A micro-hydropower system model with PD load frequency controller for Resort Islands in the South China Sea

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Abstract. A model of high-penetration micro-hydropower system with no storage is presented in this paper. This technology is designed in order to reduce the diesel fuel consumption and cost of electricity supply in a resort island located in the South China Sea. The optimal hydropower generation for this system depends on the available stream flow at the potential sites. At low stream flow, both the micro-hydropower system and the currently installed diesel generators are required to feed the load. However, when the hydropower generation exceeds the load demand, the diesel generator is shut down. Meanwhile, the system frequency is controlled by a secondary load bank that absorbs the hydropower which exceeds the consumer demand. This paper also presents a discrete frequency control system using proportional-derivative (PD) controller. The controller is employed in order to manipulate the system frequency by controlling the secondary load system. The simulation results indicate that a variety of load conditions can be satisfactorily controlled by the PD controller. Hence, this particular type of controller is suitable to be implemented in micro-grid systems for remote areas that require low cost and easy-to- maintain controllers.

1. Introduction

The resort island selected for this study is Tioman, as it represents the typical energy requirements of many resort islands in the South China Sea. It is situated at 2°47'47"N latitude and 104°10'24"E longitude. The island's geographical conditions, such as its hilly landscape and abundant stream flows from highland areas permits the installation of run-of-river hydropower system [1]. The renewable energy (RE) assessment for Tioman Island had been previously assessed by several researchers. Ashourian et al. proposed an optimal combination of solar energy and wind energy for the Juara village of Tioman Island [2]. Meanwhile, Chik et al. performed sustainability indicators to determine sustainability degree for solar, wind and hydro resources on the island [3]. Both of the studies performed only RE assessments and did not consider the system level modeling of an RE system for the island based on actual assessed RE resources. This paper will provide a detailed system level model of a run-of-river hydropower that has the potential to be installed on the island, based on the available hydropower resources of the island.

In previous work [1], energy audit and the surveys of available hydro resource potentials in Tioman Island were conducted. The results show that, based on annual average hydropower estimation, a total of 10 potential sites have been identified to have run-of-river hydropower potential from 26 investigated sites on Tioman Island. Therefore, it is suitable to develop a run-of-river hydropower system in order to mitigate the diesel fuel consumption on the island.

Secondary load controller (SLC) is required in the micro-grid systems to dissipate the excess hydropower and maintain the system's stability. The controller maintains a constant generator output by providing a secondary load. There are several advantages of SLC [4], such as the incorporation of a cheaper and simpler turbine with less moving parts in the run-of-river hydropower system architecture. The SLC also provides high reliability, low maintenance, and a simple operating system that can be installed anyplace in the electrical system. Therefore, SLC is the prominent solution for regulating the induction generator output voltage and frequency for run-of-river hydropower system supplying rural load with cost-effectiveness as the primary factor.

2. System level run-of-river hydropower model

The run-of-river hydropower Simulink SimPowerSystems model is shown in figure 1. The hydro turbine model uses general hydropower equation as in equation 1 to compute the turbine mechanical power (P_m).

$$P_m = Q \times h \times g \times e_f \quad (1)$$

where P_m is theoretical power output from turbine (kW), h is gross head height (m), g is gravitational constant (9.81 m/s^2), and e_f is the efficiency factor (assumed as 0.7 [1]). The turbine mechanical power is then converted to turbine torque output (T_m) as an input to the asynchronous generator.

The grid voltage is controlled at its nominal value by the synchronous condenser and its excitation system. The secondary load block is designed to absorb the excess power generated by the hydropower system. The secondary load system architecture comprised of eight sets of three-phase resistors connected in series with Gate turn-off thyristor (GTO) switches. The nominal power of each set follows a binary progression in order for the load to be varied from 0 to 446.25 kW by steps of 1.75 kW. Meanwhile, the system's frequency is controlled by the discrete frequency regulator block.

