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Overview of Voltage and Frequency Controlling Schemes for Isolated Self-Excited Induction Generator

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Abstract—*Wind energy conversion system incorporating self excited induction generators are commonly used nowadays for feeding power to remote areas by utilizing locally available renewable sources such as wind, small hydro power plants. These are considered best alternative to other types of generators such as PMSG, DFIG because of its low unit cost ,rugged brushless construction(in squirrel cage), absence of separate dc source for excitation ,ease of maintenance , inherent protection against severe overloads and short circuits and capability of production power even at changing wind speed etc. However, in order to overcome drawbacks of induction generator in isolated mode, increase the system efficiency, reliability and power quality up to optimum level wind energy conversion system equipped with induction generator necessitates using some type of control schemes. This paper first investigates the voltage build up process of SEIG corresponding to proper capacitor excitation, wind speed and then presents the overview of different voltage and frequency controlling schemes employing IGBT based VSC for isolated mode of operation of wind driven self excited asynchronous generator.*

Keywords*: Self excited induction generator; voltage and frequency controller; voltage source converter (VSC); isolated system; insulated gate bipolar transistor (IGBT).*

1. INTRODUCTION

Exponentially increasing power demands, depletion of conventional energy sources, high oil prices and environmental problems has led scientists and engineers to investigate safe and reliable non conventional energy source to meet power demands of present and future. Self-excited induction generators (SEIG) are well promising alternative among others for small and medium scale wind power plants with advantage of operation in both isolated and grid connection mode. However SEIG do have some drawbacks which includes poor voltage and frequency regulation at changing prime mover speed, load, size of capacitor bank for excitation and loading characteristics[3].The steady state voltage and frequency in isolated operation mode of induction generator depends upon the value of excitation capacitor, generator's magnetizing characteristics, nature of load and prime mover speed. The induction generator requires continuous supply of reactive power to maintain constant voltage at its output terminal. In case of constant prime mover speed such as diesel, gasoline engines as the speed of the IG remains constant therefore frequency remains constant but the voltage at the output terminal changes at changing load requirements. In grid connected mode both the voltage and frequency of IG remains same as that of the grid and IG draws reactive power from the grid. But in case of variable speed prime mover both frequency and voltage are varying under changing load requirements. Therefore the prime challenge for satisfactory operation of isolated SEIG is to control of voltage and frequency using suitable voltage and frequency controlling scheme under different variable condition. In literature several attempts has been made to maintain voltage and frequency constant at the output terminal of induction generator.

Inverted sine carrier pulse width modulation switching strategy is used in IGBT based 3 leg voltage source converter with battery connected to its dc link as in [4].

In this scheme controller has bidirectional flow capability of active and reactive powers by virtue of that it controls the system voltage and frequency under varying wind speed and load conditions. In the recent literature [5-7], Voltage source converter (VSC) with battery energy storage system (BESS) is employed for isolated WECS. In above schemes two control loops have been used for voltage and frequency respectively. Voltage control loop controls the reactive power and frequency control loop controls the active power for controlling frequency. Investigation has been made using single voltage closed loop control in [8] using VSC. Organization of this paper is as follow. Section II classifies different types of induction generators. Section III gives general description of WECS. Section IV provides information about the process of self excitation and voltage buildup in induction generator. Classification of different VF schemes is given in section V and section VI concludes the paper.

2. CLASSIFICATION OF INDUCTION GENERATORS

2.1. On the Basis of Rotor Construction

2.1.1. Wound rotor induction generator

2.2.2. Squirrel cage induction generator

2.2. Depending Upon the Prime Movers Used

2.2.1. Constant-speed constant-frequency (CSCF)

2.2.2. Variable-speed constant-frequency (VSCF)

2.2.3. Variable-speed variable-frequency (VSVF)

From above variable speed constant frequency scheme is preferred because of higher output at both high and low wind speed which results in higher annual energy production per rated installed capacity. Popular schemes to obtain constant frequency output from variable speed are AC–DC–AC Link, Double Output Induction Generator (DOIG) and use of shunt connected FACT devices for voltage and frequency control.

