A Hardware Test Setup for Grid Connected and Island Operation of Micro Hydro Power Generation Systems

Mehmet DAL[(1)]
Elec. Dept. of Kocaeli VS
Kocaeli University
Kocaeli, Turkey
mdal@kocaeli.edu.tr

Alaattin Metin Kaya[(2)]
Dept.of Mech.Eng.
Gebze Institute of Tech.
Kocaeli, Turkey
a.kaya@gyte.edu.tr

Mahmut F. Akşit[(3)]
Dept. of Mechatronic Eng.
Sabanci University
Istanbul, Turkey
aksit@sabanciuniv.edu

S.Kadri Yiğit[(4)]
Dept.of Mech.Eng.
Kocaeli University.
Kocaeli, Turkey
kyigit@koaeli.edu.tr

İlyas Kandemir[(5)]
Dept.of Mech.Eng.
Gebze Institute of Tech.
Kocaeli, Turkey
ilyas@gyte.edu.tr

Ebubekir Yüksel[(6)]
Dept.of Civil Eng.
Gebze Institute of Tech.
Kocaeli, Turkey
e-mail: yuksel@gyte.edu.tr

Abstract—**This paper presents a micro hydro power generation hardware setup, established via a research project at Gebze Institute of Technology (GIT), Turkey. This project is founded by the government and aims to increase utilization of potential for small, local hydro power generation. The hardware setup consists of a newly designed cross flow type hydro turbine, two different generators (asynchronous and synchronous up to 20 kW power range) and all equipment necessary for grid connected operation and islanding. The setup can be used for two purposes: primarily performance tests of newly designed micro hydro turbines, and research and development studies to provide new regulations and technical guidelines regarding to energy management and grid connected and island (stand-alone) operation which concern for distributed generation versatility. The hardware setup offers a similar environment to that of real site which can easily be adapted to the clients test and turbine evaluation requirements.**

I. INTRODUCTION

Alternative energy resources have been the focus of global interest in order to identify sustainable energy sources for the last 20 to 30 years [1]. Alternative energy sources based on wind, solar, hydro power and biomass, etc are considered to be renewable and a climate change solution. With increasing awareness for global warming, renewable resources received special attention in the developed countries during the last few decades and recently in many other countries [2]. Being considered to be the pioneering renewable energy source hydroelectric power is an efficient and reliable technology among other renewable energy systems. Presently, small hydro turbines are considered one of the most promising rural electrification systems on the market. Ongoing trends in supply electricity demand with renewable sources are moving away from traditional large-scale power generation plants to small local generators (kW's to MW's) sited directly local consumers, hence major untapped hydropower capacity in the micro hydropower range are growing in demand worldwide.

Consequently, the Turkish government passed legislation allowing private investors to construct and operate hydroelectric power plants starting early 2000s, aiming to increase utilization of large micro-hydro power potential, and conforming the principle of "generate your own electricity" by using local water resources. Currently, over 2000 small hydro electric power plants are under construction. Private investors mainly target water resources ranging in the 1-30 MW range. Additionally, even if total hydro capacity of the country beyond 1MW is realized; there will be an unharnessed 30-40 % capacity scattered in small creeks and streams [3].

To take advantage of these sources, there is an emerging need for research in the development of micro-hydro systems as well as further status of micro-hydro power use in Turkey. Thus, a micro-hydro plant test system was established recently at GIT which aims to determine characterizations of new design micro-hydro turbines in the power range of 1kW to 100kW, and to provide specific technical information about plant management and operation, including interconnection of local or distributed generators to the utility grid at low voltage level.

This paper presents the hardware structure and functionality of micro-hydro plant test system at GIT.

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Summary of the work on the operation of two AC generators (asynchronous and synchronous) in grid connected operation in a lab. environment is also presented. Presently, a very low cost cross flow micro turbine coupled to a self exciting synchronous generator is currently under test in terms of performance evaluation and turbine governor control achievement. Consequently, a stand-alone operation test of the generator will be performed with passive load. These results will be presented in revised version of this manuscript.

II. Micro Hydro Power

A. Potential and government policy in Turkey

Presently, Turkish electricity energy demand is rapidly increasing due to increasing social and economic developments [5]. Foreign energy input share of total electricity generation for the country is very high. Thus, State Planning Organization (DPT) is supporting the public electricity grid, promoting renewable energy projects to increase the security of sustainable energy supplies and to provide technical information related to alternative renewable energy generation and facilitating cooperation between project and private sector investment.

