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Mitigation of Instability Issues Developed by CPL on DC Microgrid

[1] Sunil Kumar, [2] Dr. Sanjeet Kumar Subudhi, [3] Anurag Parmar

[1] [2] [3] Department of Electrical Engineering, C.V. Raman Global University, Bhubaneswar, India
Corresponding Author Email: [1] sunilkr170197@gmail.com, [2] sanjeetsubudhi@yahoo.com, [3] anuragparmar999@gmail.com

Abstract— ***Conventional power energy sources have been slowly replaced with the renewable energy sources and DC microgrid has become one of the most efficient ways of implementing them. As the amount of power electronic switches have creeped into the system, the use of Constant Power Load has solved the problem of regulated switching. However, the use of CPL in the suggested arrangement has a negative impact on the stability of the system. So, it is necessary to deal with the system instability by applying techniques that enhances the widespread use of CPLs in the microgrid. The paper deals with the microgrid topology comprising of DC voltage source, PV source and a fuel cell source as well. These arrangements are coupled through a LRC model under Amplitude death stabilization technique to critically analyze the undying oscillating waveforms and reach a stable system. Various other damping methods have been considered in the proposed system in order to couple the three different source-converter topologies to achieve a constant bus voltage, constant power output from the CPL and work in a synchronized way between the circuits to achieve stable voltage and power waveform. RC parallel, RL parallel and RL series is implemented for compensation.***

Keywords—Amplitude Death, Constant Power Load, DC Microgrid, LRC.

I. INTRODUCTION

As a result of population expansion, urbanization, and economic progress, there is an increasing demand for electrical energy. The International Energy Agency (IEA) predicts that by 2040, the world's demand for power will have doubled. But using conventional energy sources like fossil fuels to supply this demand presents serious problems for the economy, the environment, and sustainability. Solar and fuel cell technology are examples of renewable energy sources that have various advantages in a variety of contexts, including the reduction of greenhouse gas emissions, lower operating costs, increased energy security, the creation of jobs, improved health outcomes, etc.

The very essence of the consequences of switching to a renewable energy system from conventional sources is the microgrid concept. A confined energy system called a microgrid is a system that can run both independently and in tandem with the main grid. It is made up of DERs (Distribution Energy Resources), which include fuel cells, battery storage systems, and solar PV arrays. In order to create sustainable damping for a stable system, all of the DERs are also interconnected by coupled circuits. The control system makes sure that the generation of energy from various sources is effectively coordinated to meet the demand efficiently. A microgrid can offer a number of advantages, including higher energy security, fewer carbon emissions, improved energy efficiency, and increased resilience during power outages and natural disasters. Although remote or off-grid locations are where microgrids are most frequently used, with the advancement of technology, these microgrids can also be deployed to maintain the current power infrastructure.

Due to their efficiency, compatibility with RES, ease of control, safety, and lower cost, DC microgrids are occasionally chosen over AC microgrids. The selection of a microgrid, however, is based on the specific application and needs of the design, as each system type has advantages and disadvantages of its own. Power electronics components connect the loads and DERs featured in the Microgrid concept to the DC Bus. In order to achieve voltage regulation, frequency stabilization, and fault protection, these devices govern the energy flow between the various microgrid components. Data centers, hospitals, and military facilities are among the applications where DC Microgrids are best suited for use.

Different power electronics topology efficiently installed in the modern DC Microgrid arrangement consist of various DC-DC converter designs. These designs include a buck converter, boost converter or sophisticated cascaded arrangement of buck-buck, buck-boost, and boost-buck. A buck converter as shown in fig.1 consist of a switch in series with an inductor L with a diode D and capacitor C placed parallelly. It is a combination of certain switching mechanism such that the two halves of the circuit shown behaves in a manner that the output voltage will be a certain percentage lesser than the source voltage. Similarly, the boost converter arrangement consists of a similar set of power electronic devices as in the buck device but with a certain difference in the arrangements or positioning as shown in the fig.2. Here the diode and inductor are placed in series with the switch S connected parallelly between L and D such that the switching ON and OFF cycles results in the flow current through the circuit show as to achieve an output voltage higher than the source voltage by a certain percentage.

Through the paper, we have come across the fact that the DERs connected to the DC bus through coherent combination of the two DC-DC converter topologies discussed earlier. The converter connected to the solar PV array is a cascaded connection of two Buck converters so as to achieve a certain voltages level at the bus. On the other hand, the battery energy source and the fuel cell arrangement are connected to the DC Bus through a converter design which is a cascade connection of boost and buck converter. In order to obtain the similar voltage profile as the previous DERs at the bus.

