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Control of Micro Grid using Central D-ELC

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***Abstract* -- Micro-hydro power plants (MHPs) and wind power plants are popular sources of renewable energy in rural areas. Their presence in abundance and in proximity makes it convenient to consider the micro-grid system as a viable technical solution. Most MHPs have either AC Voltage Controller based Electronic Load Controllers (ACVC-ELC) or Discrete resistancetype Electronic Load Controller (D-ELC) for frequency control, while wind generators have inverter based controller. When these powerplants with different controllers are operated in parallel, this leads to an unstable operation. However, rather than operating with their individual load controllers, if these plants are governed with a central D-ELC, the operation becomes stable.**

***Keywords* — Micro-Grid, Parallel operation, Central ELC.**

I. INTRODUCTION

The Micro-Grid concept assumes a cluster of loads and micro sources such as solar, wind and hydropower operating as a single controllable system that provides power to its local area [1]. Increased number of micro sources in rural areas of developingcountries where the population is small and sparsely distributed and the extension of national grid is not financially feasible because of high cost investment required for transmission line has made the possibility of parallel operation of such sources to form a micro-grid. Micro Hydropower Plants (MHP) and wind power plants are growing source of electrical energy in the rural areas. The MHP designers and planners have made their efforts to reduce the construction cost of MHP by using ELC instead of conventional oil pressure mechanical governor. Most of the existing MHPs have either AC Voltage Controller based ELC (ACVC-ELC) or Discrete resistance type ELC (DELC). Both of these types of ELC are isochronous speed governor designed for single isolated generator without speed droop regulation. If the existing MHPs with their respective ELC are operated in parallel, their ELC will not be able to share the change in load in proportion to their capacities and will lead to unstable operation [2-3-4]. This paper presents a solution for parallel operation of two MHPs with ACVC-ELCand D-ELC and a wind turbine generator.

II. PROPOSED SCHEME

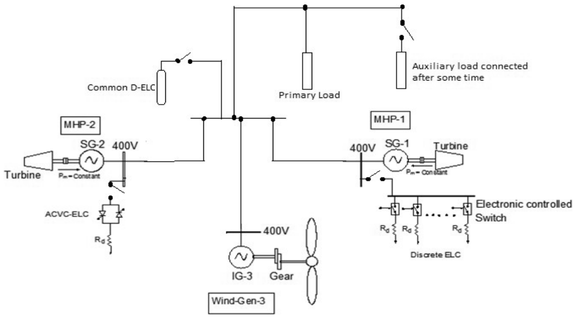

Fig. 1: Schematic diagram with the proposed scheme

Fig. 1 shows the schematic diagram of the proposed scheme with MHP-1 (64 kW SG-1 with ACVC- ELC), MHP-2 (32kW SG-2 with local D-ELC) and Wind Generator-3 (24kW IG) operating in parallel and supplying a common consumer load. A common D-ELC is proposed for speed control of the parallel operation of the three plants with their respective ELCs in Off-mode. When the three plants are operating together, their respective local ELCs are disabled and D-ELC governs the entire system.

III. MODELLING OF PROPOSED SCHEME

A. ACVC-ELC

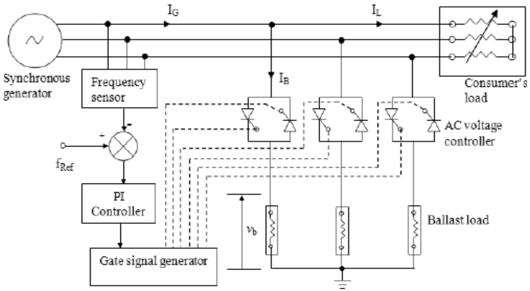

Fig: 2 Schematic diagram of MHP-1 with ACVC- ELC

Fig. 2 shows the schematic diagram of an isolated MHP with ACVC-ELC [4].The generator is driven by a constant mechanical power input which is unregulated. It produces corresponding amount of constant electrical power. Power is supplied to the load as per demand and the excess of the generated power is consumed by the ACVC-ELC into the ballast load, keeping the total load on the generator constant.