In light of official reports [7] ,[8], prediction of Turkey's long term electric energy demands, both the technical and economical feasibility of hydro potential were evaluated in several recent studies [9], [10]. The evaluation results show that Turkey's hydro power capacity is significant as a cost effective sustainable energy resource and estimated hydropower potential according to three different scenarios evaluated by General Directorate of State Hydraulics Works (DSI) can meet nearly 33 %, 38 % and 46 % of Turkey's total electric energy demand in 2020 [3]. In hydro power potential, small hydro power sources have been found significant by DPT. Based on this prediction it is claimed that Turkey will provide significant part of its domestic electric energy demand from its own hydro power resources [5].

The main developments in Turkey came in 2005 with the passing of the Renewable Energy Law 5346 a policy which aimed to encourage investment in renewable technologies by guaranteeing projects a seven-year (amended to 10 years by Energy Productivity Law 5627) [6]. Renewable projects were also offered an 85% discount on the purchase of government land and priority connection to the transmission grid. An important distinction for investors was that the law defined river- or canal-type projects in three categories i) less than 50 MW, or a hydropower plant with a reservoir volume of less than ii) 100 million square meters or iii) a surface area of less than 15 km^2, as a renewable project. Larger hydropower projects were not eligible for the benefits offered by law 5627.

On the other hand ongoing trends with small distributed generation resources such as photovoltaic (PV), heat and power, micro hydro power or others types of generators are leading to new technical requirements for operation and energy management. Therefore, new regulations and guidelines are needed to determine utilization of distributed generation system [7]. These new regulations were declared without common concern by governments such as Japan, some European and other countries. However this issue is currently on the Turkish government agenda, but studies are at present incomplete and regulations are undeclared by official authorities. Hence, new research and development regarding to evaluation of technical guide lines are essential in order to utilize renewable energy resources.

B. Micro Hydro Power

Hydro-turbines convert water pressure into mechanical shaft power which can be used to rotate generators to produce electricity. The power on the turbine shaft is proportional to the product of pressure head and water discharge. Although micro hydro turbines are currently sold for a variety of both commercial and domestic uses; but still there is much need for cost effective small sized (under 500kw) hydro turbines for increasing and facilitating the utilization of micro hydro potential by the suppliers and consumer societies located near the sites that are suitable for own electricity generation.

Difficulties encountered in developing micro hydro systems depend on the following three factors: i) site location i.e. access due to remote locations, ii) investment costs i.e. depending on site specific location and equipment requirements and finally iii) human resources i.e. limited in rural areas for plant management and ongoing operation. The main advantages are expected to be reduced maintenance costs and the option of remote control of power production.

Another issue is that to date, there is not an official internationally agreed definition of 'small', "mini" and micro hydro power ranges; however, there are alternative suggestions for distributed generation [11]. In Turkey, the upper limit is accepted as 50 MW for small hydro power systems and Turbines up to 200 kW (micro turbines). One alternative suggestion for definition of hydro power ranges is as follows [12]:

- Large-hydro More than 100 MW feeding into a large electricity grid
- Small-hydro: Between 1-15 MW usually feeding into the grid
- Mini-hydro: Above 100 kW, but below 1 MW either stand alone schemes usually feeding into the grid
- Micro-hydro: Between 5-100kW, usually providing power for a small community or remote industrial areas away from the grid.
- Pico-hydro: From a few hundred watts up to 5kW for remote areas away from the grid.

III. Hardware Test Setup

C. Structure of Micro Hydro Power Test Setup

The main specifications that are considered in design of overall system determine the requirements for planning of mechanical and civil works, and plant management and operation. The picture of established micro hydro system is shown in Fig. 1. The micro hydro system can be divided into three main segments: civil works, hydro-mechanical works and electricity generation. The schematic of overall system structure is depicted in Fig.2.

1) Civil work:

- Reinforced reservoir with volume of 150m^3 stores the required water.
- Water storage tower with 3m diameter and 16m height cylindrical steel structure. Attached to which is a lighting protection system. A pipe line with 12m height is fitted vertically inside the tower to reject disturbances of water flow at the entrance to the turbine
- Steal pipelines with 500mm diameter and 6m lenght at supplementary side and 600mm diameter and 8m lenght at exit side

Fig.1. Pictures of the small hydro power system (overview and pumps)

- Power house: To maintain the safety and quality of electricity supply within defined limits, the small plant must be operated in such a way that the utility is able to fulfill its operating requirements.Therefore various associated electrical devices are required within the powerhouse for the safety and protection of the generator and other related equipment.

