

## DROOP CONTROL STRATEGIES OF DC MICROGRID

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**Abstract**—As a consequence of the increasing demand for electricity and environmental issues, the generation of electrical energy from renewable energy sources has improved in recent times. The renewable energy sources are connected with power grids all around the world. The increasing part of distributed energy resources in the current power system, has formed new chances and tests. Microgrid is the primary stage of future smart grid. This paper generally investigates the switching structures of microgrid reliant upon conventional power system droop control. Microgrid droop switch schemes are deliberated in specifics for improving the understanding in microgrid control. This paper analyses droop control strategy of DC microgrid. As DC microgrid goes on developing, the control strategies of DC microgrid draw more and more attention. An ample survey of variety of issues associated with droop control strategies of DC microgrid is presented in this paper.

**Keywords**—DC microgrid, Control strategy, Frequency control, Power flow, Droop control.

### I. INTRODUCTION

The power industries worldwide has noticed a huge change in utilization of power because of increased use of distributed energy resources, accompanied by beginning of recent development in power electronics with cost reduction. Now days the power system is more intricate and more organized. It produces electricity by combustion of fossil fuels like diesel, coal, nuclear fuel, natural gas, etc. This generates injurious particles and gases which spoils environment also reduces life.

Distributed energy resources are comprised of different distributed generation technologies like wind energy, wave / tidal power, Genset (range of fuels), fuel cell, solar thermal / solar photovoltaic, geo-thermal, micro-hydro, energy storing structures (hydrogen fuel cell, flywheels, batteries, ultra-capacitors, compressed air etc.), combined heat and power (CHP) that are connected with sharing grids near to load request [1]. While changing from traditional AC distribution to DC microgrid the trends like telecommunication, military operations, data centers, transportation, etc. are involved [2]. The output of solar PV, energy storages and most of the loads are of DC type. So DC microgrid is preferred over AC microgrid [3]. The joining of clean and renewable energy system can be achieved by microgrid with multi-energy

generations (MGMEG) and storing like photovoltaic production, fuel cells, ultra-capacitors, wind generation, micro turbines, battery banks etc. The quality and reliability of power because of devolution of source can be increased by the request organization and extreme effectiveness of existing energy [4-6].

Microgrid is bunch of micro sources, storage devices, distributed loads (non-critical and critical), CHP, electric vehicles, controllable and flexible interface close to customers. Microgrid can work in both grid connected mode or islanded (or isolated) mode. Microgrid provides reliable, green and safe electric power, reduces harmful emission, develop network quality. It has DC, AC and hybrid DC-AC configuration [7-17]. The line figure of usual microgrid have been shown in Fig. 1.

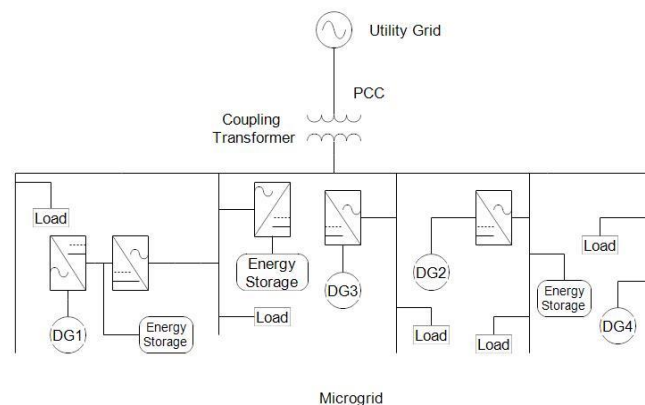


Fig. 1. Line figure of a classic microgrid

For controlling microgrid, we need to control the voltage and frequency mainly. Frequency is global phenomenon while voltage is local. For stable and secure operation of power system, the frequency should be within specified limit ( $\pm 3\%$ ). The decrease of reference voltage with increase in resultant current helps in implementing power distribution in droop controlled DC microgrid [18]. The objectives of DC microgrid operation are control of inverter, proportional load sharing and voltage regulation [19]. The types of generation control loops are:

- i. Automatic generation control / Capacity frequency switch/MW frequency switch /automatic load frequency control
- ii. MVAR- Voltage switch / excitation switch.