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$$P_{gen} = P_{load} + P_{elc} \qquad (1)$$

Where, P_{gen}= generated power

P_{load} = power consumed by load

P_{elc} = power consumed by ballast load

When active power demand by the load increases, frequency of the generator decreases. This change in frequency is sensed by the frequency sensor and compared with the reference frequency and an error signal is produced which drives the PI controller to changes the firing angle(α) of the ACVC depending on the error signal. This change in firing angle causesa decrease in the power flow to the dump load so that the total load on the generator remains constant. The change in firing angle is caused by chopping of current waveform. This causes addition of harmonics into the system.

B. D-ELC

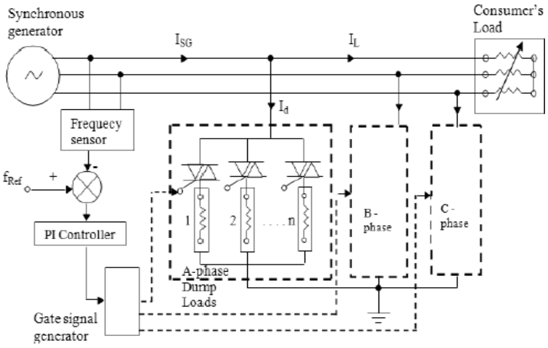

Fig.3 Schematic diagram of MHP-2 with D-ELC

Fig.3 shows the schematic diagram of an isolated MHP with D-ELC [4]. In this type of ELC, calculated numbers of resistances are kept in parallel as the dummy load and depending on the loading, required number of resistances among them are switched on and off. When consumer load increases, frequency decreases. This change in frequency is sensed by the frequency sensor and compared with the reference frequency to generate an error signal. The P-controller uses this error signal to produce a control signal to turn off required number of TRIAC switches to decrease the number of resistances in ON state. Thus, power flow to dump load resistances decreases so that the total load on the generator remains constant. Since no chopping of waveform is performed, the resultant output has no harmonic problems.

C. WIND TURBINE

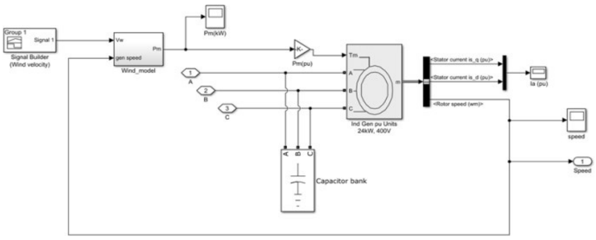

Fig.4 Wind turbine and induction generator model

Fig 4 shows the model of wind turbine driving an induction generator. The power output of a wind turbine is given by the equation: [5-6]

$$P_m = \frac{1}{2}\rho A C_p v^3 \; \mathbf{(2)}$$

where,

ρ = density of air in kilograms per cubic meter

A = area swept by rotor blades

C_p = power coefficient

v = velocity of wind in m/s

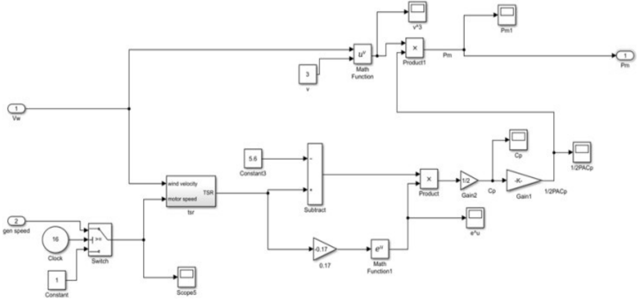

Fig.5 Detail of wind turbine model

Fig. 5 shows the detail of wind turbine model.Thevalue of power coefficient, $c_p$is calculated as:

$$C_p = \frac{1}{2}(\gamma - 0.22\beta^2 - 5.6)e^{-1.17\gamma} \; \mathbf{(3)}$$

where,

β = blade pitch angle

γ = Tip speed ratio(TSR)

$$TSR = \frac{(speed\ of\ rotor\ tip)}{(wind\ speed)} = \frac{\omega r}{v} (4)$$

As per eqn (2), when wind velocity increases, the corresponding value of power generated increases.

The rotational speed of wind turbine is used to calculate Tip Speed Ratio. This implies that when the rotor speed of IG changes, TSR also changes as defined by the eqn (4). The change is TSR changes the power coefficient as per eqn (3) and ultimately mechanical power output as per eqn.(2).

