# Pv Cell Dvr with Industrial Drive Application

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***ABSTRACT* - In this paper various power quality problem caused by voltage sag or swell on power system are discussed. These problems will create failure of end user equipments which are sensitive to power quality supply. Here an attempt is taken in this paper to review from its establishment to an up to date bibliography on DVR for power quality improvement. Basically the main function of DVR is to eliminate voltage sag. Various control strategies and its improvement is analyzed. Dynamic voltage restorer (DVR) is one product that can provide improved voltage sag and swell compensation with energy storage integration. Ultra capacitors (UCAP) have low-energy density and high-power density ideal characteristics for compensation of voltage sags and voltage swells, which are both events that require high power for short spans of time. The novel contribution of this paper lies in the integration of rechargeable UCAP-based energy storage into the DVR topology. Ultra capacitors (UCAP) have low energy density and high-power density ideal characteristics for compensation of voltage sags and voltage swells, which are both events that require high power for short spans of time. With this integration, the UCAP-DVR system will have active power capability and will be able to independently compensate temporary voltage sags and swells without relying on the grid to compensate for faults on the grid like in the past. The proposed concept can be implemented with RES for Induction motor applications**

***Keywords— power quality, voltage sag, dynamic voltage restorer, ultra-capacitor, series compensation***

## I INTRODUCTION

The term power quality refers to the characterization of the quality of power being delivered to the customers' premises in terms of certain indices like the magnitude and frequency of voltage, waveform shape etc. Many occurrences, both under as well as outside the utility's control, cause deviations from the nominal values of these indices. Some of the salient power quality issues include voltage sags/swells, harmonics, long term voltage disruptions etc. Switching of loads and capacitor banks, faults or short circuits in the power system, starting currents of large machines and many such occurrences may manifest as power quality issues [1]. A survey conducted by International Energy Agency lists voltage sag as the most important power quality issue to be dealt with [2]. Voltage sag/swell is a momentary dip/rise in voltage from 0.9 - 0.1 p.u (sag) / 1.1 – 1.8 p.u (swell) of the nominal rms value. Typically the duration of voltage sags or swells can lie anywhere between half cycle to one minute [3].Extensive research has been undertaken in literature for the mitigation of these power quality issues. The studies have primarily been into developing custom power devices.

A term coined by Hingorani [4] for a class of power electronic devices that can be used to improve quality and reliability of power in a distribution network. These devices could either be connected in series or shunt depending on the compensation strategy. Dynamic voltage restorer is one such series connected custom power device to mitigate voltage sags and swells. Zhan et al. [5] discuss a dynamic voltage restorer with lead acid battery as active source for injecting real power. A self-charging control is proposed, that eliminates the need for separate charging circuitry for the energy source. In [6], Nielsen et al. explain different topologies for dynamic voltage restorers. DVR topologies without any energy storage, but injecting the voltage by just reactive power compensation are also discussed. The most common energy storage device discussed in the literature are batteries. However, the focus in recent research has shifted to the use of ultra-capacitors as energy source, as discussed in [7]. Reference [8] discusses how a battery-ultracapacitor combined system can be efficient in catering to transient as well as steady demand. Also in literature, control strategies for different kinds of sags – with/without unbalance are discussed. Omar and Rahim have proposed a control strategy to mitigate balanced as well as unbalanced voltage sag using Space Vector PWM technique in [9]

In literature till date, the control strategies for injecting compensating voltage have mainly focused on the DC/AC inverter control. These schemes employ complex vector control with more than one P-I controller. Also, in most of the literature, the energy storage is directly interfaced with the inverter thereby necessitating a higher voltage rating of the storage device. In this , a new control strategy has been developed to mitigate three phase balanced voltage sags and swells, by varying the dc link voltage at the input side of the inverter. The proposed scheme employs a simple control of the DC/DC converter used to interface an ultra-capacitor to the inverter. The presence of a buck boost converter in between the storage and the inverter implies that the voltage rating of the storage device could be minimized. Sine Pulse Width Modulation technique (SPWM) is used in the inverter, with constant modulation index (ma). The new control scheme works on direct control of DC quantities rather than transforming the AC quantities to DC and then transforming it back to AC.

## II DYNAMIC VOLTAGE RESTORER

A Dynamic Voltage Restorer (DVR) is a device that is used for mitigating voltage sags and swells. It consists of a voltage source inverter (VSI) and three single-phase injection transformers that are connected to the line in series. The control scheme of the DVR system senses the changes in magnitude and phase angle of the supply voltage and injects a suitable voltage in series with the line, so that the load sees no deviations from nominal conditions. Fig.1 shows a basic block diagram of a typical DVR system.

