DROOP BASED CONTROL USING ELECTRIC SPRINGS IN INTEGRATED MICRO GRID FOR SMART LOAD MANAGEMENT

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ABSTRACT:

Meeting the increase in demand will be the upcoming challenge which is met by the use of micro grids. Micro grid is useful in improving the local energy delivery, increasing reliability and is also economical.

Managing the increasing demand is the strategy preferred so that the resources could be utilized efficiently. Demand response management is generally done using droop control technique among various sources of micro grid. In this paper the droop control technique is used at load side to control the voltage across the load. This method uses an adaptive virtual output impedance to achieve reactive power sharing among various types of loads. This method improves the reliability and has ease of management. The proposed technique contains electric springs in back to back configuration which varies the voltage across non-critical loads accordingly as well as consumes less amount of power thereby improves the efficiency.

INDEX TERMS: Non-critical loads, electric spring, demand response, droop control

NOMENCLATURE:

DB-DR	Droop based demand response
DR-L	load adjustment using DB-DR
ω_{sj}, V_{sj}	frequency and voltage, respectively of j[th] source of micro grid
ω_{rf}, ω_{rf}	reference frequency and voltage, respectively for source droop relation
K_{qj},K_{pj}	frequency and voltage droop coefficients, respectively of j[th] source
P_{sj} ,Q_{sj}	real and reactive power ,respectively of j[th] source in micro grid
$\omega_{rf,DRi}$, $V_{rf,DRi}$	reference frequency and voltage droop relation , respectively of j[th] DR-L
ω_{rf}, V_{rf}	reference frequency and voltage for source droop relation
$V_{DCi,\Delta}$	DC bus voltage compensation term in the droop relation of the i[th] DR-L

I. INTRODUCTION:

The increase in the demand of the power is the upcoming challenge to be met without compromising in the reliability of the supply to loads. According to the traditional methods the generation capacity has been increased which is a non-economical way of approach and expanding the transmission lines is the impractical method. Therefore to challenge this problem demand response (DR) is the modern and efficient way of meeting the increase in the demand.

Demand response is the variation in the consumption of power by an electric utility customer in order to match the demand and supply. DR is in also used to encourage the consumers to reduce demand during peak hours. DR can be done either by voluntary or by involuntary actions which involves predefined program. There are many advantages in using DR method which include participant financial benefits and reliability.

The various approaches for DR systems are by exchanging messages from system to operators [1], by transmitting pricing data to DR systems [2] or by using local frequency measurements [3]. The main drawback of such data exchange methods is the time lapse in power system stabilization[4].

Micro grid plays an important role in improving the resiliency of the power system. The micro grid can be operated in grid connected mode as well as islanded mode of operation. Utilizing the demand response to c

Particularly in the Micro grid application various demand response methodologies have been used. One of the method is by maintain the frequencyof micro grid by giving signals to loads from central controller[5][6]. Optimal resource utilization is done by controlling using central control unit[7]. But in the above ways of controlling central control unit is needed which raises reliability concern and coordination between the actions of various loads is needed to avoid destabilization.

Among the various source control methodologies used in the micro grid droop based control method gives more efficient results[8]. Demand response can also be done by using droop control.

II. DROOP BASED CONTROL STRATEGY

Droop based control method is generally used to manage the supply on source side in micro grid. This strategy is generally used in load sharing or parallel operation of generators by changing frequency or voltage. The drop in frequency causes increase in the power output according to the defined droop characteristic. The primary frequency control creates control over power output. In general to control active power frequency variation is done and to control reactive power voltage variation is done.

One of the main functions of the micro grid is to regulate the micro grid's voltage magnitude and frequency within their normal ranges during autonomous mode and also to control active power and reactive power flow from various power source units to loads while working in autonomous mode.