In this paper, section II gives control scheme of conservative power system. Section III gives literature review of control scheme of microgrid and the section IV gives conclusion.

**II. CONTROL SCHEME OF CONVENTIONAL POWER SYSTEMS**

The speed governing system is provided to all the generators in conventional power system. The generators frequency regulation characteristics are as indicated in Fig. 2.

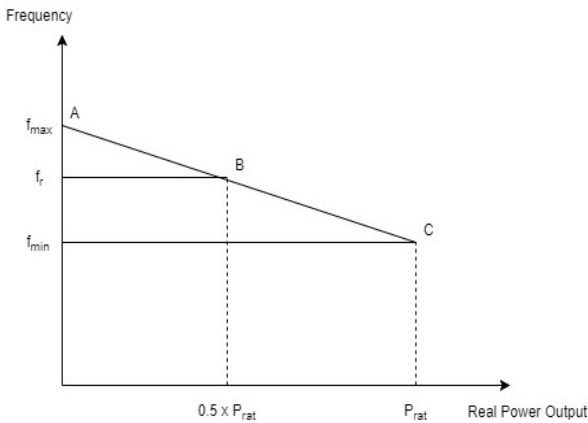


Fig. 2. Frequency droop characteristic of generator

With the rise in load demand frequency falling, the governor increases input to the prime mover to increase the speed. And when the decrease in load demand frequency falling, the governor decreases input to the prime mover to decrease the speed. This is done to settle the specified range i.e.  $\pm 3\%$ . The closed loop control is used for control purpose. Types of frequency control is explained below:

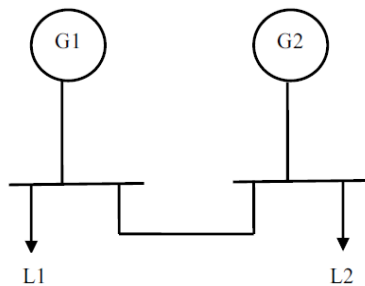


Fig. 3. Two generators connected over tie line

The two generating stations G1 and G2 are coupled over tie line as shown in Fig. 3. The loads L1 and L2 are joined to two generators separately. The kinds of frequency control are:

- i. Flat frequency regulation: When any one of the generator G1 or G2 supplies the increased load demand.
- ii. Parallel frequency regulation: When both the generators equally share the increased load.
- iii. Flat tie line: When the increase in load of a specific zone is lit by the generator of the same area.

**A. Primary load frequency control (PLFC)**

PLFC is composed of speed governing scheme, load, spinning apparatuses (generators and turbines) and power system [20]. Block illustration exemplary of PLFC control scheme is as shown in Fig. 4.

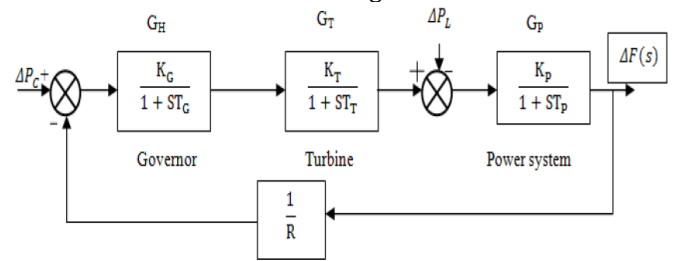


Fig. 4. Model of PLFC control strategy

Here,

$\Delta P_C$  is variation of position location

$G_H$  is transfer function of governor

$G_T$  is transfer function of turbine

$\Delta P_L$  is variation of capacity

$G_P$  transfer function of power system

$\Delta F$  variation of frequency

R is droop value or regulation in speed governor

For usual circumstances, the variation of position location  $\Delta P_C = 0$ , then,

$$V_{ld} = \frac{\frac{KV_{dc}}{2}Cs^2 + KK_p\frac{V_{dc}}{2}s + KK_i\frac{V_{dc}}{2}}{LCs^3 + \frac{KV_{dc}}{2}Cs^2 + (1 + KK_p\frac{V_{dc}}{2})s + KK_i\frac{V_{dc}}{2}} V_{ld}^* - \frac{LS^2}{LCs^3 + \frac{KV_{dc}}{2}Cs^2 + (1 + KK_p\frac{V_{dc}}{2})s + KK_i\frac{V_{dc}}{2}} (I_{ld} + I_f) \quad (1)$$

