A STATCOM BASED CONTROL SCHEME FOR GRID CONNECTED WIND ENERGY SYSTEM FOR POWER QUALITY IMPROVEMENT DURING ASYMMETRICAL FAULTS

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***Abstract*—** With growing demand of electrical energy and limited availability of fossil fuels has led to the use of non-conventional sources (like Wind, Solar, Tidal etc.) which are abundant in nature and pollutant free. The brushless generation using Induction generator with excitation capacitor known as self-excited induction generators driven by constant speed prime movers are becoming more popular because of its low cost, ruggedness, low maintenance and no need of DC excitation system since last two decades. Moreover, these generators can also be operate as stand-alone system to provide electricity to isolated rural areas where transmission of power through grid is difficult and uneconomical. However the fundamental problem associated with such generation scheme are poor voltage regulation under varying load. In order to regulate its terminal voltage with varying load the active and reactive power levels at PCC (point of common coupling) have to be maintained constant.

The active and reactive power level are regulated by using modern power electronic converters. But survey shows that existing controllers are either difficult to implement or uneconomical or designed for particular load only. This thesis is intended to develop a STATCOM based voltage controller using PI controller for SEIG feeding both linear and non-linear loads driven by constant speed prime mover.

***Index Terms*— Wind Energy Conversion System, STATCOM, Power Quality Improvement.**

I. INTRODUCTION

With increasing demand for electrical power, more emphasis is given on the renewable source of energy for producing electrical power. The depletion of conventional fuels has led to the use of renewable sources of energy like solar, wind, biomass, tidal, etc. Of these, the wind energy is found to be most suitable, clean, abundant and economical form of the non-conventional sources.

Earlier Synchronous generators are used for power generation using wind energy. But their application is limited as they cannot produce electricity at variable speed, require separate DC excitation system and require more maintenance. But now the brushless generation using Induction generator are more commonly used. The induction generator can be used either in grid connected mode or in standalone mode as self-excited induction generators [2]-[10]. The operation of induction generator as standalone system is gaining more attention, as they can provide power to remote areas where it is difficult or uneconomical for power transmission line to supply power. Thus the advantage of using induction generator are low cost, ruggedness, low maintenance, simple operation, good dynamic response and no need of separate DC excitation system.

The SEIG are proved to be best candidate for generating electricity from wind because they don't need external power supply for excitation and hence can be operate in remote areas [30]-[35].

The main problem with SEIG is poor voltage regulation under varying loading conditions. They demand variable reactive power for voltage regulation under different loading conditions [3]-[8]. This work mainly deals with the investigation on voltage controller for SEIG driven by constant prime movers. In order to maintain the SEIG terminal voltage constant, the necessary reactive power as demanded by the load must be provided, for this purpose various controllers are developed which can provide reactive power [18]-[27].

Thus in order to regulate the SEIG terminal voltage and frequency both active and reactive power level at point of common coupling must be maintained constant. With the development of solid state power electronics converters, various controllers like static var compensation (SVC), static compensator (STATCOM) controller, and generalized impedance controller (GIC) have been developed for SEIG [1]-[10]. This thesis aims to investigate the STATCOM based voltage regulator for SEIG which is driven by constant speed prime mover feeding both linear and non-linear loads for wind energy application. Thus for maintaining the SEIG terminal voltage constant, the necessary capacitive power demanded by the excitation system of the generators.

II. Literature Survey

There are several research in the field of modeling, steady state performance and transient analysis of SEIG as an isolated power generation. Earlier induction machines are commonly used as motors and its application as a generator is very rare. However, the application of induction machine as a self-excited induction generator is first discovered by Basset and Potter et al. [1]. Basset proposed the process of voltage built up using induction machine with the help of capacitor self-excitation. Induction machine can be operated as generator if sufficient amount of inductive VAR is given to machine, to provide machine excitation at particular speed. The dynamic model of SEIG is based on d-q reference frame models based on machine model developed by Krause [11]. Novotny et al. [12] developed a model for induction generator in synchronously rotating d-q reference frame under steady state operation. The only demerit with this model is that this can be used under steady state analysis only, not for transient analysis. Bahrain et al. [13] described that there is minimum and maximum value of capacitor with in which the machine will excite at no load for particular speed. Also it shows that there is a critical value of load impedance below which machine will not excite for any value of capacitor. Wang et al. [14] represented the dynamic d-q model of SEIG which shows that with variation in loads the generator voltage varies, but it does not show any relation regarding the dynamic speed of rotor when generator is loaded. The effect of magnetizing inductance on self-excitation is discovered by Seyomut et al. [15] and the loading analysis of an isolated induction generator is also presented and discusses how the operating frequency and generated voltage are affected by taking only resistive load.