The reference signals of droop control are set-points for voltage & frequency. Change in voltage causes change in field excitation of synchronous generator which there by causes change in reactive power and compensation in voltage. Similarly, change in frequency cuses change in generator torque and thereby active power changes and compensates frequency variation.

In general the droop control is done based on varying parameter relations. Let $P = \frac{V_1 V_2}{X} Sin\delta$, $Q = \frac{V_2}{X}(V_2 - V_1 Cos\delta)$. Where

P Active power

Q Reactive power

V_1 Sending end voltage

V_2 Recievng end voltage

δ Power angle

X Reactance

As power angle δ is small, sinδ=δ, cosδ=1.

Therefore$\delta = \frac{PX}{V_1 V_2}$;$(V_2 - V_1) = QX/V_2$

So, P has large influence on power angle δ, Q has large influence on $(V_2 - V_1)$. That is controlling of active power and reactive power. With respective to string equation f (frequency) is related to δ.

$$f = f_0 - kp(P - P_0) \quad (1)$$

$$V = V_0 - kq(Q - Q_0) \quad (2)$$

Where, f :frequency

f_0 frequency

K_p frequency droop control setting

P_0 base active power

V_0 base voltage

K_q voltage droop control setting

Q_0 base reactive power

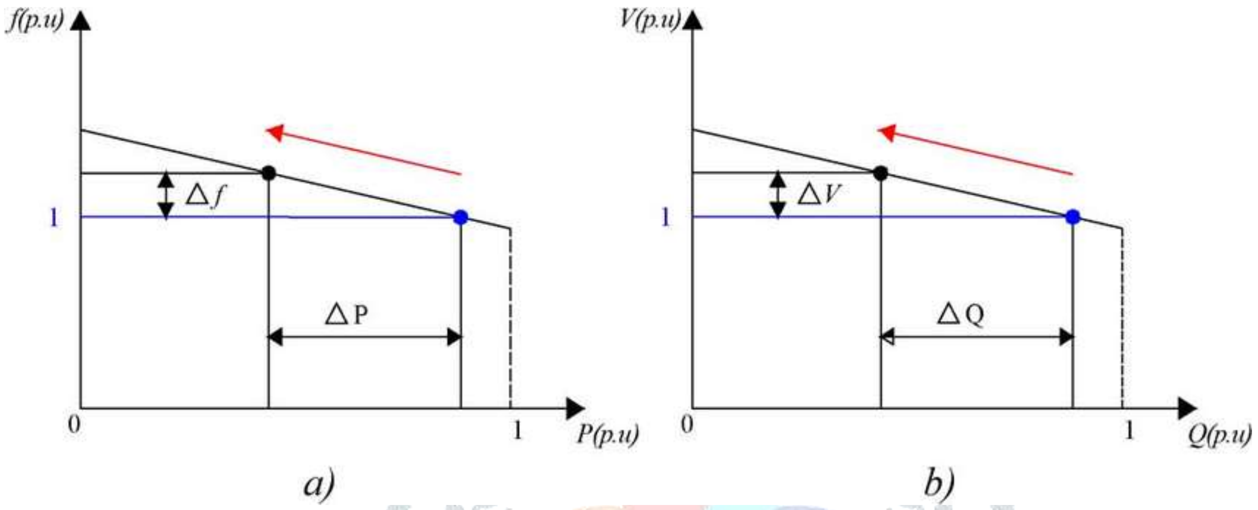

Figure 1 a) DROOP CONTROL OF ACTIVE POWER b) DROOP CONTROL OF REACTIVE POWER

Droop settings are normally quoted in % droop. The setting indicates % amount the measured quantity must change to cause 100% change in the controlled quantity.

The main advantages of droop control method is it doesn't depend on communication signal, has more flexibility, highly reliable, simple in structure, easy to implement and free laying.

