Economical & Renewable Techniques for Power Generation, Energy Storage and Voltage Sag Mitigation

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***Abstract* — This paper presents some economical and renewable resources those have been proven most effective in the journey of power for the grid. Solar energy which is a never ending source of energy has become an increasing trend of using photovoltaic system. The electric spring has been proven to be an effective and emerging technology. It reduces the energy storage requirement in power grid. This technology can also be effective in substantial penetration of intermittent renewable energy sources. Electric spring presents reactive power compensation as well as automatic power changes in non-critical load. Because of this variation there is a problem of voltage sag and swell in the transmission line. FACTS based devices are widely accepted as the most prominent solution for voltage sag prevention. The FACTS based devices like Dynamic voltage restorer (DVR) are widely used to reduce the power quality problem Simulation results of PV cell and DVR are presented to understand the performance of the model. It is considered to be most efficient and active solution. Evolutions of these solutions are to mitigate the high demand of economical and renewable resources for the power generation.**

***Index Terms* — Photovoltaic (PV) cell, electric spring, voltage mitigation, dynamic voltage restorer (DVR).**

I. Introduction

The most important concern in the power sector is the day-to-day increasing power demand as well as the unavailability of enough resources to mitigate the power demand using the economical and conventional energy sources. Global environment has created a booming interest in renewable energy generation system. The PV effect is the most important and sustainable way because solar energy is widely available during daylight and it is a never ending source of energy. Various researchers have been proposed several models for Matlab/Simlink in the literature. Salmi et al. proposed a model of PV cell based on a basic circuit depend on physical and environmental values. Tsai et al. explains a model with sunlight irradiance and cell temperature as input parameter [1] also developed a model of photovoltaic cell using Matlab/Simlink and this model is verified for the experimental purpose.

II. Body Of Paper

A. Photovoltaic System a renewable power generation device

1. PV cell model based on diode circuit

The basic principle of PV cell is same as the diode with a pn junction. This pn junction absorbs the sun light; this energy is absorbed by the photon and transferred to electron proton system, creating charge carriers that are separated at the junction. During this process there are some losses. These losses are expressed by connecting two resistances in that circuit which is shown in Fig. 1.

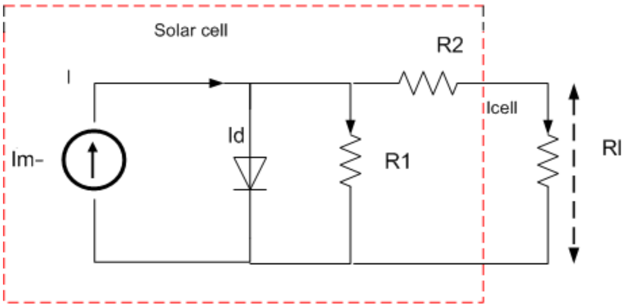

Figure. 1 PV cell equivalent circuit.

In the above circuit the output voltage depends on the value of series resistance. PV power conversion efficiency is changed by changing the value of series resistance. The current and voltage of the PV cell depends the load values. The overall current and voltage which PV cell can provide is given below:

$$I_{cell} = I_r + [\alpha \left(\frac{G}{G_r}\right)(T_c - T_{cr}) + \left(\frac{G}{G_r} - 1\right) I_{sc}] \quad (1)$$

$$V_{cell} = -\beta\left(T_c - T_{cr)}\right) - R_s \Delta I + V_r \quad (2)$$

Where $\Delta I = I_{cell} - I_r$

- G and Gr are active and the reference radiation.
- Tc and Tcr are module temperature and reference temperature.
- Isc is short circuit current.
- α is temperature coefficient of the short circuit current.
- β is temperature coefficient of the open circuit current.
- Ir and Vr are the reference values taken from the I-V curve.

B. Electric Spring an energy storage device

With the increasing use of intermittent renewable energy sources, it is impossible to determine the instantaneous total power generation in real time. In order to achieve balance of power supply and demand, Energy storage is probably the most effective means for instantaneous energy balancing [6] [7]. Energy storage systems called as restoring technologies, are used to provide the electric loads with low voltage ride through (LVRT). For the fast transient energy storage elements such as battery banks flywheels, super-capacitors and superconducting magnetic energy storage (SMES) are installed with parallel connected super-capacitors. Storage element such as battery bank, SMES have higher cost and a source of pollution. Chi Kwan Lee developed a new technique in the field of storage system i.e. 'Electric Spring'. This is a new smart grid technology for achieving the control of load demand. Traditional series reactive power compensators use output voltage control.

