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Modelling and Analysis of SEPIC using DVR for Solar PV System

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Abstract: Dynamic Voltage Restorer (DVR) is a series controller which has capability to control voltage profile at the load end under all operating conditions. The device is mainly used in distribution system with low and medium voltages. The controller has now much importance (due to its capability in maintaining power quality) as most of the loads are becoming very sensitive to power quality events like voltage sags, swells etc. However energy storage requirement has put limitations on high power rating of DVR. This project tries to find a solution to energy storage limitations: renewable sources. The project proposes modelling of PV array, Single Ended Primary Inductive Coil (SEPIC)/Boost converter for mitigating voltage disturbances using DVR. Performance of DVR will be investigated using motor load.

***Keywords**: Solar Photovoltaic, SEPIC, Power Quality, DVR*

I. INTRODUCTION:

Now a day's electrical energy plays a major role in day to day life of humans. For giving the supply voltage to DVR, in this project renewable energy sources are used. In this project Solar Energy is used as a source of energy for supplying the supply voltage to DVR. In this solar energy is converted into electrical energy. From the Photo Voltaic array we can get low voltage, so we have to increase this voltage. For this purpose Single Ended Primary Inductor Converter (SEPIC) is used in this project. SEPIC converter can acts as both Buck converter and Boost converter. It has a switching device MOSFET, by adjusting the gating signals of MOSFET we can get the desired output voltage. For the purpose of controlling PI controller is used in this converter. The output of the SEPIC converter is given to the DVR as input. When there is any voltage sags or swells the DVR injects the missing voltage. By connecting different loads we can find out the performance of the DVR. This work is done in MATLAB/SIMULINK.

II. PHOTO VOLTAIC SYSTEM:

The Solar-PV cells are used to produce electricity by directly converting solar energy to electrical energy. Each solar cell is basically a p -n diode. As sunlight strikes a solar cell, the incident energy is converted directly into electrical energy without any mechanical effort. The voltage and current levels are produced from PV cells are very less, thus these PV cells are connected in series and parallel called modules and arrays to produce required voltage and current levels. The solar PV array is modelled by considering the output characteristics of PV panel which directly have relation with power converters which exists in the system. The solar PV cell is a non linear device which can be represented by a current source connected parallel with diode as shown in Fig. 1.

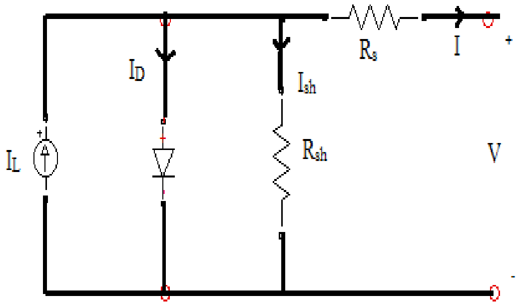

Fig 1: Electrical Model of a PV cell

By writing the equation for the PV circuit using the Kirchhoff's current law for current is,

$$I = I_L - I_D - I_P \quad ....(1)$$

Where, I_L is the light generated current in the cell

I_D is the voltage dependent current lost to recombination

I_p is the current lost due to shunt resistance

The diode model equation is represented as,

$$I_D = I_0\left[\exp\left(\frac{V + IR_S}{nV_T}\right) - 1\right] \quad ....(2)$$

Where, n is the diode ideality factor

I_0 is the diode saturation current

V_T is the thermal voltage

Now, the equation for the PV module is expressed as,

$$I_m = I_L - I_o\left[\exp\left(\frac{V_m + I_m N_S R_S}{nN_S V_T}\right) - 1\right] - \left(\frac{V_m + I_m N_S R_S}{N_S R_p}\right)$$

Where, N_S is the identical number of series cells

V_m is the module voltage and I_m is the module current

The equation (3) is simulated using MATLAB/Simulink and P-V and I-V characteristics are obtained. The operating curves shows that solar PV output power is function of solar irradiation. Fig. 2 shows I -V and P-V characteristics of a one PV module. The specification of a solar PV module for grid connected solar PV system is given in Table I.

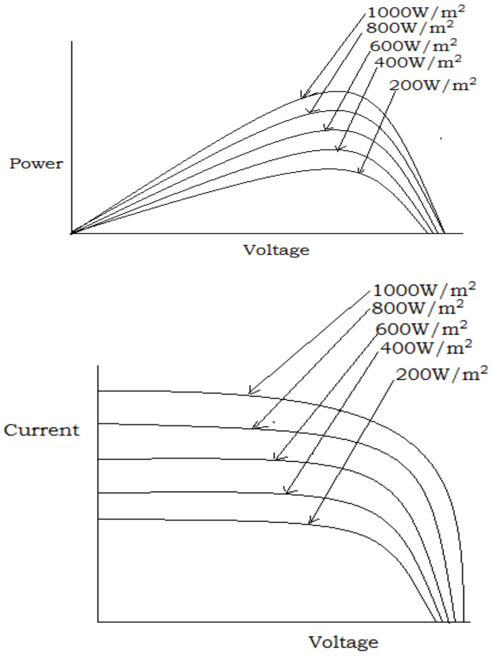

Fig 2: PV and IV characteristics

Parameters	Values
Irradiation	1000W/m^2
Short circuit current	5.45A
Open circuit voltage	22.2V
Current at P$_{max}$	4.95A
Voltage at P$_{max}$	18V