III. PRUPOSED DROOP BASED DEMAND RESPONSE SYSTEM WITH ELECTRIC SPRINGS

Droop control requires, the ability to adjust power consumption dynamically. So only certain loads which are flexible to adjust their consumption as required by control can be used. For example, loads like cooling systems can be used which are generally characterized as non-critical loads and critical loads are those which work only at specified ratings. So critical loads are not used for this purpose.

Loads which can be used in demand response are batteries [9] which can behave as both source and load. Even heating/cooling acts as major power consuming load in demand response system [10], as many buildings are cooled using chilled water which can produce during non-peak hours. Some appliances like washing machines, clothes dryers and dish washers could be modified to support DROOP BASED DEMAND RESPONSE SYSTEM.

The main the proposed system contains Demand response control block which controls the voltage across the non-critical load which with respect to the current flowing in the main transmission line. Fig.2 describes the overall simulated power system.

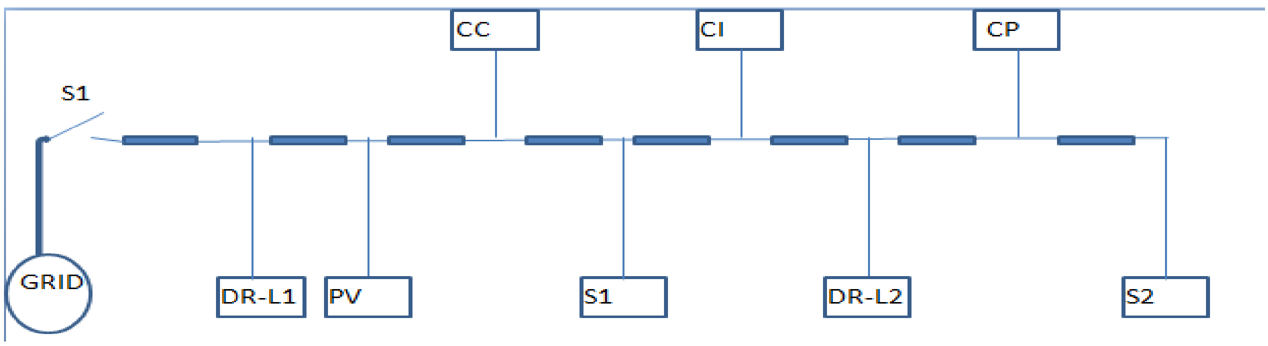

Figure 2 Simulated power system

The suggested structure of the proposed DR management system is shown in fig.3. the combination of non-critical loads, converter is known as DB-DR based load (DR-L). As shown in fig.3 DR-Ls are connected next to interfacing point of grid and may also be connected at different points in micro grid. Each of the DR-L are based on the power flowing in downstream at the connected point.