This thesis proposed the analysis and development of STATCOM based voltage controller for SEIG feeding driven by constant speed prime movers feeding linear and non-linear loads. The STATCOM consist of current controlled voltage source inverter (CC-VSC) and two conventional PI controller. This controller provide voltage regulation for both balanced or unbalanced load and linear or non-linear loads.

III. Modelling of SEIG

The dynamic model of SEIG is developed using stationary q-d reference frame considering both main and cross flux saturation. The schematic diagram of SEIG is illustrated in Fig. 1 with capacitor bank, load and prime mover. The schematic q-d diagram of three phase SEIG along with balanced three phase excitation and load connected across its terminal is shown in Fig.

2. For development of self-excited induction generator model, the q-d arbitrary reference frame model of the machine is transformed into stationary reference frame model.

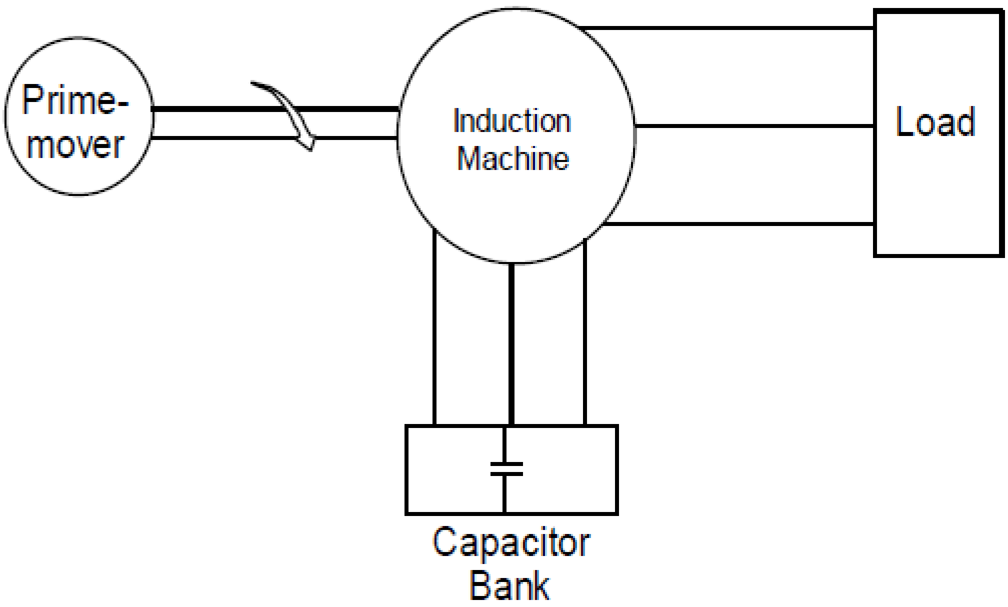


Fig. 1 Schematic diagram of SEIG

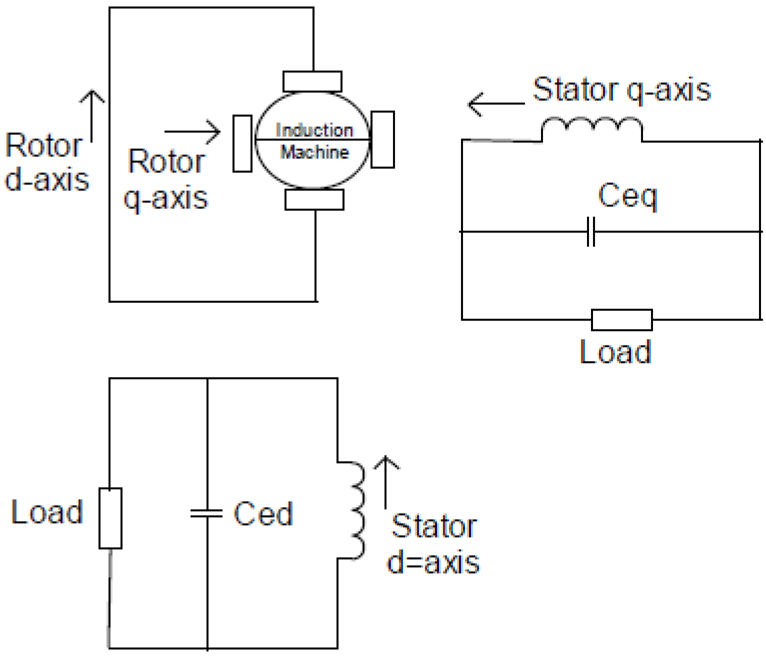


Fig. 2 q-d axis diagram of SEIG

For the two phase machine as shown in Fig. 3, we need to represent both stator and rotor variables in stationary reference frame. The stator equation in stationary reference frame is represented as

