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SIMULATION OF ISOLATED WIND – HYDRO HYBRID SYSTEM USING CAGE GENERATORS AND BATTERY STORAGE

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ABSTRACT

Power Generation from Renewable energy sources like wind, solar, geothermal, biomass, and hydro is predominant now days and among the renewable energy sources, small hydro and wind energy have the ability to complement each other. For Power generation by small or micro hydro as well as wind systems, the use of squirrel-cage induction generators (SCIGs) is mostly adopted. As regards in recent years, wind turbine technology has switched from fixed speed to variable speed because of the several advantages like i.e. reduction in mechanical stresses, dynamically compensate for torque and power pulsations, improve power quality and system efficiency. In Modern there are still few many isolated locations which cannot be connected to the grid and where the wind potential and hydro potential exist simultaneously. For such locations , a " NEW ISOLATED WIND – HYDRO HYBRIDSYSTEM USING CAGE GENERATORS AND BATTERY STORAGE" is Proposed , employing one squirrel-cage induction generator (SCIG) driven by a variable-speed wind turbine and another SCIG driven by a constant-power hydro turbine along with BESS feeding three-phase four-wire loads. So the main objectives of the control algorithm for the VSCs are to achieve maximum power tracking (MPT) through rotor speed control of a wind-turbine-driven SCIG under varying wind speeds and control of the magnitude and the frequency of the load voltage. The proposed wind-hydro hybrid system has a capability of bidirectional active- and reactive-power flow, by which it controls the magnitude and the frequency of the load voltage. The design procedure for selection of various components for analyzing performance of the proposed hybrid system has been demonstrated under different electrical (consumer load variation) and mechanical (with wind-speed variation) dynamic conditions.

Index Terms — Battery energy storage system (BESS), small hydro, squirrel-cage induction generator (SCIG), wind-energyconversion system (WECS).

1. INTRODUCTION

Renewable energy sources have attracted attention worldwide due to soaring prices of fossil fuels. Renewable energy sources are considered to be important in improving the security of energy supplies by decreasing the dependence on fossil fuels and in reducing the emissions of greenhouse gases. The viability of isolated systems using renewable energy sources depends largely on regulations and stimulation measures. Renewable energy sources are the natural energy resources that are inexhaustible, for example, wind, solar, geothermal, biomass, and small hydro generation. Among the renewable energy sources, small hydro and wind energy have the ability to complement each other generation by small or microhydro as well as wind systems, the use of squirrel-cage induction generators (SCIGs) has been reported in literature. The water powers a turbine, and its rotational movement is transferred through a shaft to an electric generator. When SCIG is used for small or microhydro applications, its reactivepower requirement is met by a capacitor bank at its stator terminals.

The SCIG has advantages like being simple, low cost, rugged, maintenance free, absence of dc, brushless, etc., as compared with the conventional synchronous generator for hydro applications.

2. SYSTEM DESCRIPTION AND MODELLING

In the case of grid-connected systems using renewable energy sources, the total active power can be fed to the grid. For standalone systems supplying local loads, if the extracted power is more than the local loads (and losses), the excess power from the wind turbine is required to be diverted to a dump load or stored in the battery bank. Moreover, when the extracted power is less than the consumer load, the deficit power needs to be supplied from a storage element, e.g., a battery bank. In the case of stand-alone or autonomous systems, the issues of voltage and frequency control (VFC) are very important. In [16]–[18], the authors have addressed the issues of VFC for stand-alone systems using SCIGs. Some work has also been reported for stand-alone WECSs using doubly fed induction generator. In, a battery-based controller is proposed for control of voltage and frequency in the isolated WECS. The proposed control algorithm for load-side converter requires sensing of the load voltage and stator currents of SCIGh.

