AUTONOMOUS MICRO-HYDRO POWER SYSTEM FOR DISTRIBUTED GENERATION: A POWER QUALITY ANALYSIS

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Abstract— Small scale hydro power generation is becoming an attractive energy alternative for remote areas. They are mostly run-of-river type which is coupled to fixed speed conversion systems while regulating the water flow rate mechanically. A synchronous generator based micro-hydro system with diesel generator is developed in this paper. To eliminate all mechanical adjustments a power conditioning system (PCS) is proposed. Power conditioning system comprises of a back-to-back ac/dc/ac static converter through which grid connection can be made. This proposed design is simple, reliable, and efficient. FFT analysis is done and THD is analyzed at load and inverter. Using MATLAB Simulink based simulations topology and dynamic performance of the proposed system is validated.

Index Terms— Micro-hydro, synchronous generator, Isolated system, power quality analyzer, FFT analysis, DG.

I. INTRODUCTION

Distributed generating systems are coming out to be into one of the most promising ways to cater the electrification requirements of isolated consumers all over the world. In all distributed generating alternatives, micro-hydro power systems are considered as the most consolidated ones. Renewable energy systems (i.e. systems not connected to the utility grid) can be considered as an effective way to provide continuous power to isolated loads. For isolated loads, sufficient power generation involves using a micro-hydro turbine with DG to create a stand-alone system is one practical approach. [1-4].

Both synchronous (SG) and induction (IG) types of ac generators are suitable for micro-hydro power generation. Induction generators are less common but are increasingly being used in small schemes. The voltage of a simple synchronous generator falls very rapidly with load. An AVR (automatic voltage regulator) must therefore be provided to control the dc field current to stabilize the voltage. The frequency of a synchronous generator is directly related to shaft speed. A larger-size IG costs more than a synchronous generator of same rating.

Depending upon the generator size, full-load efficiency of synchronous generators may vary from 75 to 90%.

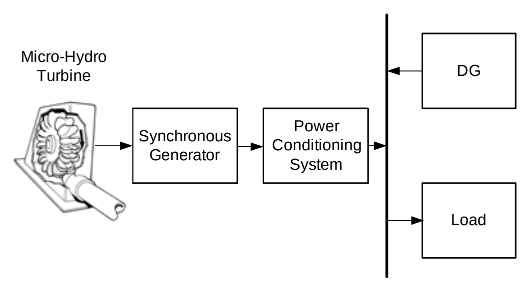

Fig 1: Block diagram of proposed system

In case of induction generators efficiency varies approximately from 75% at full load to as low as 65% at part load. These figures are very important for generator selection because it affects the overall efficiency of the system.

Motor loads require high-surge power during start-up which cannot be supplied by IGs in standalone mode [5-6]. Above mentioned problems can be solved by using multi-pole direct-driven generators, i.e. generator driven at the turbine speed without gearbox [7].

In this paper a SG based isolated micro-hydro power system is modeled and simulated using MATLAB [8-9]. A full detailed modeling and a novel control scheme of a isolated micro-hydro power generation system is proposed here.

The proposed micro-hydro power generation system model consists of a micro-hydro turbine directly coupled to a synchronous generator and an electronic power conditioning system consisting of a ac/dc/ac static converter connected back-to-back [10]. Power quality improvement analysis is done using power quality analyzers and FFT analysis.

II. BLOCK DIAGRAM

Fig. 1 shows isolated power system consisting of micro-hydro turbine, Synchronous generator (50Hz, 1500rpm, 400V), Converter system, DG (8.1kVA, 1500rpm, 400V) (Backup) and load 40kW.

III. MATHEMATICAL NONLINEAR MICRO-HYDRO POWER GENERATION MODEL

Mathematical modeling is done for isolated micro-hydro power generation system using Pelton hydro turbine. For high heads and low water flow rate Pelton turbines are used.

Hydro-electric system components are classified mainly into two groups. One is hydraulic system components including the turbine, penstocks, tunnel and surge tank. Other is the electric system components including the synchronous generator.