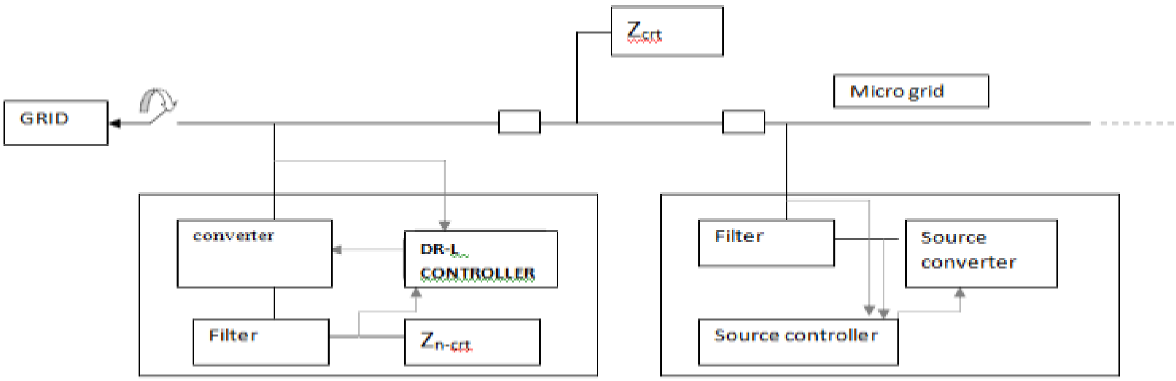

Figure 3 DR management system in micro grid

The DR-L's main role is to maintain the voltage across the non- critical load ($Z_{n\text{-}crt}$) according to the power flow in the main transmission line. This can be done by determining the amount of current flowing along the downstream where the DR-L is connected and along with the voltage across DR-L and current flowing in the DR-L. The electric spring in the converter consumes less power and it is also economical than using back-to-back converter.

IV. DROOP RELATION FOR THE PROPOSED SYSTEM

This section describes about the generalized droop relation for both islanded and grid connected modes of operation. Considering the defined system as in figure.4, the total power required by critical loads be $P_{cr.}$ Conventional droop relations can be expressed as,

$$\omega_{sj} = \omega_{rf} - K_{pj} P_{sj} \tag{3}$$

$$V_{sj} = V_{rf} - K_{qj} Q_{sj} \tag{4}$$

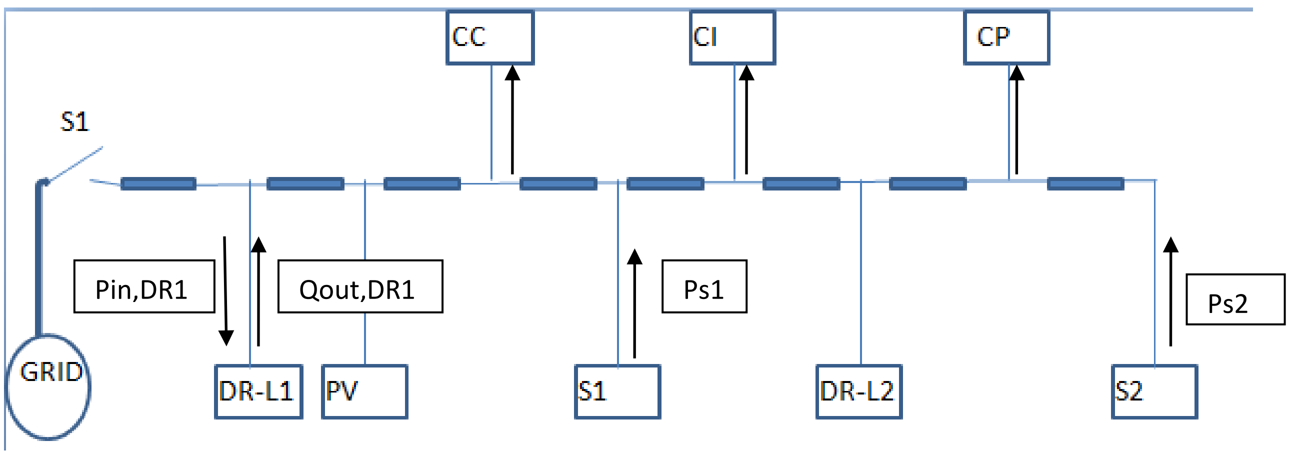

Figure 4 Micro grid power system with DR-L

$\omega_{rf,DRi} = \omega_{rf} - \delta_i$ (5)

where δ_i has to be determined. All sources and DR-Ls operate at same frequency ω_{op}. This implies

$\omega_{op} = \omega_s = \omega_{DRi}$ (6)

The generalized droop relation for DB-DR to support various operating conditions is done by adjusting the $\omega_{rf,DRi}$ based on the amount of power supplied to the critical loads. As the power supplied to the DR-L is passed to the back-to-back inverter DC bus, the adjustment of $\omega_{rf,DRi}$ and can also maintain the voltage in acceptable range. To satisfy these requirements $\omega_{rf,DRi}$ should be modified as,

$\omega_{rf,DRi} = \omega_{rf} - \delta_i + K_{g,pi}P_{fi} - V_{DCi,\Delta}$ (7)