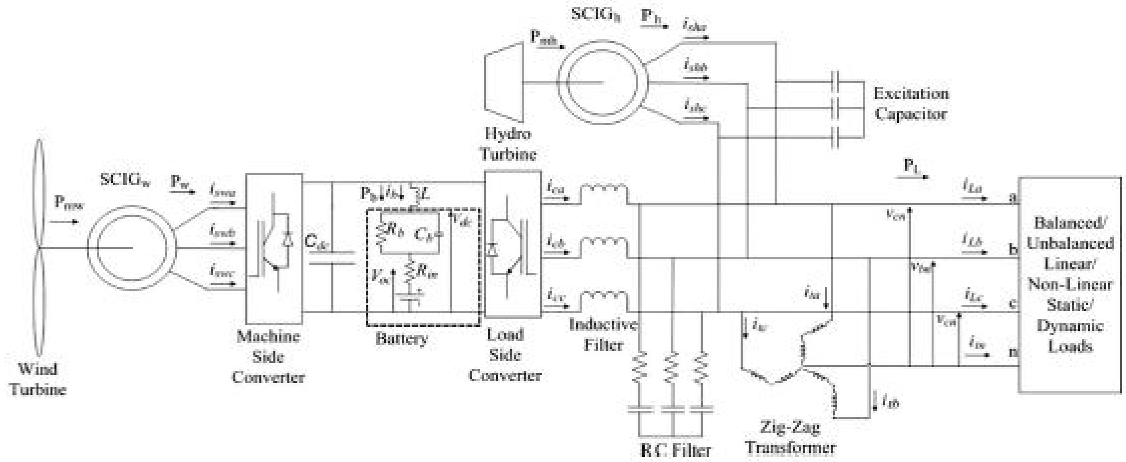

Fig. 1. Schematic diagram of wind–hydro hybrid system.

A novel control strategy using indirect current control is proposed for the load-side converter. The control signals for switching of the load-side converter are generated from the error of the reference and the sensed stator currents of SCIGh rather than by the errors of the load-side converter currents. With this control strategy, the switching of the load-side converter is controlled to make the SCIGh currents balanced and sinusoidal at the nominal frequency.

3. PRINCIPLE OF OPERATION

As already stated, the proposed system uses two back-to- back-connected PWM-controlled IGBT-based VSCs. These VSCs are referred to as the machine (SCIG$_w$) side converter and load-side converter. The objectives of the machine (SCIG$_w$) side converter are to provide the requisite magnetizing current to the SCIG$_w$ and to achieve MPT, and the objective of the load-side converter is VFC at the load terminals by maintaining active- and reactive-power balance. The operating principle of the controller for the machine (SCIG$_w$) side converter is based on the decoupled control of *d*- and *q*-axes stator currents of the SCIG$_w$ with the *d*-axis aligned .

4. CONTROL ALGORITHM

As already mentioned in Section II, the objectives of the machine (SCIG$_w$) side converter are to achieve MPT and to provide the required magnetizing current to the SCIG$_w$, and the objective of the load-side converter is to control the magnitude and the frequency of the load voltage. The detailed control algorithm for the two converters is described in the following sections.

Control of Machine (SCIG$_w$) Side Converter

The objectives of the machine (SCIG$_w$) side converter are to achieve optimum torque for MPT for SCIG$_w$ and to provide the required magnetizing current to the SCIG$_w$. The control strategy for the machine (SCIG$_w$) side converter control is shown in Fig. 5. The tip speed ratio (λ_w) for a wind turbine of radius r_w and gear ratio η_w at a wind speed of V_w is defined as

$$\lambda_w = \frac{\omega_{rw} r_w}{\eta_w V_w}. \quad (1) \qquad \omega^*_{rw} = \lambda^*_w V_w \eta_w / r_w. \quad (2)$$

The reference rotor speed of SCIG$_w$ is compared with ω_{rw} to calculate the rotor-speed error (ω_{rwer}) at the *n*th sampling instant as and integral gain $K_{i\omega}$ gives the reference *q*-axis SCIG$_w$ stator current ($I\square_{qsw}$) as

$$\omega_{rwer(n)} = \omega^*_{rw(n)} - \omega_{rw(n)}. \quad (3) \qquad \begin{aligned} I^*_{qsw(n)} &= I_{qsw(n-1)} \\ &+ K_{p\omega}\left(\omega_{rwer(n)} - \omega_{rwer(n-1)}\right) + K_{i\omega}\omega_{rwer(n)}. \end{aligned} \quad (4)$$