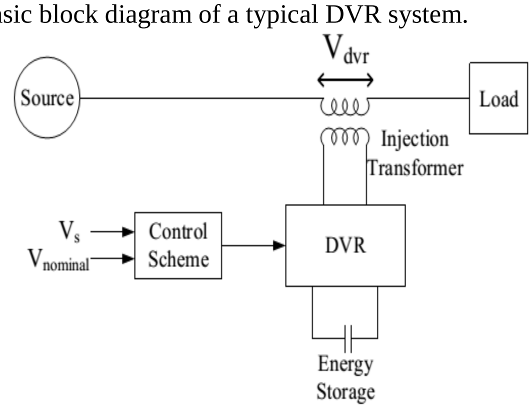


Fig. 1. Block diagram of a typical DVR system

As mentioned in the previous section, a voltage sag is characterized by a dip in voltage levels in the range 0.9 pu to 0.1 pu, typically for a duration of half cycle to one minute. Similarly a voltage swell is characterized by a rise in voltage level from 1.1 pu to 1.8 pu. Smaller sags/swells can be mitigated by absorbing or delivering reactive power alone, whereas deeper sags/swells might require active power support from the DVR system [10]. Based on this, DVR topologies are classified into two categories – DVR systems with energy storage and systems without energy storage. Energy storage devices include super-capacitors, batteries, flywheels etc. In the case of DVR systems with no energy storage, the energy required for mitigation is routed from the grid supply itself [6]. Due to technological improvements in the field of energy storage devices, there has been considerable reduction in the cost of such energy storage options, and research is being more focused on DVR topologies with energy storage these days. Depending on the type of voltage sag/swell, and also on the nature of the load, different compensation techniques are employed. Some loads are intolerant to phase jumps in voltage whereas some are tolerant. The former type of loads require a technique that compensates for both magnitude as well as phase deviations in the sagged voltage. Pre-sag compensation is one such technique that is most suitable for such loads that require both magnitude and phase compensation. In other types of loads where the phase jump is not too serious an issue, inphase compensation can be used. There is yet another compensation technique known as minimal energy compensation, wherein the primary objective is to reduce the active power requirement.

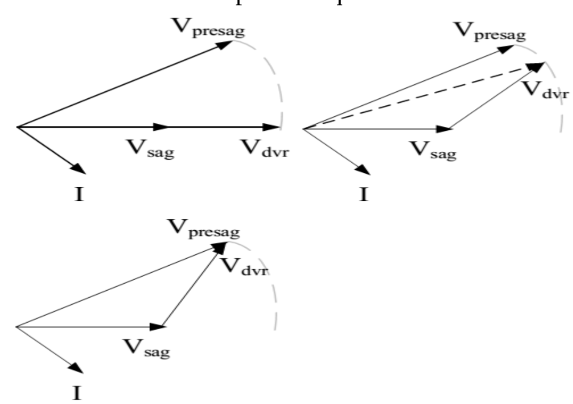


Fig.2. Compensation techniques (clockwise) – In-phase compensation, minimal energy compensation, pre-sag compensation

## III PROPOSED CONTROL SCHEME

A new control strategy is proposed to inject suitable compensating voltages in series with the line. The control strategy aims to inject the required voltage by dynamically varying the DC link voltage at the input of the inverter. Closed loop control is implemented in the bidirectional converter that is used to interface the energy storage device with the rest of the DVR system. The voltage source inverter is used in open loop mode, for converting the DC power at its input to suitable AC output. Sinusoidal Pulse Width Modulation (SPWM) technique is implemented in the inverter with a constant modulation index.

The load voltage is continuously sensed for deviations from nominal voltage levels and compared with set reference voltage. As soon as the voltage across the load sags or swells, an error voltage is generated. This error signal gives the magnitude of the sinusoidal voltage that needs to be injected in series with the line, so as to maintain the load voltage to nominal voltage levels. The nature of sag considered in this paper is a three phase balanced sag with no phase jump. Fig. 3 shows the block diagram representation of the conventional DVR control strategy and Fig.4 shows the block diagram representation of the proposed control strategy. In the control strategy proposed in this paper, in-phase compensation technique is implemented. The phase angle of the sagged voltage is obtained from a PLL and the compensating voltage is injected with the same phase angle as that of the sagged voltage. A resistive lamp load is considered for simulation studies as well as hardware implementation. In-phase compensation technique requires the injection of reactive as well as active power, depending on the load characteristics. To provide the required active power, an ultra-capacitor is used, due to the advantages it offers over conventional batteries like faster charging, long cycle life, high power density, wide temperature range etc. [11].