Electric spring provides reactive power compensation as well as automatic load variation in the non-critical loads (with electric springs embedded). This advantageous feature provides the possibility of reducing energy storage requirements in future smart grid. [8]

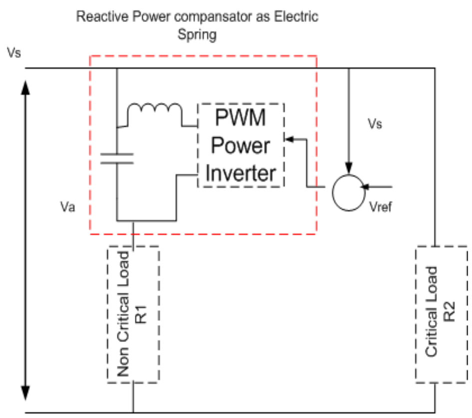

Figure 2. Series connected Electric Spring

Fig. 2 shows a typical installation of a single-phase electric spring connected in series with a non-critical load.

For pure reactive power control, the vector of the electric spring voltage and the current must be perpendicular. [9]

Power consumption for the non-critical load i.e. resistive R1

$$P_1 = \frac{Vs^2 - Va^2}{R1} \quad (3)$$

Power consumption for the critical load i.e. resistive R2

$$P_2 = \frac{Vs^2}{R2} \quad (4)$$

The total power in the circuit is

$$P_T = P_1 + P_2 \quad (5)$$

Where V_s = rms value of the AC main

V_a = voltage of Electric Spring

Power consumption for the non-critical load, when Electric Spring is not considered $(V_a = 0)$

$$P_1^{max} = \frac{Vs^2}{R1} \quad (6)$$

When Electric Spring is activated

$$P_1^{es} = \frac{Vs^2 - Va^2}{R1} \quad (7)$$

This is clear from (6) and (7) equations that

$$P_1^{max} > P_1^{es} \quad (8)$$

The equation (8) shows that electric spring can vary the non critical load power.

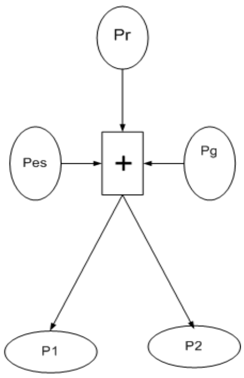

Figure. 3 Power flow diagram

Fig. 3 shows the power flow diagram in which the power from energy storage can be positive or negative depends on the devices charging or discharging.

The power balance equation can be written as:

$$P_g + P_r + P_{es} = P_1 + P_2 \quad (9)$$

Where Pg = power generated by AC generator

Pr = power generated by renewable energy source

Pes = Power from the Energy Storage.

{(+) - when battery is discharging}

{(-) - when battery is charging}

$$P_{es} = -P_g - P_r + P_1 + P_2 \quad (10)$$

Energy Storage without Electric Spring for time 0 to T

$$E_{es}^{max} = \int_0^T P_{es} dt = -\int_0^T P_g\, dt - \int_0^T P_r\, dt + \int_0^T P_1^{max} dt + \int_0^T P_2 dt \quad (11)$$

Energy Storage with Electric Spring for time 0 to T

$$E_{es}^{es} = \int_0^T P_{es} dt = -\int_0^T P_g\, dt - \int_0^T P_r\, dt + \int_0^T P_1^{es} dt + \int_0^T P_2 dt \quad (12)$$

Subtracting equations will be as below

$$E_{es}^{max} - E_{es}^{es} = \int_0^T P_1^{max} dt - \int_0^T P_1^{es} dt \quad (13)$$

From equation (13)

$$\int_0^T P_1^{max} dt > \int_0^T P_1^{es} dt \quad (14)$$

$$E_{es}^{max} > E_{es}^{es} \quad (15)$$

The equation (15) shows that the use of electric spring can be reduce the energy storage requirement in power grid.