Reference d-axis SCIG$_w$ Stator-Current Generation:

The reference *d*-axis SCIG$_w$ stator current ($I\square_{dsw}$) is determined from the rotor flux set point ($\square\square_{drw}$) at the *n*th sampling instant as

$$I^*_{dsw(n)} = \phi^*_{drw} / L_{mw} \quad (5) \qquad \theta_{\text{rotorfluxw}} = \theta_{\text{slipw}} + \left(\frac{p_w}{2}\right)\theta rw \quad (6)$$

where L_{mw} is the magnetizing inductance of SCIG. For generation of three-phase reference SCIG$_w$ stator currents ($i\square_{swa}$, $i\square_{swb}$, and $i\square_{swc}$), the transformation angle $\theta_{\text{rotorflux}w}$

where $\theta_{\text{slip}w}$ is the slip angle, which is generated by integrating the slip frequency ($\omega_{\text{slip}w}$) as

$$\theta_{\text{slip}w(n)} = \int \omega_{\text{slip}w(n)} dt. \quad (7) \qquad \omega_{slipw(n)} = \left(R_{rw} I^*_{qsw(n)}\right) / \left(L_{rw} I^*_{dsw(n)}\right) \quad (8)$$

The references for $d - q$ components of SCIG$_w$ stator currents ($I\square_{dsw}$ and $I\square_{qsw}$) are converted to three-phase reference SCIG$_w$ stator currents ($i\square_{swa}$, $i\square_{swb}$, and $i\square_{swc}$) by $d - q$ to *abc* transformation using angle $\theta_{\text{rotorflux}w}$ as

$$\begin{aligned} i^*_{swa} &= I^*_{dsw}\sin(\theta_{\text{rotorfluxw}}) \\ &\quad + I^*_{qsw}\cos(\theta_{\text{rotorfluxw}}) \end{aligned} \quad (9) \qquad \begin{aligned} i^*_{swb} &= I^*_{dsw}\sin(\theta_{\text{rotorfluxw}} - 2\pi/3) \\ &\quad + I^*_{qsw}\cos(\theta_{\text{rotorfluxw}} - 2\pi/3) \end{aligned} \quad (10)$$

$$\begin{aligned} i^*_{swc} &= I^*_{dsw}\sin(\theta_{\text{rotorfluxw}} + 2\pi/3) \\ &\quad + I^*_{qsw}\cos(\theta_{\text{rotorfluxw}} + 2\pi/3). \end{aligned} \quad (11)$$

Control of Load-Side Converter

The objectives of the load-side converter are to maintain rated voltage and frequency at the load terminals irrespective of connected load. The power balance in the system is maintained by diverting the surplus power generated to the battery or by supplying power from the battery in case of deficit between generated power and load requirement.

Generation of Reference Three-Phase SCIG$_h$ Currents:

The reference voltages ($v\square_{an}$, $v\square_{bn}$, and $v\square_{cn}$) for the control of the load voltages at time *t* are given as

$$v^*_{an} = \sqrt{2}V_t\sin(2\pi ft) \quad (12) \qquad v^*_{bn} = \sqrt{2}V_t\sin(2\pi ft - 120^0) \quad (13)$$

$$v^*_{cn} = \sqrt{2}V_t\sin(2\pi ft + 120^0) \quad (14)$$

The load voltages (v_{an}, v_{bn}, and v_{cn}) are sensed and compared with the reference voltages. The error voltages ($v_{an\text{err}}$, $v_{bn\text{err}}$ and $v_{cn\text{err}}$) at the *n*th sampling instant are calculated as