So,  $V_{ld} = G(s)V_{ld}^* - Z(s)(I_{ld} + I_f) \quad (2)$

First section of equation (1) is indicating resultant capacity unconstrained and second section is resultant variation in production because of speed governing system. We want additional switch accomplishment to carry stationary

miscalculation to nil and for controlling of changing aspects in scheme [21].

**B. Secondary load frequency control (SLFC)**

Recommended control scheme requirements:

- Control loop essentially take adequate amount of steadiness.
- Resulting a stage capacity variation, stationary miscalculation must be nil.
- Fundamental of frequency miscalculation should be reduced.

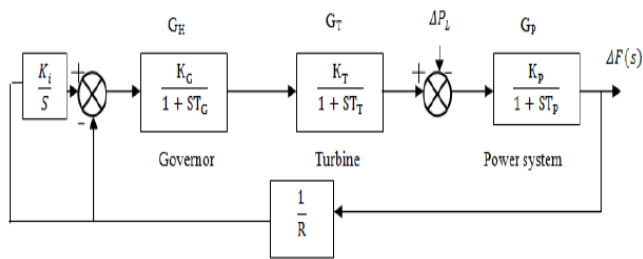


Fig. 5. Model of SPLFC control strategy

The various categories of controllers are integral controller, proportional controller, differential controller, proportional –derivative (PD) controller, proportional-integral-derivative (PID) controller and proportional-integral (PI) controller. The integral type controller is used for dropping the static error to zero. Fig. 5 shows the block figure exemplary of SPLFC switch scheme, here  $K_i$  is an increase. Choice of cost is quite difficult because this selects energetic performance of the system.

**C. Tertiary load control (TLC)**

TLC is also called as economic load dispatch. In this, the cost of  $K_i$  and  $\beta$  is selected in a way so that switch accomplishment is ideal. The multi-area system requires this control. A typical power system is distributed among sub-systems in that generators work in comprehensible manner and adjacent to individual.

**III. CONTROL STRATEGY OF MICROGRID**

The renewable energy sources are the favorable replacement to fossil fuel. They endeavor many benefits over conventional power sources. The only disadvantage is that the resultant power is intermittent also stochastic in nature. To overcome this disadvantage and to improve the superiority of power resource to make the system more effective, the renewable distributed generators are used. An autonomous microgrid is designed by establishing energy storage system (ESS) [22]. Microgrids can work in both grid connected mode and islanded mode of operation. Islanded mode can be switched depending upon energy price, power quality, error in key grid and steadiness apprehension. The

system frequency and voltage is imposed by microgrid in grid connected mode. The droop control of frequency and voltage is an important method for power division. In microgrids, for coordinated voltage and frequency regulation and to ensure power sharing, the most popular droop control method is used [23-25].

The droop control strategy optimally synchronizes distributed generation units' droop characteristics. During inadequate generation periods, it controls the shading of microgrid power demand. To upkeep the IMG process for a big time frame, the PEVs charging / discharging control is done by droop control strategy. [26] presented a hierarchical microgrid controlling scheme for integrating the key control stages required for microgrid action by using task sharing and dispatch strategy based on a transformative game theory as a coordinated algorithm. [27] proposed a graded switch to understand best destabilizer imbursement for improved power quality. For making the scattered generators likewise part the compensation exertions and for realizing the distorted reimbursement for serious bus, the primary and secondary controllers are put on. [28], proposed a decentralized control strategy that permits storing stage of individual microgrid for going about a standard cost by supportive allotment of power among microgrids. [29], presented the novel robust switching scheme required on behalf of an islanded microgrid in the existence of capacity unmodeled changing aspects.