- Artesian well: used for water requirement.

2) Hydro-mechanical equipment and accessories

Centrifugal Pumps: Total power output of 180kW are activated by five induction motors. Three are 20kWs driven

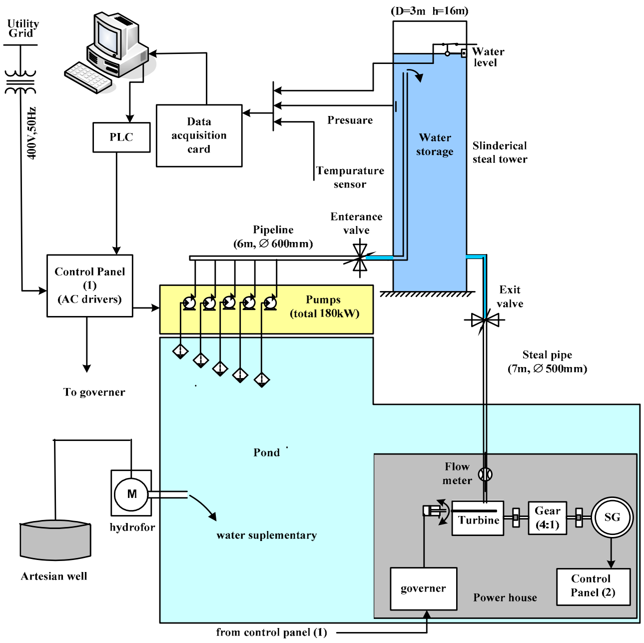

Fig. 2. Overall structure of the hardware setup.

by AC drivers the remaining two are 50kWs driven by soft starters.

Turbines: Two different sized cross flow type Micro hydro turbines 20 kW and 40 kW were specifically designed for this project.

Control panel-1: equipped with starters, protection relays, fuses, two AC soft starters and three AC drivers for pumps control.

Flow meter: acoustic type Mag 5000 with a 400mm diameter (Siemens) measures the turbine water flow.

Measurement of water level: pressure sensors: to measure atmospheric pressure in storage tower, a capacitive sensor Keller PA21Y with upper limit pressure of 4 bars is mounted within tank. Water level tracking task within the storage tower is enabled by a water buoy sending an on/off signal to the data acquisition card.

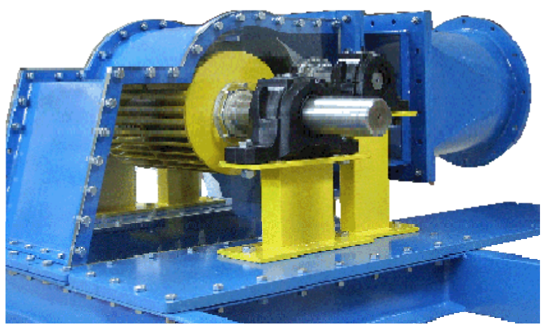

Fig.3. Picture depicts recently designed cross flow micro hydro turbine.

Data acquisition card: NI USB 6009 hardwired to PC collects signals from the sensors. These signals are used to keep water levels within parameters and to protect the storage tower from environmental abnormalities.

Control devices: PLC s7 200, CPU 222 (Siemens) which communicates with a host PC via PPI/PC cable, automatically activates the water pumps according to pressure and turbine water flow.

Coupling aparatus: A gear box with ratio of 4:1 inserted between the turbine and generator increases turbine revolutions.

Valves: A valve at both the entrance and exit of the storage tower are fitted for fill and discharge operations.

A pump: Draws required water from artesian well and fills the reservoir.

Lightning arrestor: one arrestor is mounted on top of water storage tower to protect the system against lightning strikes.

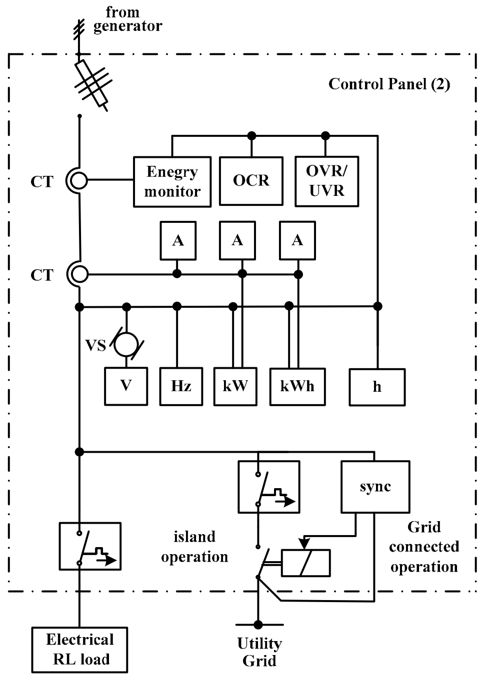

Fig.4. Single line diagram of control panel 2

3) Electrical and other equipments:

Generators: There are two choices of generator: One is a 18kW power, star connected asynchronous (squirrel cage type induction motor) generator (GAMAK) which can be utilized either for grid connected (over synchronous speed mode) or stand alone operations. Second option is a self-excited (brushless), 20kVA synchronous generator (GENSAN) which is already installed to the turbine shaft with direct coupling through a gear box and can be utilized for islanding and/or grid connected generation mode. The synchronous generator has an onboard automatic voltage regulator (AVR) which can be used to adjust generator voltage and reactive power.

Control panel-2: Contains necessary equipment needed for energy monitoring, recording and metering, for the safe operation of the power generation system. Moreover switches and breakers for manual on/off operation and interconnection, emergency stop buttons, voltage check switch, indicators for mains generator supply and breaker position. Manual switches and contactors for synchronizing controls.

Metering devices: These devices are mounted on panel-2: three ammeters (A) for each phase current, voltmeter (V) with voltage selector switch (VS) for line to line voltage measurements, frequency meter (f), active power meter (kW), meters of reactive power (kVAr), apparent power (S), active energy kWh and reactive energy kVArh.

Monitoring device: To perform energy monitoring and recording tasks using device UMG507 (Jenitza), which is capable of measuring voltage, current, power, both harmonic contents of voltage and current, power factors, frequency and energy consumption etc. and also capable to communicate with other devices through the Profi-bus, RS 432 or Ethernet card.

Synchronizing relay: in order to provide automatic synchronization to connect a generator to grid the SELCO T4000 auto-synchronizer is used.

Protections: Two seperate earthing points are provided one for the generator neutral point, and one for body of the generator and control panel. Earthing protection is performed by the relays installed on control panel 2. Each of these relays sends a trip signal to the associated devices to interrupt generation system if an electrical fault occurs. These relays are:

Over voltage relay (OVR) and under voltage relay (UVR): responsible to protect consumer load against over voltage and under voltage respectively. Normally automatic voltage regulator (AVR) maintains generator terminal voltage within certain limits. If terminal voltage is out of these limits then OVR and/or UVR provides trips.

Over current relay (OCR) protects the generator against excessive current due to faults such as short circuits or overloads.

Mains loss protection: with the removal of grid supply generator is automatically disconnected by an auxiliary relay energized by mains.

D. *Operation of Micro Hydro Power System*

Hydraulic power generation can be explained on the schematic of overall system structure depicted in Fig.2. Water requirement for hydraulic power generation is supplied from an artesian well via a pump to the water reservoir. Centrifuge type five water pumps with total power output of 180kw fill a water storage tower. To reject water disturbances on the turbine input, water input is passed through a pipe line which is fitted vertically within the tower. This pipe line is 12m in height. There are two valves one at entrance of the tower and one at exit point. In the system, a newly designed cross flow type hydraulic turbine powered by 20kVA is used. Water flow to generator and level of the water in tower are controlled by a host PC in accordance with sensor feedback signals. An acoustic flow meter Mag 5000 (400mm diameter) is used to measure water flow into the turbine. A pressure sensor (Keller PA21Y) with upper limit pressure of 4 bars is fixed within the tower to measure atmospheric pressures. The signals generated by these devices and others obtained from temperature and speed sensors are collected by data acquisition card NI USB 6009 which is connected to a PC. Water input to hydro turbine is regulated by a revolver clamp fixed internally to the turbine,

Governor control: Block diagram of turbine speed regulation governor for hydro power system is shown in Fig.4. The actuator is controlled by a hydraulic power unit (HPU) by regulating oil pressure. Operation is planned automatically but, automatic control unit is under development.