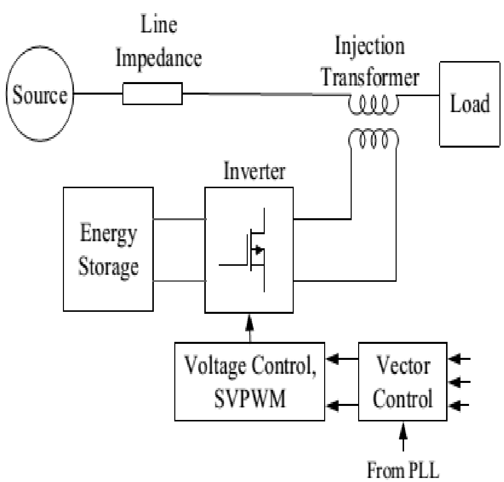

Fig. 3. Conventional DVR control strategy

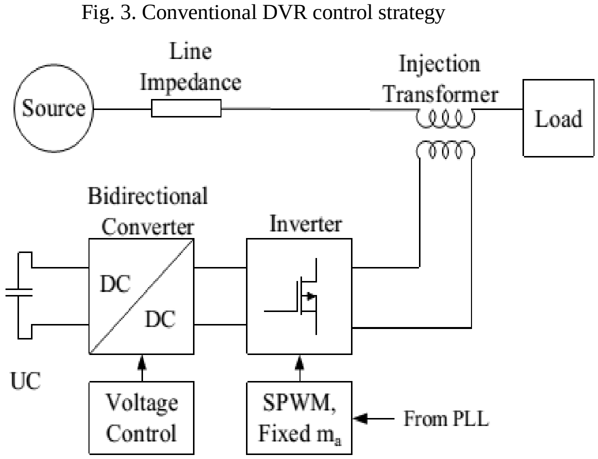

Fig. 4. Proposed DVR control strategy

## A Sag Detection

The block diagram of the sag detection algorithm implemented in the proposed control strategy. The source voltage $V_{abc}$ is sensed and transformed into rotating d-q frame by Park's Transformation to obtain DC values $V_d$ and $V_q$. The magnitude Vs of the supply voltage is obtained from $V_d$ and $V_q$ by using (1). This is continuously compared with the set reference value through a comparator. During healthy condition of the supply network, the supply voltage magnitude will be same as the set reference value and the comparator outputs a zero value. During a sag or swell, the comparator outputs a non-zero value that gives the peak value of voltage that needs to be injected. During a sag, the difference in magnitude between sensed supply voltage and set reference will be a positive value, whereas during a swell, the difference will be negative. The sag/swell detection control acts in such a way that, if the difference is negative i.e during a swell, the phase of the modulating signals of the inverter are shifted by 180o. The phase angle θ is obtained from the PLL synchronized to the supply voltage. Fig. 5.6 shows the flowchart of the events that occur once a sag/swell is detected.

$$V_s = \sqrt{V_d^2 + V_q^2} \tag{1}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = T \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2}$$

Where

$$T = \frac{2}{3}\begin{bmatrix} \cos(\omega t) & \cos(\omega t - \frac{2}{3}\Pi) & \cos(\omega t + \frac{2}{3}\Pi) \\ -\sin(\omega t) & -\sin(\omega t - \frac{2}{3}\Pi) & -\sin(\omega t + \frac{2}{3}\Pi) \end{bmatrix} \tag{3}$$

