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Design Of An Integrated Dynamic Voltage Restorer-Ultracapacitor For Improving The Power Quality Of The Distribution Grid

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Abstract- In this paper, a new idea is presented to improve the power quality under sag condition when microgrid is connected to the grid, and therefore, the voltage compensation is achieved. Now-a-days integration of energy storage technologies into the power grid is becoming a reality with the advent of the smart grid. One among the major applications is Dynamic Voltage Restorer (DVR), it is a custom power device to guard sensitive loads against voltage disturbances such as voltage sag and voltage swell, both considered to be important parameters of power quality. A dynamic voltage restorer-ultracapacitor is a new device for sag mitigation where UCAP is integrated into the dc-link of the DVR through a bidirectional dc-dc converter which helps in providing a stiff dc-link voltage, and the integrated UCAP-DVR system helps in compensating temporary voltage sags and swells, with lower THD. Here we are using PI controller instead of using other controllers. The validity of the proposed configuration is verified by simulations using MATLAB/ Simulink software.

Index Terms: Bidirectional dc-dc converter, ultra-capacitor, dynamic voltage restorer, power quality, voltage sag, PI controller

I. INTRODUCTION

The technological advancements have proven a path to the modern industries to extract and develop the innovative technologies within the limits of their industries for the fulfillment of their industrial goals. And their ultimate objective is to optimize the production while minimizing the production cost and thereby achieving maximized profits while ensuring continuous production throughout the period.

As such a stable supply of un-interruptible power has to be guaranteed during the production process. The reason for demanding high quality power is basically the modern manufacturing and process equipment, which operates at high efficiency, requires high quality defect free power supply for the successful operation of their machines. More precisely most of those machine components are designed to be very sensitive for the power supply variations. Adjustable speed drives, automation devices, power electronic components are examples for such equipments.

Failure to provide the required quality power output may sometimes cause complete shutdown of the industries which will make a major financial loss to the industry concerned.

Thus the industries always demands for high quality power from the supplier or the utility. But the blame due to degraded quality cannot be solely put on to the hands of the utility itself.

It has been found out most of the conditions that can disrupt the process are generated within the industry itself.

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For example, most of the non-linear loads within the industries cause transients which can affect the reliability of the power supply. Following shows some abnormal electrical conditions caused both in the utility end and the customer end that can disrupt a process.

1. Voltage sags
2. Phase outages
3. Voltage interruptions
4. Transients due to Lighting loads, capacitor switching, non linear loads, etc..
5. Harmonics

As a result of above abnormalities the industries may undergo burned-out motors, lost data on volatile memories, erroneous motion of robotics, unnecessary downtime, increased maintenance costs and burning core materials especially in plastic industries, paper mills & semiconductor plants.

Among those power quality abnormalities voltage sags and surges or simply the fluctuating voltage situations are considered to be one of the most frequent type of abnormality. Those are also identified as short term under/over voltage conditions that can last from a fraction of a cycle to few cycles. Motor start up, lightning strikes, fault clearing, power factor switching are considered as the reasons for fluctuating voltage conditions.

As the power quality problems are originated from utility and customer side, the solutions should come from both and are named as utility based solutions and customer based solutions respectively. The best examples for those two types of solutions are FACTS devices (Flexible AC Transmission Systems) and Custom power devices. FACTS devices are those controlled by the utility, whereas the Custom power devices are operated, maintained and controlled by the customer itself and installed at the customer premises.

Both the FACTS devices and Custom power devices are based on solid state power electronic components. As the new technologies emerged, the manufacturing cost and the reliability of those solid state devices are improved; hence the protection devices which incorporate such solid state devices can be purchased at a reasonable price with better performance than the other electrical or pneumatic devices available in the market. Uninterruptible Power Supplies (UPS), Dynamic Voltage Restorers (DVR) and Active Power Filters (APF) are examples for commonly used custom power devices. Among those APF is used to mitigate harmonic problems occurring due to non-linear loading conditions, whereas UPS and DVR are used to compensate for voltage sag and surge conditions.

In this paper voltage compensation is done using DVR-UCAP and the control of a Dynamic voltage restorer for single phase voltage sags has been studied. Voltage sag may occur from single phase to three phases. But it has been identified single phase voltage sags are the commonest and most frequent.

A control technique to detect and compensate for the single phase voltage sags was developed and simulated using the MATLAB/SIMULINK software.

II. DVR-UCAP OPERATING PRINCIPLE

A DVR-UCAP is a solid state power electronics switching device consisting of whichever GTO or IGBT, a ultracapacitor depository as an power storage device and injection transformer. It is linked in series between a distribution and a load that shown in figure 1.