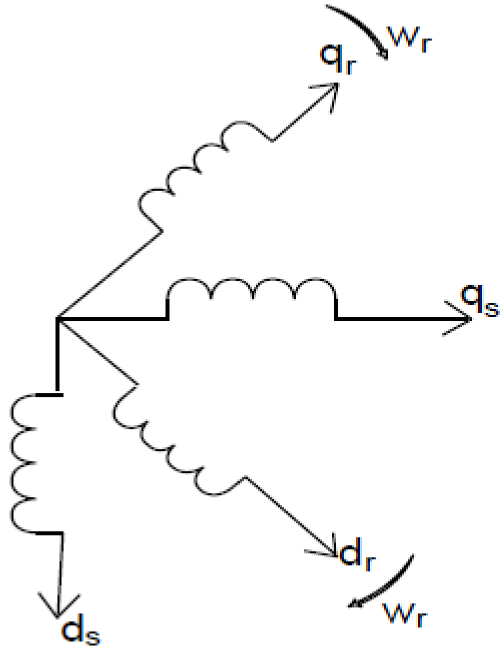


Fig. 3 Equivalent two phase machine

$$v_{qs}^{s} = R_s i_{qs}^{s} + \frac{d}{dt}\varphi_{qs}^{s} \quad (1)$$

$$v_{ds}^{s} = R_s i_{ds}^{s} + \frac{d}{dt}\varphi_{ds}^{s} \quad (2)$$

The rotor equation in stationary equation are

$$v_{qr}^{s} = R_r i_{qr}^{s} + \frac{d}{dt}\varphi_{qr}^{s} - \omega_r \varphi_{dr}^{s} \quad (3)$$

$$v_{dr}^{s} = R_r i_{dr}^{s} + \frac{d}{dt}\varphi_{dr}^{s} + \omega_r \varphi_{qr}^{s} \quad (4)$$

The equation given above are of general induction machine.

The steady state model of self-excited induction machine is illustrated in Fig. 4. The initiation of voltage build process and its sustenance depends on several parameters, such as load, the capacitance value, the residual flux and speed. Thus for self-excitation of SEIG, a capacitor bank of suitable value must be connected across the machine terminals, the core of machine must retain some amount of residual flux. The capacitor is used to provide necessary reactive power, which can produce magnetizing flux necessary for developing the voltage. But self-excited induction generator shows variation in its terminal voltage with variation in load.