The voltage profile and line power at the DC bus is maintained at a more or less same level by the installation of a closed loop system control system-based converter termed as the constant power load (CPL). This block maintains a constant power consumption irrespective of the fluctuation in the generation capacity of the DC microgrid. The control loop of CPL senses the input current and the low current values at a given voltage level estimate the power consumptions and generates switching pulses to levelized the power value during a mismatch. The presence of power electronics devices in the CPL creates a challenge of an unstable system or even system failure. In order to achieve a constant power at the load side during a severe case of voltage sag, will result into an excessive inrush current causing the threat to a stable system. Since the CPL creates a negative incremental resistance, the overall damping of the system reduces leading to a greater chance of an unstable system. Since such systems are frequently exposed to fluctuating conditions experiencing an oscillating power system profile, the damping through various compensation techniques plays a vital role in achieving stability.

In this paper we have adopted three different compensation techniques for meeting instability issues in DC microgrid namely Amplitude death stabilization, Phase displacement stabilization and passive damping method. In the amplitude death stabilizing method, an LRC based circuit is directly coupled with the three DERs at the tie line connecting the DC-DC converters with the CPL. A coupled systems model is offered as a solution to the problem of instability. This design permits the employment of open-loop feedback techniques that result in system amplitude death. Scientists have discovered the mathematical conditions known as amplitude death, which they define as a coupling-induced stabilization of the fixed point. They discovered that sufficiently strong coupling and sufficiently diverse natural frequencies of the connected systems are the two essential necessities for amplitude death. By using delayed coupling to generate amplitude death, these criteria for amplitude death were further investigated. The phenomena were then extended to various topologies of limit-cycle oscillators with equal frequencies, and the results were experimentally verified.

To increase a system's stability, passive stabilization uses passive components including resistors, capacitors, and inductors. One method is to increase stability by adding a resistive load to change the dynamic characteristics of the load. Another method that is frequently employed to lessen the impedance variations of LC filters is passive damping. Researchers suggested employing both RC parallel and RL parallel dampers to stabilize a DC-DC converter that behaved like a CPL. They also used numerical approaches to calculate the damper specifications. By assuming a large blocking capacitor, the RC parallel damper design problem was made simpler for analytical treatment. This paper presents a systematic way for passive damper stabilization of CPLs. We looked into RC parallel, RL series, and RL parallel passive damping circuits. Using a prototype CPL system made up of a voltage source, an LC filter, and an ideal CPL, it is shown that a CPL system can always be stabilized by a passive damper. Instead of employing the numerical or approximate design methods used in other studies, this study gives closed-form analytical formulas that determine the damper parameters necessary for stabilizing a given CPL. Time- and frequency-domain data from an experimental system support the study's conclusions.

II. CONVERTER TOPOLOGIES IN DC MICROGRID

A DC Microgrid is a enclosed system which produce DC output as the main output of the power system. There are various application of DC Microgrid which is being used such as data centers, remote village and renewable energy system. For connecting different sources and loads within a DC Microgrid, various converter topologies are being used. Some of them which are used in DC Microgrid are listed below:

1. Buck Converter: It refers to the step-down converter which converts a high voltage value to a low voltage value. The use of this is to supply power to the load s that require low voltage than the input voltage.

It works by turning the input voltage ON and OFF at a higher frequency using a switching device like transistor, IGBT or MOSFET. When the input voltage is turned ON, the input voltage is feed to the inductor which stores energy in the form of magnetic field. When switch is turned OFF, the stored energy is being discharged into the output of the load via a diode. Meanwhile inductor current flows continuously but now diode being a carrier of the load current and doesn’t allow to the output voltage from dropping to zero. A capacitor which is connected to parallel in the output load to filter the ac ripple so that pure DC voltage can be obtained.

This process of turning ON and OFF being repeated at high frequency and the output voltage is restrain by changing the duty cycle of the switch. More the duty cycle more is the output voltage and less is the duty cycle less is the output voltage.

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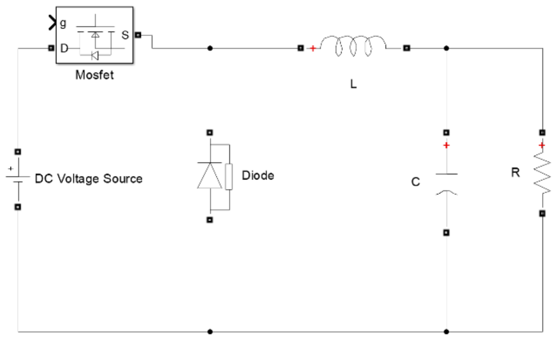

Fig 1 Buck Converter

2. Boost Converter: A type of DC-DC converter that converts a low voltage to a high voltage It operates with the help of switching devices like IGBT, MOSFET or a transistor to ON and OFF the input voltage at higher frequency. While turning ON the switch, the input voltage is feed to the inductor which results in the storing of energy in magnetic field form. At the time when switch is being turned OFF, the inductor dissipates the energy stored into the load of output with help of a capacitor and diode.

The capacitor which is connected in series of the load which helps to increase the voltage output. The process repeats i.e., turn ON/OFF at higher frequency in the range of 100KHz to many MHz. Output voltage is regulated by adjusting the duty cycle.