A. *Hydraulic system modeling*

The Hydro power output, as the turbine model is based on equations for steady state operation, is given by,

$$P_t = \rho g Q_t H_e \tag{1}$$

Where,

P_t = turbine power,

ρ = water density,

Q_t = water flow,

H_e = effective head.

In case of Pelton turbine, it becomes:

$$P_t = \rho Q_t V_t (V_1 - V_2)(1 + m\cos\beta) \tag{2}$$

Where, V_t = drive speed of the turbine, V_1 = water speed in the contact of the jet with the buckets, m = report of V_1 and V_2, β = angle between V_1 and V_2.

B. *Electrical system modeling*

The generator is synchronous machine, model is considered as a classical fourth-degree model as given below:

$$E_d = I_q (x_d' - x_q) / (1 + sT'_{qo}) \tag{3}$$

$$E_q = I_d (x_d' - x_d) / (1 + sT_{do}) + E_{fd} / (1 + sT_{do}') \tag{4}$$

Where, E_d = direct axis transient voltage, I_q = quadrature axis armature current, x_d' = direct axis transient reactance, x_q = quadrature axis reactance of generator, T'_{qo} = quadrature axis open circuit time constant, E_q = quadrature axis transient voltage, I_d = direct axis armature current, x_d = direct axis synchronous reactance, T_{do}' = direct axis open circuit time constant, E_{fd} = direct axis field voltage.

1. *Mechanical system modeling*

$$\Delta\acute{\omega} = (P_m - P_e) / (D + sM) \tag{5}$$

$$\delta = \acute{\omega}_0 \Delta\acute{\omega} / s \tag{6}$$

Where:- $\acute{\omega}$ = angular speed, P_m = generator input power, P_e = electrical output, D = damping coefficient, M = inertia constant of generator, δ = rotor angular position, $\acute{\omega}_0$ = base angular speed.

2. *Exciter Modeling*

$$E_{fd} = (V_{tr} - V_t - V_s) K_E / (1 + sT_E) \tag{7}$$

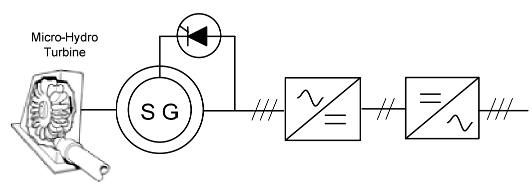

Fig. 2. Variable speed synchronous generator with AC-DC-AC converter block diagram

$$V_s = E_{fd}\, sK_F / (1 + sT_{FE}) \tag{8}$$

Where, V_{tr} = reference value of the terminal voltage, V_t = generator terminal voltage, V_s = stabilizing transformer voltage, K_E = exciter gain, T_E = time constant of exciter, K_F = current gain of stabilizer, T_{FE} = time constant of stabilizer circuit.

3. Terminal equations

$$V_{td} = E_d' - R_a I_d - x_d' I_q = -V_0 \sin\delta + R_e I_d + x_e I_q \quad (9)$$

$$V_{tq} = E_q' - R_a I_q - x_d' I_d = V_0 \cos\delta + R_e I_q - x_e I_d \quad (10)$$

$$P = E_d' I_d + E_q' I_q \quad (11)$$

Where,
V_{td} = direct axis component of terminal voltage,
R_a = armature resistance, V_0 = infinitive bus voltage,
R_e = total equivalent resistance of transmission lines,
x_e = total equivalent reactance of transmission lines,
V_{tq} = quadrature axis component of terminal voltage.

IV. POWER CONDITIONING SYSTEM

For efficient, flexible, reliable and high quality electric power generation a good power conditioning system (PCS) is needed. Fig. 2 shows proposed PCS which consist of ac/dc/ac converters connected back-to-back that fulfils all the requirements stated above.

As synchronous generator is directly connected to variable speed hydro turbine, generator output voltages have variable amplitude and frequency. As per the demand of the grid a controller is required to fulfill the amplitude and frequency requirements.

As three-phase uncontrolled full-wave rectifier robust, simple and cheap and also don't require any control. To perform AC/DC conversion a three-phase uncontrolled full-wave rectifier bridge is used. A three-phase voltage source inverter (VSI) using IGBTs is used for AC/DC conversion and finally grid connection. Output voltage of VSI can be controlled through pulse width modulation (PWM) techniques. To reduce the high-frequency switching harmonics generated by the PWM control technique and perturbation on the distribution system, a low pass filter is used.