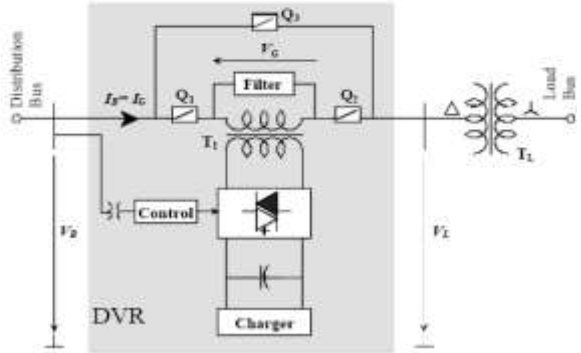

Fig. 1. Principle of DVR with a Response Time of Less Than One Millisecond

MATHEMATICAL MODELLING OF DVR

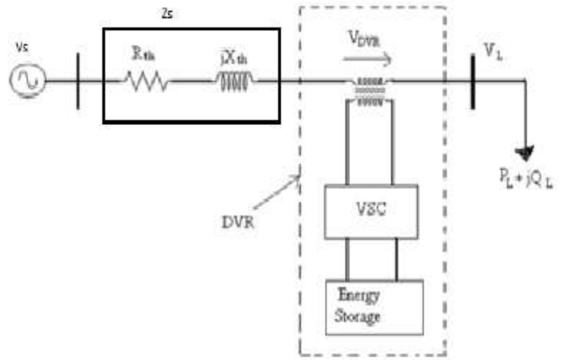

Fig.2 DVR equivalent structure

Equivalent structure is represented in Fig 2. Here, load bus fault level decides system impedance Zs. At the time of voltage disturbance injection transformers injects voltage Vdvr to maintain load voltage magnitude Vl.

If system voltage Vs drops, the injected voltage of DVR can be calculated as -

Where

$$v_{dvr} + v_s = v_l + z_s i_l \quad \ldots(1)$$

$$v_{dvr} = v_l + z_s i_l - v_s \quad \ldots(2)$$

Where,

Vl = desired load voltage magnitude

Zs = System impedance

Il = load current

Vs = system voltage during fault condition

Load current can be written as –

$$i_l = \left(\frac{p_l + jq_l}{v_l}\right)^* \quad \ldots(3)$$

$$v_{dvr} < \alpha = v_1 < 0 + z_s i_l < (\beta - \theta) - v_s < \delta \quad \ldots(4)$$

Where α, β and δ are the angle of Vdvr , Zs and Vs, respectively and θ is the load power factor angle with

$$\theta = \tan^{-1}\left(\frac{q_l}{p_l}\right) \quad \ldots(5)$$

DVR injected power can be written

$$s_{dvr} = v_{dvr} i_l \quad \ldots(6)$$

III. PROPOSED COMPENSATION SCHEME AND CONTROL STRATEGY IMPLEMENTATION

The general principle of DVR is that whenever the system detects a voltage sag/swell, the DVR should react as fast as possible and inject an ac voltage into the grid.It can be implemented using the synchronous reference frame (SRF) technique based on the instantaneous values of the supply voltage. The control algorithm produces a three-phase reference voltage to the PWM inverter that tries to maintain the load voltage at its reference value. The voltage sag or swell is detected by measuring the error between the supply voltage and the reference value. The reference component is set to a rated voltage. The SRF method can be used to compensate all types of voltage disturbances, voltage sag/swell, voltage unbalance, and harmonic voltage.

The difference between the reference voltage and the supply voltage is applied to the ZSI to produce the load rated voltage, with the help of pulse width modulation (PWM) through the

PI controller:

$$v_d = \frac{2}{3}\left[v_a * \sin(\omega t) + v_b * \sin\left(\omega t - \frac{2\varphi}{3}\right) + v_c * \sin\left(\omega t + \frac{2\varphi}{3}\right)\right] \quad \ldots(7)$$

$$v_q = \frac{2}{3}\left[v_a * \cos(\omega t) + v_b * \cos\left(\omega t - \frac{2\varphi}{3}\right) + v_c * \cos\left(\omega t + \frac{2\varphi}{3}\right)\right] \quad \ldots(8)$$

$$v_o = \frac{1}{3}\left[v_a + v_b + v_c\right] \quad \ldots(9)$$

where ω = rotation speed (rad/s) of the rotating frame. We have

$$v_a = \left[v_d * \sin(\omega t) + v_q * \cos(\omega t) + v_o\right]$$
$$v_b = \left[v_d * \sin\left(\omega t - \frac{2\varphi}{3}\right) + v_q * \cos\left(\omega t - \frac{2\varphi}{3}\right) + v_o\right]$$
$$v_c = \left[v_d * \sin\left(\omega t + \frac{2\varphi}{3}\right) + v_q * \cos\left(\omega t + \frac{2\varphi}{3}\right) + v_o\right] \quad \ldots(10)$$

