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Energy Management in Micro Hydro Power Plant Using Battery Bank

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***Abstract*— Micro Hydro Power (MHP) plants are very much successful for village electrification in Nepal with compared to many other countries in the world. Electrification in rural areas by grid extension seems economically not feasible because of high cost of transmission line and higher power loss in the transmission line. In MHP, the generator is driven by un- regulated water turbine with constant mechanical power output and the speed of the generator is controlled by using ELC. At varying consumer's load condition, the dump load in ELC consumes excess of power generated bythe generator so that total load on the generator at any instant is constant and equal to its full rating resulting in constant speed. In this paper, a new control logic is presented to utilize the wasted energy in the dump load during light load period to charge the battery and utilize it during peak load period. Simulation model of the proposed scheme is developed to study the technical feasibility of the proposed scheme.**

***Keywords* - Micro-Hydro power plant, Bi-directional converter, Energy Management.**

I. INTRODUCTION

Hydro power plant in the range of 10 kW to 100 kW has be classified as Micro Hydro Power (MHP)plant in Nepal[1]. Many isolated MHP plant had been installed in Nepal to electrify the rural settlements where the extension of national grid become expensive due to high cost of transmission line and high power loss in the transmission line. In MHP, the speed of the generator is controlled by using Electronic Load Controller as shown in Fig.1.

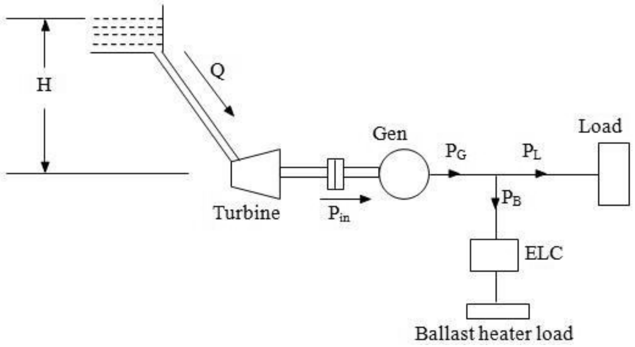

Fig. 1. Schematic diagram of MHP plant

At varying consumer's load condition, the ballast load in ELC consumes excess of power generated by the generator so that total load on the generator at any instant is constant and equal to its full rating resulting in constant speed. The power balanced equation is shown below.

$$PG = PL + PB \tag{1}$$

Where, PG = power generated by generator
PL = power consumed by load
And PB = power consumed by Ballast

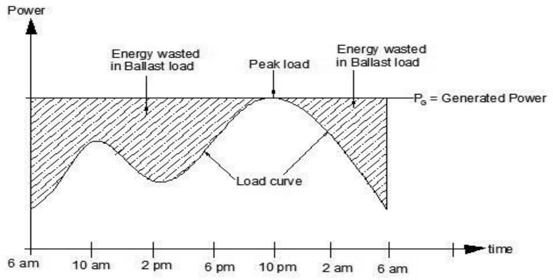

Fig. 2. Typical load curve for MHP plant

Fig.2 shows a typical load curve for a MHP plant. Thecapacity of the plant is designed to meet the peak consumer's load. The shaded area in the Fig.2 represents the energy wasted as heat loss in the ballastload. If the peak power demand in MHP area increases after some years of MHP installation as shown in Fig.3, the existing capacity of the generator will not be sufficient to meet new peak load demand.