IV. SIMULATION RESULTS

A. Simulation Results for MHP-1:

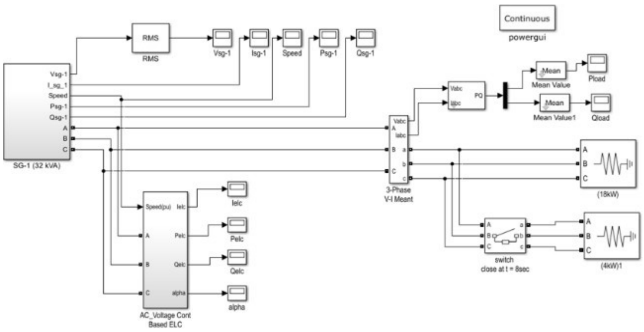

Fig.6 Simulation model of MHP-1:

Fig.6 shows the Simulink simulation model of MHP- 1 with 32 kW synchronous generator. It is stabilized with the use of a local ACVC-type ELC. A load of 18kW is connected in the beginning and at t=5 sec, an additional load of 4kW is added. The simulation was performed for 10 seconds. Fig.7 shows the speed response of MHP-1 with step change in load. The speed is stable at 0.999 pu in the beginning and after addition of 4kW load, the speed is stabilized at 0.997 pu. Since both values are close to 1, we consider that the speed is stabilized by the ELC during addition of the load.

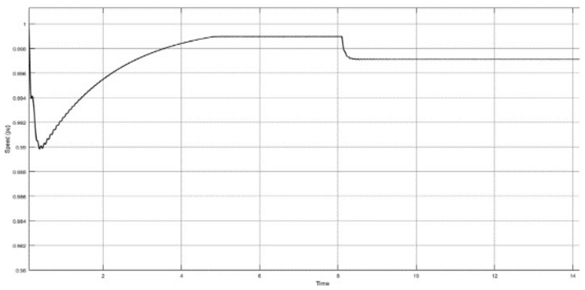

Fig.7 Speed response of MHP-1 with step change in load

B. Simulation results for MHP-2:

Similarly, Simulink model of MHP-2 with capacity of 64 kW was developed as in above step. A load of 36 kW was connected in the beginning and additional load of 8 kW is switched on at t= 5 sec. The

simulation was run for 10 seconds. Fig.8 shows the speed response of MHP-2 with step change in load. The speed is stable at 0.999 pu in the beginning and after addition of 8kW load, the speed is stabilized at 0.997 pu.

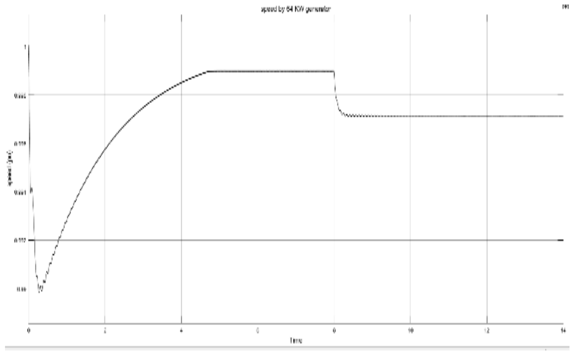

Fig.8 Speed response of MHP-2 with step change in load

The Simulink results of the two cases are tabulatedbelow:

MHP- 1	t = 0 to 8s	t = 8 to 14s
V_P (pu)	1	1
Speed (pu)	0.999	0.997
alpha (deg)	55	65
P_{Gen} (kW)	30	30
P_{elc}(kW)	12	8
P_{Load} (KW)	18	22

MHP -2	t = 0 to 8s	t = 8 to 14s
V_P (pu)	1	1
Speed (pu)	0.999	0.997
Alpha (deg)	55	65
P_{Gen} (kW)	60	60
P_{elc} (kW)	22	16
P_{Load} (kW)	36	44

The MHP-1 and MHP-2 are giving stable operation when they are operated in isolated mode with respective ACVC type ELC.

C. Simulation results of parallel operation of MHP-1 and MHP-2 with their respective ELCs

Fig.9 shows the simulink simulation model of parallel operation of MHP-1 and MHP-2 with their respective ACVC ELC. A common load of 60 kW is connected in the beginning and additional load of 9 kW is switched on at t = 8 sec.

