage source converter (CCVSC). The control principle of CCVSC which intends to provide the VAR requirement of IG based on the power curves along with voltage regulation and maximum power tracking (MPT) with PI (proportional-integral) based controllers claims the merit of the setup. The sinusoidal reference current templates of CCVSC are generated with voltage loop delivering the peak value and MPT loop delivering phase value. The frequency synchronization is effected with a 1Ø Phase Locked Loop (PLL). The wind power is utilized by meeting the load demand and supplying the excess power to DCM through PWM rectification of CCVSC without dissipating it through any dump load. During conditions of machine stall, the system amenably transfers power to AC loads by PWM inversion of CCVSC with fixed modulation index and frequency. When there is any fall in DCM voltage, DC voltage regulation is effected by the PWM rectification operation of CCVSC. To execute the reliable power transfer scheme, a supervisory control is employed for the automatic smooth change over in the modes of operation depending on load and wind availability. The successful operation of the system for various load/speed conditions is proved through extensive MATLAB based simulation and dSPACE 1104 controller based experimentation on a 500 W induction machine.

1. Introduction

Wind is an imperative energy to meet the energy demand in areas with high wind velocity. Nowadays, owing to the need of uninterrupted, clean and green power supply, generation moves from large conventional power plants to small renewable power plants increasing micro Renewable Energy (RE) grids [1,2].

In today's world, major loads such as, home appliances, LED lights, variable speed DC driven pumps and DC industrial loads demand DC supply. With suitable power electronic interfaces, many renewables are connected to a common DC bus thus framing a DC RE grid. Harmonic and reactive power less DC grids are an attractive amaze enabling the ease of connection of storage devices, hybrid vehicles, etc. [3–7]. DC grids with many renewable can play an effective role by operating in islanded mode when there is any issue on the main grid [8,9]. Nowadays, DC grids are also employed with converter interfaced wind generators, of which, Self-Excited Induction Generators (IG) gain fame owing to its rugged construction, absence of brushes and slip rings, simple maintenance [10,11]. DC grids play an effective role in providing voltage support by injecting reactive power as an ancillary service to the system. The supply of power to DC loads associated with DCM fed by hybrid excited IG is dealt in Refs. [12,13] with voltage control alone involving mathematical manipulations in the control algorithm.

Any wind energy system aims for stable and maximum power tracking (MPT) operation. MPT achievement for battery charging application through perturb and observe method along with various modes of operation as discussed in Refs. [14–16] suffers from limitation on charging. Intelligent method dealt in Refs. [17,18] to track maximum power lacks the knowledge of the system. When any modification is made in the system, the above method may fail to track the accurate maximum power. Few control methods involving various parameters are proposed in literature for supplying maximum power from IG to grid [19]. Due to voltage and frequency limitations of grid, the operating speed range is restricted leading to stress on machine and losses may also increase. Synchronization of IG voltage and frequency to the grid specifications using an impedance controller as discussed in Refs. [20,21] may also lead to machine stress and losses. The power management system for the stabilization of micro grid discussed in Refs. [22,23]

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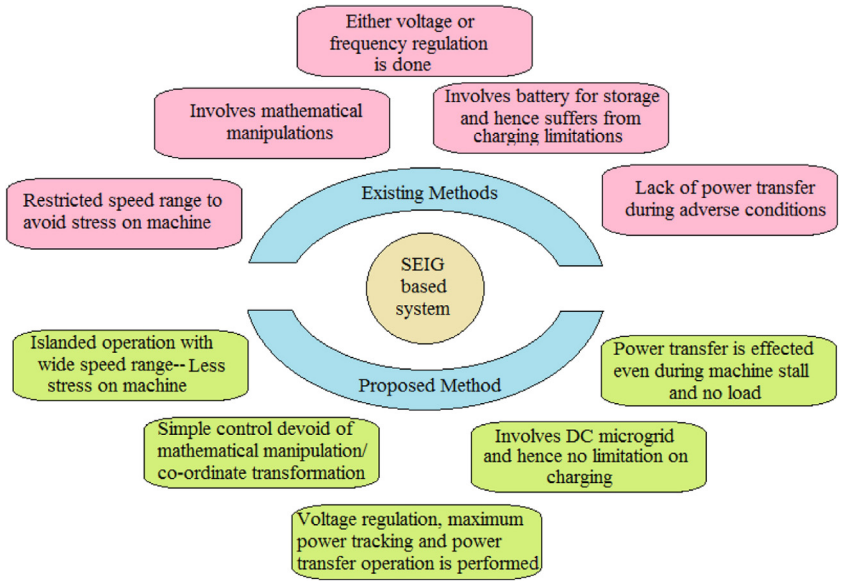