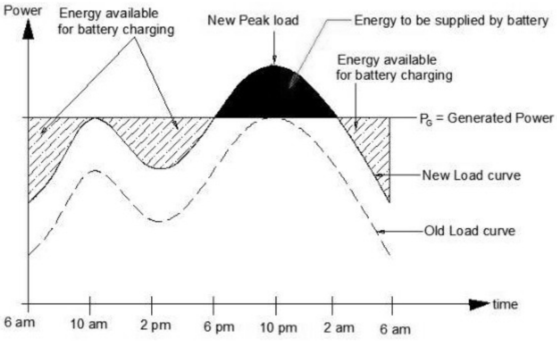

Fig. 3. Load curve with increased consumer's load inMHP plant

The dark area in Fig.3 represents the energy that cannot be

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supplied by MHP generator. The shaded area represents the excess of energy generated by the generator during light load period. This energy can be utilized to charge storage battery through the bi-directional converter as shown in Fig.4 thus by maintaining power balance equation as follow:

$$P_G = P_L + P_B + P_{BC} \quad (2)$$

Where, P_{BC} = Power consumed by battery.

During the peak load period, the bi-directional converter shall be controlled in such a way that the battery supplies the power to the load and power balance is maintained as per following equation.

$$P_G + P_{BC} = P_L + P_B \quad (3)$$

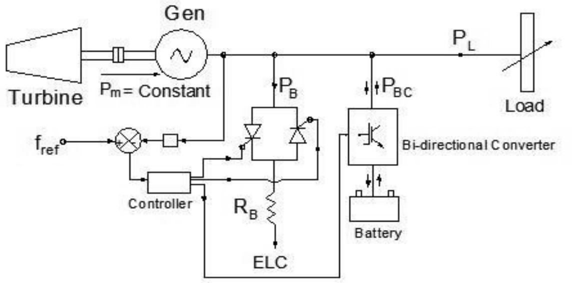

Fig. 4. Proposed scheme

II. MODELING OF THE PROPOSED SCHEME:

I. Turbine model

In MHP plant, the turbine is driven with constant water discharge and head to produce constant mechanical power output (Pm) which drives the electrical generator. In simulation model, the turbine is represented by a constant block of 1pu which is equal to its full capacity as shown in Fig.5

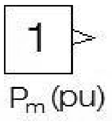

Fig. 5. Turbine model in Simulink

II. SG model

Fig.6 shows the MATLAB Simulink model of synchronous generator. The block has two input terminals as mechanical power input (P_m) and excitation voltage (V_f). The output terminals are three phase AC voltage ports marked A, B and C respectively and port 'm' is the measurement port. The stator windings are star connected. The synchronous generator used in this system has following rating:

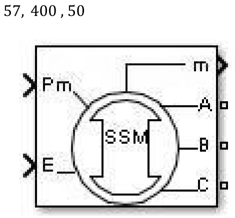

Fig. 6. Synchronous generator

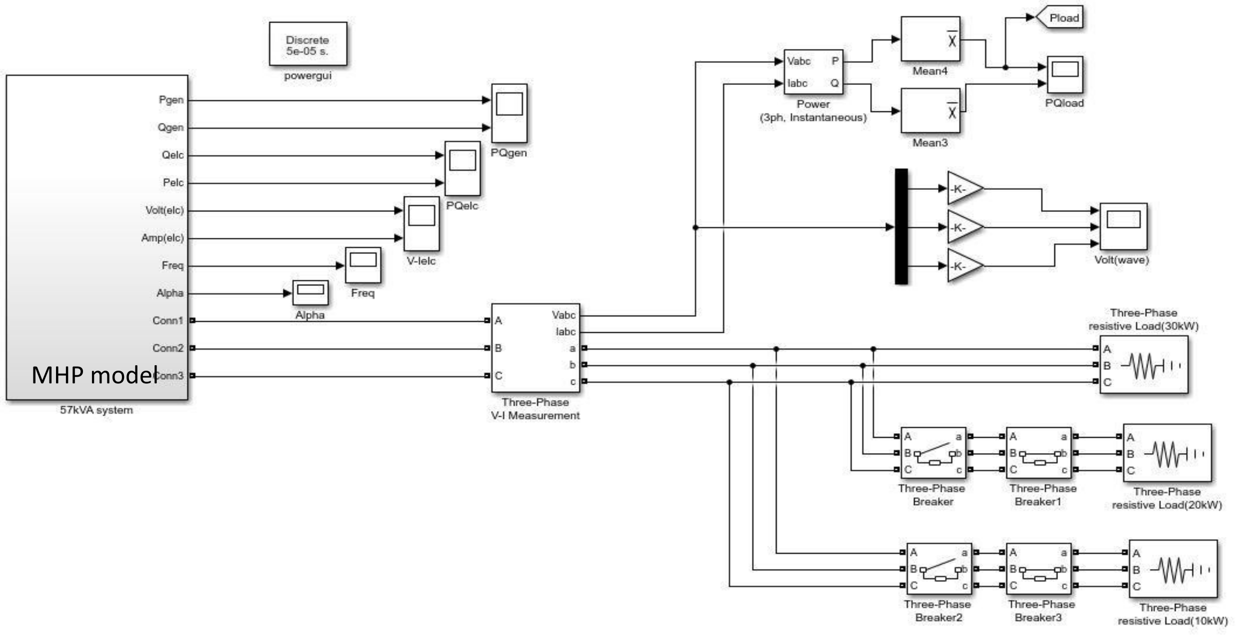

Fig. 7. Overall simulation model of the proposed scheme

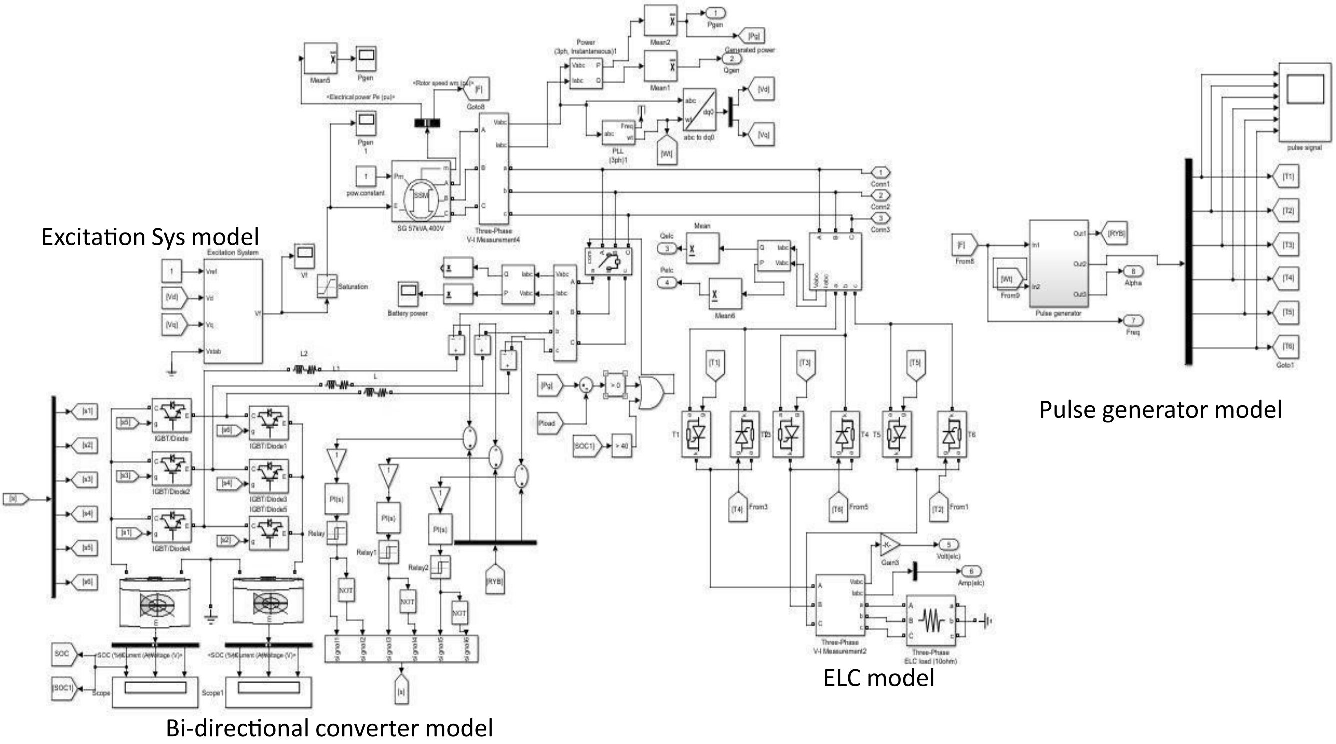

Fig. 8. Detail of MHP model

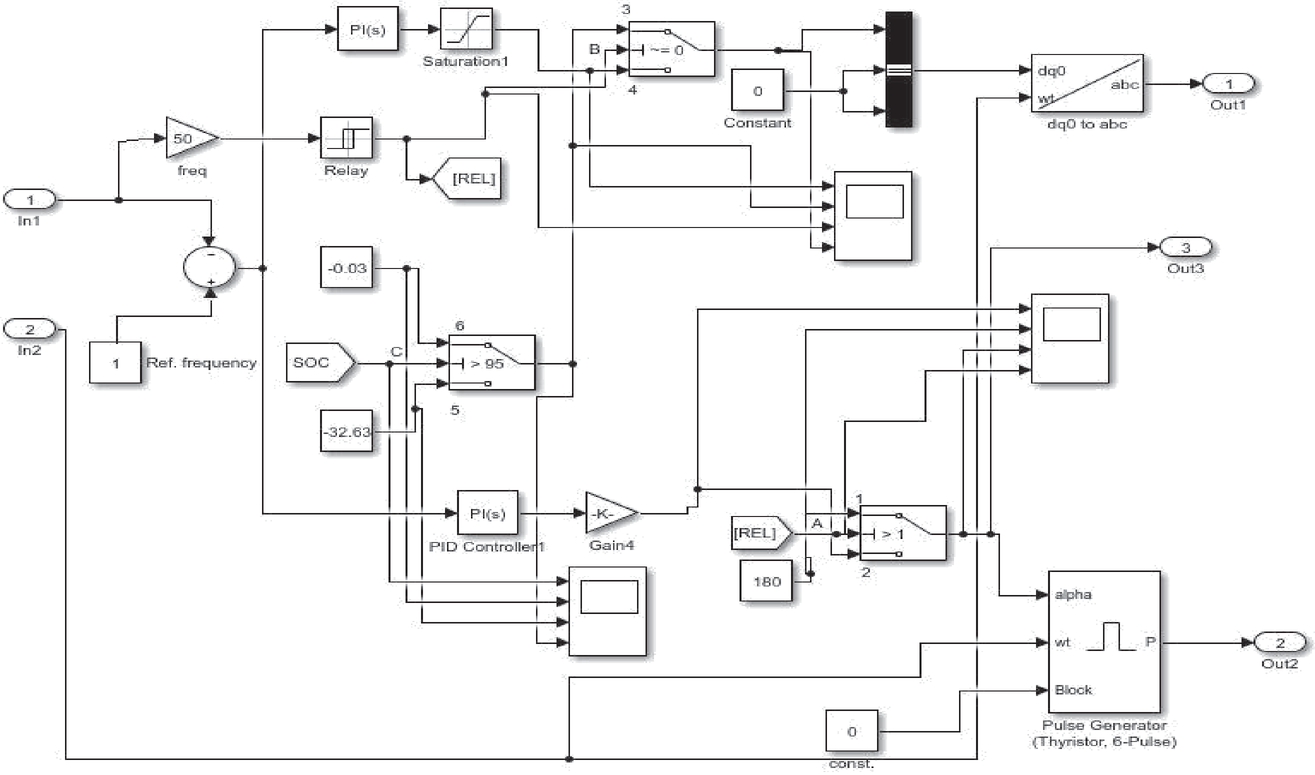

Fig. 9. Detail of pulse generator model

Fig.7 shows the overall simulation model of the proposed scheme. The MHP model shown in Fig.7 consists of 57 kVA synchronous generator driven by turbine with constant mechanical power output, an excitation system to control terminal voltage, a bi-directional converter with storage battery and ELC. The model consists of three parallel braches of resistive loads. A load of 35 kW is initially connected in the system. A load of 20 kW (second branch) is switched on at t = 3 sec and it again turned off at t = 16 sec.