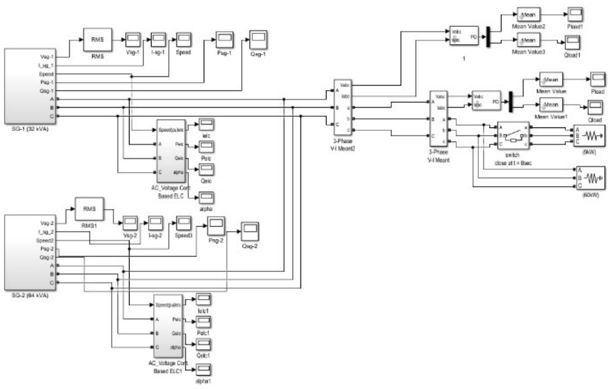

Fig.9 Simulink model of parallel operation of MHP- 1 and MHP-2 with their respective ELC.

Speed of both generators are stable at 0.9955p.u. in the beginning and after addition of 9kW load, the speed is stabilized at 0.9941 pu.

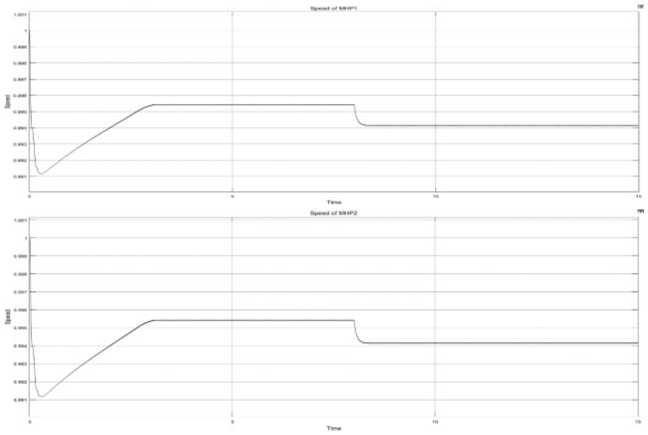

Fig.10 Speed response of MHP-1 and MHP-2 with their respective ELC.

The simulation results are tabulated below :

	t = 0 to 8s		t = 8 to 15s	
	MHP 1	**MHP 2**	**MHP 1**	**MHP 2**
V_P (Volts)	230	230	230	230
Speed (pu)	0.9955	0.9955	0.9941	0.9941
alpha (deg)	73	71	79	84
P_{Gen} (KW)	30	60	30	60
P_{elc} (KW)	10	20	7	14
P_{Load} (KW)	60		69	

This simulation results shows the successful parallel operation of two MHPs with ACVC type ELCs. Also, it can be observed that the two generators have constant speed before and after the addition of load. The only parameter different in these MHPs other than their rating is the value of resistance connectedin their ELCs. The resistance in ELC 1 was 5 ohm whereas the resistance in ELC 2 was 2.5 ohm. These different values of resistances are serving as the droop characteristics in the parallel operation and ELCs shares the excess of power in proportional to their respective ratings.

D. Simulink model of MHP-3 (64KW) as isolatedplant with local DLC

A 64KW MHP model is developed in the Matlab- Simulink implementing a discrete load type ELC as shown in Fig.11. Fig.12 shows the details of DLC block and Fig.13 shows the details of switching logic of discrete ballast resistance loads.

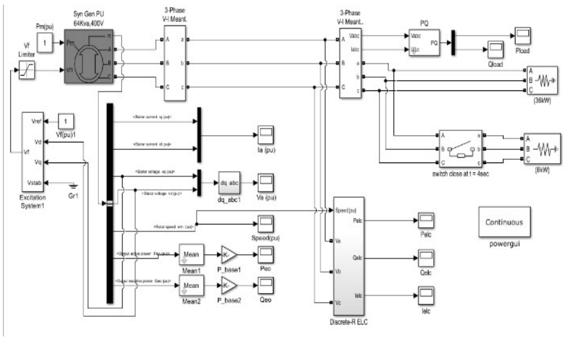

Fig.11 Simulink model of MHP-3 with 64kW generator and DLC.

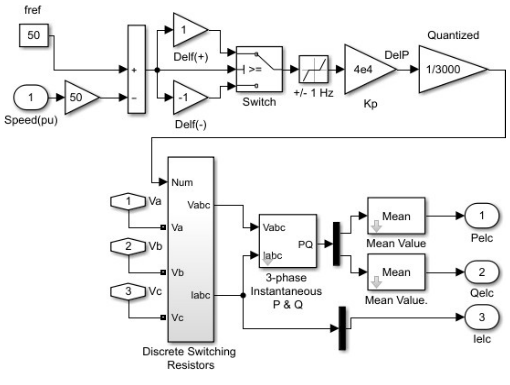

Fig.12 Detail of DLC block.