3. GENERAL DESCRIPTION OF ISOLATED WIND POWER CONVERSION SYSTEM

Fig. 1 shows schematic diagram of the system under study. The wind turbine is connected to the induction generator shaft through a step-up gear box. The excitation capacitor bank which can be connected in delta or star and consumer loads is connected across the generator stator terminals which may be linear/nonlinear/static/dynamic/three wire/four wire. Capacitor bank is usually shunt connected for the purpose of providing self excitation. As induction generator require continuous supply of reactive power for its operation another source of reactive power in addition to capacitor bank is necessary for its successful operation as generator. A shunt connected closed loop voltage source converter with or without battery is best alternative from other schemes present in literature. Bidirectional capability of igbt switches makes it possible to exchange both real and reactive power from the system in order to control both voltage and frequency.

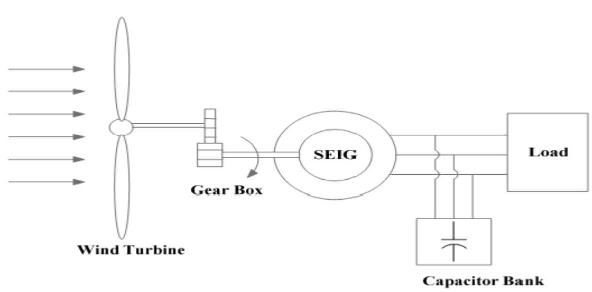

Fig. 1: Schematic diag. of general wind energy conversion system

4. PROCESS OF SELF EXCITATION AND VOLTAGE BUILDUP

When an induction machine is driven at a speed greater than the synchronous speed (negative slip) by means of an external prime mover, the direction of induced torque is reversed and it starts working as an induction generator. To build up voltage across the generator terminals, excitations must be provided by some means therefore, the induction generator can work in two modes (i.e., grid connected and isolated mode). For an isolated mode, there must be a suitable capacitor bank connected across the generator terminals. This phenomenon is known as capacitor self-excitation and the induction generator is called a "SEIG." To achieve a given voltage level in an induction generator, an external capacitor must be able to supply the magnetizing current of that level. Also there must be a suitable value of residual magnetism present in the rotor iron. In the absence of a proper value of residual magnetism, the voltage will not build up. So it is desirable to maintain a high level of residual magnetism. The operating conditions resulting in demagnetization of the rotor (e.g., total collapse of voltage under resistive loads, rapid collapse of voltage due to short circuit, etc. should be avoided [10]). The magnetization curve of the induction generator can be obtained by running the machine as a motor at no load and measuring the armature current as a function of terminal voltage. Fig. 2 shows the voltage build up process of isolated induction generator at constant wind speed of 12m/s and the with reactive power value of 2.5 KVAR for the 3.7 KVA induction machine. The waveform for generated voltage, current, wind speed, rotor speed, magnetizing inductance and magnetizing current are shown in fig.

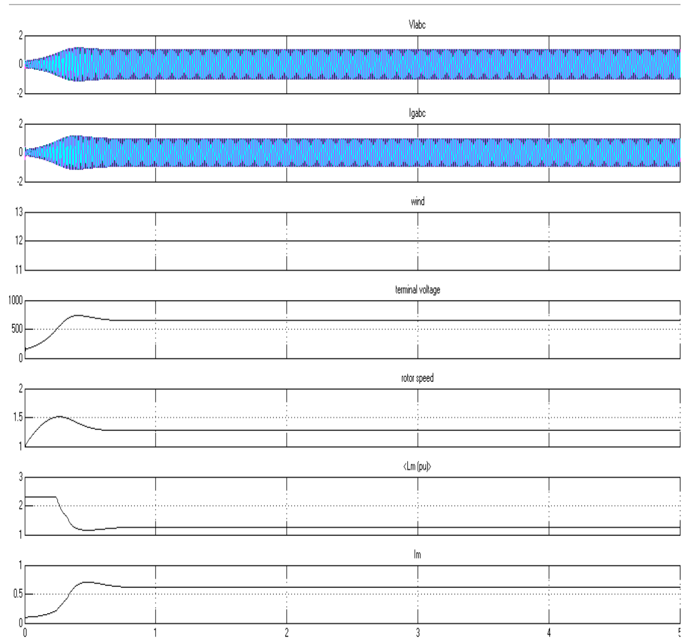

Fig. 2: Process of self excitation and voltage build up of SEIG

5. CLASSIFICATION OF VOLTAGE AND FREQUENCY CONTROL SCHEMES

Various configuration of VFCs are found in literature for isolated asynchronous generator (IAG) driven by wind turbine .Most of the VFCs are based on the IGBT based VSC with or without battery energy storage system. Depending upon the application (three-phase three-wire or three -phase four -wire consumer loads) these VFCs are mainly classified as follow.