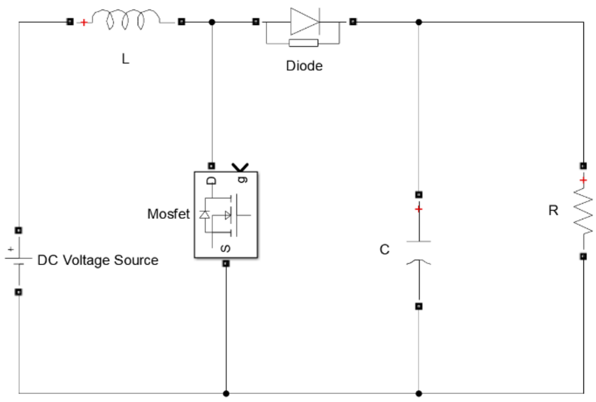

Fig 2 Boost Converter

3. Buck-Buck Converter: It is kind of DC-DC converter and also known as two-stage buck converter which steps down the input voltage to lower output. It consists dual inductors and two switches to execute this operation. Condition 1- the input voltage applied in inductor L1 and switch S1 closed. The increases through inductor increases and stored energy in the form of magnetic field. At sometimes, the S1 is opened and the S2 is closed. The energy which is stored in the form of magnetic field of L1 is transferred to the L2 via S2. Condition 2- Switch 2 is opened and the energy present in the L2 is transferred to the capacitor output and load. Then this process repeats at higher frequency.

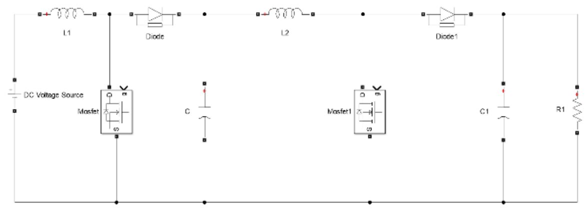

Fig 3 Cascaded Buck-Buck

4. Boost-Buck Converter: It is a kind of DC-DC converter which can step up or step down the input voltage to a wanted output voltage. Case-1 the input voltage applied to inductor L1 and switch S1 is closed. Then there is a increase in the current of the inductor which stores its energy in the form of magnetic field. At times the S1 is opened and S2 is closed the stored inductor energy L1 gets transferred to the inductor L2 through S2. Case-2 the Switch S2 is opened and the stored energy in the inductor L2 is transferred to capacitor and output load. This overall process repeats at high frequencies.

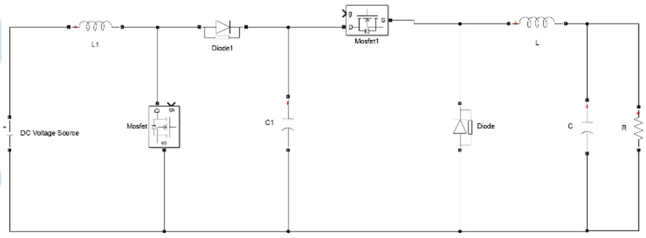

Fig 4 Cascaded Boost Buck

III. METHODOLOGY

The work in this paper comprises of a DC microgrid arrangement with tightly controlled CPL along with compensation techniques. The figure 5 shows the system simulation diagram for the proposed dc microgrid connected with a constant power load. The model 1 is a Solar PV Array based source connected to the buck converter and the output tie line is connected to a buck converter which is tightly controlled by the PI controller to maintain a constant power. It fixes the output power to achieve a constant voltage irrespective of the varying generation. The switching pulses of the stage 1 buck converter is controlled using an MPPT controller.

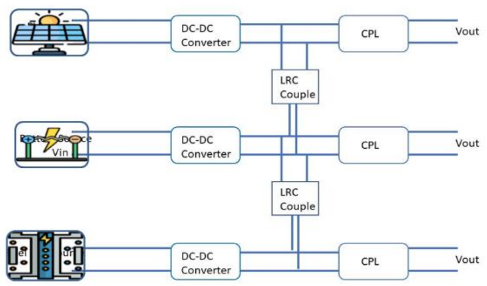

Fig 5 Dc microgrid with CPL

The model 2 is a battery energy source connected to the boost converter circuit. The output of this circuit is connected to the tightly controlled buck converter through the DC tie line showcasing the CPL model. However, the switching pulses for the stage 1 boost converter is directly receiving signals from a pulse generator.

The model 3 is fuel cell powered voltage source connected to the boost converter circuit the output of which is supplied to the buck converter with PI controller acting as the CPL model, through a tie line. The switching signals to the boost converter is provided based on the PI control output generated by measuring the output voltage at bus.

When the model is connected then the buck or the boost converter based on the circuit it is connected to, increases the voltage level, or decreases the voltage level to a desired voltage value which is estimated to be around 30V at the DC bus. This profile is then supplied to the tightly controlled buck converter resembling the CPL model such that all three models generate the same voltage value at CPL which is around 10V. The display in the Matlab Simulink model shown in figure 6, figure 7 and figure 8**,** for solar, battery and fuel cell respectively show the voltage values at the DC bus and the CPL as well.