Table 1: Parameters of the PV system

III. SEPIC:

It is a converter which can converts the DC voltage from one level to another level that means it can step-up or step-down the output voltage by varying the Duty cycle of the MOSFET. It has advantages like low component stresses, low energy storage requirements, compact in size and the efficiency also high compared to Buck-Boost converter. The circuit diagram of SEPIC is shown in fig.2;

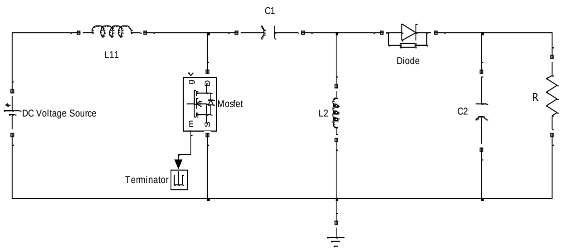

Fig .3. Circuit diagram of the SEPIC converter

Design of SEPIC converter:
For closed loop simulation we go for state space transfer function. For SEPIC the input to output relationship and associated signal state relationship can be represented as,

$$\frac{V_{OUT}}{V_{in}} = \frac{D}{(1-D)}$$

$$I_{L1} = \frac{D^2 V_{in}}{(1-D)^2 R_L}$$

$$V_{C1} = V_{in}$$

$$I_{L2} = -\frac{D\ V_{in}}{(1-D)\ R_L}$$

$$V_{C2} = \frac{D\ V_{in}}{(1-D)}$$

Now, duty cycle to output relationship can be expressed as,

Where,

$$\frac{V_{out}}{D}(S) = \frac{X_1 S^3 + X_2 S^2 + X_3 S + X_4}{X_5 S^4 + X_6 S^3 + X_7 S^2 + X_8 S + X_9} * V_{in} \quad ..(4)$$

$$X_1 = -L1C1L2D = -1.4557*10^{-11}$$

$$X_2 = L1C1R_L D^2 = 7.3062*10^{-11}$$

$$X_3 = -D^2 L1 = -3.645*10^{-3}$$

$$X_4 = D^2 R = 21.573$$

$$X_5 = (1-D)^2 L1C1L2R_L = 7.9128*10^{-15}$$

$$X_6 = (1-D)^2 L1C1L2 = 3.966*10^{-3}$$

$$X7 = (1-D)^2 R_L [L1C1(1-D)^2 + L2C2(1-D)^2 + L2C1(1-D)^2 + L1C2D^2]$$

$$X_8 = (1-D)^2 [L2(1-D)^2 + L1D^2] = 8.6923*10^{-5}$$

$$X_9 = (1-D)^4 R_L = 0.01601$$

$$\frac{V_{out}}{V_{in}}(S) = \frac{Y_1 S^2 + Y_2}{Y_3 S^4 + Y_4 S^3 + Y_5 S^2 + Y_6 S + Y_7} \quad ....(5)$$

Where,

$$Y_1 = L2C1R_L(1-D) = 1.5443*10^{-8}$$

$$Y_2 = D(1-D)\ \ R_L = 3.8668$$

$$Y_3 = L1C1L2C2R_L = 3.4249*10^{-13}$$

$$Y_4 = L1C1L2 = 1.7167*10^{-11}$$

$$Y_5 = R_L[L1C1(1-D)^2 + L2C2(1-D)^2 + L2C1(1-D)^2 + L1C2D^2]$$

$$= 7.5061*10^{-5}$$

$$Y_6 = L1D^2 + L2(1-D)^2 = 3.7622*10^{-3}$$

$$Y_7 = R_L(1-D)^2 = 0.69312$$

By substituting the L1, L2, C1, C2, R_L and D values we can get that input to output relationship,

$$\frac{V_{out}}{V_{in}}(S) = \frac{1.5443*10^{-8}S^2 + 3.8668}{3.4249*10^{-3}S^4 + 1.7167*10^{-11}S^3 + 7.506*10^{-5}S^2 + 3.7622*10^{-3}S + 0.69312} \quad ...(6)$$

By using the above transfer function we can get the desired output voltage.

Element	Value
Supply Voltage	107V
Inductor, L_1	5.069mH
Inductor, L_2	5.069mH
Capacitor, C_1	668.13pF
Capacitor, C_2	665µF
Diode Voltage drop, V_D	0.8V
Resistance, R	33.33Ω
Buck Output Voltage	52V
Boost Output Voltage	602V

Table 2: SEPIC elements and its values

IV. DYNAMIC VOLTAGE RESTORER:

DVR is a series controller which is used to compensate voltage sags and swells. DVR is used for short time faults only. DVR injects the voltage in phase to the supply. So, that it can maintain a good power quality profile at the load. DVR contains a Voltage Source Converter (VSC), an Energy Storage System, an Injection Transformer and a LC-Filter. In this VSC will convert the DC into AC and by this converting process it will produce some harmonics. To reduce these harmonics we use an LC-Filter and it doesn't allow harmonics across it. Filter is connected in between the VSC and Injection Transformer. Injection Transformer will inject the voltage in series with the supply lines. Depending on the compensation the storage of energy will be stored and for energy storage capacitors and batteries are used. In this DVR we use fast switches, due to these fast switching operations we can get the desired output. By using fast switches the cost of the DVR will increases and the DVR cost will depends on the power rating and other equipments.