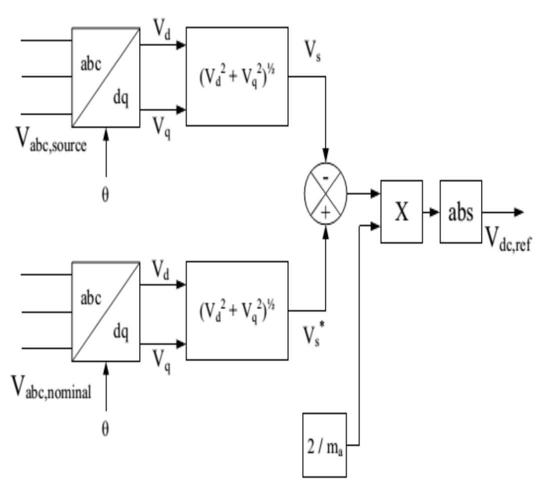

Fig.5. Sag detection and $V_{dc,ref}$ calculation

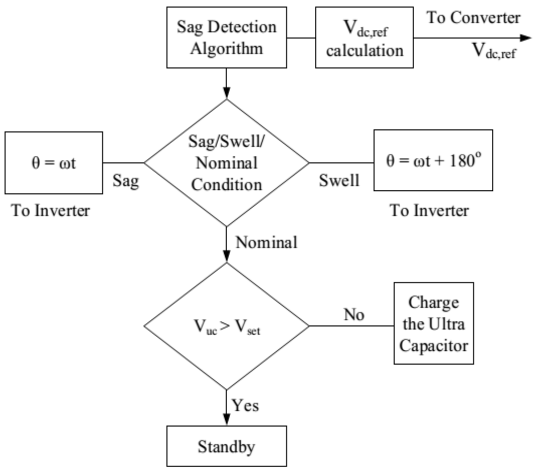


Fig. 6. Flowchart – operation during Sag/Swell

**B $V_{dc,ref}$ calculation**

The non-zero output from the comparator indicates either a sag or a swell has occurred. The absolute value of the comparator output is then used to back-calculate the dc link voltage required by the inverter. Using (4) for SPWM, $V_{dc}$ is then calculated and set as the reference voltage for the bidirectional converter. The PI controller based voltage loop of the DC/DC converter then adjusts the duty ratio of the switches so that the DC link voltage reaches a steady state value of $V_{dc}= V_{dc,ref}$. Fig.5 also shows a block diagram representation for $V_{dc, ref}$ calculation.

$$\hat{V}_{A1} = m_a \times \frac{V_{DC}}{2} \quad (4)$$

## IV A Photovoltaic System And Induction Motor (IM)

A photovoltaic system, converts the light received from the sun into electric energy. In this system, semi conductive materials are used in the construction of solar cells, which transform the self contained energy of photons into electricity, when they are exposed to sun light. The cells are placed in an array that is either fixed or moving to keep tracking the sun in order to generate the maximum power [9]. These systems are environmental friendly without any kind of emission, easy to use, with simple designs and it does not require any other fuel than solar light. On the other hand, they need large spaces and the initial cost is high.

PV array are formed by combine no of solar cell in series and in parallel. A simple solar cell equivalent circuit model is shown in figure. To enhance the performance or rating no of cell are combine. Solar cell are connected in series to provide greater output voltage and combined in parallel to increase the current. Hence a particular PV array is the combination of several PV module connected in series and parallel. A module is the combination of no of solar cells connected in series and parallel.

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The fig.1.4 manifests the equivalent circuit of PV cell. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as.

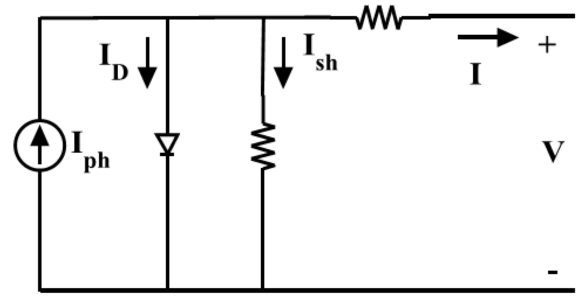


Fig 7 Equivalent circuit of Single diode modal of a solar cell

$$I = I_{PV} - I_0\left[\exp\left(\frac{V+IR_S}{aV_T}\right)-1\right]-\left(\frac{V+IR_S}{R_P}\right)$$

Where

*IPV*–Photocurrent current,

*IO*–diode's Reverse saturation current,

*V*–Voltage across the diode,

*a*– Ideality factor

VT –Thermal voltage

Rs – Series resistance Rp –Shunt resistance

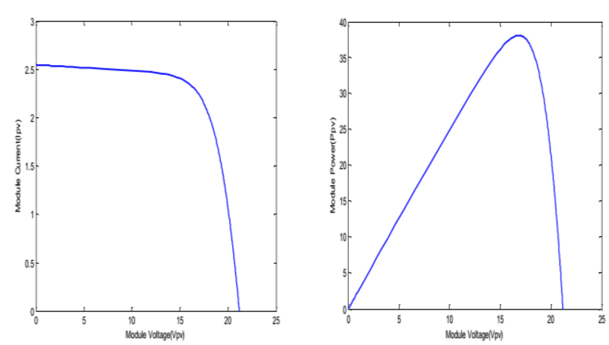

Fig.8 V-I & P-V Characteristics of a 36w PV module

INDUCTION MOTOR (IM)