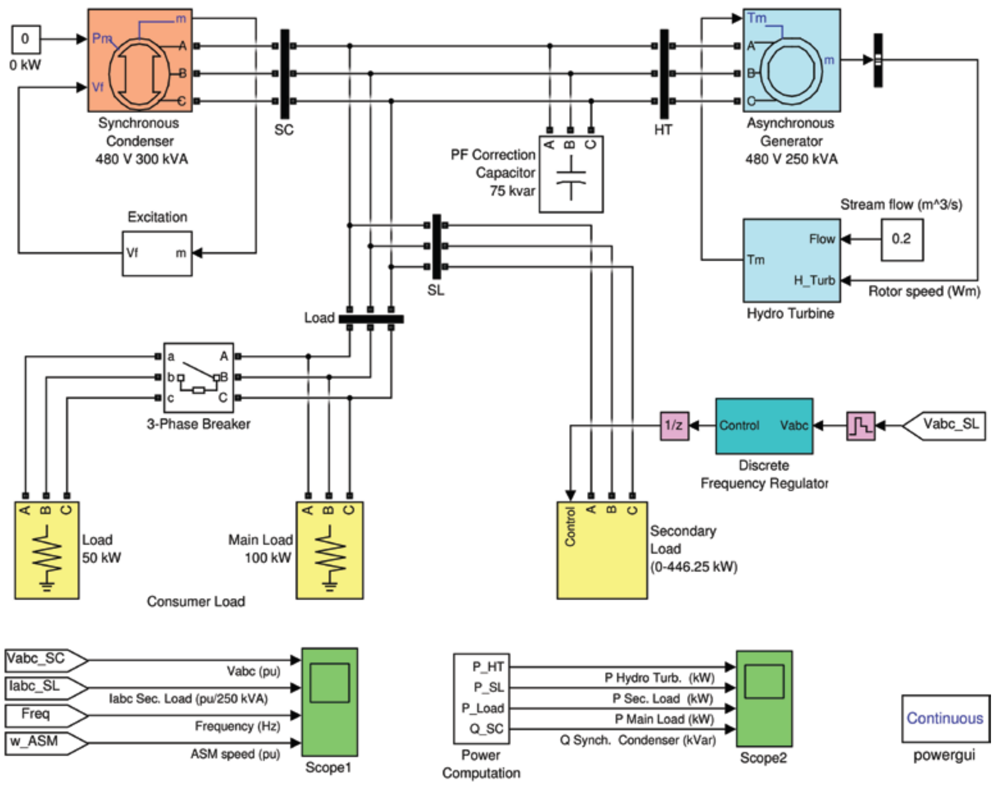

Figure 1. Simulink model of run-of-river hydropower system with load frequency control.

3. System level run-of-river hydropower model

The block diagram of the system control design is presented in figure 2. The controller is employed in order to manipulate the system frequency by controlling the secondary load system. Three Phase locked loop (PLL) systems are used to measure the system frequency. Then, the system frequency is compared to the reference frequency (50 Hz) in order to obtain the frequency error. This error will be integrated in order to get the phase error, which will be used by the controller to produce an output signal representing the required secondary load power. This signal is converted to an 8-bit digital signal for controlling the switching of the three phase secondary loads. All switching is performed at zero crossing voltage in order to minimize the voltage disturbances.

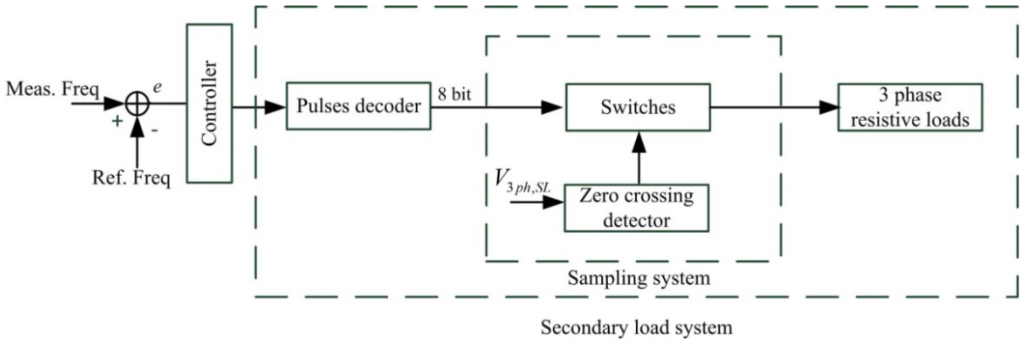

Figure 2. Secondary load system block diagram.