Another load of 10 kW(third branch) is switched on at t = 6 sec and it again turned off at t = 18 sec.

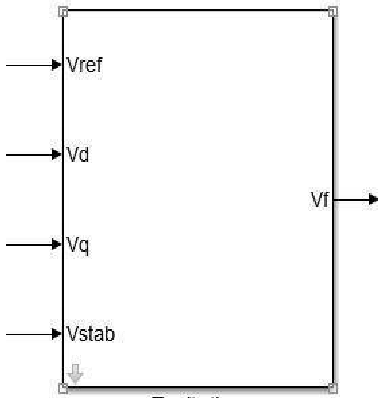

Fig. 10. Excitation system model

III. Excitation system of SG

Fig.10 shows the Simulink model of excitation system of the synchronous generator. The terminal voltage (V_{abc}) is sensed and it is converted into its d-q components (V_d and V_q) and it is given as input to the excitation system model. The V_{ref} is set as 1 pu and the excitation system block gives proper value of excitation voltage (V_f) so that the generator generates constant terminal voltage of nearly 1 pu at varying load conditions.

IV. Bidirectional converter model

If the consumer's load is less than full rating of the generator, the excess power shall be stored ina battery through the bi-directional converter. If the battery is fully charged, then the excess of power shall be expended in the ballast load through ELC [2]. When the consumer's load is greater than the generator capacity, the battery shall supply the power to the load through the bi-directional converter to make power balance. Fig.9 shows the details of pulse generating model which generates required gate pulses for bi-directional converter and ELC.

When the active power of the load decreases, thefrequency of the generated voltage increases. The frequency (in pu) is sensed and compared with the reference frequency of 1pu. The error so obtained is proportional to the decreases in active power. The error signal is passed through the two separate PI controllers in parallel. One controller is designed to generating gate pulses for bi-directional converter and the other controller is designed to generate gate signals for ELC. The State Of Charge (SOC) of the battery is sensed and depending on its values, the controllers are designed to operate as follow:

If SOC < 95%, then charging current is set as - 32.63 Amp.

If SOC > 95%, the charging current is set as - 0.03 Amp.

Surplus power left after charging the battery is dumped in the ballast load of ELC

The PI-controller for bi-directional converter is tune to produce proper value of I_d proportionalto the active power to be dumped into battery.Since the battery consumes only active power, $I_q$and I_0 are set zero. Dqo to abc conversion block generates corresponding reference currents i_a, i_b and i_c for AC system. The actual currents passing through the AC side of the bi-directionalconverter are sensed and compared with thereference currents. The error signal so obtainedis passed through the hysteresis band currentcontrol relays [3]. The hysteresis band current controller relays produce proper gate signals forswitches of the converter so that the actualcurrent tracks the reference current within setupper and lower bands. Depending on decreasein load or increase in load the error signalbecomes negative or positive and accordingly $I_d$becomes negative or positive. If the I_d isnegative, the battery absorbs power and if the Idis positive, the battery supplies power.

In order to dump the surplus power left after charging the battery to the ballast load of ELC, PI-Controller of ELC branch is tuned to generateproper value of firing angle for thyristors used inELC.