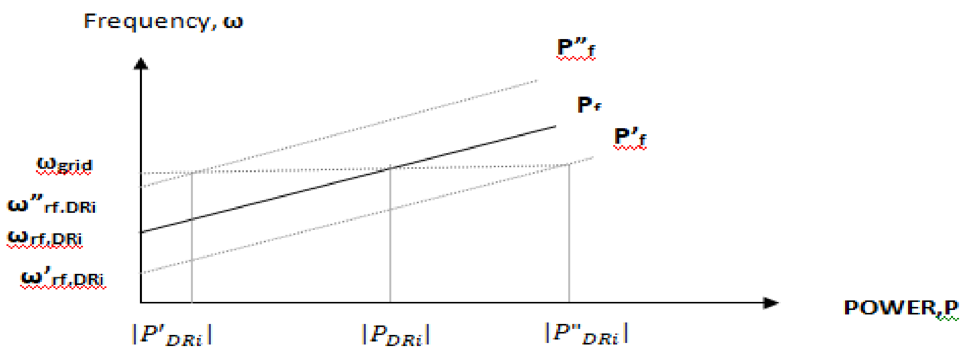

Figure 5 Droop Characteristics of proposed system

Looking into the droop characteristics in fig.5 where micro grid is operated in grid connected mode, the power fed to critical load is $\mathbf{P_f}$ with the respected frequency is $\boldsymbol{\omega_{rf,DRi}}$ and the power taken by DR-L is P_{DRi}. When the peak hours occurs that is the critical loads are in need of more power $\mathbf{P''_f}$ then according to equation(7) the frequency is adjusted to $\boldsymbol{\omega''_{rf,DRi}}$ so that DR-L's power consumption reduces to P'_{DRi}. Similarly during non-peak hours the power to critical loads reduces to $\mathbf{P'_f}$, frequency accordingly adjusts to $\boldsymbol{\omega'_{rf,DRi}}$, and DR-L consumption increases to P''_{DRi}.

When the droop relation exceeds the demand of the non-critical loads, the dc bus voltage keeps increasing , when it exceeds a limit the error is compensated using PI controller through this relation,

$V_{DCi,\Delta} = min(0, (k_{p,d} V_{er} + \int k_{i,d} V_{er} dt))$ (8)

$V_{er} = V_{DC,L} - V_{DCi}$ (9)

The generalized droop relation for DR-L becomes

$\omega_{DRi} = \omega_{rf} - \delta_i + K_{g,pi}P_{fi} - V_{DCi,\Delta} - K_{p,DRi}\,|P_{DRi}|$ (10)

The DR-L proposed in this paper behaves as a voltage source inverter (VSI). A droop control can be implemented mainly by the following equation,

$V_{DRi} = V_{rf,DRi} - K_{Q,DRi}Q_{DRi}$ (11)

The power calculations in the figure 6 can be done by first calculating the direct and quadrature components and then by using the following equations,

$P = \frac{[V_d I_d + V_q I_q]}{2}$ (12)

$Q = \frac{[V_q I_d + V_d I_q]}{2}$ (13)

Here with the use of electric springs the amount of power consumption would be very less and the overall cost reduces. There by the total efficiency of the system increases. By using a back to back topology in electric spring the range of operation is also improved.