3.1. PD controller

The PD controller has an error signal e(t) as its input, which is obtained from desired output r(t) and actual output y(t), as seen in equation (2). The error signal used by the controller in order to produce a control signal u(t) as its output is seen in equation (3).

$$e(t) = r(t) - y(t) \tag{2}$$

$$u(t) = K_P e + K_D \frac{de}{dt} \tag{3}$$

4. Simulation results and discussions

The model simulated under two different scenarios: an additional 50 kW load at t=1 second, and a 50 kW load drop at t=1 second. The system's frequency output for the PD controller is shown in figure 3.

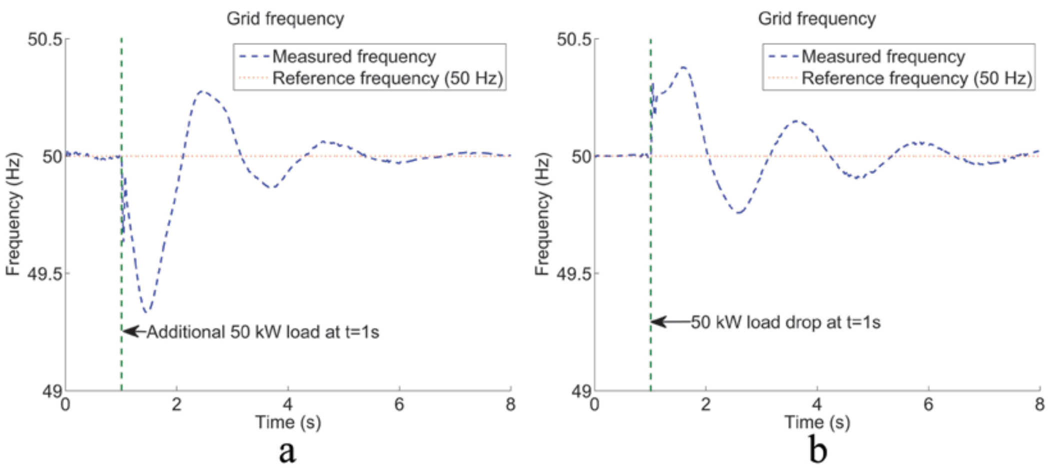

Figure 3. Simulation results of grid frequency for a) 50 kW additional load b) 50 kW load drop.

To demonstrate the performance and robustness of the proposed controller, performance indices such as overshoot, undershoot, settling time (at 0.05 %), steady state error (SSE) integral of the absolute error (IAE), integral of the squared error (ISE) and integral of time multiplied by the absolute error (ITAE) were considered in the analysis. The performance indices of the PD controller are shown in table 1.

Table 1. Performance indicators of the PD load frequency controller.

Performance indicators	Load conditions	
	50 kW additional load	50 kW load drop
Overshoot (%)	0.554	0.756
Undershoot (%)	1.333	0.484
Settling time (s)	5.132	6.316
SSE (Hz)	0.004	0.023
IAE	2.430	2.404
ISE	0.641	0.630
ITAE	9.583	9.487

5. Conclusion

In this paper, a system level of a run-of-river hydropower system model with PD secondary load controller was presented to describe the system's behaviour under different load conditions. The system frequency was regulated by a secondary load bank that absorbs the hydropower, which exceeds the consumer's demand. The simulation results indicate that a variety of load conditions can be satisfactorily controlled by the PD controller since it exhibits small overshoot, settling time, SSE, IAE, ISE and ITAE in the frequency control.

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