5.1. VFCs for Three-Phase Three-Wire IAG Systems

Various types of three phase three-wire loads using IAGs are presented below-

5.1.1. Three-Leg VSC with BESS based VFC-The VFC shown in fig.2 consists of three leg IGBTs based VSC with a DC bus capacitor, DC chopper and AC inductors. The output of the VSC is connected through the AC filtering inductors to the IAG's terminal. The DC bus capacitor is used to filter voltage ripples and provides self-supporting DC bus. The DC chopper is used to control surplus power into the controller due to change in consumer loads [7]. The excitation capacitor is selected to generate the rated voltage at no load while additional demand of reactive power is met by the controller. This VFC serves the purpose of harmonic elimination, load balancing, load leveling and reactive power compensation.

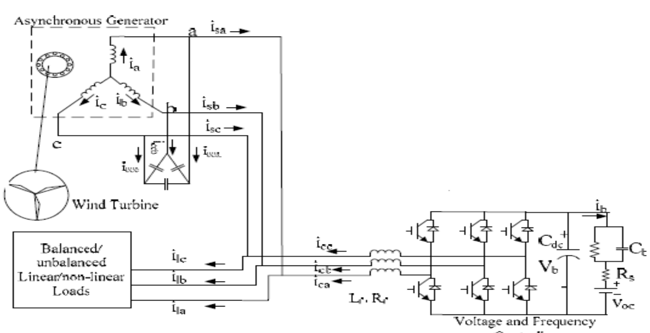

Fig. 3: Three leg VSC with BESS based VFC for three phase three wire system

5.1.2 Three leg VSC without BESS based VSC-This scheme[13] is same as that of above except presence of dump resistor(Rd) in place of battery.

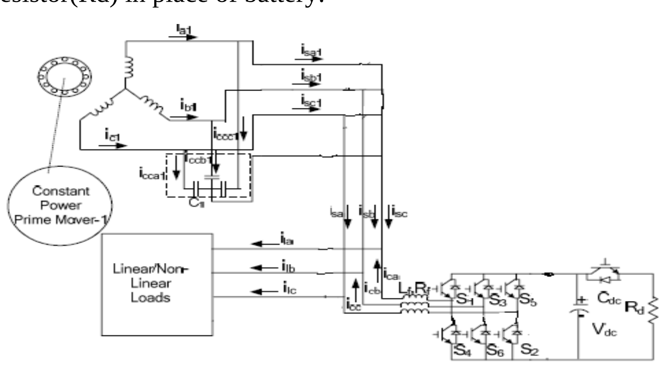

Fig. 4: Three leg VSC without BESS based VSC

The dump resistor is used to maintain the power balance in the system during change in load or wind speed. Switch is connected across dc link and in series with this resistor automatically turned on/off according to power demand. this scheme has drawback that excess generated power is wasted in dump load for regulation of frequency.

5.1.3. Two Leg VSC-Based VFC- In this scheme two-leg VSC-based VFC is utilized with battery at its dc link. Two legs of VSC are connected to the two phases and the third phase of the generator is connected to the midpoint of the two capacitors connected to make third leg. This VFC configuration requires less number of switches hence simplifies circuit.

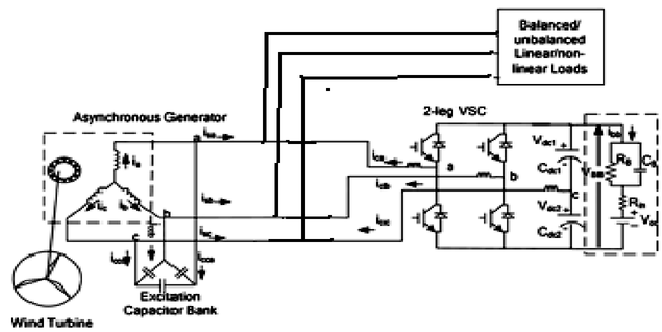

Fig. 5: Two-leg VSC with BESS-based VFC for a three-phase three-wire IAG system.