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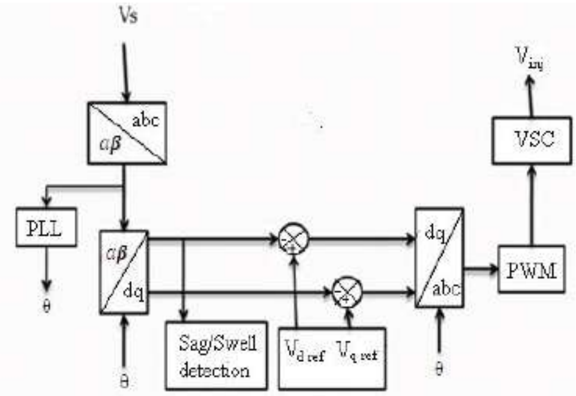

Fig.3.DVR control model

IV. PI CONTROLLER

The definition of proportional feedback control is still

$$U = k_p e \qquad \text{… (11)}$$

Where

e = is the error, k_p = Proportional gain

The characterization of the essential feedback is

$$U = k_i \int_0^t e(t)\, dt \qquad \text{…(12)}$$

k_i =Integration gain factor

In the PI controller we have a combination of P in addition to I control, that is:

$$U = k_p e + k_i \int_0^t e(t)\, dt \qquad \text{…(13)}$$

$$U = k_p e + \frac{1}{t_i} \int_0^t e(t)\, dt \qquad \text{…(14)}$$

$$U = k_p \left(e + \frac{1}{t_n} \int_0^t e(t)\, dt\right) \qquad \text{…(15)}$$

Where Ti = Integration time, Tn = Reset time

In Proportional plus Integral Control action the actuating signal consists of proportional error signal with integral of the error signal. The block diagram is as shown in fig.4

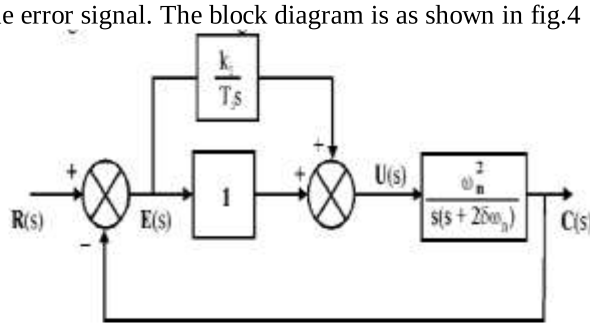

Fig4. Block diagram of proportional plus integral controller (here k_p=1)

The input output relationship of PI control action when Kp = 1/t is

$$U(t) = e(t) + \frac{k_i}{t_i} \int_0^t e(t) dt \qquad \text{…(16)}$$

The transfer function of the system is

$$\frac{u(s)}{e(s)} = \left[i + \frac{k_i}{t_i s}\right] \qquad \text{…(17)}$$

Where gain, Kp = 1 (already assumed) and Ti =integral time Kp and Ti are constant and can be adjusted to any required values. Any change in Kp will affect the both the actions i.e. propositional and integral control of the controller while change in Ti would affect only the integral control action.

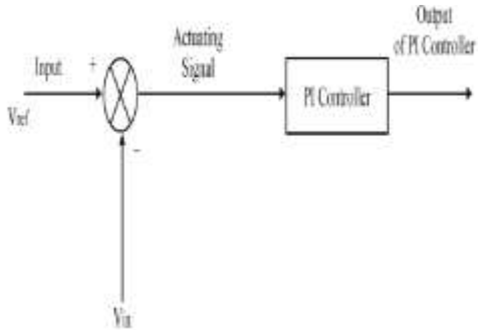

Fig.5. schematic diagram of a typical PI controller

Sag occurs when there is increase in load or during the occurrence of fault and swell occurs when there is a sudden removal of load or due to addition of capacitor banks. This sag or swell in load voltage is sensed and its magnitude is compared with a reference voltage and the error.

signal is given to the PI controller as shown in Figure 5. The output of error detector is

$$V_{ref} - V_{in}, \qquad \text{…(18)}$$

where Vref is the reference voltage and Vin is the load voltage .