The proposed configuration reduces inverter current rating, improves performance and hence reduces the cost of whole system.

A. *Uncontrolled Three Phase Rectifier modeling*

Variable voltage, variable frequency alternating current output from synchronous generator can be converted to direct current by using three phase uncontrolled rectifier. The rectifier output voltage is given by,

$$V_r = 3\sqrt{3} V_{td}/\pi \quad (12)$$

If we assume rectifier current output to be continuous and ripple-free, the rectifier DC output power is given by,

$$P_d = V_r I_r \quad (13)$$

Where: V_r: DC output voltage of the rectifier, I_r: DC output current of the rectifier.

If we neglect losses in the rectifier, the rectifier DC output power is equal to the rectifier AC input power and is given by,

$$V_r I_r = 3(V_{tq} I_{qL} + V_{td} I_{dL})/2 \quad (14)$$

The direct axis of rectifier input current may be expressed by

$$I_{dL} = 2\sqrt{3} I_r/\pi \quad (15)$$

B. *DC Filter Modeling*

When rectifier is used to convert AC power to DC, there is undesirable component of AC in DC output. This AC component can be filtered out from the output by using DC filter. The DC filter is comprised of a series reactor and shunt capacitor. The voltage at the capacitor terminals is given by,

$$dV_{dc}/dt = (I_r - I_{in})/C \quad (16)$$

The current through the inductor, is given by:

$$dI_r/dt = (V_r - V_{in})/L \quad (17)$$

Where: V_{in}= Inverter input voltage, V_r=Output voltage of the rectifier, I_r= Current through the inductor, I_{in}= Inverter side current, C & L are capacitance of capacitor and inductance of inductor respectively.

C. *Pulse Width Modulation Inverter Modeling*

The DC bus voltage is converted to 50Hz AC voltage by sinusoidal PWM inverter. The analysis of modulation phase voltage can be done by using Fourier analysis. Only the fundamental harmonic of the inverter is considered here. The fundamental harmonic of the inverter output voltage is given by,

$$V_{1ph}(t) = mV_{dc}\sin(\acute{\omega}t)/2 \qquad (18)$$

Where, V_{ph1} represents fundamental harmonic of the phase voltage and m the modulation index.

For simplification of the analysis, the initial orientation of quadrature axis is assumed to be coinciding with the output voltage axis. Hence, quadrature and direct axis components of inverter output voltage of the inverter (line to neural) are as given below,

$$V_{qinv} = V_{iphm} = mV_{dc}/2$$
$$V_{dinv} = 0 \qquad (19)$$

If we assume lossless inverter and harmonic components of the output waveform are negligible. Then, the DC input and AC output power of the inverter are equal,

$$V_{dc}I_{in} = 3V_{qinv}I_{qinv}/2 \qquad (20)$$

The quadrature component of inverter output current may be expressed as,

$$I_{qinv} = 4I_{in}/3m \qquad (21)$$

V. Simulation and Results

The proposed system is modeled and simulated using MATLAB environment. The configuration includes the micro-hydro turbine, synchronous generator, a back-to-back AC-DC-AC converter, DG (8.1kVA), power quality analyzer, RL-load.

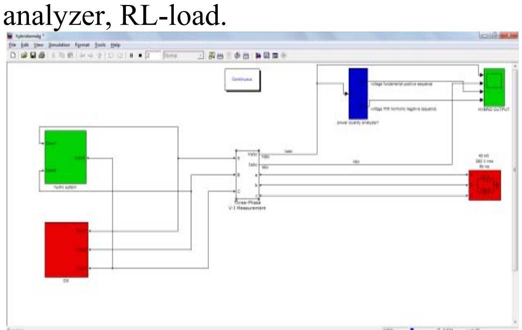

Fig 3: MATLAB/Simulink model of isolated Micro-Hydro generator/DG supplying the load