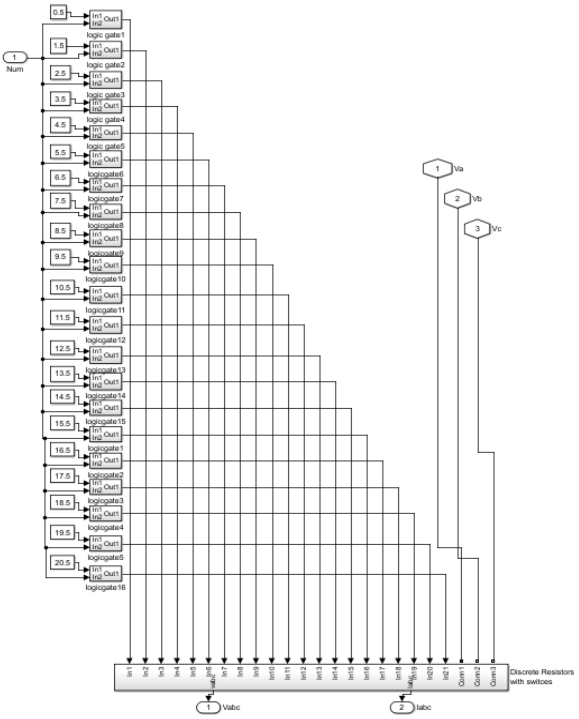

Fig.13 Detail of switching logic of discrete ballast resistance loads.

A discrete R-ELC is designed and operated in the circuit to control the speed of the generator as shown above.21 resistive loads of 3 kW each were used in the discrete ELC. Consumer's load of 36 kW is connected in the beginning and additional load of 8 kW is switched on at t=4 sec. Fig.14 shows the simulation result of speed response showing the stable operation.

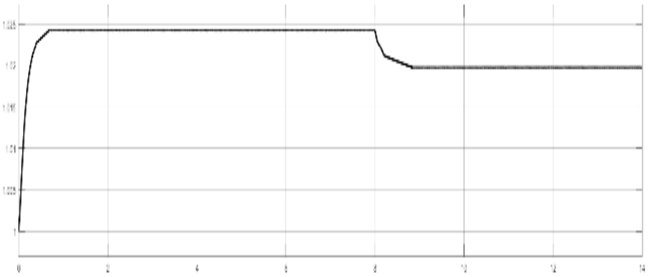

Fig.14 Speed response with DLC

E. Simulation results of parallel operation of MHP-1and MHP-3 with their respective ELC:

Fig.15 shows the Simulink simulation model of parallel operation of MHP-1and MHP-1. MHP-1 is 32 kW MHP with ACVC ELC and MHP-3 is 64 kW MHP with DLC.

Fig.16 shows the speed responses of MHP-1 and MHP-3 with their respective ACVC ELC and DLC. The speeds of both MHPs are increasing and found to be unstable. That means two different type of ELC cannot coordinate each other to give stable operation.

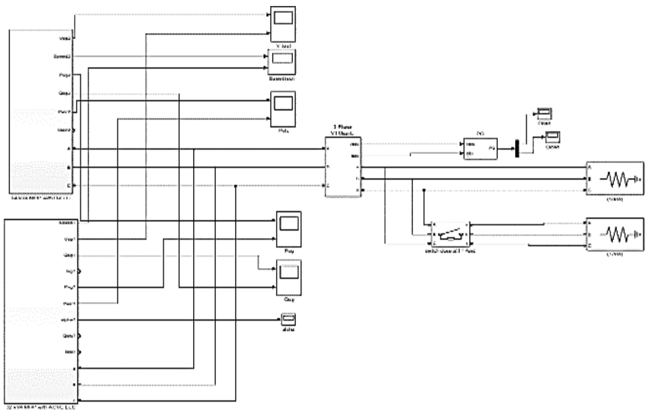

Fig.15 Simulation model of parallel operation of MHP-1 and MHP-3 with their respective ELC:

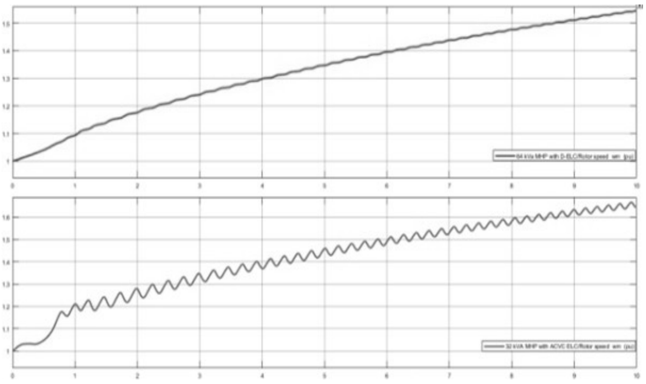

Fig.16 Speed response of parallel operation of MHP-1 and MHP-3 with their respective ELC:

F. Simulation results of parallel operation of MHP- 1, MHP-3 and wind turbine with Induction Generator:

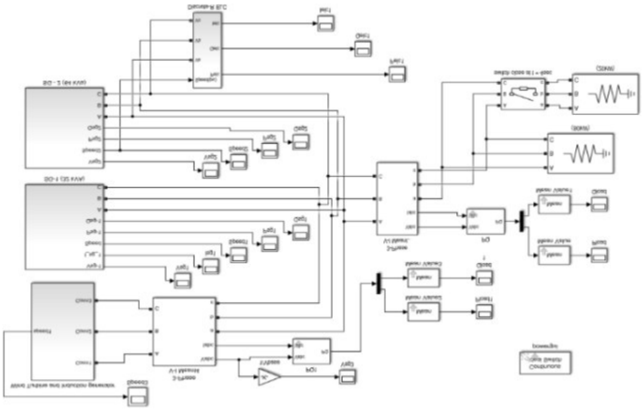

Fig.17 Parallel operation of MHP-1, MHP-3 and wind turbine with induction generator

Finally, MHP-1, MHP-2 and wind generators were connected in parallel and the central D-ELC controlled the unused power to dissipate in the ballastload and the operation was smooth and all three generators were running at constant speed as shown in the graphs below. Also, the load was shared proportionally which is depicted in the table.

	t=0 to 4 secs			t=4 to 18 secs				
	MHP-1	MHP-2	Wind Generator	MHP-1	MHP-2	Wind Generator		
						t = 4 to 7s	t = 8 to 11s	t= 12 to 18s
Voltage (pu)	1	1	1	1	1	1	1	1
Speed (pu)	1.04	1.04	1.04	1.03	1.03	1.035	1.036	1.038
Power generated (KW)	29	60	19	29	60	19	20	21
Power consumed by ELC (KW)	29					8	11	12
Power consumed by load (KW)	79			98				

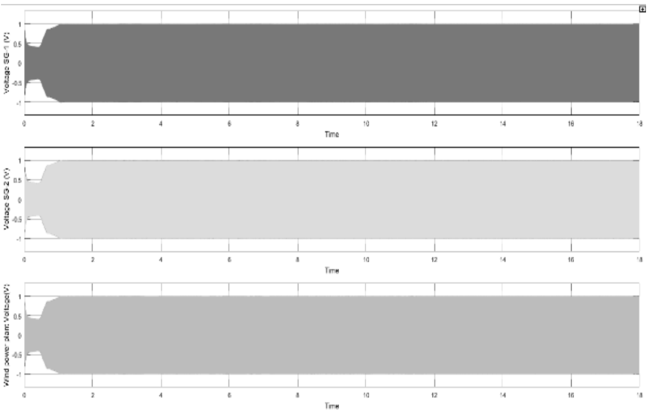

Fig.18 Waveform of voltage generated by MHP-1, MHP-3 and wind generator respectively

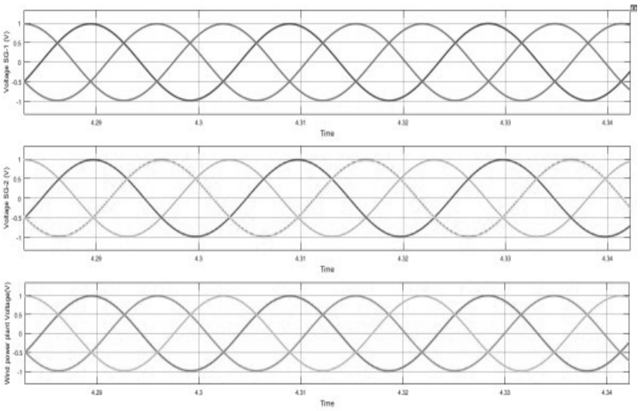

Fig.19 Magnified view of the generated voltage waveforms

Fig.18 and Fig.19 show that the generated voltage waveforms are sinusoidal and their peak valueconstant at 1p.u.