Reasons for selecting a PI controller:

The function of the proportional action is to respond quickly to the changes in the error deviation. Integral action is slower than the proportional response but used to remove the offsets between the input and the reference at steady state . Before the DVR starts injecting voltage to the system, a considerable time period was allowed for the synchronization. The synchronization process was made according to the possible system frequency deviation. As the system frequency is not much deviate from 50 Hz the fast synchronization is not a necessity. Hence it helps the load voltage without phase jump. Therefore the derivative action is not needed and the need of PID controller was omitted.

The difference between load voltage, Vin, and reference voltage, Vref, is supplied to the PI controller. From the controller, the voltage magnitude is taken as feedback. The IGBT inverter is triggered from the pulse generated by the PWM generator. The IGBTs are triggered depending on the firing angle, α, which introduces additional lag or lead in the voltage

$$v_o = \frac{1}{3}(v_a + v_b + v_c) \qquad \text{…(19)}$$

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \frac{2}{3} r\omega tc \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad \text{…(20)}$$

The supply side voltages, v_a , v_b *and* v_c , are transformed into *d-q* values of positive sequence:

$$C = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \qquad \text{…(21)}$$

$$r(\omega t) = \begin{bmatrix} \cos\omega t & -\sin\omega t \\ \sin\omega t & \cos\omega t \end{bmatrix} \qquad \text{…(22)}$$

(ωt) is a matrix that rotates by phase angle ωt. Subscripts d and q represent the direct and quadrature axes. v_o is the output voltage.

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V. SIMULATION RESULTS

To investigate the system performance in voltage sag compensation, several simulations have been done in the MATLAB/Simulink software on a single-phase DVR-UCAP.

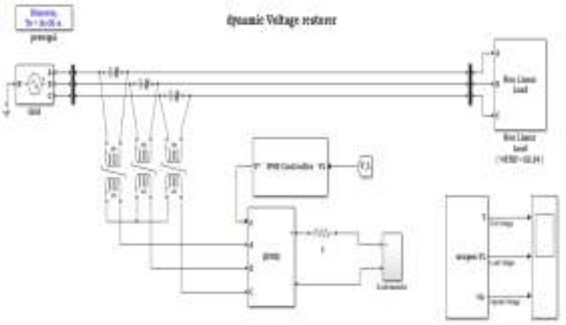


Fig.6.DVR with Ultra-Capacitor

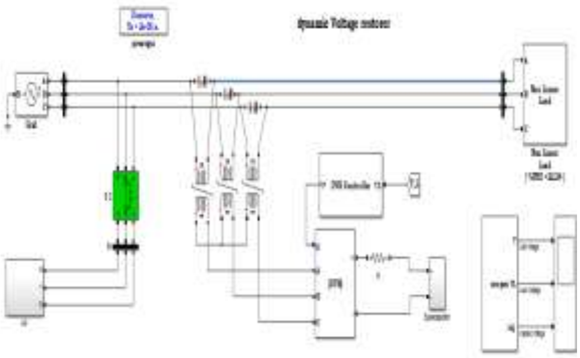


Fig.7. ultracapacitor based DVR under microgrid

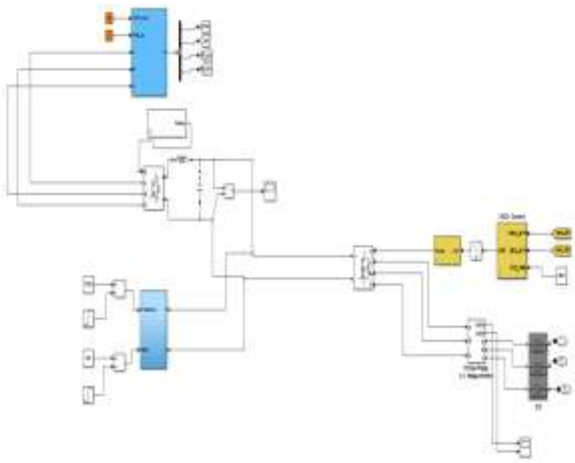
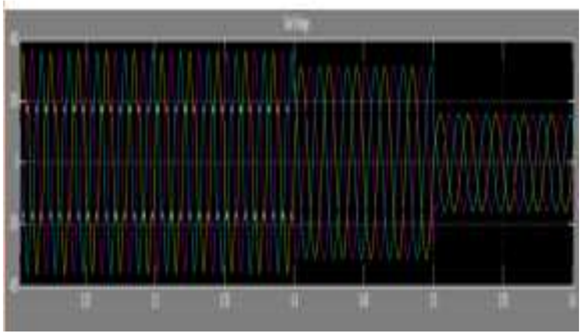
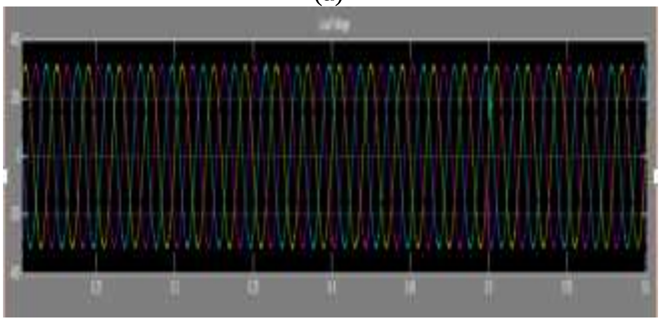