5.2 VFCs for a Three-Phase Four-Wire IAG System

Similar to VFCs for a three-phase three-wire IAG system VFCs for three-phase four- wire IAG system has various configurations of VSCs with/without BESS at its DC link for VF control. The advantage of using this three-phase four wire configuration is that the voltage rating of the battery is selected at an optimum level and the transformer provides the path for neutral current.

5.2.1. Three Single-Phase VSC as a VFC-This controller consist of three single-phase IGBT-based voltage source converters (VSC) with a battery at its DC link with each VSC connected to each phase of the generator through single-phase transformer as shown in fig.5 [6].

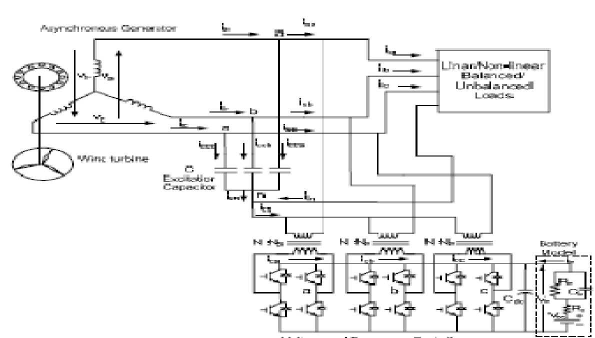

Fig. 6: Three single-phase VSC with BESS-based VFC for a three-phase four wire IAG system.

The neutral point for the load is created through neutral point of capacitor bank and transformer terminals. This scheme increases the number of switches to be used and hence is more complex.

5.2.2. Three Leg VSC with Midpoint Capacitors as a VFC- This system is made up of a three –phase four wire load. Three leg current controlled voltage source converter is used for control of voltage and frequency of the system. Neutral terminal for the load is created through the midpoint of a pair of capacitors connected in parallel to the BESS. This scheme is preferred because it reduces the number of power semiconductor devices used [10].

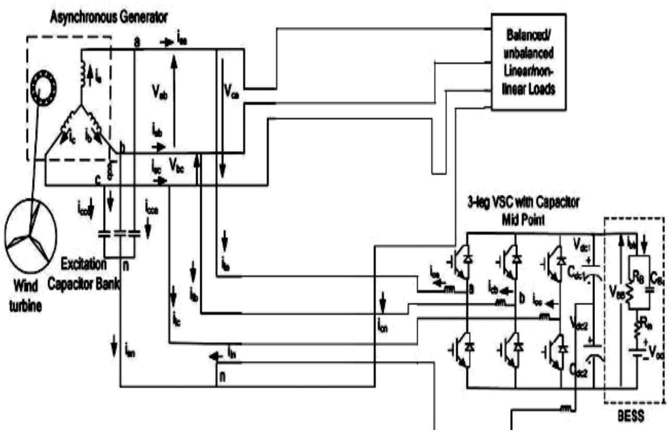

Fig. 7: Three-leg VSC and midpoint capacitor with BESS-based VFC for three phase Four-wire IAG system.

5.2.3. Three-Leg VSC with T connected transformer as a VFC-This scheme employs three leg voltage source converter with battery at its dc terminal with addition of T connected transformer to generate neutral terminal for the load. The neutral terminal of the T connected transformer connected to the consumer load this is the fourth leg of proposed VFC (shown in fig 6.) [12]. The transformer act as a path for a zero-sequence component of load current while VSC along with the battery serves the purpose of harmonic elimination and load balancing.

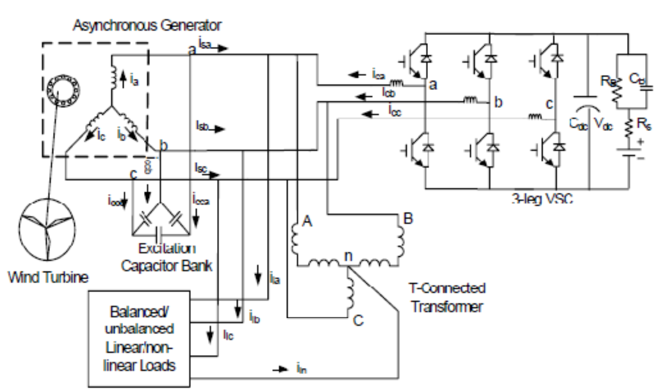

Fig. 8: Three-leg VSC with T-connected transformer based VFC for a three-phase four-wire IAG system.