The microgrid involves parallel assembly of several DER arrangements and a limited capacity. [30], presented a heuristic methodology for dynamic request side organization in the off grid arrangements for a group of definite requests. [31], proposed an incorporated reimbursement context by means of mutual load ailment in limited controller, to pay compensation the voltage fall and capacity allotment miscalculations. The voltage eccentricity is counterbalanced through a relative regulator when capacity sharing is remunerated over a relative important regulator. [32], refers to the dynamic power distribution of several distributed generators (DGs) among a microgrid.

**IV. SIMULATION WORK**

**A. The Design of Droop Controller**

Droop control is related to inverters control mode. It is same as primary frequency regulation of generator. We can regulate frequency by using droop characteristics of active power vs. frequency. Similarly, to regulate voltage, use droop

characteristics of reactive power vs. voltage. This gives the new stable system state.

The droop characteristic curve is shown in figure 6.

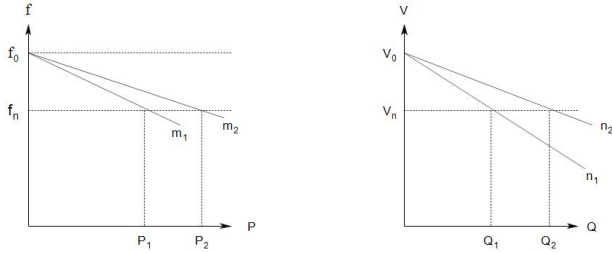


Fig. 6. Droop Characteristic

The nominal frequency and nominal amplitude of inverters output voltage are given by the following formulae:

$$\begin{aligned} f_n &= f_0 - m_n p_n \\ V_n &= V_0 - n_n Q_n \end{aligned}$$

- If the output of some source has more active power, then reduce its frequency so as to reduce active power output.
- If the output of some source has less active power, then increase its frequency so as to increase active power output.
- If the output of some source has more reactive power, then reduce its voltage so as to reduce reactive power output.
- If the output of some source has less reactive power, then increase its voltage so as to increase reactive power output.

**B. The parameter design of power control loop**

The formula for droop ratio is given as:

$$\begin{aligned} m_n &= \frac{P_{max} - P_n}{f_n - f_{min}} \\ n_n &= \frac{Q_{max}}{V_0 - V_{min}} \end{aligned} \quad (2)$$

In this formula,

- $P_{max}$  is maximum real power output
- $P_n$  is active power at nominal frequency
- $f_n$  is nominal frequency

$f_{min}$  is minimum allowable frequency for which DG gives maximum output power

$Q_{max}$  is maximum reactive power

$V_0$  is the amplitude of output voltage when reactive power of DG is zero

$V_{min}$  is the minimum allowable amplitude of voltage

The designed power controller is shown in figure 2.

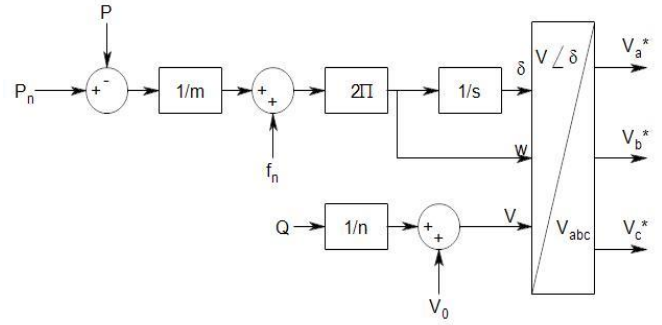


Fig. 7. Power Controller

The necessary conditions of active and reactive power output for the power controller are:

1.  $0 \leq P \leq P_{max}$
2.  $-Q_{max} \leq Q \leq Q_{max}$

Assume that, when microgrid is operating in islanded mode, the microsource can provide sufficient active power for the connected loads. Then the designed parameter should change the amplitude of voltage less than  $\pm 5\%$  and change in frequency less than  $\pm 1\%$ .

**C. The parameter design of voltage and current double loop**

$$L \frac{di_{inv}}{dt} = \frac{1}{2} m V_{dc} - V_{ld} \quad (3)$$

In the formula (3), m indicates the signal of controllable sinusoidal modulation

$$\begin{aligned} m &= m \sin(\omega t - \theta - i \frac{2\pi}{3}) \\ i &= 0, 1, 2; \end{aligned} \quad (4)$$

$I_{inv}$  is the output current vector of the inverter;

$V_{ld}$  is the load voltage vector.