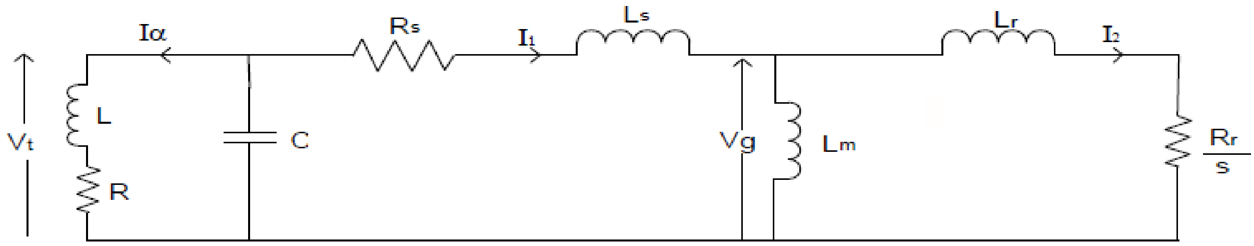


Fig. 4 Steady-state circuit model of self-excited induction generator

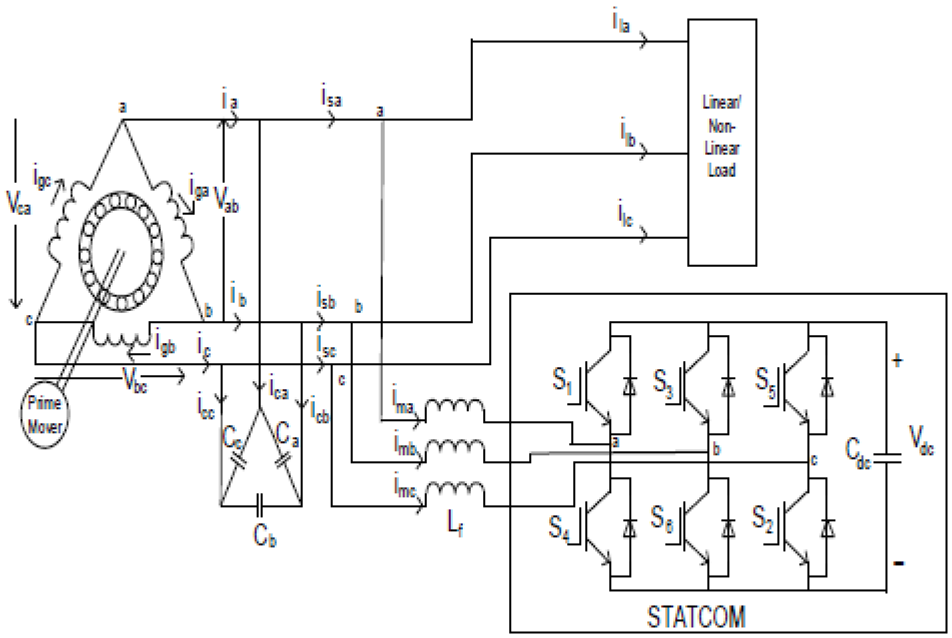
IV. Modelling Based STATCOM Based SFIG

we have seen that will sudden application of load or change in rotor speed causes the variation in SEIG terminal voltage. For regulating voltage various controllers are developed by researchers [15]-[28]. Earlier attempts were made for regulating the voltage of SEIG by using thyristor controlled inductor and fixed capacitor [20], and short-shunt connections of capacitor [21]. But the voltage control provided by this type of controllers are discrete in nature and produces harmonics in the voltage waveform. With the advent of solid state devices, the control of SEIG terminal voltage has become more effective and reliable, as it can provide variable reactive power to generator and load to keep the terminal voltage constant with varying load conditions. Geng e.al. [23] Proposed the direct voltage control (DVC) strategy using PI regulator with a feed-forward compensator and lead-lag corrector. But its implementation is very complex because of design of lead-lag corrector and complexity involve in feed-forward compensator. Singh et al. [38] has proposed a static synchronous series compensator (SSSC) and static compensator (STATCOM) to feed static and dynamic load. These controllers are not designed for non-linear loads, also the dynamic response of controller is very poor.