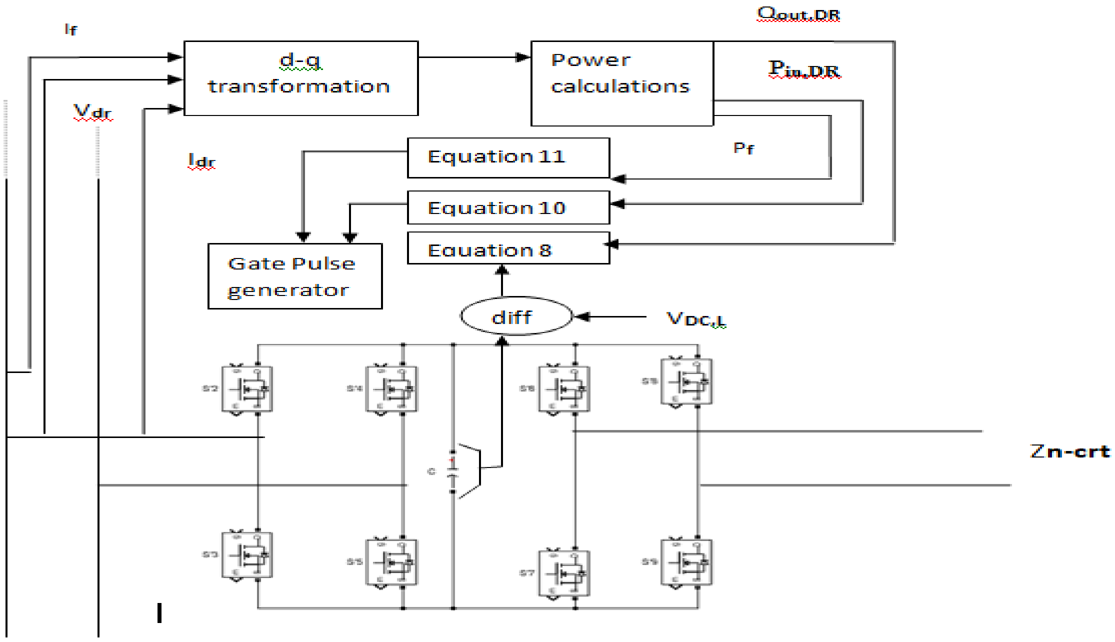

Figure 6 Block Diagram of proposed control system

V. SIMULATION RESULTS

The performance of the above proposed system are obtained in the below figures. The micro grid is assumed to be operated in grid connected mode. The system contains two dispatchable sources, PV sources, two DR-Ls and critical loads.

The various values are taken as respectively for PV source, and the following variations are considered in the critical loads.

TIME	T<3	3≤t≤4	4≤t≤5	5≤t
PV power (KW)	5	2.2	2.2	2.2
CC current(A)	12	12	9	9
CP power (KW)	16	16	16	8.5

Table 1 Load variations during simulation

The constant current load, constant impedance load and the constant power load variations are shown in the figures 7,8,9.