$$v_{anerr(n)} = \left\{v^*_{an(n)} - v_{an(n)}\right\} \quad (15) \qquad v_{bnerr(n)} = \left\{v^*_{bn(n)} - v_{bn(n)}\right\} \quad (16)$$

$$v_{cnerr(n)} = \left\{v^*_{cn(n)} - v_{cn(n)}\right\}. \quad (17)$$

The reference three-phase SCIG$_h$ currents ($i\square_{sha}$, $i\square_{shb}$, $i\square_{shc}$) are generated by feeding the voltage error signals to PI voltage controller with proportionate gain K_{pv} and integral gain K_{iv} as

$$\begin{aligned} i^*_{sha(n)} &= i_{sha(n-1)} + K_{pv}(v_{anerr(n)} - v_{anerr(n-1)}) \\ &\quad + K_{iv}v_{anerr(n)} \end{aligned} \quad (18) \qquad \begin{aligned} i^*_{shb(n)} &= i_{shb(n-1)} + K_{pv}(v_{bnerr(n)} - v_{bnerr(n-1)}) \\ &\quad + K_{iv}v_{bnerr(n)} \end{aligned} \quad (19)$$

$$\begin{aligned} i^*_{shc(n)} &= i_{shc(n-1)} + K_{pv}(v_{cnerr(n)} - v_{cnerr(n-1)}) \\ &\quad + K_{iv}v_{cnerr(n)}. \end{aligned} \quad (20)$$

The reference three-phase SCIG$_h$ currents are then compared with the sensed SCIG$_h$ currents (i_{sha}, i_{shb}, and i_{shc}) to compute the SCIG$_h$ current errors as

$$i_{shaerr} = i^*_{sha} - i_{sha} \quad (21) \qquad i_{shberr} = i^*_{shb} - i_{shb} \quad (22) \qquad i_{shcerr} = i^*_{shc} - i_{shc}. \quad (23)$$

5. DESIGN OF SCIG-BASED WIND-HYDRO HYBRID SYSTEM

The system is designed for an isolated location with the load varying from 30 to 90 kW at a lagging power factor (PF) of 0.8. The average load of the system is considered to be 60 kW. *Selection of Voltage of DC Link and Battery Design* The dc-bus voltage (V_{dc}) must be more than the peak of the line voltage for satisfactory PWM control. Thevenin's model is used to describe the energy storage of the battery in which the parallel combination of capacitance (C_b) and resistance (R_b) in series with internal resistance (R_{in}) and an ideal voltage source of voltage 700 V are used for modeling the battery in which the equivalent capacitance C_b is given as

$$V_{\text{dc}} > \left\{2\sqrt{(2/3)}V_{\text{ac}}\right\}m_a \quad (24) \qquad C_b = \frac{(\text{kW}\cdot\text{h}^*3600^*1000)}{0.5\,(V^2_{\text{oc max}} - V^2_{\text{oc min}})}. \quad (25)$$

$$L_f = \left\{(\sqrt{3}/2)m_aV_{\text{dc}}/\left(6af_sI_{r(p-p)\text{lsc}}\right)\right\} \quad (26) \qquad P_m = 0.5C_p\pi r^2\rho V_w^3. \quad (27)$$

In (27), C_p is a function of tip speed ratio λ and blade-pitch angle β [28] as

$$c_p(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.002^*\beta - 13.2\right)e^{-(18.4/\lambda_i)} \quad (28) \qquad \frac{1}{\lambda_i} = \frac{1}{(\lambda + 0.08\beta)} - \frac{0.035}{\beta^3+1}. \quad (29)$$

Computation of Controller Gains

The gains of the controllers are obtained using Zeigler–Nichols step-response technique [29]. A step input of amplitude (*U*) is applied, and the response is obtained for the open-loop system. The gains of the controller (K_p and K_i) are computed using the following equations:

$$K_p = \left|\frac{1.2U}{GT}\right| \quad (30) \qquad K_i = \left|\frac{0.6U}{GT^2}\right|. \quad (31)$$

6. MATLAB-BASED MODELING

A simulation model is developed in MATLAB using Simulink and Sim Power System set toolboxes. The simulation is carried out on MATLAB version 7 with ode3 solver. The electrical system is simulated using Sim Power System. The different loads are modeled using resistive and inductive elements and diode-rectifier-fed resistive loads combined with an *LC* filter. The unbalanced load is modeled using breakers in individual phases. The developed MATLAB model for the wind-hydro hybrid system is shown in Fig. 2.