C. DVR a power quality improvement device

Voltage sag is known as a short duration voltage dip which includes both voltage magnitude and duration. A custom power device connected in series, used for the prevention of sensitive load from sag disturbance at source location. DVR and static synchronous series compensator are currently used for voltage sag compensation in series. The basic principle of the DVR is to add a suitable voltage in series with the supply through transformer when voltage swell or sag is identified. Moreover DVR can also use for some other tasks like harmonic compensation and Power Factor improvement. A DVR includes a series voltage source inverter and an output filter inverter connected with the DC link as shown in Fig. 4.

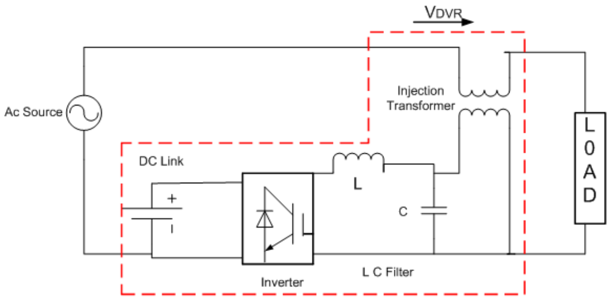

Figure. 4 Basic structure of Dynamic Voltage Restorer

DVR essentially connected in the distribution system between the supply and load. At the time of disturbance to avoid the load power disruption, DVR is used to increase the voltage on load side. This control approach used by DVR depends on the load type.

There are two ways of DVR compensation.

1. Pre-dip compensation

During fault and pre-fault situation, pre-dip compensation technique used to trace supply voltage and compensates the load voltage. In this technique the voltage on load can be restored ideally and it is determined by some external conditions like the type of faults and load, Moreover the introduced active power cannot be controlled in this technique as shown in Fig. 5.

$$S_{1DVR} = I_L V_{DVr}$$

$$S_{1DVR} = I_L \sqrt{V_L^2 + V_S^2 - 2V_L V_S \cos(\theta_L - \theta_S)} \quad (16)$$

$$P_{1DVR} = I_L (V_L cos\theta_L - V_S cos\theta_S) \quad (17)$$

$$V_{1DVR} = \sqrt{V_L^2 + V_S^2 - 2V_L V_s \cos(\theta_L - \theta_S)} \quad (18)$$

$$\theta_{1DVR} = tan^{-1}\left(\frac{V_L Sin\,\theta_L - V_s sin\theta_s}{V_L cos\theta_L - V_S cos\theta_s}\right) \quad (19)$$

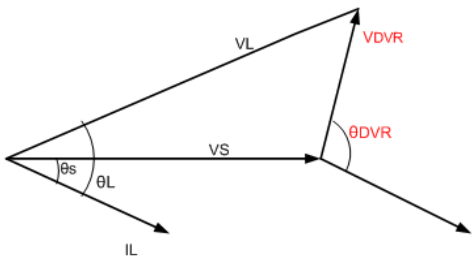

Figure. 5 Pre-dip compensation

3. In-Phase Compensation (IPC)

The in-phase compensation technique is ideal for minimum voltage and minimum energy operations. This is the widely used technique where the supply voltage and DVR voltage are in same phase, apart from pre-fault voltage and load current as shown in Fig. 6

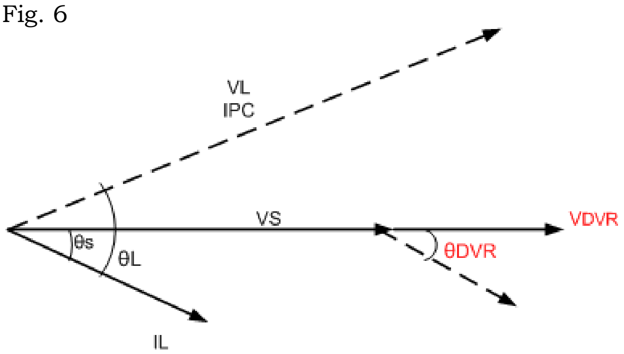

Figure 6. In-Phase Compensation

The apparent and active power of DVR is:

$$S_{2DVR} = I_L V_{DVr} = I_L (V_L - V_S) \quad (20)$$

$$P_{2DVR} = I_L V_{DVR} cos\theta_S = I_L (V_L - V_S) cos\theta_S \quad (21)$$

$$V_{2DVR} = V_L - V_s \quad (22)$$

$$\theta_{2DVR} = \theta_s \quad (23)$$

III. Proposed Methodology & Simulation Results

A. PV cell model on Matlab/Simulink

Fig. 7 shows a simulink simulation of the PV module connected to resistive load of value 4.4Ω. A reference radiation G of 1000 W/m2 and temperature Tc of 25 oC were used here. Transient response of PV module, when connected to the resistive load is shown in Fig. 8(a) 8(b) and 8(c). [4] Voltage and current of the load are settled to its steady state value. Power injected the load by PV module was reached to its steady state conditions.

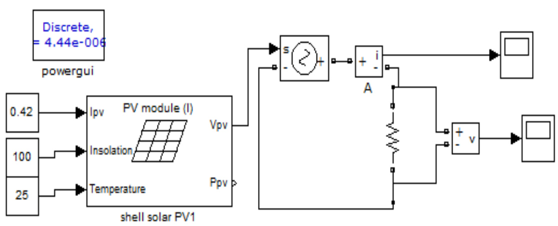

Figure. 7 Simulation model of PV module with a DC load

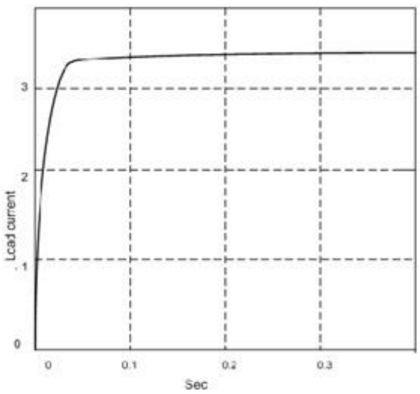

Figure. 8(a) – Current

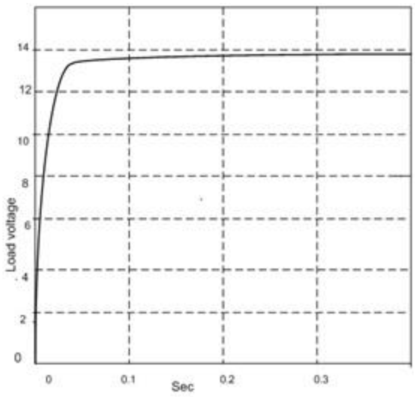

Figure. 8(b) – Voltage

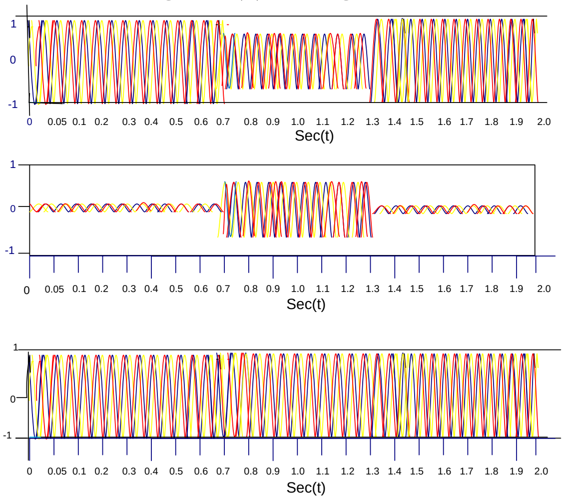

Figure. 9 Three phase voltage sag

1. Voltage Swell

An increase in voltage for a short duration known as voltage swell. The sudden disconnection of heavy load is the main reason of voltage swell. The simulation system presents a 50% voltage swell starts from 700 ms to 1300 ms and the total duration of voltage swell is 600 ms. The result of DVR system shows that the load voltage is found at 1 p.u. during the whole simulation, which includes the voltage swell period. During the simulation it is found that, if voltage swell is detected, it quickly injects the voltage with 1800 phase shift so that the resultant voltage gets subtracted.

The simulation results for voltage swell are shown in Fig. 10.