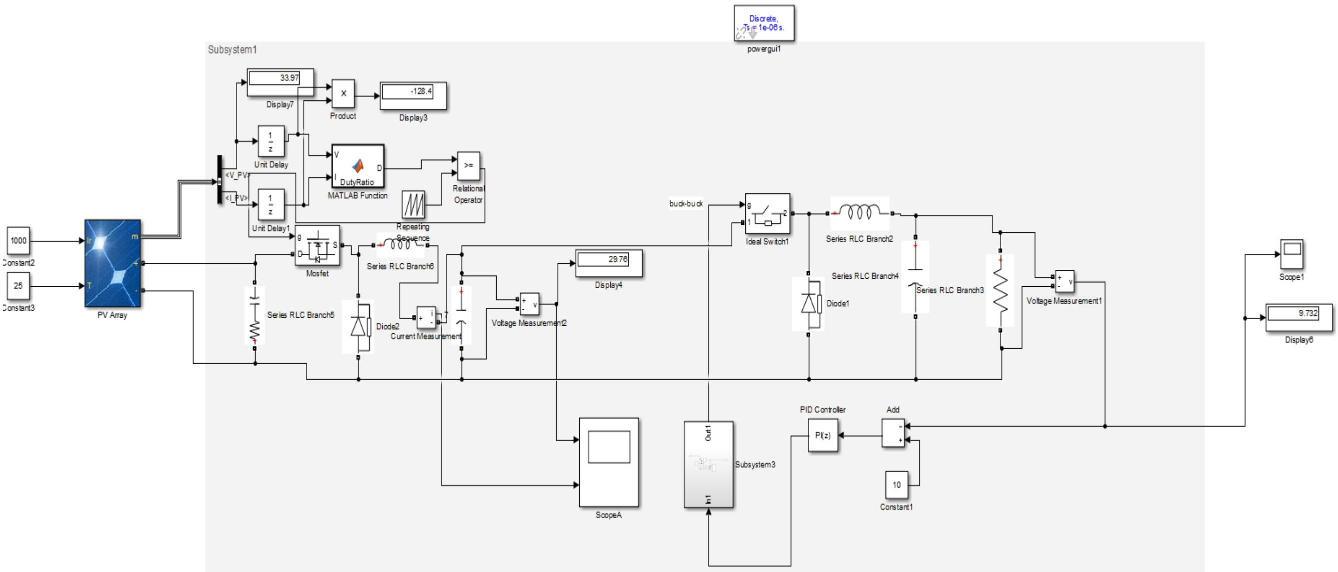

Fig 6 Solar source dc microgrid simulation

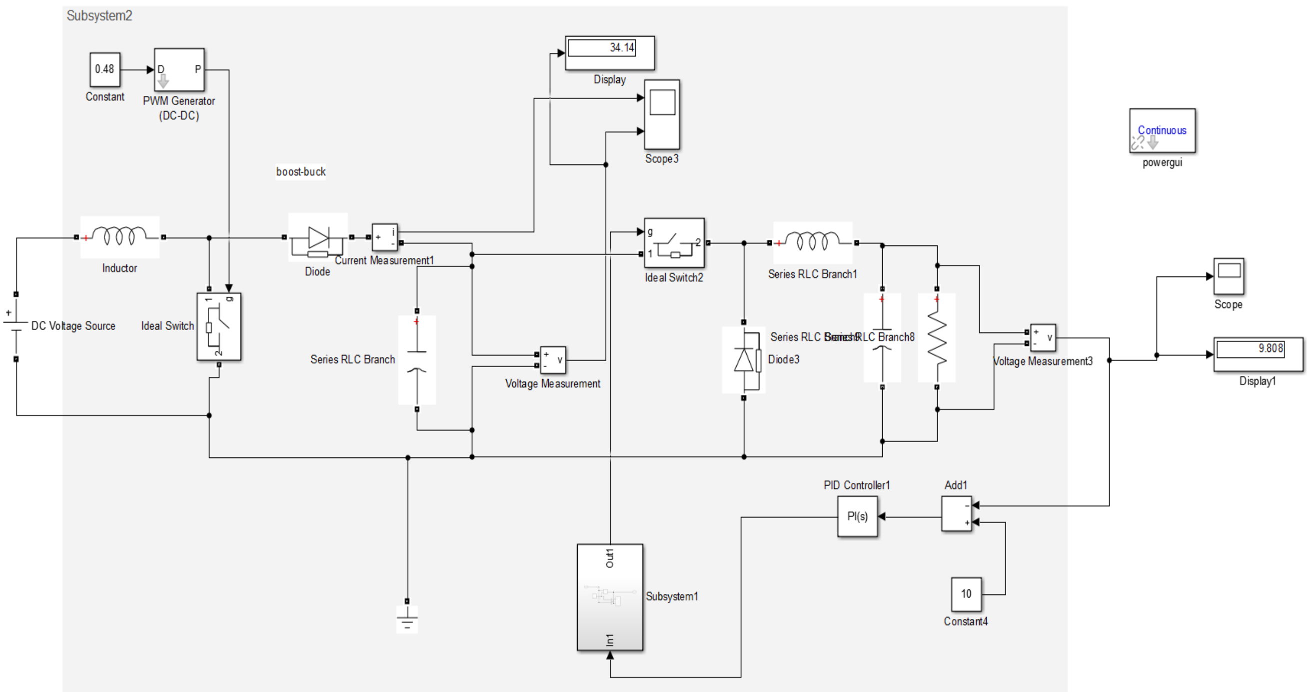

Fig 7 DC source microgrid simulation

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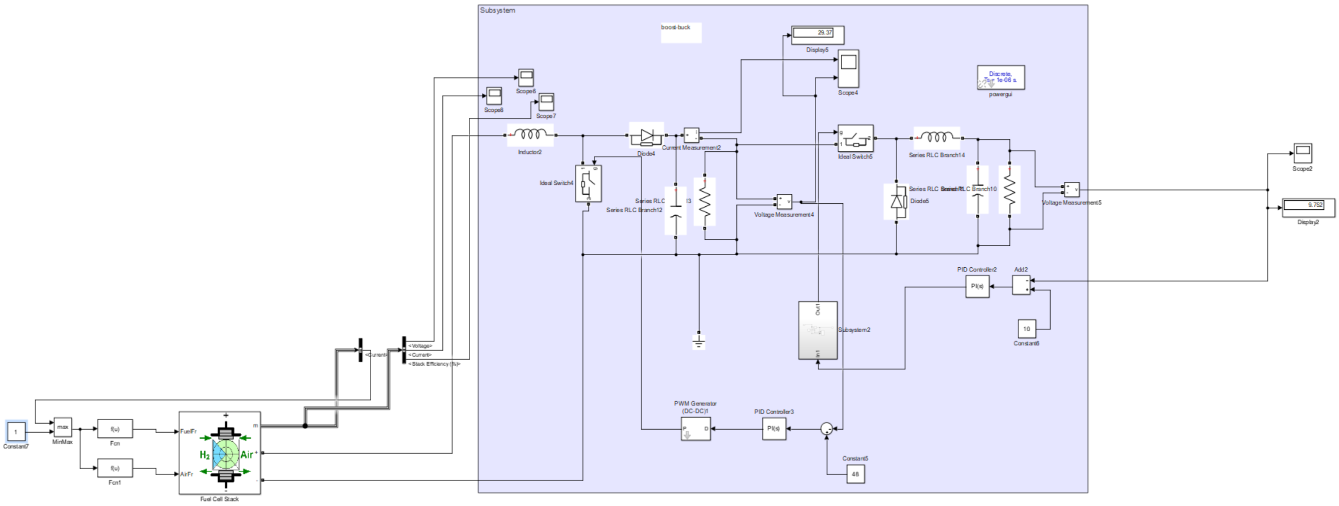

Fig 8 Fuel cell microgrid simulation

IV. CPL MODELLING

A. Constant Power Load

A CPL is kind of load which is able to maintain a fixed power usage regardless the input voltage or current. In power electronics converters, CPL can be challenging because it causes the output voltage to become unstable. It happens because a CPL will cause the converter to draw high current from the input source in order to maintain the required output power which causes the drop in the output voltage. A constant power load reduces the damping of the system as it creates a negative incremental resistance or impedance which unfortunately destabilize the system. When an electrical system is subjected to sudden change in load, it might experience oscillation as the overall damping get reduced. However, the presence of a CPL, incremental resistance of load reduces as the voltage across it reduces, arising a negative incremental resistance. This can

effectively amplify the oscillations in the system, reducing damping and make it more prone to instability. This effect in converters, where the presence of a CPL can cause the output voltage to oscillate or become stable.

B. Working Principle of Constant Power Load

The circuit model as shown in figure 9**,** consists of a switch, inductor in series with the switch, a diode in parallel between the switch and inductor and a parallel RC is connected at the load side. The inductor is rated at 0.3mH, the capacitor is rated at 1000µF and resistor of 1Ω.

The output voltage measured across the resistor is compared with the reference output voltage. The error signal thus generated is given to the PID controller which generates an output signal provided to the switch of the CPL such that the output voltage is always maintained at a fixed value to operate under the constant power mechanism.