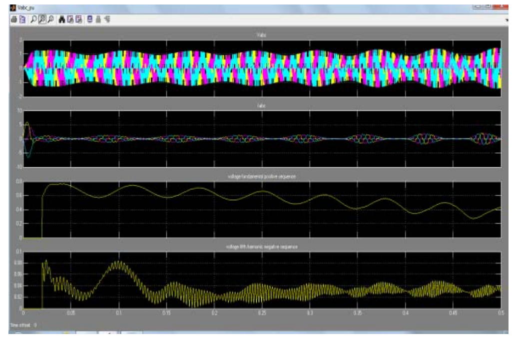

Fig 4: Three phase voltage, current, voltage fundamental positive sequence and 5th negative sequence waveform using power quality analyzer (at generator terminal) of micro-hydro system supplying RL-Load

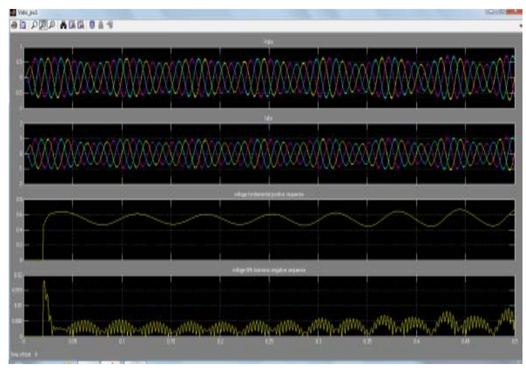

Fig 5: Three phase voltage, current, voltage fundamental positive sequence and 5th negative sequence waveform using power quality analyzer 1(at load) of micro-hydro system supplying RL-Load

Fig 6: V_{dc}, V_{ab} inverter, Vab load and modulation index of micro-hydro system supplying RL-Load.

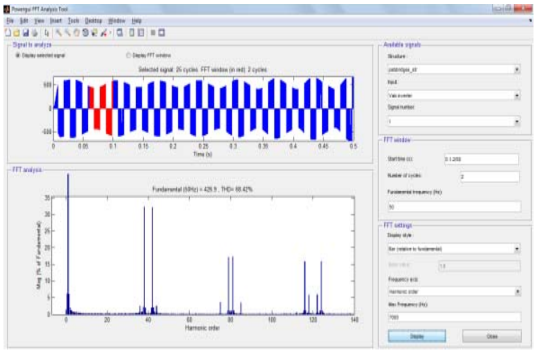

Fig 7: Display selected signal and FFT Analysis (bar relative to fundamental) of Vab inverter of micro-hydro system

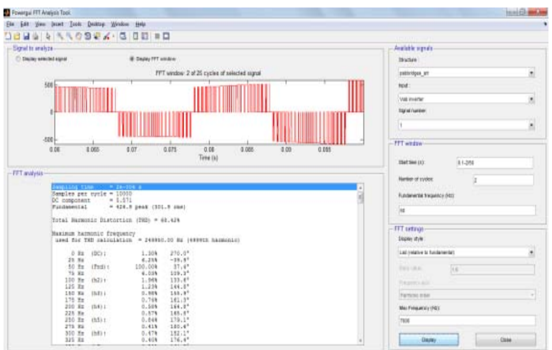

Fig 8: Display FFT window and FFT Analysis (list relative to fundamental) of Vab inverter of micro-hydro system

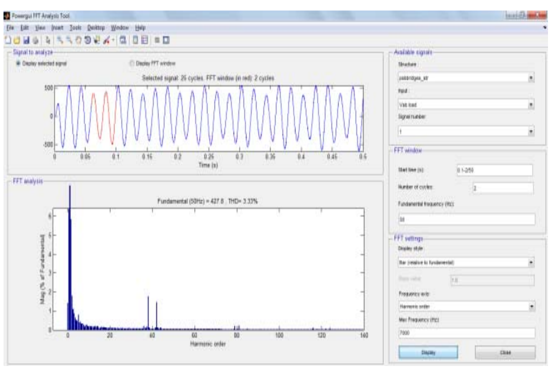

Fig 9: Display selected signal and FFT Analysis (bar relative to fundamental) of Vab load of micro-hydro system.