So the differential equation of the filter capacitor is given as below:

$$C \frac{dV_{ld}}{dt} = I_{inv} - (I_{ld} + I_f)$$

In the formula (4),  $I_{ld}$  is the load current vector;  $I_f$  is the current vector which flow to the power grid.

By considering formula (3) and (4), the voltage and current double loop controller is designed as shown in figure (4). The stabilization of load voltage is achieved by voltage loop. To make the steady-state precision zero, the PI controller is used.

$K_p$  is scale factor

$K_i$  is integral factor

K is proportional constant

For enhancing the system dynamic response, the current loop is used.

In high voltage system, line inductance is much greater than resistance. Therefore droop control theory is applicable. But in low voltage system, line resistance is greater than line inductance. Therefore droop characteristics no longer exist in low voltage system. So in order to make droop control strategy applicable to low voltage distributed power system, the parameter of the inverter of DG should be designed such that the resultant output impedance is inductive. Therefore, the design of PI parameter is much significant. If use  $V_{ld}^*$

as the input,  $V_{ld}$  as the output, transfer function of the voltage loop can be calculated:

$$V_{ld} = \frac{\frac{KV_{dc}}{2}Cs^2 + KK_p \frac{V_{dc}}{2}s + KK_i \frac{V_{dc}}{2}}{LCs^3 + \frac{KV_{dc}}{2}Cs^2 + (1 + KK_p \frac{V_{dc}}{2})s + KK_i \frac{V_{dc}}{2}} V_{ld} * - \frac{LS^2}{LCs^3 + \frac{KV_{dc}}{2}Cs^2 + (1 + KK_p \frac{V_{dc}}{2})s + KK_i \frac{V_{dc}}{2}} (I_{ld} + I_f) \quad (5)$$

So,  
 $V_{ld} = G(s)V_{ld} * -Z(s)(I_{ld} + I_f) \quad (6)$

In the formula (6),  $G(s)$  is the proportion gain transfer function and  $Z(s)$  is the equivalent output impedance of the inverter.

From the expression of  $Z(s)$  we can calculate output impedance of the inverter. It is closely related to the parameter of the controller.

$$Z(s) = \frac{LS^2}{LCs^3 + \frac{KV_{dc}}{2}Cs^2 + (1 + KK_p \frac{V_{dc}}{2})s + KK_i \frac{V_{dc}}{2}} \quad (7)$$

For the current loop controller,

- $K = 5$
- $L = 0.6\text{mH}$ ,
- $C = 1500\mu\text{F}$ ,
- $V = 800\text{V}$

For the voltage loop controller,  $K_i = 100$ .

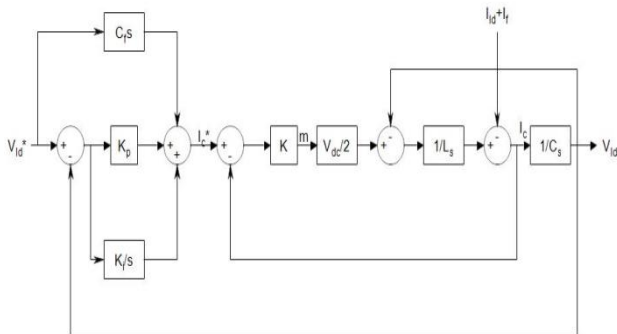


Fig. 8. Voltage and current double-loop controller

When  $K_p < 1$ , then the output impedance of the inverter is more resistive.

When  $K_p > 1$ , then the output impedance of the inverter is more inductive.

The width of the frequency band of the inductive impedance is directly proportional to  $K_p$ .  $K_p$  should be chosen such that the inductive frequency band of the output impedance is not too broad because high frequency output impedance can suppress harmonics because of its resistive character.