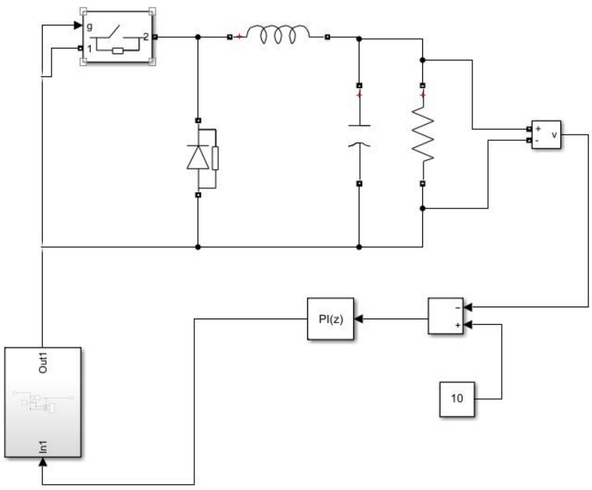

Fig-9 CPL model

V. COMPENSATION TECHNIQUES

A. Amplitude Death Solution

This method used to mitigate the effect of instability of constant power load in converter system. CPL sometimes causes the oscillations and instability in the power supply, which can badly affect the efficiency of the system. It is the adequate technique used for stabilization of power electronics converters which are subdued to CPL, as this allows precise controlling over the power supply helps to reduce the fluctuations and de-stability in the system's performance.

The circuit shown in figure 10, fig 11, fig 12, resemble the equivalent amplitude death stabilization technique implemented on the dc microgrid. The circuit consist of the LRC model. It has a switch in series with L, R and C. a diode is placed in parallel with switch and inductor. When the CPL

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is connected to the circuit it increases the negative incremental resistance of the circuit causing oscillations. When the pulses are rising, the inductor allows the flow of current through it and when the pulses are falling, since inductor disallows sudden change, it discharges the initially charged current and so a decaying ng waveform arsis. For a continuous mode of conduction, the waveform becomes stable.

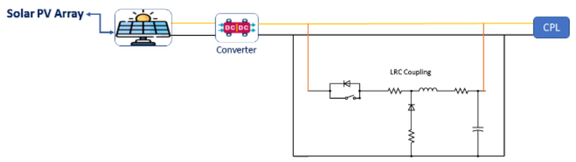

Fig 10 Solar-LRC

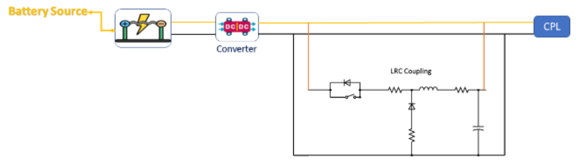

Fig 11 Battery-LRC

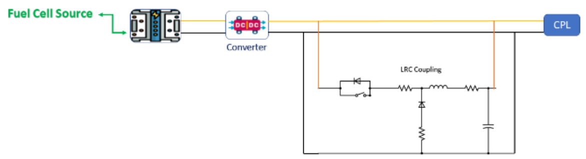

Fig 12 Fuel Cell-LRC

B. Passive Damping

Passive components like a resistor (R), an inductor (L), a capacitor (C), or any combination of these can be added to a system for better damping. Changes in the load converter's input impedance or the source converter's output impedance in a cascaded system are too responsible for the improvement. This article outlines a methodical strategy for CPL stabilization utilizing passive dampers. The RC parallel, RL series, and RL parallel passive damping circuits are explored. Using a voltage source and a sample CPL system, we will show that a CPL system can always be stabilized by a passive damper using an LC filter and a perfect CPL. We will offer closed form analytical formulas that determine the damper parameters required for stabilizing a specific CPL in place of numerical or approximate design methods, as used in prior publications. In this study a resistive load is applied and to change the dynamic properties of the load, enhancing system stability. Additionally, passive damping is frequently utilized to reduce LC filter impedance peaking or dipping. Although the effects of the three damping approaches on stability are comparable, practical considerations like size, weight, and power dissipation may favor one over the others depending on voltage, current, and source impedance characteristics.

If the resistive load **R > CPL fig (13)**, it is implied that the CPL predominates and that the system states operate without energy loss at the output terminals and with an undamped response. However, the system becomes passive, or a stable system, if **R<CPL** by adding more resistive load (R = 2 ohm) across capacitor circuit. On the other hand, it loses a lot of energy at the output terminals. By altering the system's energy through a closed-loop feedback controller to make up for the energy discrepancy between the system's energy and the energy injected by the controller, the same result can be achieved without using any additional energy.