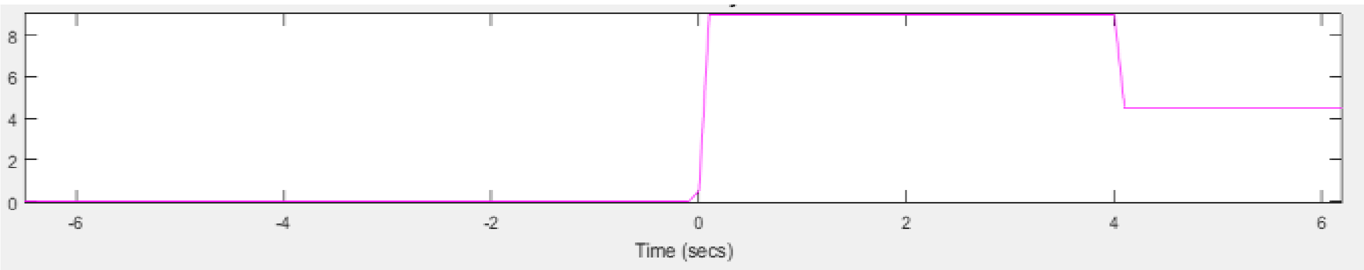

Figure 7 Load power consumption in constant power load in KW

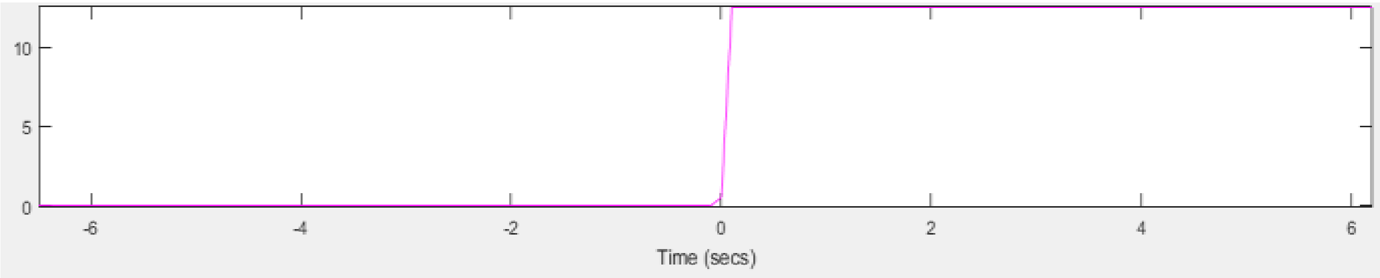

Figure 8 Load power consumption in constant impedance load in KW

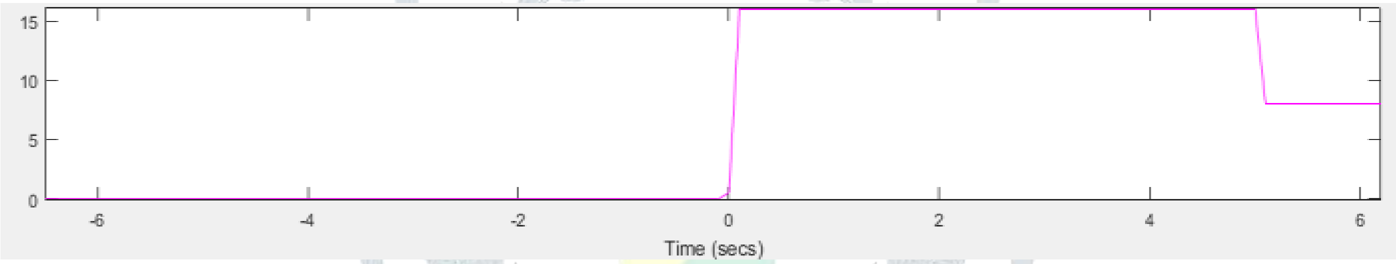

Figure 9 Load power consumption in constant current load in KW

The PV source power variation is shown in figure 10.

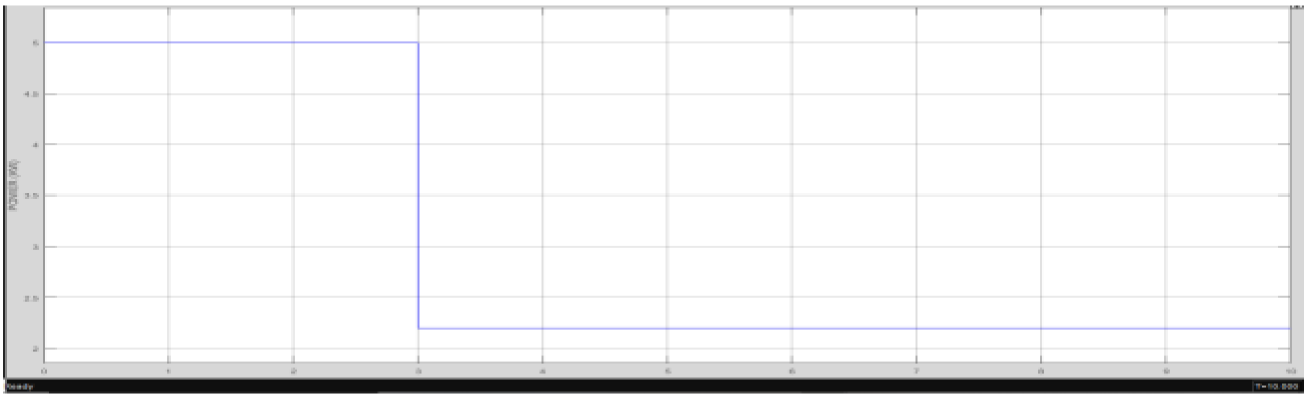

Figure 10 PV Power production

The two DR-Ls vary according to the loads as shown in figure 11.