Rating of various components used in thesimulation are as follow:

Two Battery in the DC side of converter:

560 V each DC

Resistance of dump load in ELC:

2.32 ohms/phase

V. SIMULATION RESULTS

The simulation model is run for total time periodof 20 seconds. In the beginning, a resistive load of 35kW is connected in the system, the generated power is enough to fulfill the demand and there is some excess power remained so battery can becharged. After 3 sec the load of 20 kw is added andthe excess power is almost zero so it is not charged. After 6 sec again load of 10 kw is added, in this case generated power is less than load and hence the battery compensate the deficit power.

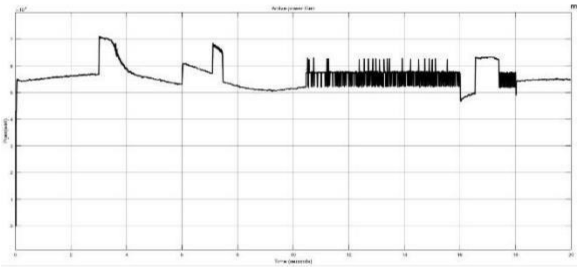

Fig. 11. Plot of active power generated by MHP (W)

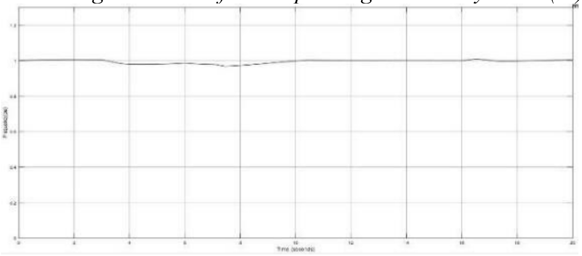

Fig. 12. Frequency response (pu)

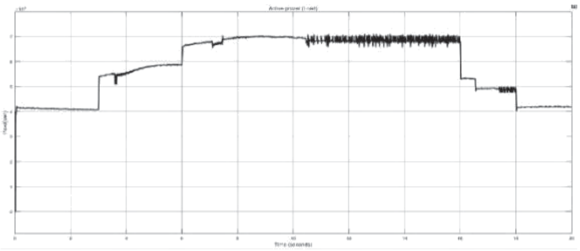

Fig. 13. Plot of active power consumed by load (W)

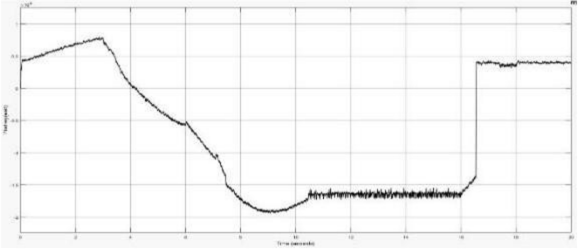

Fig. 14. Plot of power consumed by Battery (W)

Following table shows the power balance chart for entire simulation period.

Time ⟶ Parameters ↓	0-3 sec	3-6 sec	6-16sec
P_{Gen}	57kw	57kw	57kw
P_{Load}	35kw	55kw	65kw
$P_{Battery}$	10.5kw	2kw	-8 kw
P_{ELC}	11.5kw	0	0

During simulation period of 0-3 sec, the consumer's load is less than generator power by 22kW. 10.5 kW is absorbed by the Battery and ballast load in ELC consumed 11.5 kW thus by maintaining power balance. During simulation period of 3-6 sec, the consumer's load is less than generator power by 2kW and the surplus power of 2 kW is absorbed by the Battery thus by maintaining power balance. During simulation period of 6-16 sec, the consumer's load is more than generator power by 8 kW. This depict power of 8 kW is supplied by the battery thus by maintaining power balance. Fig.12 shows that the frequency of the generated voltage remains fairly constant within acceptable limits.

IV. CONCLUSION

The proposed scheme is successfully simulated in MATLAB-Simulink. The simulations shows that by controlling the bi-directional converter and ELC, the active power balance can be maintained to result constant speed operation of the MHP plant. During the peak load period, even the consumer's load is greater than the capacity of the generator, power balance can be maintained by discharging the battery which wascharged during light load period.

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