The resistivity of inverters output impedance is directly proportional to the integral parameter  $K_i$ . The output impedance is inductive when  $K_i=1$ . The output impedance is completely resistive when  $K_i= 5000$ .  $K_i$  should be chosen such that the inductive frequency band of the output impedance is not too broad. To make sure that the output impedance is inductive, define  $K_p$  as 10.

## V. OUTPUT OF MATLAB SIMULATION

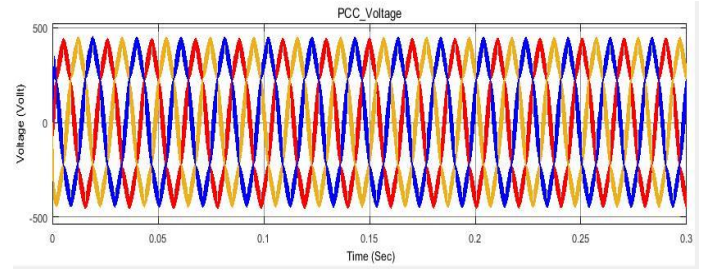


Fig. 9. PCC Voltage

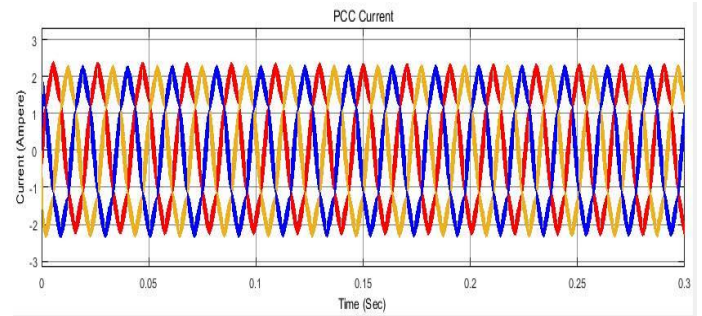


Fig. 10. PCC Current

Fig. 9 and 10 shows the phase to ground voltage and current from the point of common coupling. Ideal three-phase voltage and current measurements is done by three-phase VI measurement block.

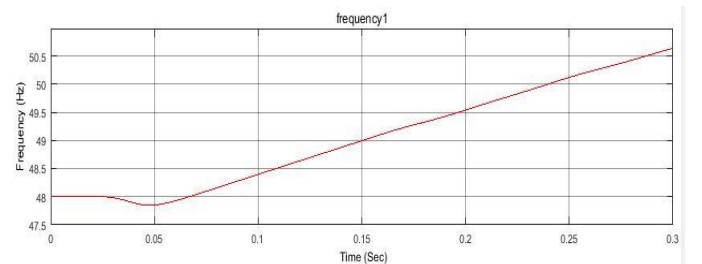


Fig. 11. Frequency 1

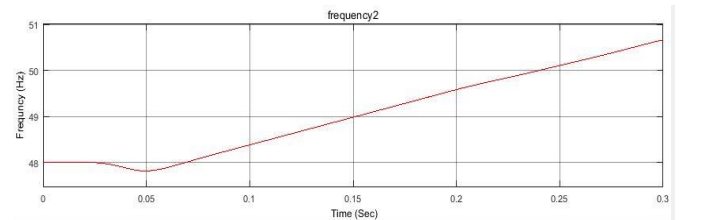


Fig. 12. Frequency 2

Fig. 11 and 12 are the output frequencies from two discrete three phase, Phase Locked Loop (PLL) systems. This Phase Locked Loop (PLL) system is used to synchronize on a set of variable frequency, three-phase sinusoidal signals. If the Automatic Gain Control is enabled, the input (phase error) of

the PLL regulator is scaled according to the input signals magnitude.