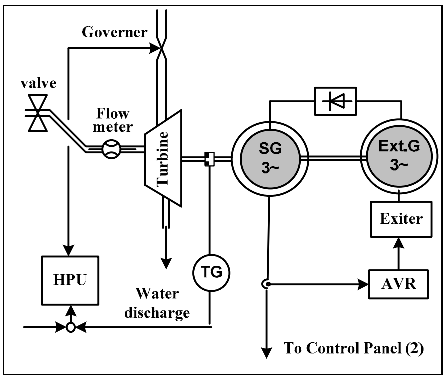

Fig.5. Governer control system

IV. Testing Micro Hydro Power Generation

A. Tests carried out at Lab.

As pioneer work, before installing both generators into the micro hydro system, an electrical power flow test from both generators to utility grid were performed under lab.conditions. In the test another induction motor powered with 22kW, 1GL4-M186 4AA was used as a prime mover instead of a hydro turbine. The mover machine is delta connected and controlled in a closed loop speed mode by a vector controlled AC driver MICMASTER 440 with 47kW (Siemens). Each test setup is shown in Fig.5. Synchronization of the asynchronous generator to grid was performed as follows: generator shaft is rotated by an AC driver at synchronous speed and then generator stator windings are connected to utility lines by a contactor. After grid connection increasing rotor shaft speed generator stars to feed grid. In the experiment a long term loaded grid connected operation is achieved at driver frequency of 50.8Hz.

In case, grid connected operation of synchronous generators, some additional requirements are necessary. These requirements are voltage and frequency matching between grid and the generator which will be connected to grid and the phase angle between generator terminal voltage and the grid supply must be same at least within specified range. Then, interconnection can be done automatically by synchronizing check relay SELCO T4000 providing the phase shift remains within specified limit for 10 seconds. Power factor correction and voltage regulation can be provided by the generator excitation system via adjustment of automatic voltage regulator (AVR).

The normal operating status of low voltage (400V) distribution network is achieved separately by each generator in the lab. During each test, measured data which is associated to variables such as voltage, current, power, power factor and so on were recoded via the monitoring device UMG507 and only one value for each variable is provided at full load condition see Table 1.

The recorded data in Table.1 shows that the power factor of each generator is different. This value should be 0.8 for proper operation of the generators with unity power

Fig.6. Laboratory test setups, for both genrators syncronous (up) and asynchronous (down)

requirements. Therefore, power factor correction is needed for both generators; this can be achieved in different ways: Paralleling capacitors for the asynchronous generator and regulating excitation voltage for synchronous generator via AVR device that provides capacitive load to offset the demand for lagging reactive power.

TABLE I GRID CONNECTED TEST RESULT OF AC GENERATORS

for synchronous generator				
P (W)	*S* (VA)	*Q* (vAR)	*I* (L1) (A)	*U* (L1-L2) (V)
-16524,730	34126,832	29739,199	50,788	378,318
I(N) (A)	*cos*(phi) average	*f* (Hz)	*U*(L1Thd) %	*I*(L1Thd) %
5,624	-0.4830	49,979	5,539	2,080
for asynchronous generator				
P (W)	*S* (VA)	*Q* (vAR)	*I* (L1) (A)	*U* (L1-L2) (V)
-21962,400	28545,883	-18014,721	39,588	387,231
I(N) (A)	*cos*(phi) Average	*f* (Hz)	*U*(L1Thd) %	*I*(Thd) %
4,962	0.7735	50,134	3,631	7,417

B. Tests carried out at the micro hydro plant

Micro hydro power system is newly installed. Fig.4 shows turbine-gear box- generator group installed into power house of micro hydro system. Stand alone operation with RL load currently under testing. Test results to be added to the revised manuscript. Grid connected operation is a logical next step however at present still in development phase.

C. Further studies and tests

This micro hydro test system is taking advantage of having real objects. Thus it can also be used for aims at serving research studies of current problems related to connection of a single source using renewable energy to low voltage network under loads; impact of source and loads operation on the network; influence of the network on the source. Moreover, monitoring and control of different type generators including control of network and stand-alone operation. Further more, power flow studies will be performed to check the nominal operating status at low voltage network; interconnection with inverter interfacing or direct connection with/without reverse power flow; the requirement necessary for safety operation studies

Fig.7. Turbine-gearbox-generator group

may help to determine additional requirements such as individual cases being able to exceed present standards.

CONCULSION

Structure of a micro hydro hardware setup is presented. A new designed cross flow type micro hydro turbine with 20kW is under testing. The objectives such as protection from reverse power flow, metering and management of grid connected operation and islanding are considerable concern on their impact, hence in further studies, power quality, stability and safety in distributed system connected to the grid at low voltage possibly will be focused. Thus, the hardware structure will be provide capability of testing different managing operation of distributed generators, extending the system with other types of generation system like solar and wind power. In essence a fully efficient and reliable Hydro electric generation test system for country wide usage is an achievable goal.

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