An induction motor is an example of asynchronous AC machine, which consists of a stator and a rotor. This motor is widely used because of its strong features and reasonable cost. A sinusoidal voltage is applied to the stator, in the induction motor, which results in an induced electromagnetic field. A current in the rotor is induced due to this field, which creates another field that tries to align with the stator field, causing the rotor to spin. A slip is created between these fields, when a load is applied to the motor. Compared to the synchronous speed, the rotor speed decreases, at higher slip values. The frequency of the stator voltage controls the synchronous speed. The frequency of the voltage is applied to the stator through power electronic devices, which allows the control of the speed of the motor. The research is using techniques, which implement a constant voltage to frequency ratio. Finally, the torque begins to fall when the motor reaches the synchronous speed. Thus, induction motor synchronous speed is defined by following equation,

$$n_s = \frac{120f}{P}$$

Where f is the frequency of AC supply, n, is the speed of rotor; p is the number of poles per phase of the motor. By varying the frequency of control circuit through AC supply, the rotor speed will change.

*A. Control Strategy of Induction Motor*

Power electronics interface such as three-phase SPWM inverter using constant closed loop Volts l Hertz control scheme is used to control the motor. According to the desired output speed, the amplitude and frequency of the reference (sinusoidal) signals will change. In order to maintain constant magnetic flux in the motor, the ratio of the voltage amplitude to voltage frequency will be kept constant. Hence a closed loop Proportional Integral (PI) controller is implemented to regulate the motor speed to the desired set point. The closed loop speed control is characterized by the measurement of the actual motor speed, which is compared to the reference speed while the error signal is generated. The magnitude and polarity of the error signal correspond to the difference between the actual and required speed. The PI controller generates the corrected motor stator frequency to compensate for the error, based on the speed error.