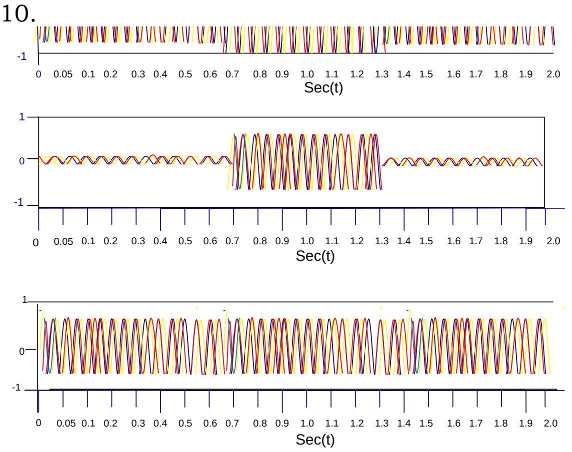

Figure. 10 Three phase voltage swell

IV. Conclusions

In this paper, a literature review of Photovoltaic Cell with Simlink model, Electric Spring as an energy storage device, DVR for mitigating the problem of voltage sag are presented. These models based on the fundamental circuit equations. The PV cell is the most reliable renewable energy system with negligible GHG emissions. Although the cost of PV cell is reducing but it is still high and more work needs to be done on this areas to make PV energy more competitive among other energy resources. Electric Springs can be incorporated into many existing noncritical electric loads such as water heaters and road lighting systems to form a new generation of smart loads that are adaptive to the power grid. The DVR is used to introduce required voltage component, if there any sag observed in supply system. It is a very economical system to balance the unbalance supply voltage and keeps the load voltage at a constant value. Future trends of DVR are increasing due to low cost and high reliability of system.

References

[1] H.L. Tsai, C.S. Tu, and Y.J. Su, “Development of generalized photovoltaic model using Matlab/Simulink,” In the event of the World Congress on Engineering and Computer Science 2008, WCECS’08, San Francisco, USA

[2] M. Calais and V. G. Agelidis, “Multilevel converters for single-phase grid connected photovoltaic systems” An overview, in Proc. IEEE Int. Symp. Ind. Electron., 1998, vol. 1, pp. 224–229

[3] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi “MATLAB/Simulink Based Modeling of Solar Photovoltaic Cell", “INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH”, Tarak Salmi et al., Vol.2, No.2, 2012

[4] Moreno-Mun oz, A., D. Oterino, M. González and F.A. Olivencia, 2006. “Study of Sag Compensation with DVR" Benalmádena (Málaga), Spain. IEEE MELECON May, pp: 16-19

[5] Shu Yuen (Ron) Hui, ChiKwan Lee, Felix F. Wu, "Electric Springs—A New Smart Grid Technology" IEEE TRANSACTIONS ON SMART GRID, VOL.3, NO. 3, SEPTEMBER 2012

[6] P. Kienzle and G. Andersson, “Valuing investments in multi-energy conversion, storage, and demand-side management systems under uncertainty,” IEEE Trans. Sustainable Energy, vol. 2 , no. 2 , pp. 194–202,2011

[7] P. Varaiya, F. Wu, and J. Bialek, “Smart operation of smart grid: Risklimiting dispatch,” Proc. IEEE, vol. 99, no. 1, pp. 40 57, 2011

[8] Shu Yuen (Ron) Hui,ChiKwan Lee,Felix F. Wu, "Reduction of Energy Storage Requirements in Future Smart Grid Using Electric Springs" IEEE TRANSACTIONS ON SMART GRID, VOL. 4, NO. 3, SEPTEMBER 2013

[9] C. Benachaiba and B. Ferdi "Power Quality Improvement Using DVR", American Journal of Applied Sciences 6 (3): 396-400, 2009 ISSN 1546-9239

[10] Buxton, R., 1998. “Protection from voltage dips with the dynamic voltage restorer”. In IEE Half

Day Colloquium on Dynamic Voltage Restorers-Replacing Those Missing Cycles, pp: 3/1-3/6

[11] Sng, E.K.K., S.S. Choi and D.M. Vilathga-Muwa, 2004. “Analysis of series compensation and DC-link voltage controls of a transformer less self-charging dynamic voltage restorer”. IEEE Trans. Power Delivery, 19: 1511-1518

[12] “Modeling and Simulation Using MATLAB Simulink”, Author: Dr. Shailendra Jain