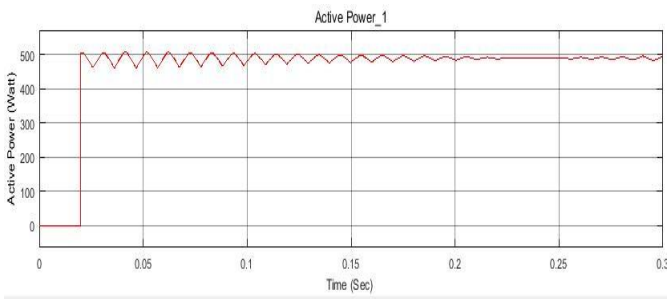


Fig. 13. Active power 1

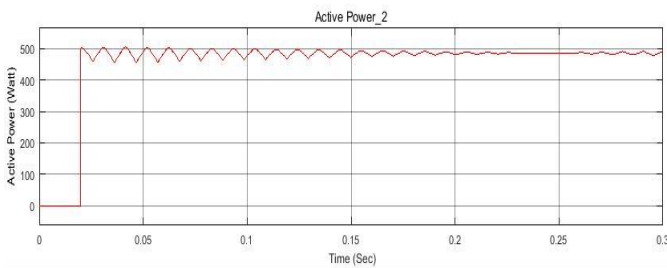


Fig. 14. Active Power 2

Fig. 13 and 14 shows the outputs of two power (mask) blocks. Power mask computes the active and reactive powers of a voltage-current pair at fundamental frequency. For the first cycle of simulation, the outputs are held constant to the powers computed for the Voltage initial input and current initial input parameters.

#### VI. DRAWBACKS OF DROOP CONTROL STRATEGY

It makes decisions based on local information only. This increases the reliability of the system. The system is easy to expand. It cannot make changes to control strategies depending on different working conditions because there is no information sharing between terminals. There will be a drop in voltage and power quality of the system in decentralized control. Also, the load sharing is the major problem.

Droop control is a type of decentralized control strategy. It makes decisions based upon local information. In droop control, micro-generators and energy storage systems share the loads according to characteristic lines (V-I characteristic lines), as shown in Fig. 3.6. It can detect the local voltage and the working points moving on the characteristic lines when the required power is changed. However, due to the resistance of the transmission lines, the load cannot be shared accurately as expected. The voltage drops a lot that result in the poor power quality.

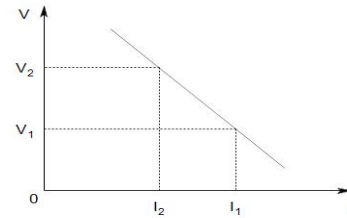


Fig. 15. Droop characteristic line of DC microgrid

#### VII. SOLUTION OF THESE PROBLEMS

In the proposed control strategy, the bus voltage is divided into several levels. The control strategy makes different decisions in different levels for arranging the power flow in better way. The grid connected mode differs from isolated mode by the presence of utility grid. In grid connected mode, the utility grid takes part in the power balance. The DC micro grid can switch among several modes according to the differences of voltage level as shown in Fig. In different modes, different control strategies are applied to micro generators and energy storage systems to keep the voltage fluctuation deviation within 5% rated voltage.

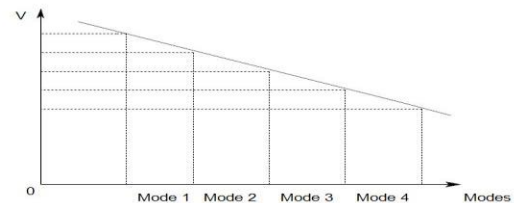


Fig. 16. Control theory of the proposed control strategy.

#### VIII. CONCLUSION

In this paper, various aspects for droop control strategies of DC microgrid are reviewed as anticipated in recent research literature. There are some problems accessible by researchers for enlightening the complete presentation of power system. However, utmost principally the concentration of maximum of the research work compacts with spaces like switch algorithms and improving the steadiness of system. Microgrid is developing as a superlative substitute to encounter the increasing request of reliable, green and charge actual power. Microgrid is the primary phase of upcoming smart grid. It should be noted that there does not exist universal unanimity over switching scheme of microgrid.

In recent times, researchers are more concerned about the occupation of droop switching techniques. It has subsequent benefits than others:

- Free of communication / cable for consistent working.
- Have desirable characteristics like modularity, elasticity, expandability and idleness.
- Laidback execution.

Though, it has few disadvantages like amplitude and frequency eccentricities, slow temporary reaction and there exist risk of flowing current. Earliest two disadvantages can be stunned by remedy of right controllers. Forthcoming days, microgrid would show a substantial part for distant and countryside area electrification.

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