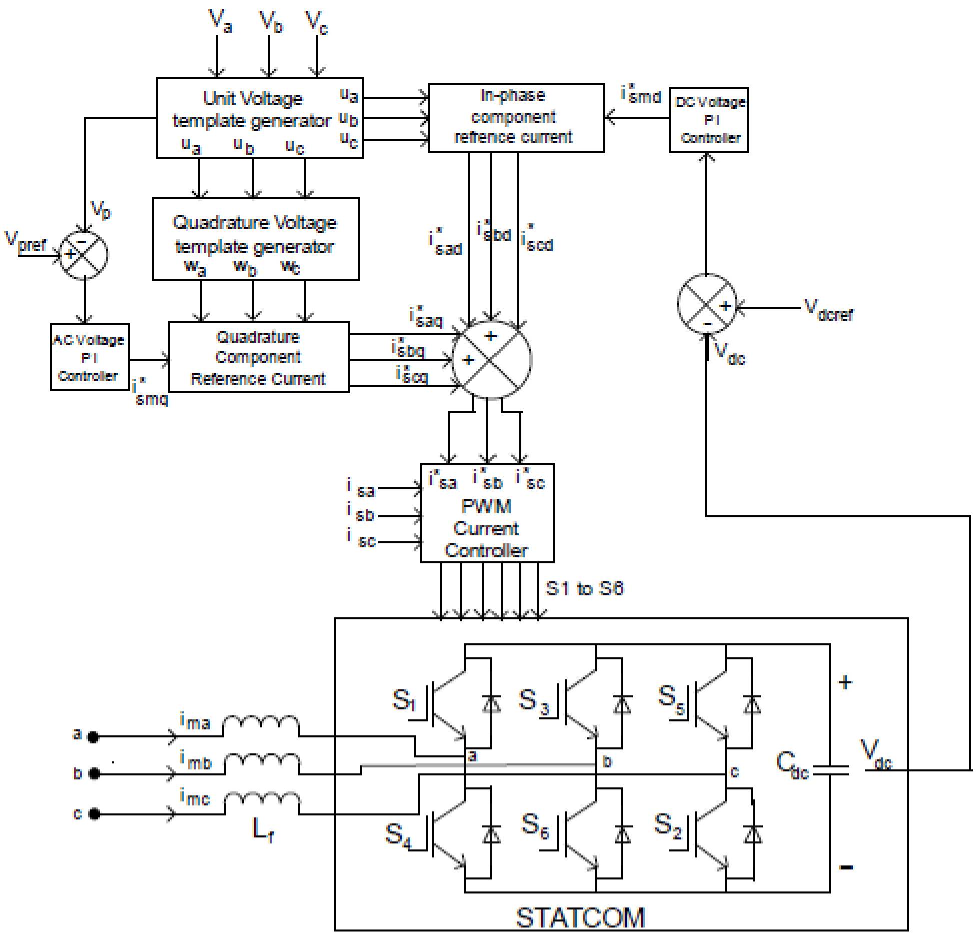
This section present the analysis and development of STATCOM based voltage regulator for SEIG using conventional PI Controller feeding balanced or unbalanced load or linear and non-linear loads. The STATCOM eliminates the harmonics present in the system, it also provide load balancing and reactive power fulfillment as demanded by load and generator.

STATCOM

The STATCOM consist of three phase current controlled voltage source inverter (CC-VSI) with IGBTS used as switches, a dc bus capacitor, ac inductors (for removing harmonics) and two conventional PI controller. The excitation capacitors in SEIG are used to generate the rated voltage of SEIG at no load. When load is applied, the additional demand of reactive power of load is fulfilled by STATCOM. The STATCOM acts as source of leading or lagging power supply depending on loading conditions. The dc bus capacitor act as energy storage device and provide reactive power as demanded by load. The block diagram of STATCOM with SEIG 7is shown in Fig. 5 along with control scheme applied to STATCOM for generating the gate signals.