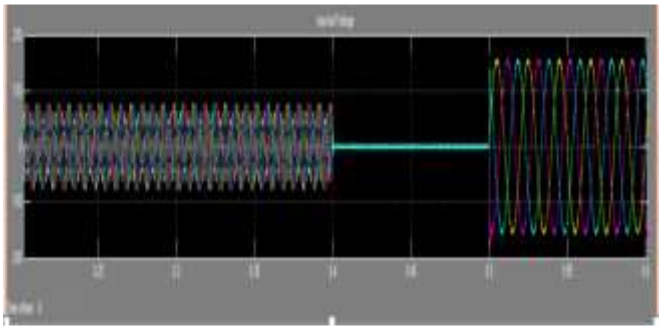
Fig.8. Matlab model for microgrid of PV cell and wind mill



(a)

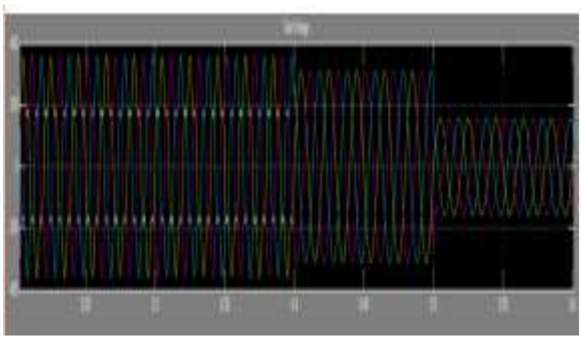


(b)

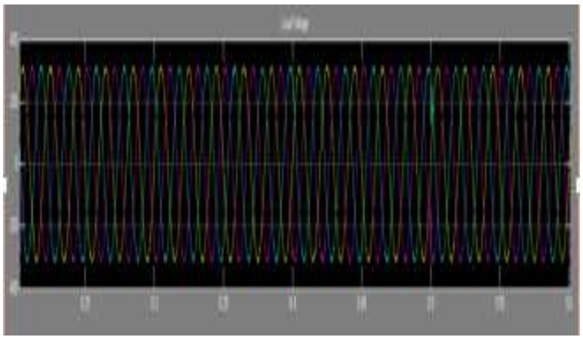


(c)

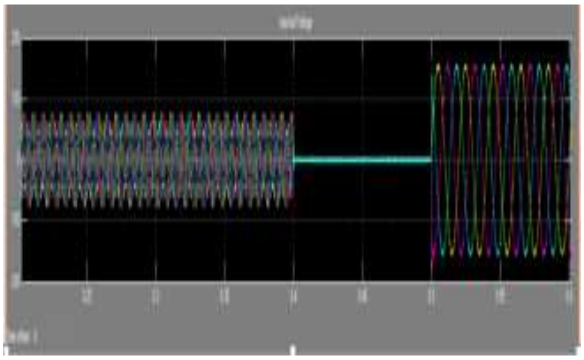
Fig. 9. Investigating the DVR-UCAP performance during sag and swell (a) grid voltage (b)load voltage (c) injected voltage



(a)



(b)



(c)

Fig. 10. Investigating the DVR-UCAP based hybrid power(combination of solar and wind) performance during sag and swell (a) grid voltage (b)load voltage (c) injected voltage

VI. CONCLUSION

In this paper Dynamic Voltage Restorer Ultra capacitor (DVR-UCAP) is used to overcome the voltage sag and swell when hybrid power is connected to the grid,using PI controller. This is proved by MATLAB simulation results. This paper proposes, not only improvement in the case of micro grid connection but also during the usage of DVR-UCAP in the distribution system. These advantages were achieved by decreasing the total harmonic distortion during sag and swell condition. Finally, the simulation and practical results of DVR-UCAP and a super capacitor based DVR under microgrid of PV cell and windmill confirmed the effectiveness of the proposed configuration and control scheme.

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