Fig.20 shows that the speed is also fairly constant at 1 p.u. which slightly increases with wind in case of wind generator.

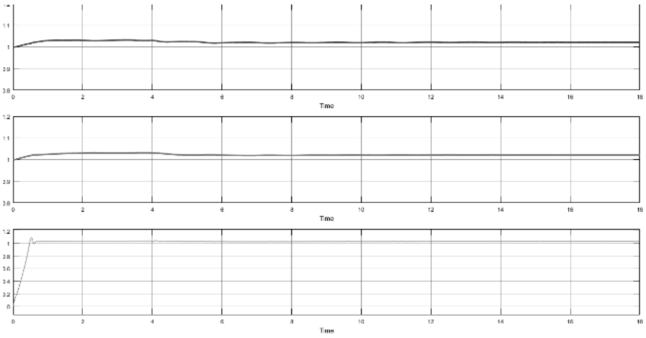

Fig.20 Speed response of MHP-1, MHP-3 and wind generator

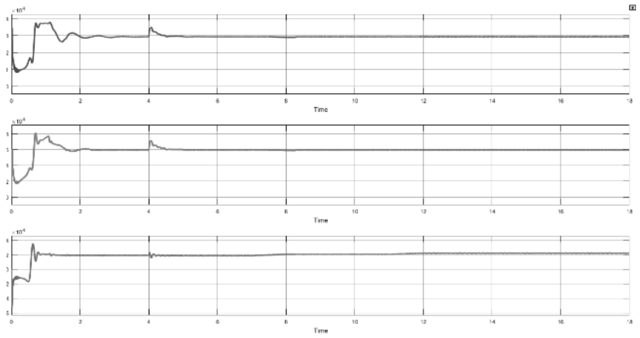

Fig.21 Power generated by MHP-1, MHP-3 and wind generator

As for the power generated by each of the units, they are constant at their capacities, i.e. 29kW for MHP-1,60kW for MHP-3 and 19kW, 20kW and 21kW with increasing wind speed for wind generator.

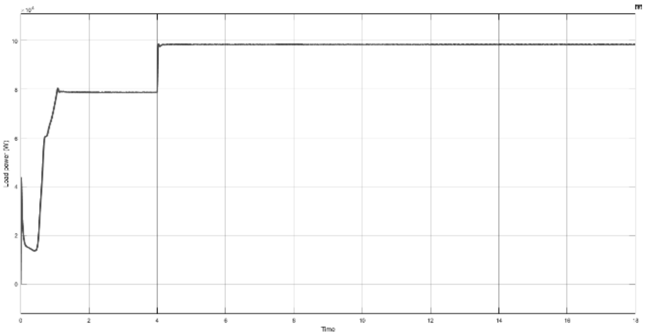

Fig.22 Power consumed by load

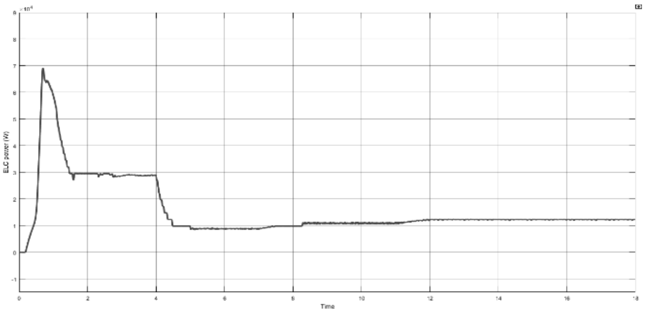

Fig.23 Power consumed by Discrete ELC

V. CONCLUSIONS

- If Two MHPs of different ratings (with their respective ELC of ACVC type) are operatedin parallel, they gives stable operation. There is no need of speed drop control in ELCs. Both ELCs share the load in proportion to their capacities.
- If Two MHPs (one with ACVC-ELC and other with Discrete ELC) are operated in parallel, it gives unstable operation.
- A Common D-ELC can give stableoperation of Microgrid with various types of Generators

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