(a)



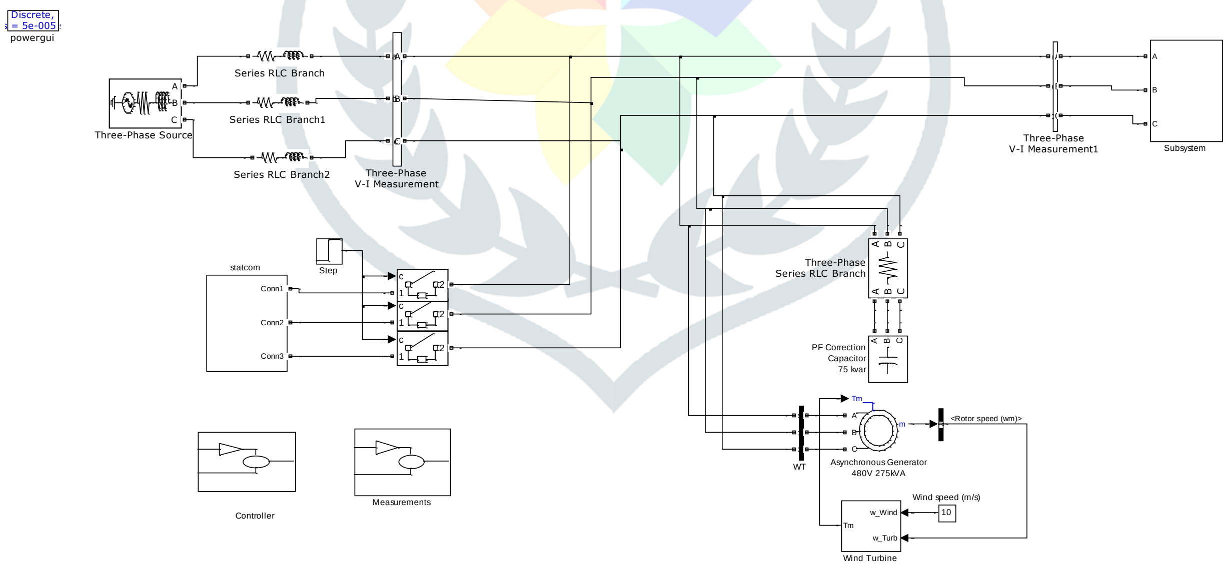
(b)

Fig. 5(a) Schematic diagram of SEIG-STATCOM system, (b) Control scheme applied to SEIG-STATCOM

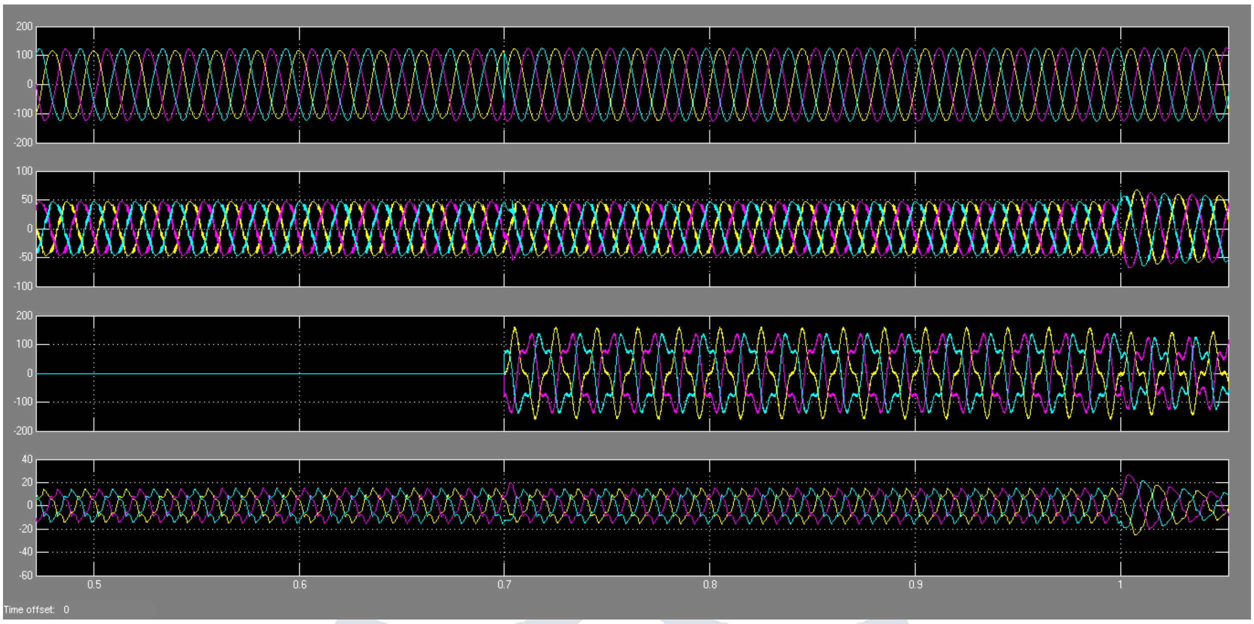
For controlling the voltage of SEIG, the source current is controlled which composed of two component in phase component and quadrature component. For maintaining the terminal voltage constant of SEIG, two control loops are deployed in