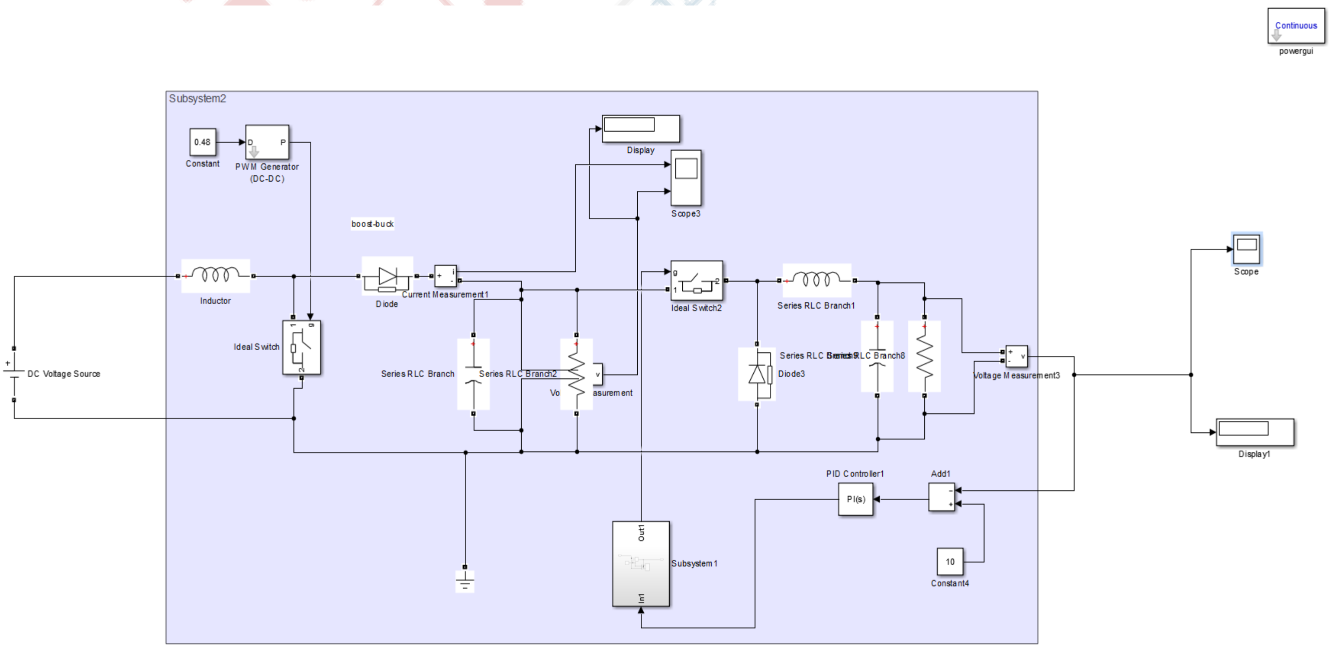

Fig 13 Passive Damping Model

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VI. RESULTS

The following figure 14 to figure 16 shows the unstable output waveform of dc microgrid. The figure 17-19 shows the output waveform under amplitude death stability technique. The figures 20-22 show the stable output waveform for passive damping system.