Fig. 1. Comparison between exiting methods and proposed method.

involves two different sources. However, single source is sufficient for stabilizing the micro grid during both islanded and grid connected modes. Literature reports only maximum power tracking operation in isolated IG and lacks voltage control operation [24–28]. In this paper, voltage regulation and maximum power extraction along with uninterrupted power supply in a single IG based system are dealt. In addition, power transfer even during conditions of machine stall and no load are also discussed.

Much research has been done on AC grid coupling and control rather than coupling to DC grid and MPT in an IG system. Most literature reports mainly the voltage regulation whereas MPT for an IG in a DCM system and effective power transfer during adverse conditions like stall and no load are not addressed extensively. The control algorithm discussed in this paper for an isolated, self-excited IG achieves voltage regulation, MPT, DCM voltage build up, power transfer during no load and machine stall and hence appeals the merit of this work. Here, hybrid excitation is provided with capacitor bank and CCVSC to meet the reactive power need of IG. The above mentioned objectives are achieved by a simple control algorithm comprising two loops with PI controllers to control voltage and to execute MPT. With voltage loop and MPT loop, reference currents are generated [29,30] and are compared with actual currents. Hysteresis controller processes the error thereby enabling CCVSC to operate effectively for wind speed/load variations. A comparison between the existing methodologies and the proposed method is given in Fig. 1.

In this study, the maximum generated power from IG is supplied to load/DCM/both by PWM rectification operation of CCVSC. During normal operation, the generated power meets the load demand and rest of power is supplied to DCM through PWM rectification operation of CCVSC. During condition of machine stall, DCM supplies load through PWM inversion. When there is any failure of power supply by other renewables to DCM, CCVSC builds the DCM voltage by PWM rectification. To analyze the dynamic operation of the setup, a smooth change over between the operations is made with a supervisory control algorithm. The analysis, discussions and results are presented in forthcoming sections.

The structure of this paper: Section 2 deals with the system description. In Section 3, the modeling of the system is discussed. The effective power transfer scheme is detailed along with the supervisory control scheme in Section 4. Section 5 holds the discussions on the performance of the system with the simulation and experimental results along with start-up procedure. Conclusions are summarized in Section 6.

2. System description

The schematic of wind driven self-excited IG delivering power to DCM is shown in Fig. 2. The system employs a squirrel cage induction machine coupled to a variable speed DC machine which emulates a wind turbine.

Irrespective of wind speed/load conditions, the variable speed IG is statically excited by means of a star-connected capacitor bank and dynamically by a three-leg, IGBT based bidirectional PWM CCVSC with its DC end connected to DCM. Hence, the IG is alleged to be hybrid excited. The capacitor bank helps in the self excitation of IG and during speed/load variations, the additional VAR required for voltage regulation will be supplied by the CCVSC. The stator is connected to switchable, frequency insensitive AC loads. To eliminate high frequency ripple components, the DC end of CCVSC holds a split capacitor arrangement whose mid-point is connected with the neutral of stator and capacitor bank thus forming the path, N-n'-n. When there is any unbalance/single phase loads at the stator, problems like poor voltage regulation and torque pulsations due to harmonics can be avoided as the bulk reactive need due to unbalance is supplied by CCVSC.

To achieve voltage regulation, maximum power extraction and to effect power transfer operation, a control principle is proposed which is detailed in Section 4. Detailed system specifications are given in Appendix A.

3. Modeling of the IG system

The system under study employs a squirrel cage IG, CCVSC and excitation capacitor. The modeling equations with which the system is modeled are detailed below.

3.1. Modeling of IG

The dynamic model of the IG is framed with the following equations and the simulation is carried out in stationary reference frame