STATCOM for generating reference supply current. The in-phase unit vectors are three phase sinusoidal functions of unit amplitude (ua, ub, uc). These are computed by diving three phase ac voltage(va, vb, vc) by their amplitude Vp. The quadrature unit vectors are also three phase unit sinusoidal functions (wa, wb, wc) , which are computed from in-phase vectors. There are two conventional PI controllers employed for maintaining the SEIG voltage constant. One PI controller sensed the input error, computed from the difference of reference ac voltage ($Vpref$) with amplitude of ac voltage (Vp). The output of obtained from this ac PI controller is taken as reference peak value of quadrature supply current component ($ismq*$), this current ($ismq*$) decided the amplitude of reactive current which is generated by the STATCOM. The quadrature unit vectors (wa, wb, wc) are multiplied with the output of ac voltage PI controller ($ismq*$) which generates the quadrature component ($isaq*, isbq*, iscq*$). of the reference supply current. The STATCOM uses capacitor as a dc bus which provided necessary reactive power requirement to the SEIG. The value of capacitor voltage (Vdc) is sensed and fed to comparator along with the dc reference voltage ($Vdcref$). The error is given to another conventional PI controller known as dc PI controller. The output of this PI controller yields reference peak in-phase supply current component ($ismq*$). This component ($ismq*$) decides the amplitude of the active power component of source current. The in-phase component ($isad*, isbd*, iscd*$) of reference supply current are generated by the multiplication of in-phase (ua, ub, uc) unit vectors with the output of dc PI controller. The sum of quadrature ($isaq*, isbq*, iscq*$) reference current and in-phase ($isad*, isbd*, iscd*$) reference current gives the reference source current ($isa*, isb*, isc*$). The reference source currents then compared with the sensed source line currents ($isa, isb, and\ isc$) and the error is given to pulse width modulation (PWM) current controller to generate switching signals for IGBTs used in VSI. Non-linear loads draw non-sinusoidal currents which composed of both fundamental as well as harmonics components of current. This non-sinusoidal current causes to inject harmonics in the systems and resulting in distortion of terminal voltage. Unbalanced loads draws unbalanced currents (composed of negative and positive sequence components) due to which the machine has to be used under derated condition. But the STATCOM filter out the harmonics and balances the unbalanced load, resulting in sinusoidal voltage and current of SEIG and also regulating its terminal voltage.

Simulation of SEIG-STACOM with PI Control in MATLAB/SIMULINK



Simulink Circuit



(a) Source Current. (b) Load Current. (c) Inverter Injected Current. (d) Wind generator (Induction generator) current.

VI. CONCLUSION

The MATLAB based model of SEIG is developed in q and d stationary reference frame. The SEIG develops its terminal voltage with the help of excitations capacitors. But with application of load, terminal voltage falls down from its rated value. A STACOM based voltage regulator is developed for regulating the SEIG voltage in MATLAB. The proposed scheme for maintaining the voltage of SEIG constant is simple and easy to implement. The STATCOM improves the voltage regulation by injection of compensation currents. The STATOM is design for various loads like linear/ non-linear, balanced/unbalanced. From the simulation result it has been found that the non-linear load injects harmonics in the system, which are also eliminated by STATCOM. Hence it is concluded that STATCOM can act as voltage regulator, load balancer and harmonic eliminator.

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