DVR works independently on the type of fault or any event that happens in the system, provided that the total system is remains constant and it is connected to the supply grid i.e., the line circuit breaker does not trip. For most practical cases, a more economical design can be achieved by only compensating the positive and negative sequence components of the voltage disturbances seen at the input of the DVR. Because of infinite impedance the zero sequence component does not pass through the step-down transformer.The injected voltage of the DVR can be expressed as,

$$V_{inj} = V_{La} + V_{Sa} \quad ....(8)$$

Where,

V_{La} is the desired load voltage magnitude

V_{Sa} is the source voltage during disturbance

The load current I_{La} is given by,

$$I_{La} = \frac{P_{La} \pm Q_{La}}{V_{La}} \quad ....(9)$$

V. SIMULATION AND RESULTS

The simulation circuit shown in below fig.3. Comprises of system with 3-phase programmable voltage source with an A.C voltage of 440V, 50Hz. Here, asynchronous machine is placed as a load replacing with the resistive load. Here, the fault is placed in the 3-phase programmable source with a time period of 0.3 to 0.4 in the total simulation time (0.5).

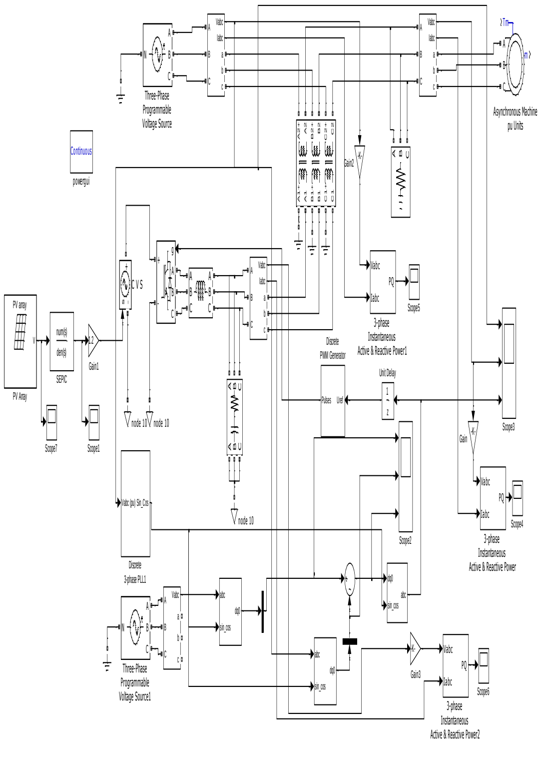

Fig.4. Simulink model of the system with motor load

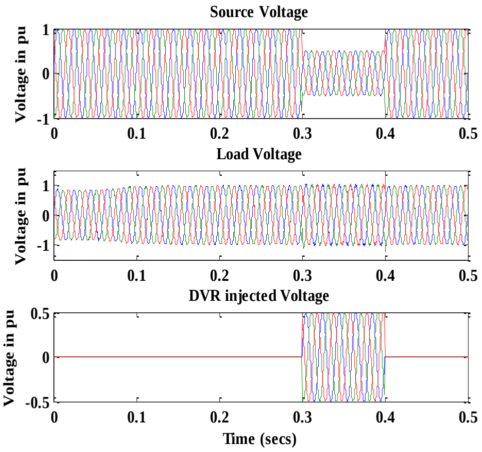

Fig .5. Output waveform of system with motor load in sag condition

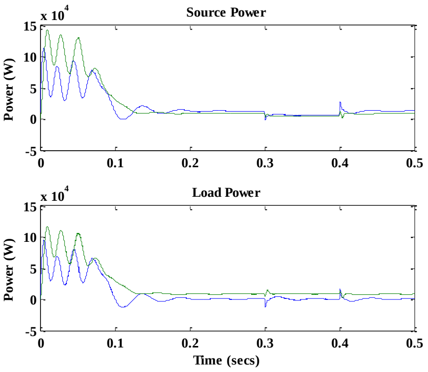

Fig.6. Output power waveform of system with motor load in sag condition.

VI. CONCLUSION

In this project SEPIC modeling is presented briefly. The open loop and closed loop simulations are presented. A DC 600V output is obtained from only 107V as input. It is observed by varying duty cycle and output also changes, duty cycle above 50% it operate as a boost converter and below 50% it act like a buck converter. A current input PV model is developed using Matlab/Simulink in modeling. By this model the I-V and P-V characteristics are obtained.

The project proposes modeling of PV array, Single Ended Primary Inductive Coil (SEPIC)/Boost converter for mitigating voltage disturbances using DVR. Performance of DVR was investigated.

VII. REFERENCES

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