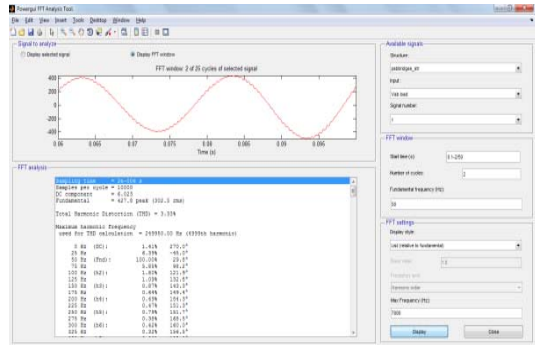

Fig 10: Display FFT window and FFT Analysis (list relative to fundamental) of Vab load of micro-hydro system

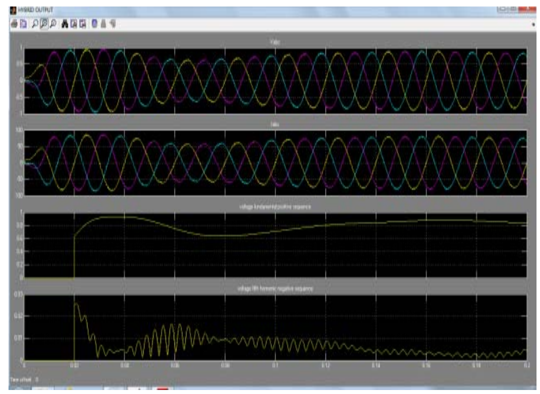

Fig 11: Three phase voltage, current, voltage fundamental positive sequence and 5th harmonic negative sequence waveform of power quality analyzer of hybrid micro-hydro/DG system supplying R-Load.

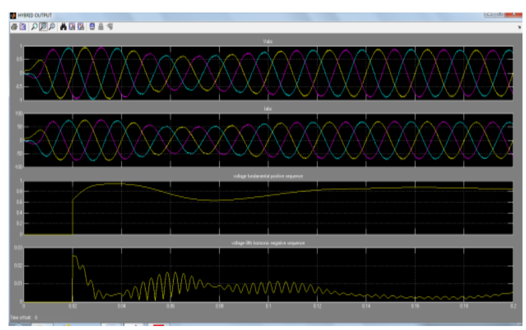

Fig 12: Three phase voltage, current, voltage fundamental positive sequence and 5th harmonic negative sequence waveform of power quality analyzer of hybrid micro-hydro/DG system supplying RL-Load.

Total harmonic distortion in Vdc, Vab inverter and Vab load are 74.92%, 68.42% and 3.33% respectively (using FFT analysis) in micro hydro power generation system supplying R-load respectively.

VI. CONCLUSION

The In this paper, an isolated system which consists of micro-hydro turbines and DG has been proposed to realize a robust, efficient, and economical system configuration using renewable energy sources. This can satisfy the basic electricity needs of remote communities where people don't have access to electricity or transmission cost is too high. The best sizing of the system according to the load demand and energy availability is done. With the enhanced performance of proposed control techniques and fast response of power electronic devices full advantages of the isolated micro-hydro power generation system can be obtained.

By using software modelling of a micro energy system provides an in-depth understanding of the system operation. The total harmonic distortion in Vab load are 3.33% (using FFT analysis) in micro-hydro power generation system supplying RL-load. The voltage 5th harmonic negative sequence is small. The topology and dynamic performance of the proposed system has been demonstrated and validated by using MATLAB Simulink based simulations.

APPENDIX

I : SG parameter for micro hydro power system

S.NO.	PARAMETER	RATING
1	POWER	42.5 kVA
2	FREQUENCY	50 Hz
3	VOLTAGE	400 V
4	SPEED	1500 RPM
5	Rs	0.04807815 ohm
6	Xd	2.19 ohm
7	Xd'	0.17 ohm
8	Xd''	0.11 ohm
9	Xq	1.01 ohm
10	Xq''	0.14 ohm

II: Synchronous generator parameters for DG

S.NO.	PARAMETER	RATING
1	POWER	8.1 kVA
2	FREQUENCY	50 Hz
3	VOLTAGE	400 V
4	SPEED	1500 RPM
5	Rs	.0820125 ohm

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