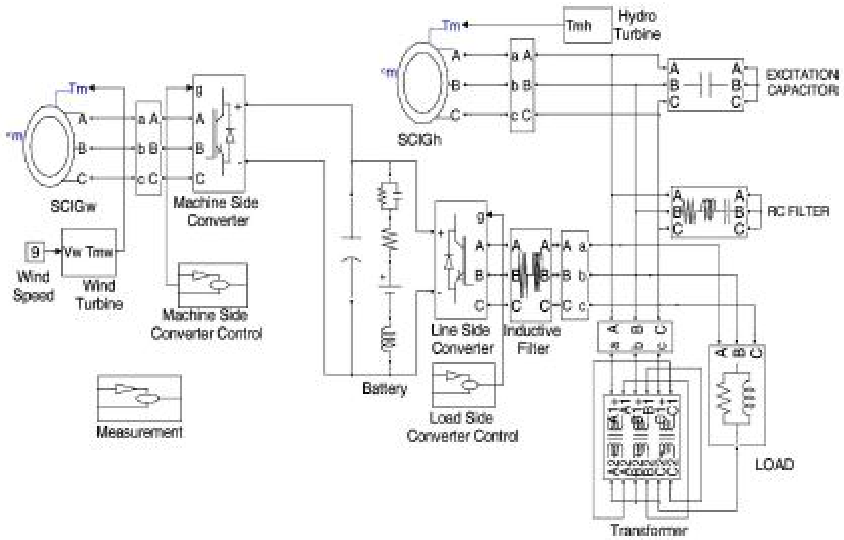

Fig. 2. MATLAB simulation diagram of wind–hydro hybrid system.

To demonstrate the harmonic-elimination capability of the system under these conditions, the THDs of the SCIG*w* stator currents, SCIG*h* stator currents, load voltages, and the load currents are given in Table I.

	Non-linear load in phases a, b and c			Non-linear load in phases b and c			Non-linear load in phase c		
	a	b	c	a	b	c	a	b	c
Load Current THD	35.12	35.11	35.29	-	35.85	35.90	-	-	36.52
Load Voltage THD	3.49	3.50	3.49	2.28	2.43	2.42	1.09	1.20	1.42
SCIG$_w$ Current THD	0.52	0.63	0.63	0.66	0.66	0.64	0.64	0.63	0.63
SCIG$_h$ Current THD	2.09	1.94	2.07	1.68	2.19	1.65	2.29	2.38	2.46

TABLE 1 - Percentage Thd Of Generator Voltage, Current, And Consumer Load Current Under Balanced/Unbalanced Nonlinear Load

7. CONCLUSION

Among the renewable energy sources, small hydro and wind energy have the ability to complement each other. Further, there are many isolated locations which cannot be connected to the grid and where the wind potential and hydro potential exist simultaneously. For such locations, a new three-phase fourwire autonomous wind-hydro hybrid system, using one cage generator driven by wind turbine and another cage generator driven by hydro turbine along with BESS, has been modeled and simulated in MATLAB using Simulink and Sim Power

System tool boxes. The design procedure for selection of various components has been demonstrated for the proposed hybrid system. The performance of the proposed hybrid system has been demonstrated under different electrical (consumer load variation) and mechanical (with wind-speed variation) dynamic conditions. It has been demonstrated that the proposed hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency. Moreover, it has shown capability of MPT, neutral-current compensation, harmonics elimination, and load balancing.

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