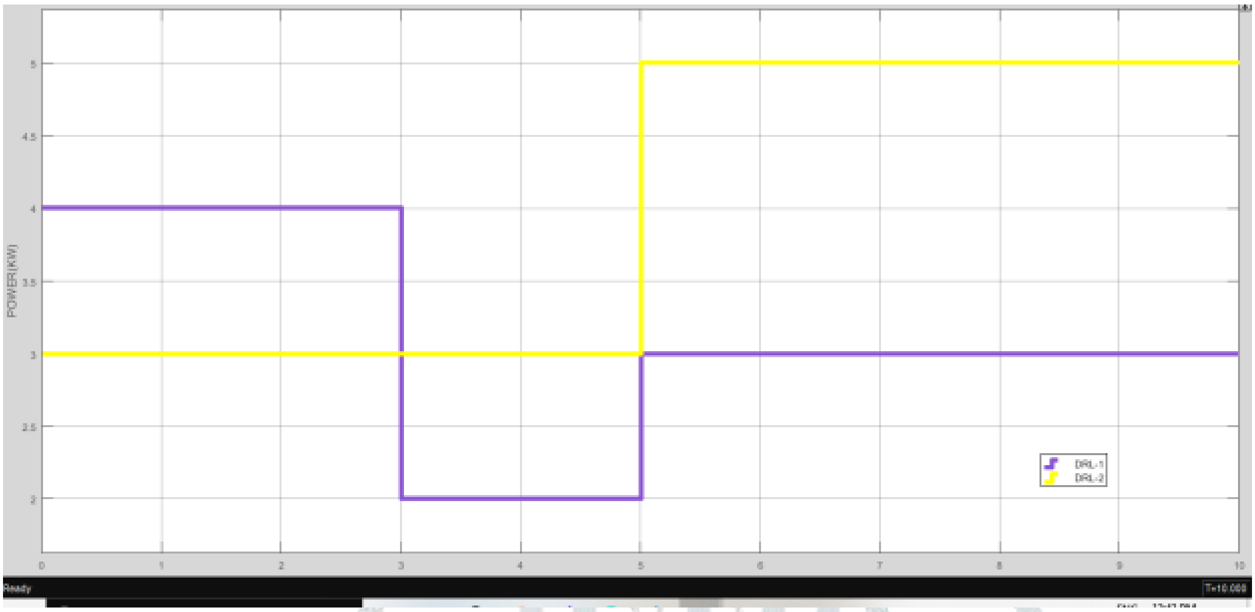

Figure 11 DR-L Power consumption

VI . CONCLUSION

In this paper, a droop based DR-L system with electric spring is proposed to support the effective energy management in MGs. As the electric spring is used for certain applications like maintaining the constant voltage across the load and also the reactive power control in micro grid. Now further in this paper electric springs are used to control the voltage across the non-critical loads.

The droop based control strategy is used to further define the characteristics of the controller according to the current in the downstream. The frequency of this voltage across load is driven using the formulated droop relation. The demand power consumption is adjusted according to the power consumption of critical loads and this can be adjust according to the operating conditions. As the power consumption is more the droop shifts upwards and as consumption reduces the droop move downwards by adjusting the frequency and the consumption of power by DR-Ls. According to simulation studies, the proposed droop-based DR system is more effective, consumes less power and economical.

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