## V.MATLAB/SIMULATION RESULTS

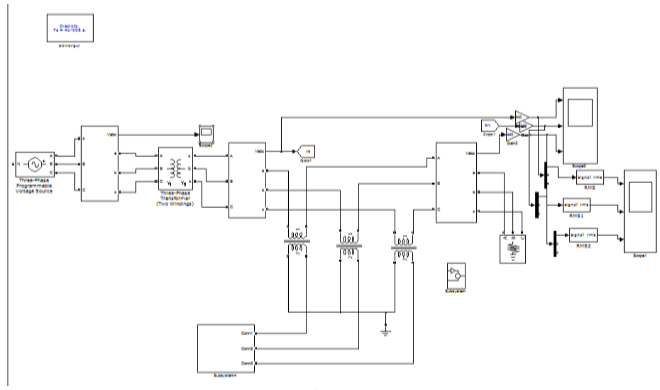

Fig 9 Matlab/simulation circuit of Conventional DVR control strategy

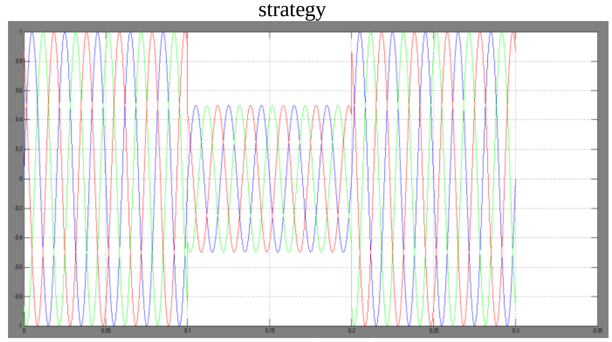

Fig 10 simulation wave form of sag voltage

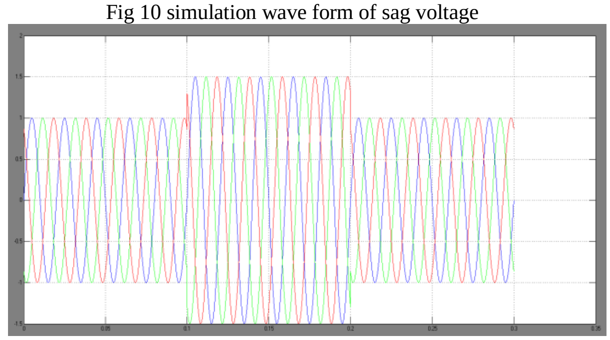

Fig 11 simulation wave form swell voltage

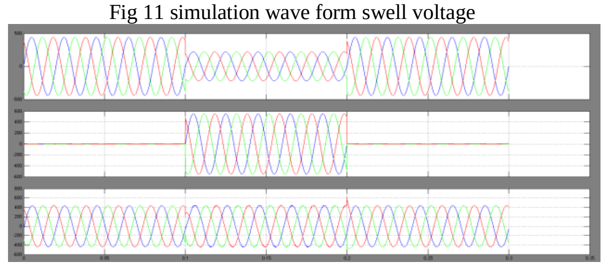

Fig 12 simulation wave form of sag compensation with DVR

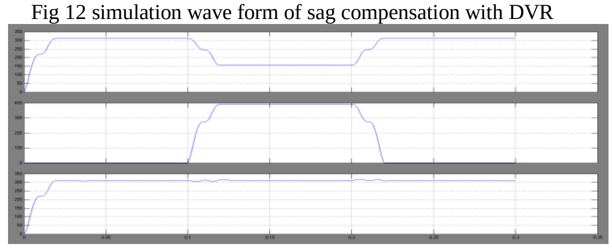

Fig 13 simulation wave form of sag and swell compensation with DVR RMS voltage

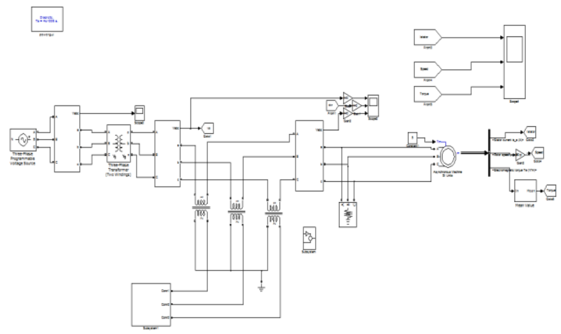

Fig 14 Matlab/simulation circuit of proposed DVR control strategy with Induction Motor

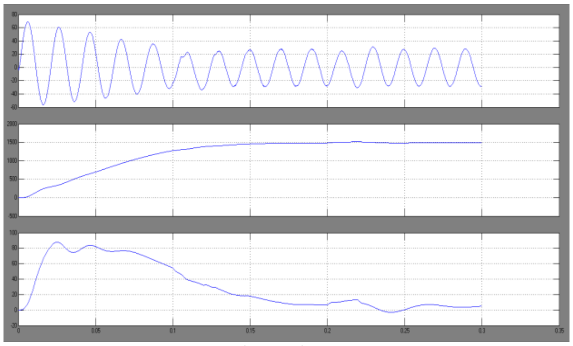

Fig 15 simulation wave form of proposed DVR sag control strategy with Induction Motor stator current, speed and electromagnetic torque

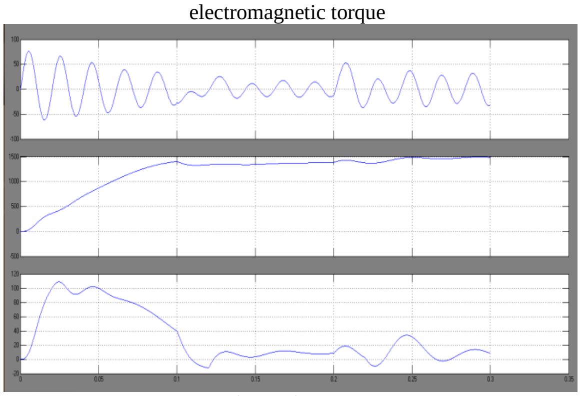

Fig 16 simulation wave form of proposed DVR swell control strategy with Induction Motor stator current, speed and electromagnetic torque

## VI CONCLUSION

A new control strategy has been proposed and validated with simulation results. A three phase balanced sag of 0.7 p.u and a three phase balanced swell of 1.4 p.u was introduced into the network and the voltage injection capability of the proposed system was tested. Waveforms that agree with expected results were obtained. FFT Analysis on the obtained waveforms gave a Total Harmonic Distortion (THD) of 1.9 % for 0.7 p.u voltage sag and 3.24 % for 1.4 p.u voltage swell. To performance the Induction Motor drive to study the characteristics of stator current, speed and electromagnetic torque

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