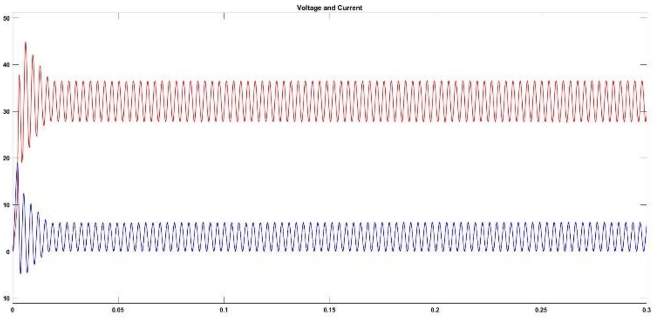

Fig 14 Unstable solar waveform

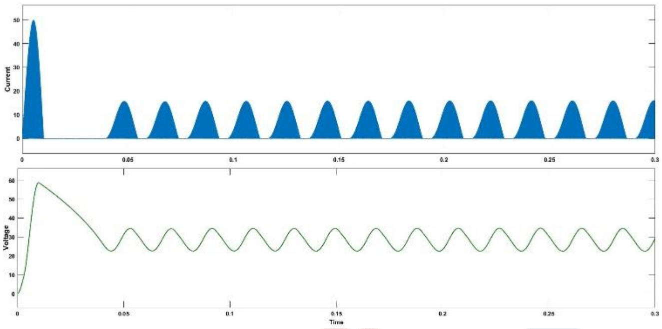

Fig 15 Unstable DC waveform

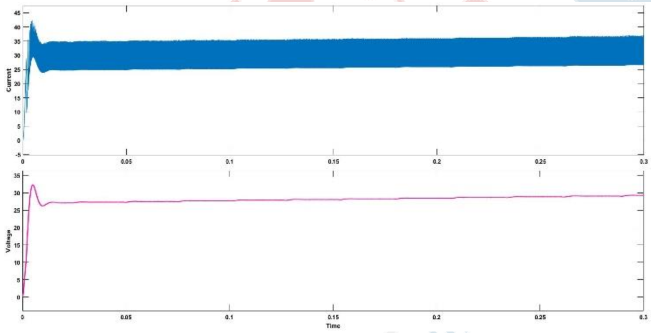

Fig 16 Unstable Fuel Cell waveform

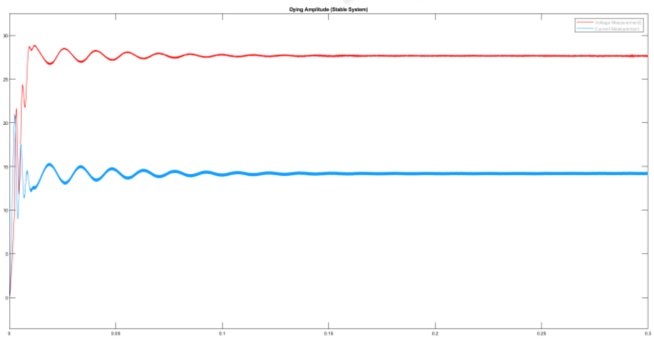

Fig 17 Stable Amplitude death solution for solar

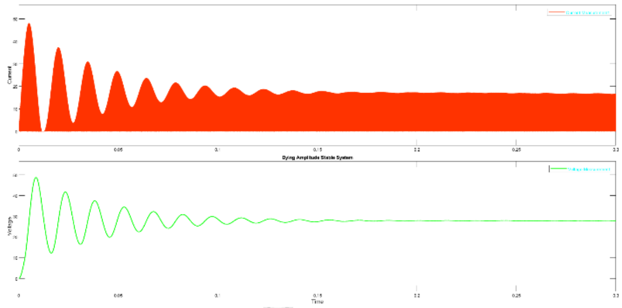

Fig 18 Stable Amplitude death solution for battery source

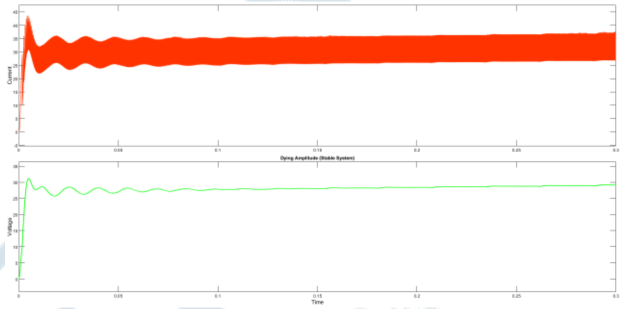

Fig 19 Stable Amplitude death solution for fuel cell

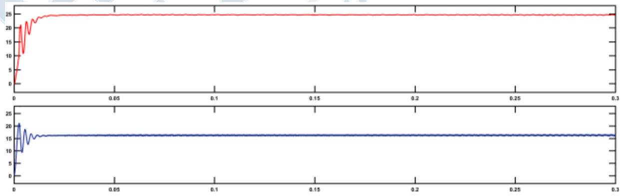

Fig 20 Stable passive damping for solar surce

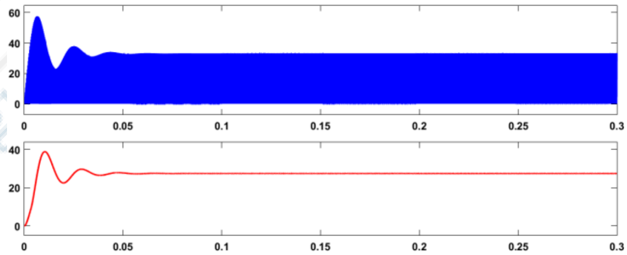

Fig 21 Stable passive damping for battery source

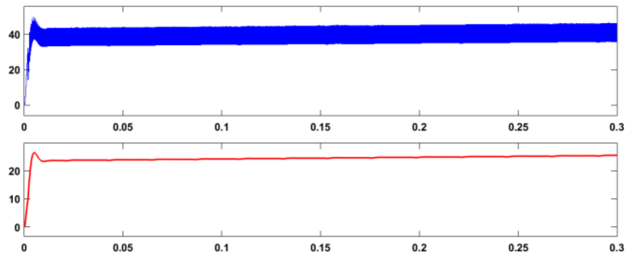

Fig 22 Stable passive damping for fuel cell

VII. CONCLUSION

This paper examined stability issues in dc microgrids. The CPLs introduce a destabilizing effect that causes unacceptably large voltage oscillations. This paper discussed some methods to achieve a stable dc voltage at the dc microgrid main buses by compensating the oscillatory action of CPLs through control-related strategies. Tightly regulated power electronics which act like CPLs and the stability issues concerning CPLs were reviewed in this paper. The stabilization challenge in this constant-power scenario is addressed in this paper using amplitude death and passive damping techniques. Stability concerns are still being monitored and will require additional attention in the future. And there is still a great deal of other ways to increase stability that need to be investigated. This analysis can be carried out in the future when connected to the microgrid. To do the stability study on the DC microgrid, a more practical approach must be developed. As well as Researchers could focus on the design and optimization of power system components such as DC-DC converters, DC-AC inverters, and energy storage systems to improve the stability of DC microgrids. Further we will also check the stability of CIL and CVL models of microgrid with the proposed compensation techniques.

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