5.2.4. Three leg VSC with star delta connected transformer-Instantaneous symmetrical component theory is implemented in [14] with three leg VSC having battery at its dc terminal. A star terminal of star delta transformer is used for neutral connection and delta terminal is used for connection of VSC with the main system. This scheme also functions as load balancer and harmonic eliminator.

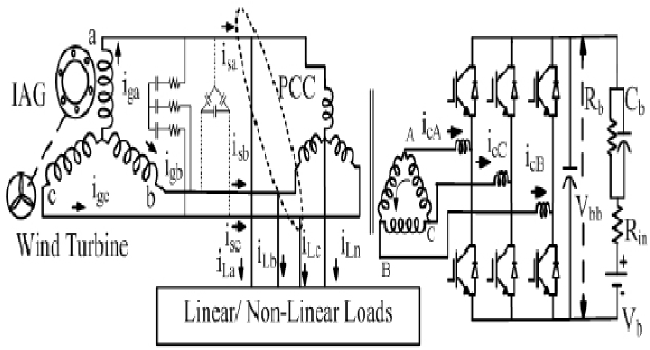

Fig. 9: Three leg VSC with star delta transformer for three phase four wire load

5.2.5. H-Bridge VSC with T-connected Transformer -Two leg VSC with T-connected transformer for three phase four wire load has been reported in [15]. In this scheme two phases are connected to the two legs of VSC while third phase is connected to the midpoint of the capacitor bank and neutral connection is taken from the T-connected transformer. Control scheme is based on the generation of reference source currents.

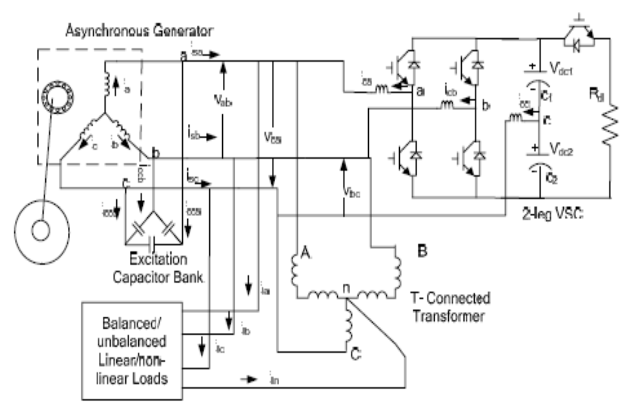

Fig. 10: Two leg VSC with T connected transformer for three phase four wire load

5.2.6. Four leg VSC for parallel operated induction generators-In [16] case of Parallel operation of induction generator is reported for pico hydro system. In this scheme four leg VSC without battery at its terminal is implemented. Fourth leg of VSC and star point of both the capacitor banks is utilized for the neutral connection. In this case excess generated power is dumped in dc chopper fed load resistor.

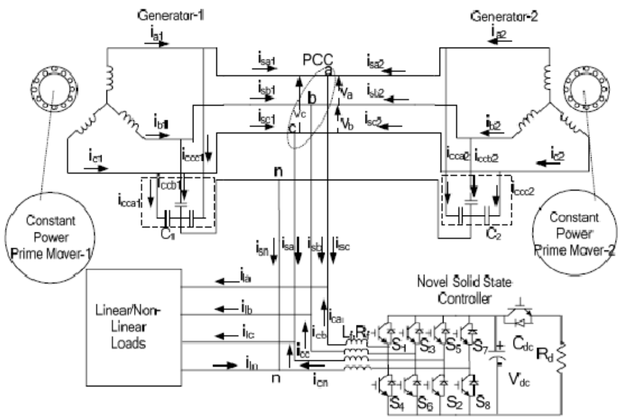

Fig. 11: Four leg VSC for VF control of parallel operated asynchronous generators.

6. CONCLUSION

Different types of VF controllers are presented and it is found that most of VF controlling schemes are based on IGBT based voltage source converter with battery connected to their DC terminals because of their addition advantage of harmonic compensator, load balancer .Depending upon the application (3 phase 3 wire, 3 phase 4 wire) a suitable VF scheme with appropriate value of dc link capacitor, dc link voltage, battery parameter, ac inductor can be chosen.

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